BOREAS An international journal of Quaternary research

The Bølling-age Blomvåg Beds, western Norway: implications for the Older Dryas glacial re-advance and the age of the deglaciation

JAN MANGERUD, JASON P. BRINER, TOMASZ GOSLAR AND JOHN INGE SVENDSEN

BOREAS

Mangerud, J., Briner, J. P., Goslar, T. & Svendsen, J. I. 2017 (April): The Bølling-age Blomvåg Beds, western Norway: implications for the Older Dryas glacial re-advance and the age of the deglaciation. *Boreas*, Vol. 46, pp. 162–184. 10.1111/bor.12208. ISSN 0300-9483.

Blomvåg, on the western coast of Norway north of Bergen, is a classical site in Norwegian Quaternary science. Foreshore marine sediments, named the Blomvåg Beds and now dated to the Bølling-Allerød from 14.8 to 13.3 cal. ka BP, contain the richest Lateglacial bone fauna in Norway, numerous mollusc shells, driftwood, and flint that some archaeologists consider as the oldest traces of humans in Norway. The main theme of this paper is that the Blomvåg Beds are overlain by a compact diamicton, named the Ulvøy Diamicton, which was interpreted previously as a basal till deposited during a glacial re-advance into the ocean during the Older Dryas (*c.* 14 cal. ka BP). Sediment sections of the Blomvåg Beds and the Ulvøy Diamicton were exposed in ditches in a cemetery that was constructed in 1941–42 and have subsequently not been accessible. A number of radiocarbon and cosmogenic ^{10}Be exposure ages demonstrate that the diamicton is not likely to be a till because minimum deglaciation ages (14.8–14.5 cal. ka BP) from the vicinity pre-date the Ulvøy Diamicton. We now consider that sea ice and icebergs formed the Ulvøy Diamicton during the Younger Dryas. The Scandinavian Ice Sheet margin was located on the outermost coastal islands between at least *c.* 18.5 and 14.8 cal. ka BP; however, no ice-marginal deposits have been found offshore from this long period. The Older Dryas ice margin in this area was located slightly inside the Younger Dryas margin, whereas farther south it was located slightly beyond the Younger Dryas margin.

Jan Mangerud (jan.mangerud@uib.no) and John Inge Svendsen, Department of Earth Science, University of Bergen, PO Box 7803, Bergen 5020, Norway and Bjerknes Centre for Climate Research, Allégt. 70, 5007, Bergen, Norway; Jason P. Briner, Department of Geology, University at Buffalo, Buffalo, NY 14260, USA; Tomasz Goslar, Faculty of Physics, Adam Mickiewicz University, Umultowska 85, Poznań 61-614, Poland, and Poznań Radiocarbon Laboratory, Foundation of the A. Mickiewicz University, Rubież 46, Poznań 61-612, Poland; received 21st June 2016, accepted 23rd August 2016.

It was almost a sensation amongst Norwegian scientists when in 1941 numerous bones were un-earthed below a compact diamicton, interpreted as a basal till, in the village of Blomvåg, ~30 km northwest of Bergen (Figs 1, 2; Undås 1942). Some bones were identified as deer and some wood as spruce, both suggesting a climate similar to the present and it was therefore thought that the fossils originated from a full interglacial – in which case the sediments would have been the first interglacial beds found in Norway. The bones were discovered during digging of drainage ditches for a new cemetery and they became known to scientists when the workers to their great surprise dug up large whale bones ~16 m a.s.l. and 2–3 m below the ground surface (Fig. 3C). They therefore alerted the Bergen Museum (presently the Bergen University Museum) and the geologist Isak Undås went out to study the site. He initiated a scientific excavation that also involved the botanist Knut Fægri and the geologist Astrid Monsen. Several other scientists visited the site during the excavations. It soon became clear that the 'deer' bones had been misidentified and in fact stemmed from reindeer. However, wood that was identified as *Alnus*, *Taxus* and *Picea* still suggested an interglacial age (Holtedahl 1953).

When the radiocarbon-dating method became available the subtill sediments, later named the Blomvåg Beds (Mangerud 1977), were dated to about 14.5 cal. ka BP, i.e. during the Bølling (Table 1; Holtedahl 1960; Nydal 1960). Even though it became clear that the strata were much younger than previously thought, the interest in the site did not abate for four main reasons: (i) the radiocarbon ages were hitherto the oldest for the deglaciation of Norway (Holtedahl 1960), (ii) the inferred till capping the Blomvåg Beds suggested that the site had been overrun by a glacial re-advance during the Older Dryas (Mangerud 1970; Mangerud *et al.* 2011), (iii) the fossil-bearing Blomvåg Beds contain the richest Lateglacial fauna found in Norway (Lie 1986; Hufthammer 2001), and (iv) it has been argued that the flint pieces and bones represent traces of human occupation (Lie 1990; Johansen & Undås 1992), which would be 3000 years older than the earliest well-documented human sites in Norway (Breivik 2014).

Surprisingly enough, a full scientific description of the site was never published, only a description in a popular science journal (Undås 1942). Here, we describe the site based on available field notes and drawings of the strata and a number of new radiocarbon ages as well as ^{10}Be ages of glacially transported erratics. The main theme of this paper is the interpretation of the Ulvøy Diamicton capping the Blomvåg Beds and the implications for the glacial history of western Norway. Mangerud (1970) produced a pollen diagram, supported by several ^{14}C ages, from an adjacent palaeolake (Dale Bog, Fig. 2) that showed a full

DOI 10.1111/bor.12208

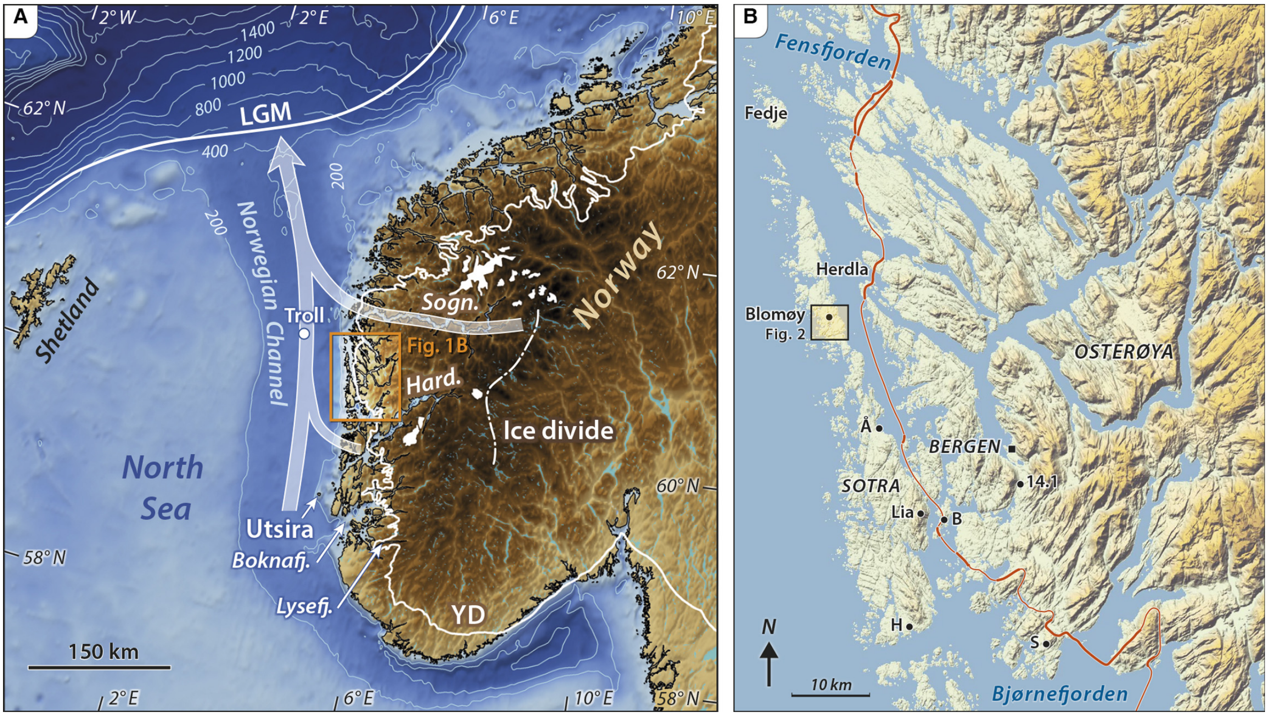

Fig. 1. A. Map of southern Norway and the northern North Sea, showing the Last Glacial Maximum (LGM) and Younger Dryas (YD) ice limits (white lines) and general ice-flow directions (arrows). Modified from Mangerud *et al.* (2013). B. The area around Bergen and Blomøy. The line shows the Herdla Moraine of late Younger Dryas age; dashed where assumed. Other sites mentioned in the text are marked: Å = Ågotnes; Lia = Liatårnet; B = Bjorøy; H = Hamravatn; S = Storum. Near Bergen, 14.1 marks the site where shell fragments are dated to 14.1 cal. ka BP. [Colour figure can be viewed at www.boreas.dk]

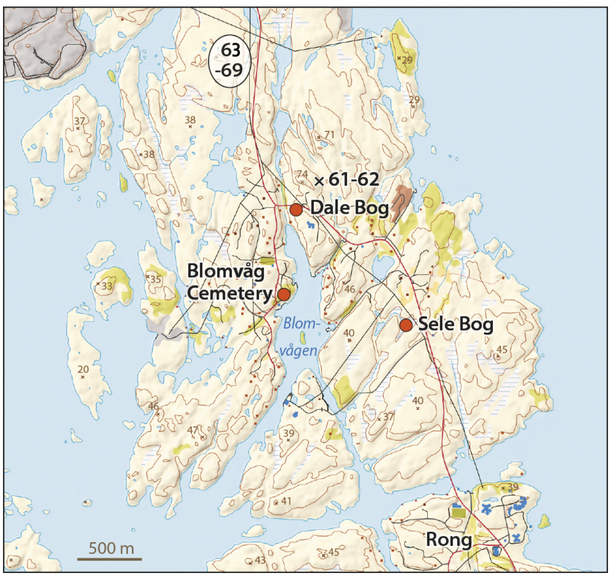

Fig. 2. Blomøy Island showing the locations of Blomvåg Cemetery, Dale Bog and Sele Bog. The areas where ^{10}Be exposure dating samples were collected are marked with the last digits of sample numbers. Contour interval is 20 m. Some summits are marked with altitudes. Modified from www.norgeskart.no. [Colour figure can be viewed at www.boreas.dk]

and undisturbed Allerød-Younger Dryas sequence of lacustrine sediments. Thus, it became clear that if the Ulvøy Diamicton was a till, it had to pre-date the Allerød, and as the diamicton overlies Bølling-age sediments, the age of the diamicton and the postulated re-advance was bracketed to the Older Dryas. Later, Mangerud (1977) considered the interpretation of the diamicton as a till to be so well founded that he even named it the Ulvøy Till (Fig. 4), against stratigraphical rules that do not accept genetic connotations to lithostratigraphical units. We therefore now re-name this unit the Ulvøy Diamicton. Mangerud (1977) noticed that several radiocarbon ages from other sites that post-date final deglaciation yielded similar ages as the youngest ages from below the Ulvøy Diamicton, but this was explained by a short duration of the glacial re-advance and/or dating uncertainties.

The interpretation that the Ulvøy Diamicton is a till, and thus that the ice sheet overran the site during the Older Dryas, has been generally accepted, but was questioned by Krzywinski & Stabell (1984). The age considerations for the Blomvåg Beds were changed when the archaeologist Elisabeth Eriksen (pers. comm. 2008) obtained radiocarbon ages on reindeer and other animal bones (also cited in Hufthammer 2001) of which the youngest is 13.3 cal. ka BP (Table 1). This young age was incompatible with the prevailing view that the Ulvøy Diamicton is a basal till dating to the Older Dryas, because the stratigraphy at the adjacent Dale Bog demonstrated that this area had been ice free

Fig. 3. Photographs from Blomvåg. A. Oblique air photo of Blomvåg, view towards north. Note the exposed bedrock almost everywhere. The site where the cemetery was later constructed can be seen as a depression rising slightly towards the north, located to the left of the church. Dashed white lines mark the positions of the two drainage ditches and solid white lines the two scientific excavations. Photograph Widerøe, 1932. B. Photograph of the excavation site at Blomvåg Cemetery; view towards SE. Signs of the main drainage ditch, including heaps of boulders, can be seen along the steep bedrock wall. The people in the left part of the photograph mark the scientific excavations. Photograph Knut Fægri, June 1942. C. Whale bones from the Blomvåg excavations, dated to about 13.8 cal. ka BP. The scale is 20 cm. [Colour figure can be viewed at www.boreas.dk]

since 13.9 cal. ka (Table 2). These new ages triggered the present investigations aiming to determine whether the Ulvøy Diamicton is a till or not; if the Ulvøy Diamicton is a till, then all organic remains below the diamicton must pre-date the age of the final deglaciation of the site.

Material

The Blomvåg site is a cemetery that has been impossible to re-excavate. A number of samples from the excavations in 1941–1942 are stored, mainly in open boxes, in the Bergen University Museum. The boxes have pieces of paper with a short description of the stratigraphical position of the sample and we were able to relate some of these descriptions to field notes or drawings by scientists who participated in the excavations. The samples have been moved several times, and with the open boxes we cannot exclude the possibility that some have been interchanged, but we do not believe that this will influence our conclusions. Some of the field notes of Isak Undås, who was the main geologist, are unfortunately lost, but some notes exist. The field notes of Knut Fægri have been crucial for establishing the stratigraphical position of the samples. One of us (J.M.) also had long talks in the 1960–70s with both Undås and Fægri about the site. A notebook from Astrid Karlsen who identified wood samples is also available. We also use ^{14}C ages from sediment sections and cores retrieved from adjacent lake basins with the aim of constraining the timing of the final deglaciation from the Blomvåg area and thus to determine if the Ulvøy Diamicton is a till. Finally, we collected a series of samples from erratic boulders deposited by the retreating ice sheet for ^{10}Be dating.

Dating methods

Radiocarbon dating

The samples previously obtained from the Blomvåg site were either dated with the conventional method (T-) at the Trondheim Laboratory, or prepared in Trondheim and measured with an accelerator in Uppsala (Tua-) (Tables 1, 2). These samples were prepared according to standard procedures in Trondheim (Nydal *et al.* 1972), except one of the whale bone samples (T-1899/1). This sample was prepared with the old

Table 1. Radiocarbon dates from the Blomvåg Cemetery site, located at 60.5304°N, 4.878°E.

Lab. ID	Conv. ^{14}C age[1]	±1σ	*ΔR*	Calibrated ages (IntCal13) B1950					Sample ID given when dated	Dated material	Sediment/ Stratigraphy	δ^{13}C	References	Comments
				Median[3]	68% confidence interval									
					From	To	Midpoint	Half range						
Dates from marine molluscs														
Poz-65 953	12 700	70	100	14 090	13 985	14 180	14 083	98	Blomvåg 2014-7	Three pieces of shells, the largest being 8 mm	In the Ulvøy Diamicton			Museum box marked 'From a pocket in the till at i ca. 2 m depth in the middle ditch, about 4 m from the corner. Undås 1942'.
			0	14 258	14 082	14 406	14 244	162						
Poz-65 879	12 920	70	100	14 515	14 271	14 699	14 485	214	Blomvåg 2014-6	Thick piece of a shell, probably *Mya* or *Hiatella*	Shortly below the Ulvøy Diamicton			Museum box marked 'Clayey transitional bed (ca. 20 cm) directly below the till. I. Undås 19-10-41'
T-139	13 110	350	100	14 860	14 191	15 350	14 770	580	H. Holtedahl; Sample 2	*Mytilus edulis*			Nydal (1960)	The reported age (12 700 ^{14}C years) has a built-in correction for marine reservoir age of 410 years (Mangerud 1972).
T-1882	12 840	90	100	14 377	14 127	14 565	14 346	219	Mangerud; Blomvåg shells	*Mytilus edulis*	Plant-bearing bed, 3–4 m depth in large cross-ditch	−1.1	Gulliksen *et al.* (1978) Mangerud (1977)	The reported age (12 430 ^{14}C years) has a built-in correction for marine reservoir age of 410 years.
Poz-65 878	12 990	70	100	14 677	14 450	14 930	14 690	240	Blomvåg 2014-5	Two shell fragments, the largest is a 1-cm piece of *Mytilus*	Lowermost sample at the eastern end of the upper (northern) ditch			Museum box marked 'Sample 12. 295–300 cm'. K. Fægri field notes 14/6/1942.
			0	14 915	14 773	15 103	14 938	165						

(continued)

Table 1. (continued)

Lab. ID	Conv. ^{14}C age[1]	±1σ	*ΔR*	Calibrated ages (IntCal13) B1950					Sample ID given when dated	Dated material	Sediment/ Stratigraphy	$\delta^{13}C$	References	Comments
				Median[3]	68% confidence interval									
					From	To	Midpoint	Half range						
The following six mollusc samples from 'the southern cross-ditch' are described in Fægri's field notes 11/7/1942 and marked with depths and thus the relative stratigraphical order should be clear														
Poz-65 858	12 670	70	100	14 055	13 960	14 144	14 052	92	Blomvåg 2014-4	Shell fragments 2–8 mm. Contains at least one *Mytilus*	175–180 cm. Just below the diamicton			Museum box marked 'Blomvåg 7'.
			0	14 197	14 040	14 314	14 177	137						
Poz-65 857	13 000	70	100	14 705	14 488	14 963	14 725	238	Blomvåg 2014-3	Piece of *Mytilus edulis*	190–195 cm			Museum box marked 'Blomvåg 6'.
T-1697	12 980	150	100		14 308	14 961	14 634	327	Mangerud; Blomvåg 4	Fragments of *Modiolus modiolus*	245–250 cm	−1.4	Gulliksen *et al.* (1978) Mangerud (1977)	Museum box marked 'Blomvåg 4'. The reported age (12 570 ^{14}C years) has a built-in correction for marine reservoir age of 410 years.
Poz-65 855	13 020	70	100	14 758	14 570	15 024	14 797	227	Blomvåg 2014-2	Piece of *Mytilus edulis*	260–270 cm			Museum box marked 'Blomvåg 3'.
T-1696	12 980	180	100	14 645	14 282	14 993	14 637	356	Mangerud; Blomvåg 2	Fragments of *Modiolus modiolus*	295–305 cm. Lowermost shell-bearing sample in this series	−1.7	Gulliksen *et al.* (1978) Mangerud (1977)	Museum box marked 'Blomvåg 2'. The reported age (12 570 ^{14}C years) has a built-in correction for marine reservoir age of 410 years.
Poz-65 854	13 020	70	0	14 972	14 831	15 137	14 984	153	Blomvåg 2014-1	Shell fragments 2–4 mm. Contains *Mytilus*	295–305 cm. Lowermost shell-bearing sample in this series			Museum box marked 'Blomvåg 2', i.e. same box as sample T-1696
			100	14 758	14 570	15 024	14 797	227						
			200	14 515	14 271	14 699	14 485	214						

(continued)

Table 1. (continued)

Lab. ID	Conv. ^{14}C age[1]	±1σ	*ΔR*	Calibrated ages (IntCal13) B1950					Sample ID given when dated	Dated material	Sediment/ Stratigraphy	$\delta^{13}C$	References	Comments
				Median[3]	68% confidence interval									
					From	To	Midpoint	Half range						
Dates from whale bones, probably the same individual of *Balaena mysticetus*, English: Bowhead whale, Norwegian: Grønlandshval														
T-1899/1	12 550	100	100	13 931	13 814	14 049	13 931	118	Mangerud; Blomvåg whale	Bowhead whale	Muddy sand	−16.6	Gulliksen *et al.* (1978) Mangerud (1977)	Dessolved in HCl; i.e. the bone apatite is dated. This preparation method is no longer used. Age omitted from the discussion.
T-1899/2	12 360	80	100	13 719	13 610	13 829	13 719	110	Mangerud; Blomvåg whale	Bowhead whale	Muddy sand	−17.4	Gulliksen *et al.* (1978) Mangerud (1977)	Prepared with the EDTA method, i.e. the collagen is dated.
Tua-5348	12 465	110	100	13 838	13 709	13 987	13 848	139		Bowhead whale	Muddy sand		Ø. Wiig, pers. comm. 2015.	Collagen date. The reported age (12 025 ^{14}C years) is corrected for 440 years marine reservoir age.
Poz-69 682	12 510	60	100	13 890	13 805	13 972	13 888	84	Blomvåg 2014-15	Bowhead whale	Muddy sand			Collagen date. A different bone from the other whale bone dates. 9.4% collagen (C/N_{at} = 3.27).
Mean for 3 last samples			100	13818	13716	13925	13820	105						
Other bone samples														
Tua-902	11 875	80	100	13 254	13 188	13 318	13 253	65		Eider, *Somateria mollissima*. Norw.: Ærfugl	Probably from the muddy sand	−14.4	Elisabeth Eriksen, pers. comm. 2008.	Reported age (11 435 ^{14}C years) is corrected for 440 years marine reservoir age (Steinar Gulliksen, pers. com. 2008).

(continued)

Table 1. (continued)

Lab. ID	Conv. ^{14}C age[1]	$\pm1\sigma$	ΔR	Calibrated ages (IntCal13) B1950					Sample ID given when dated	Dated material	Sediment/ Stratigraphy	$\delta^{13}C$	References	Comments
				Median[3]	68% confidence interval									
					From	To	Midpoint	Half range						
Tua-1152	12 240	75	100	13 591	13 486	13 686	13 586	100		Common guillemot, *Uria aalge.* Norw.: Lomvi	Probably from the muddy sand	−16.1	Elisabeth Eriksen, pers. comm. 2008.	Reported age (12 240 ^{14}C years) is not corrected for marine reservoir age (Steinar Gulliksen, pers. comm. 2008), but according to A. K. Hufthammer (pers. comm. 2008) this bird feeds only on marine food.
Tua-1153	12 645	95	100	14 033	13 905	14 142	14 023	119		Common schoter, *Melanitta nigra.* Norw.: Svartand	Probably from the muddy sand	−13.7	Elisabeth Eriksen, pers. comm. 2008.	Reported age (12 645 ^{14}C years) is not corrected for marine reservoir age (Steinar Gulliksen, pers. comm. 2008). This bird also lives in freshwater, but at that time it probably only had marine food (A. K. Hufthammer, pers. comm. 2008).
Tua-1151	11 605	85		13 432	13 334	13 539	13 436	103		Bone of reindeer, *Rangifer tarandus*	Probably from the muddy sand	−17.1	Elisabeth Eriksen, pers. comm. 2008.	
Poz-69 681	11 710	60		13 528	13 462	13 652	13 557	95	Blomvåg 2014-13	Bone of reindeer, *Rangifer tarandus.* Norw. Reinsdyr	Probably from the muddy sand			A different bone from Tua-1151. 2.6% collagen (C/N_{at} = 3.36).
Mean for reindeer	11 660	75		13 490	13 424	13 563	13 493	70						

(continued)

Table 1. (continued)

Lab. ID	Conv. ^{14}C age[1]	±1σ	*ΔR*	Calibrated ages (IntCal13) B1950					Sample ID given when dated	Dated material	Sediment/ Stratigraphy	$\delta^{13}C$	References	Comments
				Median[3]	68% confidence interval									
					From	To	Midpoint	Half range						
Wood samples														
T-138	12 200	350		14 287	13 731	14 821	14 276	545	H. Holtedahl; Sample 1	Wood			Nydal (1960)	Originally reported as 12 100 ^{14}C years, but recalculated to 12 200 (R. Nydal pers. comm. 1976) Stored in spirit.
Poz-67 670	11 600	60		13 429	13 352	13 482	13 417	65	Blomvåg 2014-10	Wood. Identified by A. Monsen as *Populus* or possibly *Salix*	Muddy sand			Stored in unknown preservatives in a small glass tube marked '33a'. Paper in the glass says: 'Wood from the bed immediately below the till in the lower cross-ditch. Undås 2/7-42'.
Poz-67 671	12 120	60		13 984	13 856	14 085	13 970	115	Blomvåg 2014-11	Wood. Identified by A. Monsen as *Salix*	Probably from the muddy sand			Stored in unknown preservatives in a small glass tube marked '34b'.
Poz-67 672	11 370	60		13 212	13 148	13 272	13 210	62	Blomvåg 2014-12	Wood Species unknown	Probably from the muddy sand			Stored in unknown preservatives in a large, unmarked glass tube. The largest piece of wood in the collection.
Mean 3 last wood dates	11 700	385		13 608	13 121	14 005	13 563	442						

[1]Conventional ^{14}C age is uncorrected for marine reservoir age.
[2]*ΔR* value used in Calib 7.1 for correction for marine reservoir ages.
[3]Median for the full probability distribution.

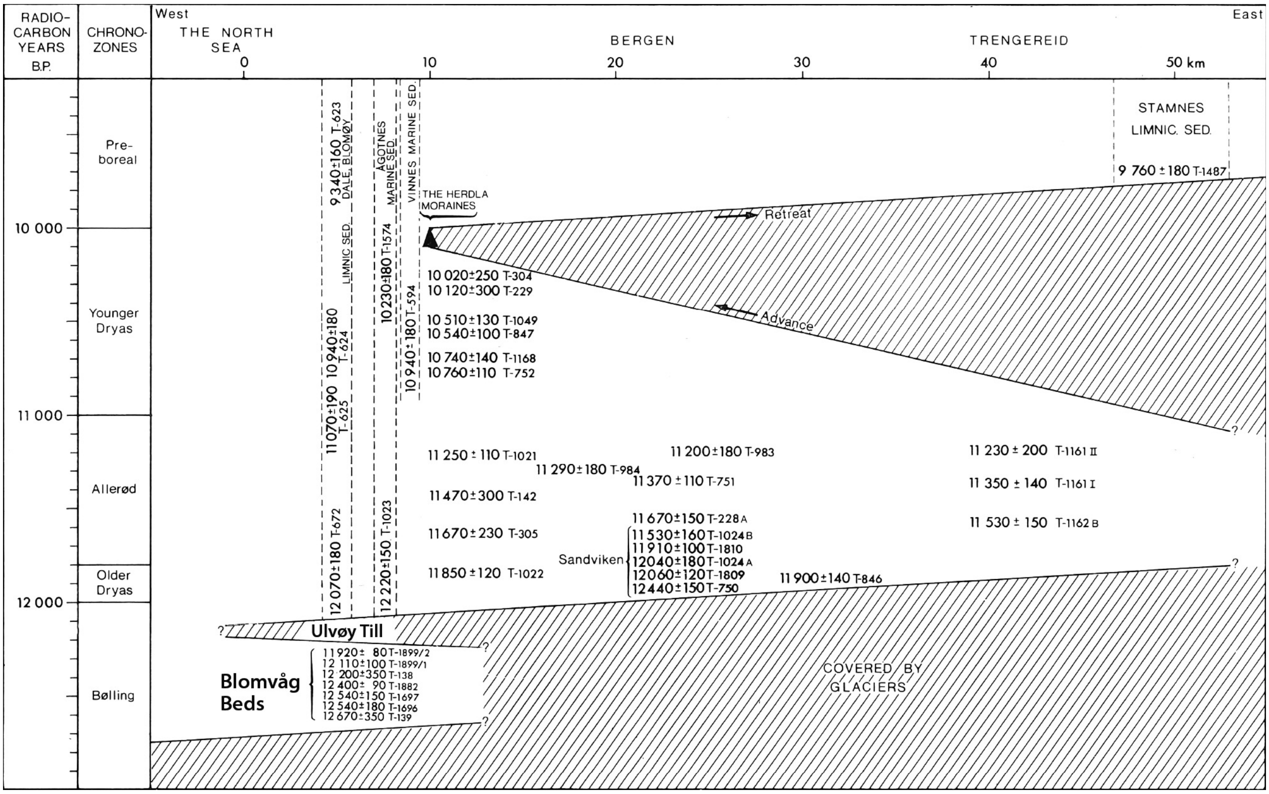

Fig. 4. A time-distance diagram from Mangerud (1977) that shows the glacial-geological interpretation of the succession at Blomvåg Cemetery that has been accepted up to now. The diamicton, on this diagram called the Ulvøy Till, covering the fossil-bearing Blomvåg Beds, was considered to represent an Older Dryas glacial advance.

method, namely dissolving the bone in HCl, and it is omitted from the discussion in the present paper, although the age overlaps within a standard deviation with the parallel sample (T-1899/2) that was prepared with the Longin (1971) method.

When we started with the new series of radiocarbon ages (the Poz- samples) it was clear that we needed high accuracy and precision to test the different hypotheses. An additional problem was that some of the samples had been treated with preservatives of unknown chemical composition. Therefore, special care was taken to select and prepare samples in order to avoid possible contamination. The preparation methods in the Poznan laboratory generally followed those described by Brock *et al.* (2010). From mollusc shells, before collecting carbon for ^{14}C, the possibly recrystallized outer layer (20–30% of the mass) was removed with HCl, and organic coating was removed with H_2O_2. From bones, extraction of collagen with the Longin (1971) protocol was preceded by removal of humic acids, and followed by ultrafiltration of the collagen (Bronk Ramsey *et al.* 2004). Quality of the collagens was indicated by high extraction yields and confirmed by atomic C/N ratios that appeared (Table 1) well inside the acceptance interval of 2.9–3.5 (e.g. Brock *et al.* 2012). Knowing that the reindeer bones had been stored in preservatives, before extracting collagen, we treated this sample several times with acetone to remove PVA and resistol, alcohol to remove shellac, and water. The issue of preservatives in wood samples was addressed similarly as with bones, including additional treatment with gasoline to remove petroleum-descending compounds, and – after the common AAA treatment – by extracting alpha-cellulose according to the method described by Nemec *et al.* (2010), thus removing the potentially mobile fraction such as lignins, waxes and resins.

Conventional radiocarbon ages were calibrated vs. the IntCal13 or Marine13 calibration curves (Reimer *et al.* 2013) for samples of terrestrial or marine origin, respectively, using the CALIB calibration program, version 7.1 (http://calib.qub.ac.uk/calib/). Calibrated radiocarbon ages are referred to 1950 using the designation BP, as for conventional radiocarbon ages. The marine reservoir correction is significant for the precision sought, especially because there is a plateau in the marine calibration curve at 14.3–14.6 cal. ka BP. Bondevik *et al.* (2006) found that that the ΔR value for this coast of Norway fluctuated during the Lateglacial, but was around 100 for much of the period from 14 to 13 cal. ka BP. Theoretically, it should be possible to determine the marine reservoir ages at the site as the

Table 2. Radiocarbon dates from Blomøy, Ågotnes, Bjorøy and Os.

Sites	Lat. °N	Long. °E	Sample ID	Lab. ID	Conv. ^{14}C age	±1σ	Δ*R*	Calibrated ages (IntCal13) B1950					Dated material	Sediment/ Stratigraphy	References
								Median	68% confidence interval						
									From	To	Midpoint	Half range			
Dale bog, Blomøy	60.5366	4.878		T-672	12 070	180		13 961	13 651	14 192	13 921	271	Gyttja clay	Lowest organic in palaeolake	Mangerud (1970)
Dale bog, Blomøy	60.5366	4.878	265–272 cm	Beta-51 465	12 030	110		13 891	13 758	14 018	13 888	130	Mosses	As sample above	H. H. Birks, pers. comm. (2014)
Dale bog, Blomøy	60.5366	4.878	260–264 cm	Beta-51 464	12 110	110		13 973	13 807	14 092	13 950	143	Mosses	Slightly higher	H. H. Birks, pers. comm. (2014)
Mean for 3 Dale bog samples											13 920	31			
Hamrevatn, Sotra	60.2068	5.0855	1312–14 cm	Poz-4817	12 090	60		13 940	13 833	14 033	13 933	100	*Rhacomitrium*, *Polytrichum*, twig	Next lowermost sample	Lohne *et al.* (2007)
Hamrevatn, Sotra	60.2068	5.0855	1348–50 cm	Poz-4818	12 270	70		14 207	14 049	14 325	14 187	138	Leaf fragments, mosses	Lowermost sample	Lohne *et al.* (2007)
Sele Bog, Blomøy	60.5288	4.8942	897–900 cm	Poz-75 514	12 800	70	100	14 258	14 082	14 406	14 244	162	Shell fragments	Lowermost sample	
Sele Bog, Blomøy	60.5288	4.8942	881–884 cm	Poz-75 515	12 690	70	100	14 078	13 977	14 167	14 072	95	Shell fragments	Next lowest sample	
Ågotnes	60.410	5.010	Sample 20	T-1023	12 660	150	100	14 090	13 819	14 280	14 050	230	Shell fragments		Mangerud (1977)
Ågotnes	60.410	5.010	Sample 20	Poz-67 900	12 690	60	100	14 076	13 990	14 156	14 073	83	Shell fragments		Mangerud *et al.* (2016)
Ågotnes	60.410	5.010	Sample 22	Poz-67 901	12 810	60	100	14 264	14 101	14 397	14 249	148	Shell fragments		Mangerud *et al.* (2016)
Store Hellervatn, Bjorøy	60.3196	5.1692		Poz-44 184	12 750	70	100	14 162	14 025	14 265	14 145	120	Shell fragments	In till	Skår (2012)
Storum, Os	60.1619	5.4137	Storum-1	Poz-79 831	12 910	60	100	14 487	14 271	14 665	14 468	197	*Hiatella arctica*	Base of glaciomarine clay	
Storum, Os	60.1619	5.4137	Storum-2	Poz-79 870	12 950	70	100	14 578	14 311	14 769	14 540	229	Paired *Hiatella arctica*	5 cm above Storum-1	
Storum, Os	60.1619	5.4137	Storum-3	Poz-79 871	12 900	60	100	14 466	14 255	14 645	14 450	195	*Chlamys islandica*	Grey silt	

Table 3. ^{10}Be samples from Blomvåg and Liatårnet. All samples with a rock density of 2.65 g cm^{-3}; zero rock surface erosion. Ages are given as conventional ^{10}Be ages, i.e. calculated relative to the year of collection (B2014). For a precise comparison with calibrated ^{14}C ages (i.e. B1950) 64 years should be subtracted.

Sample	Sample type	Boulder height (m)	Boulder width (m)	Lat. (°N)	Long. (°E)	Elevation (m a.s.l.)	Sample thick. (cm)	Topo. shield. factor	^{10}Be concentr. (atoms g^{-1})	^{10}Be age[1]	^{10}Be age[2]
Blomvåg											
14NOR-62	Boulder	1.5	1.8×2.3	60.5395	4.8816	35	1.0	1.000	63 600±2020	14 231±454	14 707±469
14NOR-66	Boulder	0.6	1.0×1.0	60.5468	4.8669	39	2.0	1.000	65 400±1400	14 687±316	15 180±326
14NOR-69	Boulder	1	1.0×1.5	60.5451	4.8656	41	2.0	1.000	67 000±1650	15 016±371	15 519±384
14NOR-67	Boulder	0.8	1.2×1.0	60.5463	4.8670	43	2.5	1.000	48 100±989	10 788±222	11 149±230
14NOR-64	Bedrock	NA	NA	60.5477	4.8670	35	3.0	1.000	72 300±1390	16 444±317	16 995±328
14NOR-61	Boulder	1.3	3.0×3.0	60.5380	4.8810	40	1.0	0.997	67 500±1560	15 069±350	15 574±361
14NOR-65	Boulder	0.5	1.3×1.0	60.5470	4.8670	56	1.0	1.000	63 100±1360	13 802±298	14 264±309
15NOR-1	Boulder	0.5	1.5×1.7	60.54356	4.8666	37	2.0	1.000	63 090±3053	14 200±689	14 676±712
Mean Blomvåg, excluding outlier (sample -67) and bedrock sample (-64)										14 501±505	14 987±522
Weighted mean Blomvåg, excluding outlier (sample -67) and bedrock sample (-64)										14 511±151	14 998±156
Liatårnet											
14NOR-73	Boulder	2.5	4.0×2.0	60.3190	5.1170	313	1.0	0.9903	82 900±2120	14 138±363	14 615±375
14NOR-70	Boulder	0.5	1.0×0.7	60.3191	5.1162	328	2.0	1	97 100±1880	16 308±317	16 859±328
14NOR-71	Boulder	1	0.5×2.0	60.3196	5.1160	319	1.5	1	94 300±2460	15 910±417	16 448±431
14NOR-72	Boulder	1.8	3.0×2.0	60.3193	5.1172	310	1.0	1	87 000±1730	14 743±294	15 241±304
Mean Liatårnet										15 275±1008	
Weighted mean Liatårnet										15 250±169	

[1]Western Norway production rate (Goehring *et al.* 2012a, b); calculated using CRONUS Earth; http://hess.ess.washington.edu/math/al_be_v22/alt_cal/alt_cal.html.
[2]Arctic production rate (Young *et al.* 2013); calculated using CRONUS Earth; http://hess.ess.washington.edu/math/al_be_v22/alt_cal/alt_cal.html.

Blomvåg Beds contain both terrestrial and marine fossils; this was done by Mangerud (1972). However, the stratigraphical positions of the samples within the Blomvåg Beds are too poorly known to obtain precise results. Because the development of ΔR through the period of focus is not precisely known, we calibrated all samples using $\Delta R = 100$. However, Table 1 shows some samples calibrated with other ΔR values. As an example of the impact of the ΔR value, we consider the age 13 020±70 ^{14}C years BP for the basal shell sample. When using $\Delta R = 0$, 100 and 200, the median calibrated age would be 15.0, 14.8 and 14.5 cal. ka BP, respectively.

In order to cite only one age in the text, and not an interval, we use the midpoint of the 68% confidence interval of the calibrated age and uncertainty as ± half of that interval (Tables 1, 2). We note that the maximum difference between this midpoint and the median for the full probability distribution is 39 years and for most samples the difference is <10 years.

Cosmogenic ^{10}Be exposure dating

Eleven erratics and one bedrock sample for ^{10}Be exposure dating were collected in 2014 and 2015 from sites 1–2 km north of Blomvåg (n = 8) and from the summit of Liatårnet (= Lia in Fig. 1B), ~25 km south of Blomvåg. Sampled boulders were perched on exposed bedrock, on either mounds or flat surfaces, in positions where it is unlikely that they had been moved or overtopped. We sampled the top 2–3 cm of surfaces using a diamond saw, a method that yields pieces of similar thickness. We sampled mostly flat surfaces and avoided edges, and used a clinometer to measure topographic shielding and a hand-held GPS receiver to record sample location and elevation. The altitude of the various sample locations north of Blomvåg ranges from ~35 to ~56 m a.s.l. and we are confident that all samples were collected from above the local marine limit. The samples were prepared for ^{10}Be analysis at the University at Buffalo Cosmogenic Nuclide Laboratory. Following crushing, sieving and quartz isolation, samples were digested and beryllium isolated following procedures described in Young *et al.* (2013). ^{10}Be/^{9}Be ratios were measured at the Center for Mass Spectrometry, Lawrence Livermore National Laboratory and normalized to standard 07KNSTD3110 with a reported ratio of 2.85×10^{-12} (Nishiizumi *et al.* 2007; Rood *et al.* 2010). Procedural blank ratios range from 1.1×10^{-15} to 3.9×10^{-15}, equating to background corrections of 1 to 4% of the sample total.

The ^{10}Be ages were calculated using the CRONUS-Earth online exposure age calculator (Balco *et al.* 2008; version 2.2 constants 2.2). We adopted a regionally constrained production rate from southwestern Norway of 4.15±0.15 at $g^{-1}a^{-1}$ (Goehring *et al.* 2012a, b) with Lm scaling (Balco *et al.* 2008). However, for comparison, in Table 3 we have also included ages calculated with the often-used Arctic production rate of 3.96±0.15 at $g^{-1}a^{-1}$ (Young *et al.* 2013). Snow shielding is not important at these elevations, certainly not at present and we consider neither during deglaciation. Some outcrops retain glacial polish; thus, postdepositional bedrock surface erosion is negligible. The field area has undergone <30 m isostatic-driven emergence since deglaciation (Lohne *et al.* 2007), and the minor influence this has on the ^{10}Be ages may be offset by effects of atmospheric pressure changes related to ice-sheet proximity and glacial-world atmospheric compression (Staiger *et al.* 2007) and the ages that we report are therefore not adjusted for isostatic uplift.

In the exposure dating community the convention is to report the age in years before the sampling year. Our ^{10}Be samples were collected in 2014 and we use the designation 'B2014' for such calculated ages, but in order to compare them with radiocarbon ages we convert them to refer to 1950, and then use the designation 'B1950'.

The Blomvåg site

Location and lithostratigraphy

The Blomvåg site is located about 5 km to the west of the Younger Dryas ice-sheet limit (Fig. 1B). The area around the cemetery is characterized by exposed gneissic bedrock; Quaternary sediments are found only in depressions (Fig. 3A). West of the Blomvåg church (the building to the right in Fig. 3A) there is a shallow depression gently rising towards the north, from about 13 to 17 m a.s.l. where a cemetery was planned in 1941. Most of the descriptions and samples are from the upper part where the original surface was at 16–17 m a.s.l. The depression to is bounded the east by an NS–trending bedrock cliff and to the west by a gently rising bedrock slope (Fig. 3B). Also to the north there is a small cliff (Fig. 3A). In order to improve the drainage for the planned cemetery, a ditch was dug along the bedrock cliff and a parallel ditch on the other side of the depression; approximate positions are marked in Fig. 3A. Two cross ditches, numbered 1 and 2, were excavated for scientific purposes, both in the upper part of the area; the deepest was about 5 m deep (Fig. 5A). Scientific ditch no. 2 connected the northern part of the two drainage ditches whereas no. 1 was an isolated ditch north of no. 2 (Fig. 3A).

Detailed descriptions of the sediments and the stratigraphy are not available and apparently there were some differences between the ditches. However, a profile drawing made by Fægri seems to be representative of the stratigraphy (Fig. 6). The excavations reached bedrock, which in at least some places was covered by a thin diamicton interpreted as basal till. In

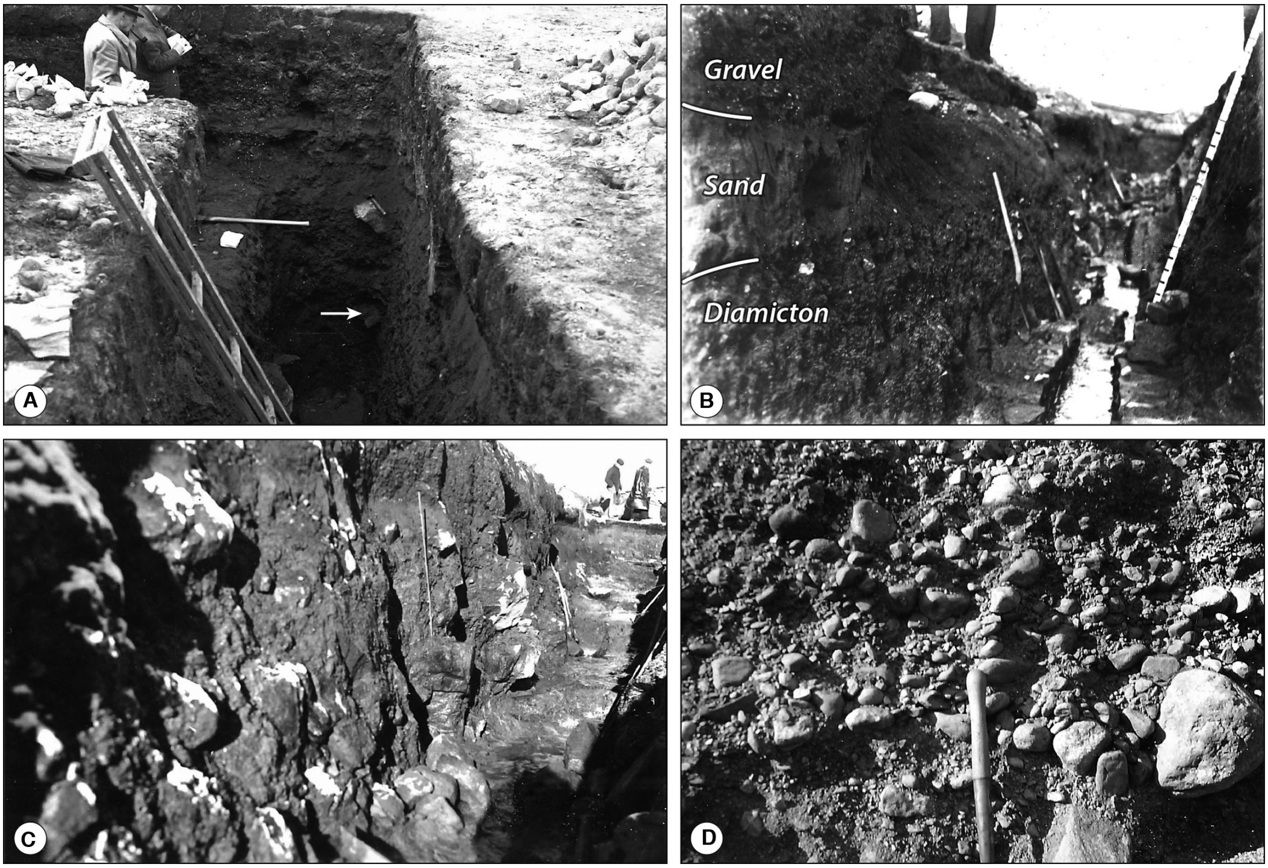

Fig. 5. Photographs of the excavations at the Blomvåg Cemetery. A. The east end of scientific excavation 1. On top is postglacial sand and gravel. The Ulvøy Diamicton is between the boulder with a hammer in the distant right-hand corner and the arrow ~1 m lower. Below the arrow are the fossil-bearing Blomvåg Beds. The heap of boulders to the right in the background probably derives from the diamicton. Photograph Knut Fægri, June 1942. B. The northern part of the eastern drainage ditch showing the Ulvøy Diamicton and overlying sediments. The boundaries were marked on the photo by Undås who used the term 'till' for the diamicton. The fossil-bearing sediments are located below the drainage construction seen in the bottom. Photograph Isak Undås, October 1941. C. The northern part of one of the drainage ditches, probably the eastern ditch. The stratigraphy was not described on the photograph, but the boulder-rich sediment in the foreground is obviously the Ulvøy Diamicton and the postglacial sand and gravel can be seen above the measuring stick in the middle of the photo. Photograph Astrid Monsen, 1941. D. A facies of the Ulvøy Diamicton containing rounded cobbles. Written on the reverse side of the photograph was that this is a close-up of the densely packed till. Scale: shaft of a shovel. Photograph Astrid Monsen, 1941.

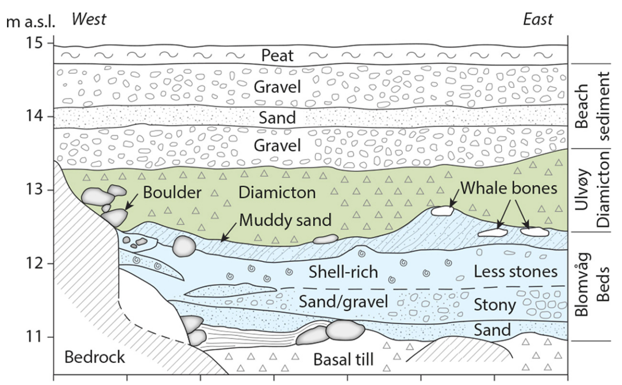

Fig. 6. Sketch of the northern wall of scientific excavation 2 (the lower cross-ditch) based on a measured profile by Fægri (field notes 1942) with some additional information from Undås (field notes 1941–42). This stratigraphy is representative for all ditches taking account of variations in facies and bed thicknesses. [Colour figure can be viewed at www.boreas.dk]

the upper part of this unit there were boulders surrounded by irregularly bedded sand (Fig. 7A), probably also of subglacial origin. The main sediment succession can be subdivided into four main units from the base: (i) glacial sediments, (ii) fossil-bearing sediments, later named the Blomvåg Beds (Mangerud 1977), (iii) a diamicton, always called 'till' by the excavating scientists, re-named the Ulvøy Diamicton here, and (iv) sand and gravel layers capping the succession, interpreted as beach sediments deposited during the postglacial emergence. We will not discuss the uppermost unit further because no datable material was found and the given interpretation appears clear.

There is an unconformity between the basal glacial unit and the overlying 1–1.5 m thick Blomvåg Beds. The lowest part of the Blomvåg Beds consists of sand with sparse small shell fragments. Above this sand is the thickest zone that Fægri described as shelly sand

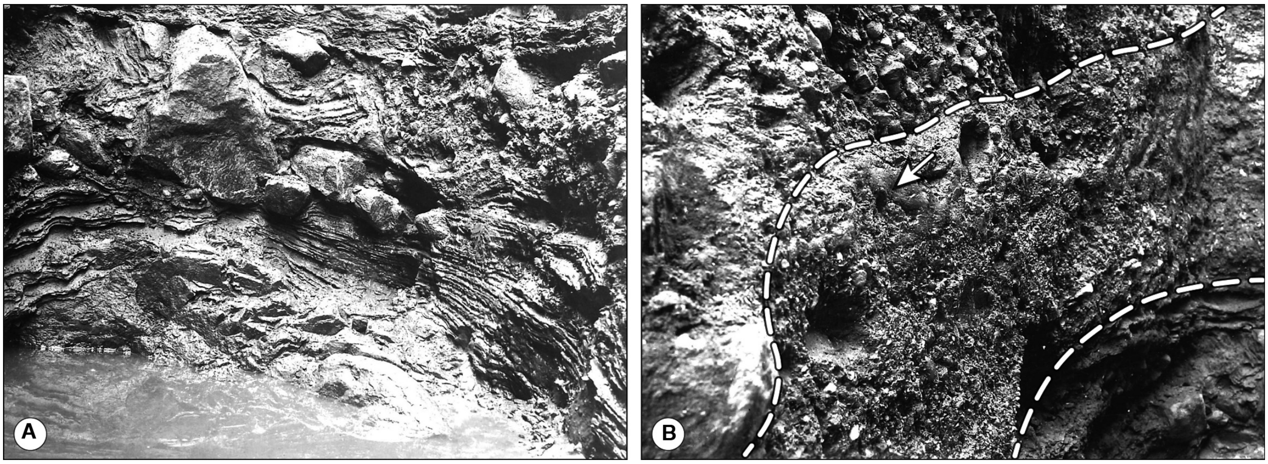

Fig. 7. Photographs from the excavations at Blomvåg Cemetery. A. Boulders and bedded sand, interpreted as glacial sediments at the base of the excavation. Northern wall of scientific excavation 2. Photograph Knut Fægri, July 1942. B. The southern wall of scientific excavation 2. Boundaries of units are marked by us, following descriptions on the reverse side of the photograph. In the lower right-hand corner, the glacial sediments overlain by the fossil-bearing Blomvag Beds are delimited by dashed white lines. Arrow points to a lens of mud. The upper unit is the Ulvøy Diamicton. Photograph Knut Fægri, July 1942.

that contains many pebbles in the lower part, but fewer in the upper half (Fig. 6). Undås described this unit as gravel with shells, but on a sketch he also drew thin beds of sand, more shell-rich zones and a horizon with more seaweed. Thus, it seems clear that this unit consists of a mixture of sand and gravel, partly as thin beds or lenses with many shells and especially shell fragments. A few bones were found in this unit, and it contains organic matter, probably mainly from marine organisms.

The uppermost zone in the Blomvåg Beds is brownish muddy sand, often termed a mud layer in the field notes. It contains fewer pebbles than the rest of the Blomvåg Beds. In some field sketches (Fig. 6), this zone was marked as a separate bed, but it was described as flames or lenses (Fig. 7B) and was disturbed by boulders in the overlying diamicton. The term 'mud' was ascribed to a high content of organic matter. The whale bones and most other bones were found in this upper zone of the Blomvåg Beds, although several whale bones penetrated into the overlying Ulvøy Diamicton. Most, and possibly all, pieces of wood also came from this zone, whereas Undås (1942) mentioned that it contained many fewer shell fragments than the underlying strata.

The Blomvåg Beds were always interpreted as shallow-water or beach sediments (Undås 1942), an interpretation that we support. Based on the present knowledge of sea-level change, it is now possible to estimate the water depth at the site. Figure 8 shows a relative sea-level curve for Blomvåg, constructed from data in Lohne *et al.* (2007). Following deglaciation, the high tide fell to a level around 18 m a.s.l. during the Allerød. The highest area excavated at the Blomvåg Cemetery site is located about 17 m a.s.l., suggesting

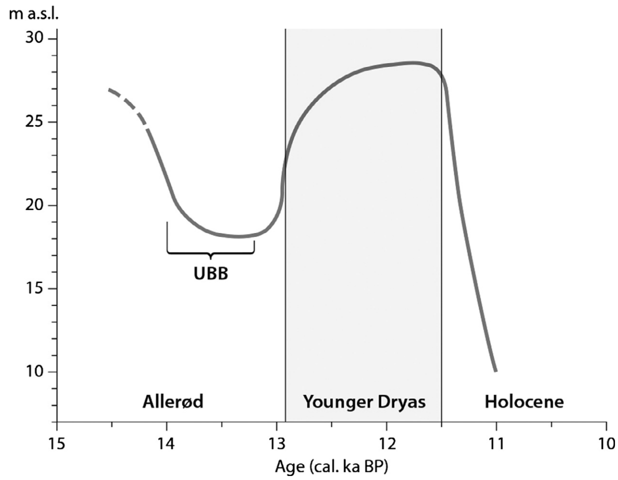

Fig. 8. A relative sea-level curve for Blomvåg constructed from data in Lohne *et al.* (2007). The curve represents the high tide level and low tide should be ~2 m lower. Maximum errors are estimated as 3–5 m in elevation. Note that sea level following deglaciation was at, or close to, the level of the Blomvåg Cemetery during the Allerød before rising 10 m in the Younger Dryas. The age of the upper parts of the Blomvåg Beds are marked UBB.

that the upper part of the Blomvåg Beds accumulated in very shallow water and some possibly even in the beach zone. The presence of driftwood in this unit supports the interpretation that the sediments represent a former beach. The age of the reindeer bones (13.5 cal. ka BP) corresponds with the start of the sea-level lowstand (Fig. 8), and most other bones and wood may also have been deposited during the lowstand period. The youngest ^{14}C ages in the Blomvåg Beds are 13.4–13.2 cal. ka BP (Table 1). Fossils and sediments dating from the last few hundred years of the Allerød are missing, probably because of non-deposition when the water depth became too shallow and/or there was erosion when the overlying Ulvøy Diamicton was emplaced.

Two observations were especially important for the interpretation of the Ulvøy Diamicton as a till. Firstly, it was described as a compacted non-sorted sediment unit that was difficult to dig by spades and picks. Secondly, the Ulvøy Diamicton contains numerous boulders. Johansen & Undås (1992) mentioned a large erratic at the site, about 20 m long and 4 m high, even though it is not evident from the description whether it overlaid the Blomvåg Beds or not. The photos show that the Ulvøy Diamicton contains a range of sediment facies. Figure 5A shows a 1-m-thick matrix-supported diamicton, apparently somewhat similar to the diamicton in Fig. 5B, whereas the diamicton in Fig. 5C contains more large boulders. A very different facies is seen in Fig. 5D (and some other photos) where the so-called till consists of rounded gravel, which almost certainly is re-deposited beach gravel. The diamicton contained some boulders of rock types originating from the bedrock in Oslofjorden and Danish areas, which were interpreted as iceberg-transported material later picked up and deposited on the site by the ice sheet. Such rock types are often found below marine limit along the coast of western Norway and are commonly considered to have been transported by icebergs or sea ice. Fægri mentioned that shells could be seen in the diamicton and in places he even refers to the diamicton as a 'fossil-bearing till'.

Radiocarbon ages

Twenty-four radiocarbon ages are presently available from the Blomvåg cemetery site (including the whalebone age we omit); 23 from the Blomvåg Beds and one from the Ulvøy Diamicton (Table 1); 11 are new ages obtained for the present paper. It should be noted that the relative stratigraphical position within the Blomvåg Beds is known only for one series of shells (Fig. 9). For these samples, the sediment depths were given on the sample boxes. It was mentioned in the field notes that most bones were found in the upper parts of the Blomvåg Beds. Therefore, we have plotted all such samples in the upper part (Fig. 9), but emphasize that their relative position to each other is unknown.

The mollusc shells yielded the oldest ages; the two oldest yielded identical ages of 14.8±0.2 cal. ka BP (Table 1), and the ages are surprisingly similar throughout the lowest 1 m of the sediments (Fig. 9). The fact that the dated shells did not yield younger ages upwards in the succession could be explained either by rapid deposition or by the re-deposition of shell fragments. According to the field notes, there were few shell fragments in the upper part of the Blomvåg Beds. It is striking that all shell ages are older than the whale bones and two of the three marine bird bones. This suggests that molluscs may not have lived at the site during deposition of the upper part of the Blomvåg Beds when water depths were very shallow. Alternatively, shells could have been dissolved due to

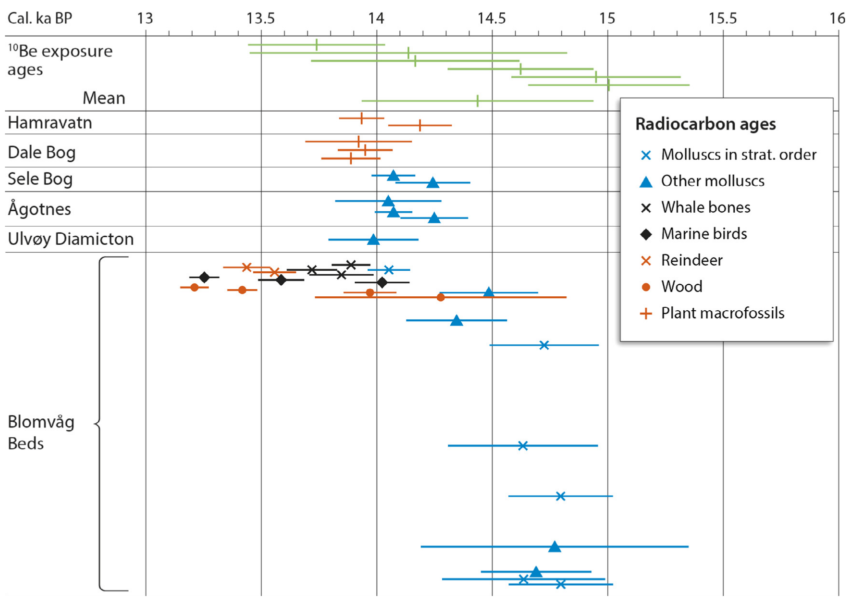

Fig. 9. Radiocarbon and ^{10}Be exposure ages. Samples from the Blomvåg Beds with known depths (mainly those marked as 'Molluscs in strat. order') are plotted correctly relative to each other, assuming that the unit was 1.3 m thick. Most other samples from the Blomvåg Beds were, however, only described as from 'the upper part' and they are here plotted in a random order for efficient use of space. The sample from the Ulvøy Diamicton is plotted above the Blomvåg Beds. Radiocarbon samples from Ågotnes, Sele Bog and Dale Bog, which all should provide minimum ages for deglaciation, are plotted in random vertical positions. All radiocarbon ages as plotted as midpoint and 68% confidence interval. Exposure ages from Blomvåg are shown at the top, including a mean. [Colour figure can be viewed at www.boreas.dk]

more acidic conditions produced by the organic matter, but we find that less probable. The size and composition of the whale bones suggest that they stem from one individual, and the ages overlap within one standard deviation; the mean age is 13.8±0.1 cal. ka BP (n = 3). The ages of the marine birds range from 13.3 to 14.0 cal. ka BP (n = 3).

It is highly probable that the reindeer bones come from one individual and the ages also overlap; the average is 13.5±0.07 cal. ka BP (n = 2). Reindeer in Norway and Svalbard do not eat seaweed (E. Reimers & N. Tyler, pers. comm. 2015) and even at South Georgia, which is sparsely vegetated, the content of seaweed in reindeer rumens was found to be minimal (Leader-Williams *et al.* 1981). Thus, we consider the reindeer ages as secure terrestrial radiocarbon ages. Two of the dated wood pieces yielded ages as young as 13.2±0.1 and 13.4±0.1 cal. ka BP (Fig. 9). Finally, we obtained an age of 14.0±0.2 cal. ka BP on shell fragments from a sample marked 'from a pocket in the till', an age similar to the youngest shell fragments below the diamicton.

We conclude that the Blomvåg Beds accumulated from about 14.8 cal. ka until about 13.3 cal. ka BP (Fig. 9) and that the shell fragments in the Ulvøy Diamicton are re-deposited from the Blomvåg Beds below.

The origin of the Ulvøy Diamicton

In view of the original descriptions and some of the photographs (Fig. 5B, C), the interpretation of the Ulvøy Diamicton as a basal till appears to be plausible. It is also noteworthy that all scientists who worked or visited the site confidently concluded that it was a basal till. However, the available radiocarbon ages contradict this interpretation. If the Ulvøy Diamicton is a till then all fossils below the diamicton have to pre-date the final deglaciation of the site. Radiocarbon ages from three sites located close to the Blomvåg Cemetery and described below have provided independent minimum ages for the final deglaciation of the area. Due to uncertainties surrounding the magnitude of marine reservoir errors, age differences are compared either between terrestrial samples only, or independently between marine samples.

Dale Bog is a palaeolake, located about 600 m north of the cemetery (Fig. 2). It contains a well-dated full Allerød-Younger Dryas pollen sequence without any disturbances, demonstrating that the final deglaciation must pre-date the Allerød. This led Mangerud (1970) to conclude that the Ulvøy Diamicton, at that time considered to be a till, was deposited by an Older Dryas re-advance of the Scandinavian Ice Sheet (Fig. 4). A sample taken at the base of brownish organic silt yielded an age of 13.9±0.2 cal. BP on bulk organic matter (Table 2). There is a 10-cm-thick layer of bluish-grey silt below the dated level. Later, plant macrofossils from the same level in a new core were dated to 13.9±0.1 and 13.9±0.1 (H.H. Birks, pers. comm. 2014; Mangerud *et al.* 2016), yielding a mean age of 13.9±0.1 cal. ka BP for all three samples. This mean age is 430±80 and 710±70 years older than the mean ages of the reindeer bones (13.5±0.07 cal. BP; n = 2) and the youngest wood sample (13.2±0.06 cal. ka BP) from levels below the Ulvøy Diamicton, respectively (Fig. 9).

At the Ågotnes site, located on Sotra island (Fig. 1B), an exposure of Allerød-Younger Dryas marine sediments showed no traces of being overridden by glacier ice (Mangerud 1977). The oldest shell samples from this section yielded ages of 14.2 and 14.1 ca ka BP (Table 2). The oldest age is 250±130 and 1000±180 cal. years older than the mean value for the whale bones and the youngest age of marine bird remains below the Ulvøy Diamicton, respectively (Fig. 9).

Sele Bog is located 1.0 km east of the cemetery (Fig. 2) at about 20 m a.s.l. and thus it was located below sea level during the deglaciation and also during the Younger Dryas (Fig. 8). We cored it with a hand-driven 'Russian' corer in 2015 in order to obtain ages on marine fossils that would yield minimum ages for local deglaciation. During coring we hit bedrock underneath a 900-cm-thick sediment succession of marine and lacustrine sediments. On the bedrock surface in the deepest part of the basin, between 900–772 cm, is massive, olive-grey marine silt that contain numerous marine shell fragments, with *Mytilus* fragments at the very base of the core. Radiocarbon dates from small shell fragments yielded the ages 14.2 and 14.1 cal. ka BP from 900 to 897 and 884 to 881 cm depth, respectively (Table 2), i.e. up to 420±200 years older than the whale bones and up to 990±180 years older than the marine bird bones below the Ulvøy Diamicton at the cemetery (Fig. 9).

At all three sites described above (Dale Bog, Ågotnes and Sele Bog), we obtained minimum ages for the deglaciation that are significantly older than several ages from below the Ulvøy Diamicton. Thus, it seems clear that the earlier conclusion that the Blomvåg Beds have been overrun by glacial ice depositing the Ulvøy Diamicton (Undås 1942; Mangerud 1970, 1977; Mangerud *et al.* 2011) is incorrect.

The site Storum, in Os, is located south of and slightly farther inland than Blomvåg, but in a similar position just outside the Younger Dryas moraine (Fig. 1B). Here, a several-metre-deep excavation down to bedrock was investigated in late autumn 2015. At the base was a 10-cm-thick unit of sterile sand probably of glaciomarine origin resting on striated bedrock. The basal sand layer is overlain by a 10-cm-thick bed of bluish-grey silty clay with a few mollusc shells of the species *Hiatella arctica*, above which is a grey silt with frequent occurrences of the mollusc species *Chlamys islandica*. These units were in turn covered by several metres of marine silt and clay containing, amongst other species, *Mytilus edulis* and *Littorina littorea*. The two lowermost *Hiatella* shells that were collected from the silty clay a few cm above the basal sand yielded similar ages of *c.* 14.5 cal. ka BP and a *Chlamys* shell from a level slightly higher up in the sequence yielded an age of *c.* 14.4 cal. ka BP (Table 2). These ages are very similar to the basal ages from the Blomvåg Beds and substantiate our conclusion based on the data from the Blomvåg area that there was no Older Dryas glacial advance that reached beyond the position of the Younger Dryas ice margin.

Our alternative interpretation of the sediment succession at the Blomvåg cemetery is that the Ulvøy Diamicton was formed by sea ice and/or icebergs during the Younger Dryas. It is well known that sea ice along Arctic shores can push and mix shallow-water sediments onto beaches (Kovacs & Sodhi 1980). Iceberg ploughing is extensively described from high-latitude continental shelves, but smaller icebergs have certainly also drifted into shallow water. During the Younger Dryas, the margin of the Scandinavian Ice Sheet was calving in the fjord a few km east of Blomvåg (Fig. 1B) and it is known that sea ice occupied the coastal waters at this time (Kristiansen *et al.* 1988; Svendsen & Mangerud 1990). Relative sea level (Fig. 8) during the Allerød must have been very close to the highest excavated field on the Blomvåg cemetery. Subsequently, relative sea level rose ~10 m, culminating during the late Younger Dryas when seasonal sea ice would have been common, with icebergs drifting along the coast in front of the calving ice sheet. As we do not have access to the diamictic layer that was described from the cemetery it was impossible for us to test this interpretation against primary observations, but we note that the rounded gravel in Fig. 5D suggests that at least some of the diamicton consisted of re-deposited beach gravel.

Deglaciation history

The oldest radiocarbon ages that we obtained for deglaciation are from two dated molluscs in the Blomvåg Beds that both yielded radiocarbon ages of 14.8±0.2 cal. ka BP. We generally assume that basal ages from lacustrine and marine sequences should yield similar ages and that both should be close to the timing of deglaciation. However, the terrestrial plant-based ages from Dale Bog (13.9 cal. ka) are about 900 years younger than the basal shells from the adjacent Blomvåg Beds (Fig. 9). One explanation might be that relative sea level was 20–30 m higher than today during deglaciation (Fig. 8) and therefore Blomøy was a small island and the vegetation cover may have been very sparse and fragmentary. Another possible explanation is that marine reservoir ages during deglaciation were considerably higher than assumed above. The Sotra Island to the south (Fig. 1B) is much larger than Blomøy but we assume that they were both deglaciated at approximately the same time. Radiocarbon ages of plant macrofossils from basal lake sediments in Hamravatn on Sotra (Fig. 1B) yielded 14.2±0.14 cal. ka BP (Table 2) (Lohne *et al.* 2007). Using the basal macrofossil ages from Dale Bog and Hamravatn to calculate ΔR values for shells at Blomvåg would yield ΔR = 600 years and 350 years, respectively. These values are much higher than those found by Bondevik *et al.* (2006), but the value of the marine reservoir age should be investigated further before any firm conclusions can be drawn.

In contrast to radiocarbon ages that provide minimum-limiting age estimates, cosmogenic ^{10}Be exposure ages from erratic boulders will in ideal circumstances provide the direct timing of deglaciation. Note that in Table 3, we have listed conventional ^{10}Be ages, i.e. calculated relative to the year of sample collection (B2014), whereas below, we cite ages relative to 1950 (B1950). The ^{10}Be age for seven boulders from Blomvåg (Figs 2, 10) range from 15.1±0.4 to 10.8±0.2 ka; one ^{10}Be age from ice-sculpted bedrock is 16.4±0.3 ka. When one young erratic outlier (10.8 ka) and the old bedrock outlier (16.4 ka) are excluded, the mean ^{10}Be age is 14.5±0.5 ka B1950; this mean age would be 500 years older (14.9±0.5 ka B1950) when using the Arctic production rate (Young *et al.* 2013).

Although we presently cannot achieve a precision for the age of deglaciation better than a few hundred years, mainly limited by the marine reservoir age for radiocarbon and production rate for exposure ages, we note that both ^{10}Be and ^{14}C ages yield a similar timing of deglaciation. Here, we conclude that the deglaciation occurred between 14.8 and 14.5 cal. ka BP (Fig. 12).

The erratic boulders from Liatårnet, the highest mountain (340 m a.s.l.) 27 km south of Blomvåg (Fig. 1B), were dated to test if the summit had protruded through the ice surface before the lower parts of the islands became ice free. The ^{10}Be ages of the four samples range from 16.3±0.3 to 14.1±0.4 ka. The mean age of 15.2±1.0 ka B1950 (Table 3) is *c.* 600 years older than the ages for the Blomvåg erratic boulders and thus may suggest that Liatårnet was a nunatak for a period of a few centuries during the initial deglaciation of the islands, although the ages overlap within one standard deviation.

Palaeoenvironment and possible human occupation

We have not made any new identifications of the fossils in the Blomvåg Beds. We assume that there was a

Fig. 10. Boulders dated with ^{10}Be. A–C are from Blomvåg, D is from Liatårnet. A. 14-NOR-62 (age 14.2±0.5 B2014). B. 14NOR-65 (age 13.8±0.3 B2014). C. 14NOR-69 (age 15.0±0.4 B2014). D. 14NOR-71 (age 15.9±0.4 B2014). The fjord towards Bergen can be seen in the background. [Colour figure can be viewed at www.boreas.dk]

collection of identified molluscs that is now lost because no named shells were found in the existing boxes. Molluscs that were identified by Astrid Monsen (Undås 1942) are given in Table 4. Most important is that *Mytilus* and *Littorina* occur throughout the beds and shells of *Mytilus* are present in almost all dated samples. The specimens identified as *Modiolus* (Mangerud 1977) might be misidentified fragments of *Mytilus*, but for palaeoclimate interpretations that will not make any significant difference. The three mentioned species are presently found along the entire coast of Norway, but they do not extend to Svalbard, except *Mytilus*, which reappeared during the last decade (Berge *et al.* 2005). The occurrence of these species thus suggests that relatively warm Atlantic water reached this part of the Norwegian coast during the Bølling and Allerød (Mangerud 1977) and that coastal water temperatures were similar to those of the water masses along northernmost Norway today. The lower boundary of the Bølling chronozone as it was defined by Mangerud *et al.* (1974) represented the first sign of warming in northwest Europe after the Oldest Dryas. We therefore argue that the presence of *Mytilus* at the base of the Blomvåg Beds suggests they are of Bølling age; pre-Bølling water would probably be too cold for *Mytilus* and *Littorina*. The start of Greenland interstadial 1e, which is approximately correlated with the Bølling (Björck *et al.* 1998; Lowe & Hoek 2001), is dated to *c.* 14.6 ice-core ka before 1950 (Rasmussen *et al.* 2006).

Bones and their identification are described in detail by Lie (1986). The mammals include reindeer, bowhead whale and harp seal. There are bones from a number of sea birds but also raven and some fishes that together support the reconstruction of a climate similar to northernmost Norway today. This means that the warmest month (July) probably had a mean temperature of 9–10 °C, i.e. 3–4 °C colder than the present day.

For wood there is a handwritten list of about 100 samples apparently identified by Astrid Karlsen. However, quite a few of the pieces appear to be broken parts

Table 4. Molluscs in the Blomvåg Beds. Identified by Astrid Monsen, cited from Undås (1942). Comments translated from Norwegian. For some species the presently used names are given below the table.

Species	Comments
Anomia ephippium L.	Rare
Astarte banksii Leach[1]	Very rare
Buccinum undatum L.	Rare
Boreochiton marmoreus Fabr	Rare
Boreochiton ruber Lowe	Rare
Cyamium minutum Fabr.	Rare
Kellia suborbicularis Mont.	Rare
Littorina littorea L.	Numerous
Littorina rudis Maton	Many
Littorina obtusata L.	Rare
Lacuna divaricata Fabr.	Common
Macoma calcaria Chemn.	Many
Margarita groenlandica Chemn.	Many
Margarita helicina Fabr.	Many
Mya truncata L.	Very rare
Mytilus edulis L.	Numerous
Pecten islandicus Müll.[2]	Common
Puncturella noachina L.	Many
Tectura virginia Müll.	Common
Thracia papyracea Poli	Very rare
Trophon truncatus Strøm	Very rare
Saxicava arctica L.[3]	Very rare
Balanus porcatus da Costa[4]	Common
Balanus crenatus Brug	Common

[1]*Astarte montaqui* Dilwyn.
[2]*Chlamys islandica* Müll.
[3]*Hiatella arctica* L.
[4]*Balanus balanus* L.

from a larger piece. Almost all are identified as *Salix* or *Populus*. Four were identified as *Betula*; two as *Juniperus* and one as *Picea*. We cannot judge the quality of the identifications but *Salix* is an early immigrant and pieces of *Salix* as well as *Juniperus* might be from local vegetation. *Picea* is probably driftwood from rivers in Siberia. The frequent occurrence of long-transported wood, and of bird bones, may provide explanations for transport of seeds and thus the immigration of plants to coastal Norway after the Last Glacial Maximum.

When he still believed that the Blomvåg Beds were of interglacial age, Undås (1942) mentioned the possible presence of humans, saying: 'The findings are unique in Scandinavia and it is indeed strange that such a richness of bones and wood have been deposited here. It is almost only human remains that are missing, but so far nothing is found to indicate that humans played a role. The few pieces of flint do not look like human tools and I have not seen any small flakes that for example are common in the Fosna Culture flint sites' (translated from Norwegian by us). Rolfsen (1972) and (Mangerud 1973) pointed out that groups of reindeer hunters lived in Denmark and Germany at the time the Blomvåg Beds were deposited and as reindeer had reached Blomvåg they said it was reasonable that some humans had followed the reindeer herds northwards to western Norway. Lie (1986, 1990) argued that the composition of the fauna strongly suggests that the bones were remnants of human activity and concluded that 'the material from Blomvåg must be regarded as the earliest traces so far of human activity in Norway' (Lie 1990). However, this argument is now weakened as the new radiocarbon dates indicate that the Blomvåg Beds were deposited during several centuries and not just during a single human dwelling period. Johansen & Undås (1992) maintained that some of the flint pieces from Blomvåg are human artefacts. If Lie (1990) and Johansen & Undås (1992) were correct, then humans immigrated to western Norway about 3000 years earlier than generally accepted (Breivik 2014). This view entered popular books on the history of Norway (Alnæs 1996; Indrelid 1997). However, later the flint material was examined by three archaeologists independently of one another, all concluding that there is no sign of human work (Bjerck 1994; Eigeland 2012; Fischer 2012), a conclusion repeated in Eigeland & Solheim (2012). We follow Bjerck (1994) in stating that no findings at Blomvåg represent reliable traces of humans. An obstacle for early immigration to southern Norway was that the ice-sheet margin blocked the land-connection from Sweden and around Oslofjorden until about 11 cal. ka BP (Hughes *et al.* 2016).

Position of the Older Dryas ice margin

We concluded above that the interpretation of an Older Dryas ice advance across Blomvåg is incorrect, and thus, the Older Dryas ice margin was situated farther inland. At the Storum site, described above, located outside but close to the Younger Dryas moraine, basal radiocarbon ages are 14.5 cal. ka BP (Table 2, Fig. 11). From Bjorøy (Fig. 1B; Skår 2012) and Bergen (Mangerud *et al.* 2016), the reported ages of *c.* 14.1 cal. ka BP from shell fragments included in Younger Dryas tills reveal that these sites were ice free at 14.1 cal. ka BP prior to being overrun by a re-advance during the Younger Dryas (Fig. 1B).

These ages show that the western coast of Norway from Bjørnefjorden to Fensfjorden and at least as far inland as the Younger Dryas moraine (Fig. 1B) became ice-free during the Bølling. If we accept an age of about 14 cal. ka BP for the Older Dryas, then the position of the Older Dryas ice margin must have been inside, but probably not far inside, the Younger Dryas margin.

Around the mouth of Hardangerfjorden (Fig. 1A) to the south, the interpretation is the opposite. Here, the Older Dryas margin was slightly beyond the Younger Dryas margin (Fig. 12; Mangerud *et al.* 2016). Furthermore, near Lysefjorden (Fig. 1A), even farther south, a dated segment of an Older Dryas end

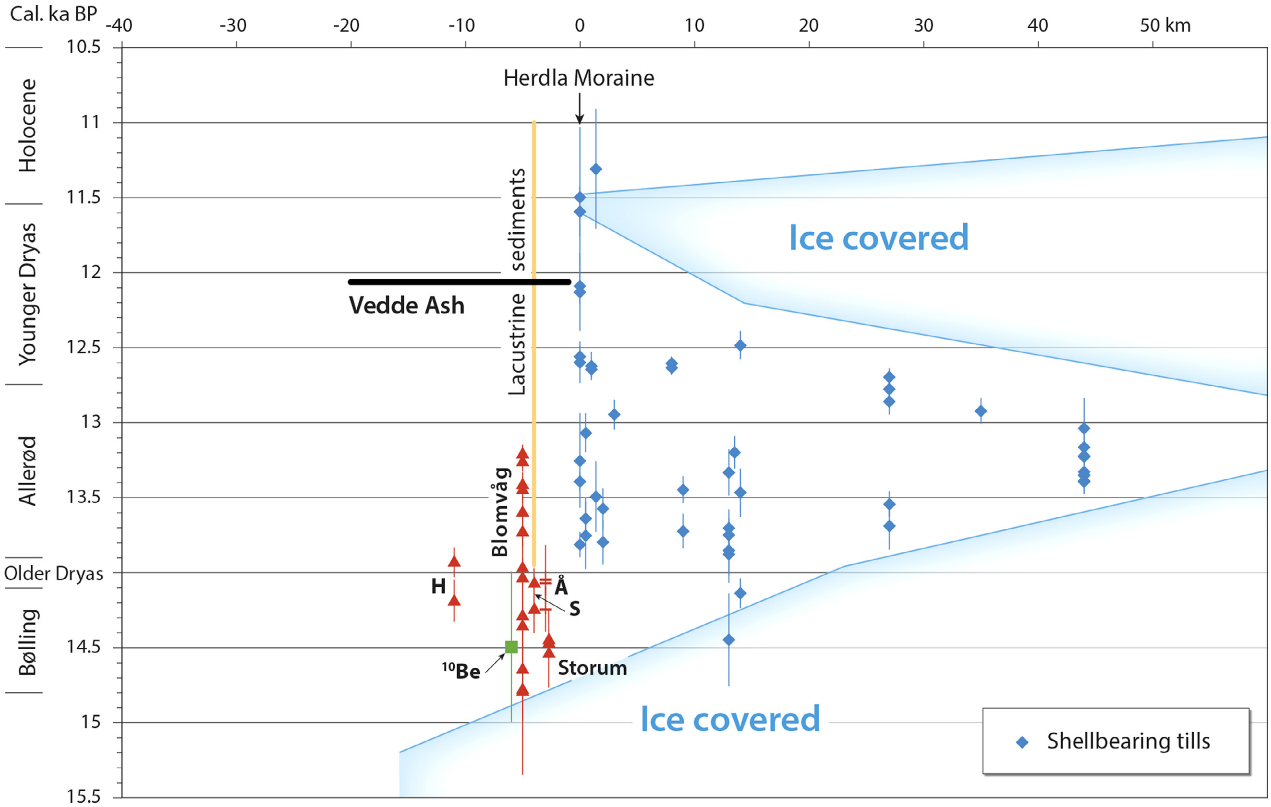

Fig. 11. Time-distance diagram showing changes in ice-margin position relative to the position of the Herdla Moraine, negative distance values indicating down-ice (towards west) and positive value up-ice (to east); modified from Mangerud *et al.* (2016) by adding new ages given in the present paper. Ages marked distal to the Younger Dryas moraine are: Blomvåg = Blomvåg Beds; Å = Ågotnes; S = Sele Bog; H = Hamravatn; Storum = the three oldest shells from the site; Lacustrine sediments = Dale Bog; ^{10}Be = the mean for the ^{10}Be ages from Blomvåg. [Colour figure can be viewed at www.boreas.dk]

Fig 12. Ice margins in western Norway. Ages are given as cal. ka BP. The Younger Dryas margin has been mapped in detail (Andersen *et al.* 1995), whereas the other margins shown are more schematic. For reference: Bergen and Boknafjorden are shown in Fig. 1A. [Colour figure can be viewed at www.boreas.dk]

moraine exists slightly outside the Younger Dryas moraines, although in the fjord proper the Younger Dryas outlet glacier overran this Older Dryas moraine (Briner *et al.* 2014).

The larger picture of the deglaciation and ice-marginal deposits

During the LGM an ice stream flowed northward along the Norwegian Channel off the coastline of western Norway (Sejrup *et al.* 2016) (Fig. 1A). Glacial striae and lineations show that ice was flowing almost due west in the Blomvåg region (Aarseth & Mangerud 1974) and bent northwards as it became confluent with the Norwegian Channel Ice Stream a short distance offshore (Fig. 13; Ottesen *et al.* 2016). During deglaciation, the Norwegian Channel Ice Stream retreated southward up the channel, leaving open water along the coast near Blomvåg so that a new ice margin generally paralleled the coast (Fig. 12). According to marine chronology based on ^{14}C dating of foraminifera, the Norwegian Channel Ice Stream retreated past the Troll field to the west of Sognefjorden (Fig. 1A) prior to 18.5 cal. ka BP (Sejrup *et al.* 2009), whereas ^{10}Be exposure ages suggest that the ice

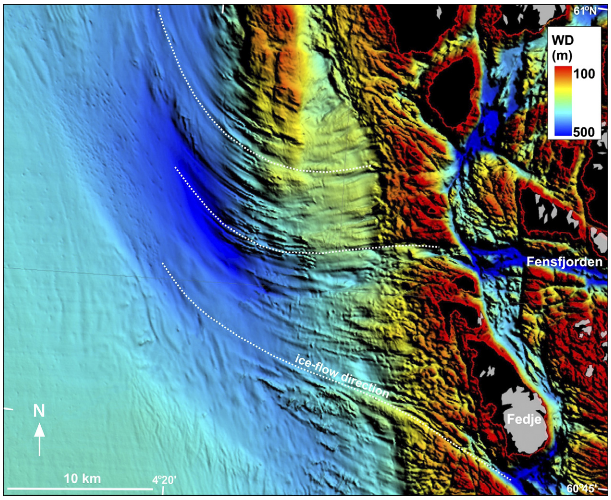

Fig 13. Sea-floor morphology showing glacial lineations offshore and bending northwards into the Norwegian Channel. Black areas are shallow water that is not mapped; legend shows water depth. The islands of Fedje and Fensfjorden are seen in the northern part of Fig. 1B. Slightly modified from Ottesen *et al.* (2016). [Colour figure can be viewed at www.boreas.dk]

margin may have retreated all the way south to Utsira (Fig. 1A) as early as *c.* 20.3 ka (Svendsen *et al.* 2015).

Accepting that the coast (Blomvåg, etc.) became ice free at 14.8–14.5 cal. ka BP, much later than the Norwegian Channel farther west, implies that the ice margin was located just off the coast for 4000 years or more (Fig. 12). Most surprising with this reconstruction is that there are no ice-marginal deposits reported in this zone, although scientists have searched for such deposits (D. Ottesen, pers. comm. 2016, H. Haflidason, pers. comm. 2016). This is even more surprising when considering the large sediment volumes deposited during a few hundred years along the Younger Dryas ice margin in this same region. We consider that one part of the explanation could be that the ice flow was slow and the ice-mass turnover small, which would imply limited precipitation in the accumulation area in the >4000 years prior to 14.8–14.5 ka. This would be consistent with cold water and increased sea-ice cover in the Nordic Seas during the Heinrich 1 event (Eldevik *et al.* 2014). In contrast, ice-mass turnover was probably larger during the Younger Dryas, which should require more precipitation, a problem we will not discuss here.

Another interesting feature is the north–south difference in geometry of the ice retreat (Fig. 12). In the Blomvåg area, the ice margin remained offshore until 14.8–14.5 cal. ka BP, whereas towards the south it had retreated up Boknafjorden by this time (unpublished data). Overall, the north–south 15 ka and Younger Dryas ice-margin configurations are similar. The ice margin was located near the ocean in the north, but well inland in the south (Fig. 12), although the 15 ka time slice represented a retreating margin, and the Younger Dryas pattern resulted from a major re-advance.

Conclusions

- We present 39 radiocarbon ages and 12 ^{10}Be exposure ages related to the Bølling-Allerød deglaciation of western Norway.
- The final deglaciation of the outermost coast at Blomvåg, western Norway, took place 14.8–14.5 cal. ka BP, in response to the Bølling warming.
- The Ulvøy Diamicton that earlier has been interpreted as a basal till and an indication of an Older Dryas glacial re-advance is not a till. We assume that it was formed by sea ice and/or icebergs during the Younger Dryas.
- The Older Dryas ice margin was located close to the Younger Dryas ice-sheet margin in western Norway; in some places it was inside and in other places outside.

Acknowledgements. – The investigations form part of the research project Eurasian Ice Sheet and Climate Interaction (EISCLIM) financially supported by The Research Council of Norway (grant no. 229788/E10). Arve Svean, Morten Nordvik Hovland and Kristian Vasskog participated in coring the Sele Bog. Sandra Cronauer, Avriel Schweinsberg and Alia Lesnek assisted with the processing of ^{10}Be ages, and Susan Zimmerman assisted in the measurement of ^{10}Be/^{9}Be ratios. Elisabeth Eriksen and Øystein Wiig allowed us to use unpublished radiocarbon dates and Svein-Olaf Dahl allowed us to use radiocarbon ages from the Master's thesis of Matilde Skår. Eva Bjørseth finalized the illustrations. The reviewers John Lowe and Ola Fredin, and the Editor Jan A. Piotrowski, suggested a number of changes that improved the manuscript. To all we proffer our sincere thanks.

References

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

Alnæs, K. 1996: *Historien om Norge. Det ligger et Land.* 496 pp. Gyldendal Norsk Forlag A/S, Oslo.

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

Balco, G., Stone, J., Lifton, N. & Dunai, T. 2008: A complete and easily accessible means of calculating surface exposure ages or erosion rates from ^{10}Be and ^{26}Al measurements. *Quaternary Geochronology 3*, 174–195.

Berge, J., Johnsen, G., Nilsen, F., Gulliksen, B. & Slagsted, D. 2005: Ocean temperature oscillations enable reappearance of blue mussels *Mytilus edulis* in Svalbard after 1000 year absence. *Marine Ecology Progress Series 303*, 167–175.

Bjerck, H. B. 1994: Nordsjøfastlandet og pionerbosetningen i Norge. *Viking 57*, 25–58.

Björck, S., Walker, M. J. C., Cwynar, L. C., Johnsen, S., Knudsen, K. L., Lowe, J. J., Wohlfarth, B. & INTIMATE-members 1998: An event stratigraphy for the last Termination in the North Atlantic region based on the Greenland Ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science 13*, 283–292.

Bondevik, S., Mangerud, J., Birks, H. H., Gulliksen, S. & Reimer, P. 2006: Changes in North Atlantic radiocarbon reservoir ages during the Allerød and Younger Dryas. *Science 312*, 1514–1517.

Breivik, H. M. 2014: Palaeo-oceanographic development and human adaptive strategies in the Pleistocene-Holocene transition: a study from the Norwegian coast. *The Holocene 24*, 1478–1490.

Briner, J. P., Svendsen, J. I., Mangerud, J., Lohne, Ø. S. & Young, N. E. 2014: A ^{10}Be chronology of south-western Scandinavian Ice Sheet history during the Lateglacial period. *Journal of Quaternary Science 29*, 370–380.

Brock, F., Higham, T., Ditchfield, P. & Bronk Ramsey, C. 2010: Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon 52*, 103–112.

Brock, F., Wood, R., Higham, T. F. G., Ditchfield, P., Bayliss, A. & Bronk Ramsey, C. 2012: Reliability of nitrogen content (%N) and carbon: nitrogen atomic ratios (C:N) as indicators of collagen preservation suitable for radiocarbon dating. *Radiocarbon 54*, 879–886.

Bronk Ramsey, C., Higham, T., Bowles, A. & Hedges, R. 2004: Improvements to the pretreatment of bone at Oxford. *Radiocarbon 46*, 155–163.

Eigeland, L. 2012: En teknologisk vurdering av mulige senglasiale funn i Norge. *Norsk Maritimt Museum, Arkeologisk Rapport 12*, 57–69.

Eigeland, L. & Solheim, S. 2012: Blomvågfunnet - veid og funnet for lett. *Viking 75*, 7–26.

Eldevik, T., Risebrobakken, B., Bjune, A. E., Andersson, C., Birks, H. J. B., Dokken, T. M., Drange, H., Glessmer, M. S., Li, C., Nilsen, J. E. Ø., Otterå, O. H., Richter, K. & Skagseth, Ø. 2014: A brief history of climate – the northern seas from the Last Glacial Maximum to global warming. *Quaternary Science Reviews 106*, 225–246.

Fischer, A. 2012: Vurdering af Vestnorske fund, som kandiderer til palæolitisk datering. *Norsk Maritimt Museum, Arkeologisk Rapport 12*, 50–56.

Goehring, B. M., Lohne, Ø. S., Mangerud, J., Svendsen, J. I., Gyllencreutz, R., Schaefer, J. & Finkel, R. 2012a: Late glacial and Holocene ^{10}Be production rates for western Norway. *Journal of Quaternary Science 27*, 89–96.

Goehring, B. M., Lohne, Ø. S., Mangerud, J., Svendsen, J. I., Gyllencreutz, R., Schaefer, J. & Finkel, R. 2012b: Erratum: late glacial and Holocene ^{10}Be production rates for western Norway. *Journal of Quaternary Science 27*, 544–544.

Gulliksen, S., Nydal, R. & Skogseth, F. 1978: Trondheim natural radiocarbon measurements VIII. *Radiocarbon 20*, 105–133.

Holtedahl, O. 1953: *Norges Geologi, Bind II*. 1118 pp. H. Aschehoug & Co., Oslo.

Holtedahl, O. 1960: Geology of Norway. *Norges Geologiske Undersøkelse 208*, 1–540.

Hufthammer, A. 2001: The Weichselian (c. 115,000–10,000 B.P.) vertebrate fauna of Norway. *Bollettino della Società Paleontologica Italiana 40*, 201–208.

Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J. & Svendsen, J. I. 2016: The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1. *Boreas 45*, 1–45.

Indrelid, S. 1997: *Frå Steinalder Til Vikingtid, Strilesoga Band 1*. 255 pp. Eide Forlag, Bergen.

Johansen, A. B. & Undås, I. 1992: Er Blomvågmaterialet et boplassfunn? *Viking 55*, 9–26.

Kovacs, A. & Sodhi, D. S. 1980: Shore ice pile-up and ride-up: field observations, models, theoretical analyses. *Cold Regions Science and Technology 2*, 210–288.

Kristiansen, I. L., Mangerud, J. & Lømo, L. 1988: Late Weichselian/Early Holocene pollen-and lithostratigraphy in lakes in the Ålesund area, western Norway. *Review of Palaeobotany and Palynology 53*, 185–231.

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

Leader-Williams, N., Scott, T. A. & Pratt, R. M. 1981: Forage selection by introduced reindeer on South Georgia, and its consequences for the flora. *Journal of Applied Ecology 18*, 83–106.

Lie, R. 1986: Animal bones from the Late Weichselian in Norway. *Fauna Norwegica, Serie A 7*, 41–46.

Lie, R. 1990: Blomvågfunnet, de eldste spor etter mennesker i Norge? *Viking 1990*, 7–20.

Lohne, Ø. S., Bondevik, S., Mangerud, J. & Svendsen, J. I. 2007: Sea-level fluctuations imply that the Younger Dryas ice-sheet expansion in western Norway commenced during the Allerød. *Quaternary Science Reviews 26*, 2128–2151.

Longin, R. 1971: New method of collagen extraction for radiocarbon dating. *Nature 230*, 241–242.

Lowe, J. J., Hoek, W. Z. & INTIMATE-group 2001: Inter-regional correlation of palaeoclimatic records for the Last Glacial-Interglacial Transition: a protocol for improved precision recommended by the INTIMATE project group. *Quaternary Science Reviews 20*, 1175–1187.

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

Mangerud, J. 1972: Radiocarbon dating of marine shells, including a discussion of apparent age of Recent shells from Norway. *Boreas 1*, 143–172.

Mangerud, J. 1973: Hordalands natur, under og like etter istiden. *Frå Fjon til Fusa 26*, 7–43.

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

Mangerud, J., Aarseth, I., Hughes, A. L. C., Lohne, Ø. S., Skår, K., Sønstegaard, E. & Svendsen, J. I. 2016: A major re-growth of the Scandinavian Ice Sheet in western Norway during Allerød-Younger Dryas. *Quaternary Science Reviews 132*, 175–205.

Mangerud, J., Andersen, S. T., Berglund, B. E. & Donner, J. J. 1974: Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas 3*, 109–128.

Mangerud, J., Goehring, B. M., Lohne, Ø., Svendsen, J. I. & Gyllencreutz, R. 2013: Collapse of marine-based outlet glaciers from the Scandinavian Ice Sheet. *Quaternary Science Reviews*, *67*, 8–16.

Mangerud, J., Gyllencreutz, R., Lohne, Ø. & Svendsen, J. I. 2011: Glacial history of Norway. *In* Ehlers, J., Gibbard, P. & Hughes, P. (eds.): *Quaternary Glaciations - Extent and Chronology*, 279–292. *Developments in Quaternary Science 15, Elsevier, Amsterdam.*

Nemec, M., Wacker, L., Hajdas, I. & Gaggeler, H. 2010: Alternative methods for cellulose preparation for AMS measurement. *Radiocarbon 52*, 1358–1370.

Nishiizumi, K., Imamura, M., Caffee, M., Southon, J., Finkel, R. & McAninch, J. 2007: Absolute calibration of ^{10}Be AMS standards. *Nuclear Instrument Methods 258*, 403–413.

Nydal, R. 1960: Trondheim natural radiocarbon measurements II. *American Journal of Science, Radiocarbon Supplement 2*, 82–96.

Nydal, R., Gulliksen, S. & Løvseth, K. 1972: Trondheim naturaal radiocarbon measurements VI. *Radiocarbon 14*, 418–451.

Ottesen, D., Stokes, C. R., Bøe, R., Rise, L., Longva, O., Thorsnes, T., Olesen, O., Bugge, T., Lepland, A. & Hestvik, O. B. 2016: Landform assemblages and sedimentary processes along the Norwegian Channel Ice Stream. *Sedimentary Geology 338*, 115–137.

Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggaard-Andersen, M. L., Johnsen, S. J., Larsen, L. B., Dahl-Jensen, D., Bigler, M., Rothlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M. E. & Ruth, U. 2006: A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research, 111*, D06102, doi:10.1029/2005JD006079.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M. & van der Plicht, J. 2013: IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon 55*, 1869–1887.

Rolfsen, P. 1972: Kvartærgeologiske og botaniske betingelser for mennesker i Sør-Norge i seinglasial og tidlig postglasial tid. *Viking 36*, 131–153.

Rood, D., Hall, S., Guilderson, T., Finkel, R. C. & Brown, T. 2010: Challenges and opportunities in high precision Be-19 measurements at CAMS. *Nuclear Instruments and Methods B: Beam Interactions with Material and Atoms 268*, 730–732.

Sejrup, H. P., Clark, C. D. & Hjelstuen, B. O. 2016: Rapid ice sheet retreat triggered by ice stream debuttressing: evidence from the North Sea. *Geology 44*, 355–358.

Sejrup, H. P., Nygård, A., Hall, A. M. & Haflidason, H. 2009: Middle and Late Weichselian (Devensian) glaciation history of southwestern Norway, North Sea and eastern UK. *Quaternary Science Reviews 28*, 370–380.

Skår, M. 2012: *Kvartærgeologisk kartlegging og rekonstruksjon av is-marginale avsetninger pa Bjorøy, Tyssøy og Håkonshella, sørvest for Bergen*. Master's thesis, University of Bergen, 142 pp.

Staiger, J., Gosse, J., Toracinta, R., Oglesby, B., Fastook, J. & Johnson, J. V. 2007: Atmospheric scaling of cosmogenic nuclide production: climate effect. *Journal of Geophysical Research: Solid Earth 112*, B02205, doi:10.1029/2005JB003811.

Svendsen, J. I. & Mangerud, J. 1990: Sea-level changes and pollen stratigraphy on the outer coast of Sunnmøre, western Norway. *Norsk Geologisk Tidsskrift 70*, 111–134.

Svendsen, J. I., Briner, J. P., Mangerud, J. & Young, N. E. 2015: Early break-up of the Norwegian Channel Ice Stream during the Last Glacial Maximum. *Quaternary Science Reviews 107*, 231–242.

Undås, I. 1942: Fossilfunnet i Blomvåg. *Naturen 1942*, 97–107.

Young, N. E., Schaefer, J. M., Briner, J. P. & Goehring, B. M. 2013: A ^{10}Be production-rate calibration for the Arctic. *Journal of Quaternary Science 28*, 515–526.