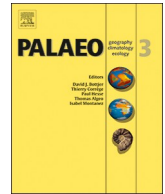




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## Radiocarbon dates of two musk ox vertebrae reveal ice-free conditions during late Marine Isotope Stage 3 in central South Norway

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## ABSTRACT

One of the most reliable proofs of terrestrial ice-free conditions within Stadials is the presence of terrestrial vertebrate fauna that require access to vegetation in the winter, for example sedentary birds such as Ptarmigans and herbivorous mammals in particular. The musk ox (*Ovibos moschatus*) is an example of the latter; modern-day distributions of this species are limited to areas with low snow accumulations. In this paper we discuss the discovery of musk ox bones in Norway. Recently obtained radiocarbon dates on this material demonstrate the presence of this species 41–35 cal kyr B.P. in southern Norway during late Marine Isotope Stage 3 (MIS3). Furthermore the dates have implications for the interpretation of climate and environmental conditions; indicating the existence of a small ice cap in the mountains and climate and vegetation supporting a large mammal fauna in South Norway at that time.

## 1. Introduction

The musk ox was widely distributed across Eurasia during the last glacial period (115–11,7 kyr B.P.) (Kahlke, 1994) and spread to North America by 90,000 years ago (Weinberg, 2011). At present, the musk ox is associated with Arctic tundra environments, in particular the steppe tundra, and it is adapted to long, extremely cold winters. The species is particularly adversely affected by high precipitation in summer (Kahlke, 1994). Some southern advances into temperate environments in the Pleistocene may be arguments against the use of “arctic” to designate the biotope of the genus (Crégut-Bonnouire, 1984). Within Europe, however, the musk ox was most abundant in the coldest and driest periods of the Pleistocene (Raufuss and von Koeningswald, 1999). They are primarily grazers feeding mainly on sedges and grasses (Weinberg, 2011) and in general adult musk ox subsist on coarse higher-roughage sedges (Groves and Leslie, 2011).

The present-day natural distribution of the musk ox ranges across Canada, Greenland and Alaska (Weinberg, 2011). This species has recently been successfully re-introduced to a few areas of Europe, for example to the Dovre region in South Norway in 1947, where they have since established a small free-living population.

## 1.1. Ancient distributions of musk ox in Europe

Within Europe, musk ox remains have been recovered in several locations, ranging from as far south as Catalonia (Crégut-Bonnouire, 1984) and Moldova (Musil, 1960) to Scandinavia in the north (Wingé, 1904; Aaris-Sørensen, 2009). The Scandinavian material derives from both Denmark and Sweden. In Denmark, two musk ox skulls were recovered from gravel pits in Romalt, Randers in East Jylland and Bannebjerg, Helsingør in North Sjælland. The latter has been radiocarbon dated to 28,490 ± 350 yr B.P. (Aaris-Sørensen, 2006). In 1905, a musk ox tibia was discovered in a gravel pit in Dösebacka in Bohuslän, Sweden (Munthe, 1905). This material has a date of 32,000 + 1110/–975 yr B.P. (Ua-2866) obtained by Fredén in 1991 (Bennike and Liljegren, 2014). The later find of a skull fragment in 1977 in Jämtland, Sweden, first described by Borgen (1979), was also dated by Fredén and produced an infinite radiocarbon age of > 40,000 yr B.P. (Ua-2330). Reanalysis by Bennike and Liljegren (2014) revealed an absolute age of 44,000 ± 1500 yr B.P. for this specimen. The dating was carried out on the collagen fraction of the bone and the date was corrected for isotopic fractionation by normalizing to a  $\delta^{13}\text{C}$  value of –25‰ on the PDB scale. This date lies close to the maximum age limit of the radiocarbon dating technique and the reliability of the date was considered. It is, however, concluded that the age is likely to be around 44,000 yr B.P., but that it might be older (Bennike and Liljegren, 2014).

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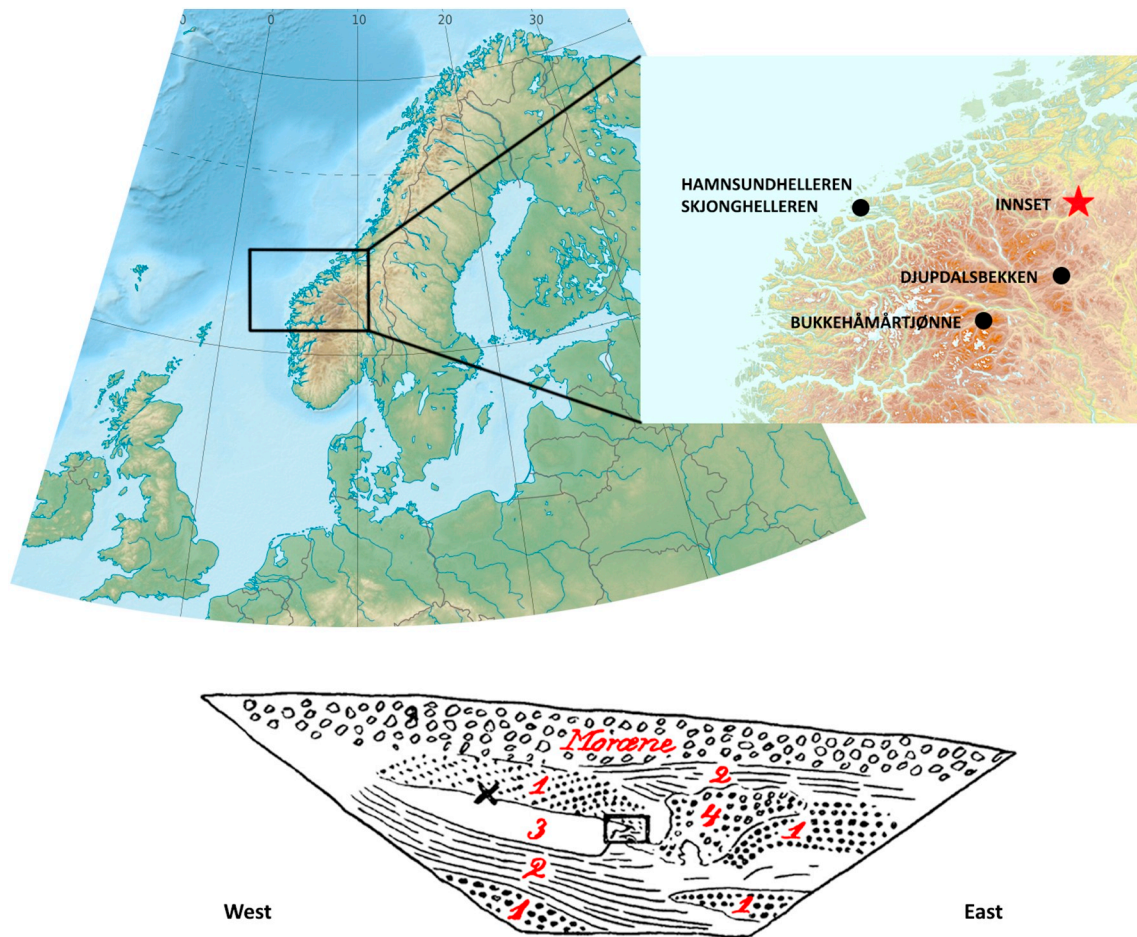


Fig. 1. Map of Norway with a partition of southern Norway with locations mentioned in the text [Hamnsundhelleren, Skjonghelleren, Bukkehåmårtjønne, Djupdalsbekken and Innset] indicated. Below (from Fig. 1 in Reusch, 1913): a) A sketch of the profile illustrating the stratigraphy of the find place (marked with an X in the profile) for the cervical vertebra. Legends: 1. Coarse well washed sand. 2. Fine layered sand. 3. Very fine clayish sand. 4. Pebble gravel. (Moræne = moraine).

### 1.2. The Fennoscandian Ice Sheet

In the late 20th century, geologists and palaeozoologists (Larsen et al., 1987; Valen et al., 1996) documented the presence of a rich vertebrate fauna 34–28 kyr B.P. in two, marine abraded, coastal caves (Hamnsundhelleren and Skjonghelleren) in North Western Norway [within Ålesund Interstadial beds (Fig. 1)]. The faunal assemblages included several bones of ptarmigan (*Lagopus* sp.) and a patella and a tooth fragment of reindeer (*Rangifer tarandus*) (Hufthammer, 2001; unpublished). The presence of these two species strongly indicates ice-free conditions along this coastal area in the middle and late MIS3. These geological studies were the starting point for a more nuanced understanding of the fluctuations in the ice cover during middle Weichselian interstadials in Norway and have been supported by a range of investigations i.e. Olsen et al. (2001) and Olsen et al. (2013). These included further analysis of the marine deposits on the Norwegian continental shelf (Sejrup et al., 2000, 2009) with the outcome that the presence of large ice-free areas in coastal regions in southern Norway 34–28 kyr B.P. [the Ålesund Interstadial] and 41–38 kyr B.P. [the Austnes Interstadial] was confirmed (i.e. Mangerud et al., 2010; Mangerud et al., 2011).

Although the climate conditions during MIS3 in Norway have been discussed extensively by Quaternary geologists, there is little vegetation data for the south central region during MIS3. The available data includes a radiocarbon sample comprising *Betula nana* catkin scale, *Salix* budscale, in addition to seeds/megaspores of both *Empetrum* and *Silene dioica* of 30,810 ± 370 yr B.P. [34,880–35,520 cal yr B.P. (0.74) and

35,940–36,190 cal yr B.P. (0.26)], from sub-till sediments in the Djupdalsbekken ravine (Thoresen and Bergersen, 1983) some 50 km east of Dovre (Table 2 in Paus et al., 2011) (Fig. 1). With reference to modern plant distribution, the sample may indicate the presence of a low/middle alpine shrub vegetation in the area. Elsewhere the presence of gyttja within a high-altitude lake in central southern Norway, at the site of Bukkehåmårtjønne 1594 m a.s.l. in eastern Jotunheimen also indicates ice-free conditions (Fig. 1). Two bulk, low organic gyttja samples from sub-till organic sediments lying 150 cm below lake sediment surface were retrieved by coring and yielded radiocarbon ages of 37,600 ± 1060 yr B.P. (Beta-103121) and 32,100 ± 580 yr B.P. (Beta-103114) (Lie and Sandvold, 1997) (43,460–39,880 cal yr B.P. and 37,720–34,780 cal yr B.P., respectively). The presence of organic sediments indicate the absence of an ice sheet in this area and the radiocarbon dates strongly indicate that ice-free conditions existed in central southern Norway during the Ålesund Interstadial.

There is supporting data for ice-free conditions present within Finland, Sweden and Denmark at this time. Helmens et al. (2007), based on a multi-proxy study (pollen, geomorphology, macrofossils, chironomids, diatoms) at the Sokli site, concluded that shrub-tundra vegetation existed in eastern-central Finnish Lapland during MIS3. Palynological data from Riipiharju, northern Sweden (Hättestrand and Robertsson, 2010) indicated two warm phases, characterized by *Betula*-dominant pollen assemblages, separated by a cold phase, characterized by high percentage of *Artemisia* and Gramineae pollen. Hättestrand and Robertsson (2010) concluded that these phases are correlated with the Odderade Interstadial and early Middle Weichselian, all in MIS3.

Palaeogeographical reconstructions from Denmark and Skåne suggest a subarctic treeless vegetation during ca. 40–30 kyr BP (Houmark-Nielsen and Kjær, 2003).

A number of recent studies have also made a major contribution to the understanding of the glacial history of Fennoscandia, with special emphasis on the climate conditions in MIS3, summarized by Wohlfarth and Näslund (2010). The presence of ice free conditions in MIS3 is documented also in southwestern Baltic Sea, by thin beds of gyttja and peat that have been radiocarbon dated to c. 36–41 cal kyr B.P. (Anjar et al., 2010). Based on  $^{14}\text{C}$  dates from Sweden, Wohlfarth (2010) proposed a scenario of ice-free conditions in Northern and Central Sweden between ca. 60–35 cal kyr B.P. and in southern Sweden between ca. 40–25 cal kyr B.P. Kjellström et al. (2010) used climate models to simulate climate conditions in Europe during Greenland Stadial (GS) 12 at 44 kyr B.P. They postulate cold and dry conditions with large ice-free regions in Sweden and Finland during MIS3, as a result of a climate that is favorable for the development of permafrost, but as all snow melts during summer, does not allow local ice-sheet formation. The results of OSL dates of quartz grains retrieved from sediments from a gravel pit at Idre in west-central Sweden indicate a regional, substantial deglaciation, if not a total decay, eastwards of the SIS during parts of MIS3 (Möller et al., 2013). The lack of an ice sheet is also supported by Alexanderson et al. (2010) who, based on OSL dates from the Pilgrimstad gravel pit in central Sweden, suggest that climate was relatively mild and that the Scandinavian Ice Sheet (SIS) was absent or restricted to the mountains for at least parts of MIS3. These scenarios are, however, only partly supported by glacial rebound modelling studies by Lambeck et al. (2010). They suggest a substantial ice cap covering most of Scandinavia 39 kyr B.P., leaving only a very narrow land strip in western Norway ice free. In the Baltic depression, glaciers were advancing through proglacial lakes towards the south between 40 and 36 kyr B.P. (Lagerlund et al., 1983). An example of the dynamics of advance and deglaciation is how Baltic glaciers expanded shortly after 38 kyr B.P. and apparently were able to reach as far south as eastern Denmark at ca. 34 kyr B.P. (Houmark-Nielsen and Kjær, 2003). By 35 kyr B.P., however, the glaciers were restricted to the north and the high mountain areas (Fig. 2, Lambeck et al., 2010). Mangerud et al. (2011: Fig. 22.5) proposed a restricted ice sheet in south Norway 38–35 cal kyr B.P. (the Ålesund Interstadial), but stated that it may have been more extensive. However, in a recent publication two scenarios of SIS 38–34 kyr B.P. in Norway were presented [Fig. 5A in Hughes et al., 2016]: scenario 2; a small ice sheet restricted to the high mountain areas, just slightly smaller than indicated as a maximum version of ice cover c. 37 cal kyr B.P. in Fig. 9a in Olsen et al. (2013), and scenario 1; a maximum extension similar to Fig. 22.5 in Mangerud et al. (2011).

## 2. The musk ox find from Innset, Sør-Trøndelag County

In 1913, during construction work for the Dovre railway line at Innset (62°43' N, 9°58'E, 424 m a.s.l.) in Sør-Trøndelag County in south Norway (Fig. 1) a vertebra of a large herbivore was found (Fig. 2). This bone was identified by Herluf Winge in Copenhagen as a cervical vertebra, possibly number 5, from musk ox. The discovery and initial description of the geology of the site was published by Øyen (1913), with the geology discussed in further detail by Reusch (1913) and Bjørlykke (1913). The vertebra lay underneath a till, at the lower part of a 2 m thick layer of coarse sand and close to the transition to a layer of fine sand (sandy-clay) underneath (Øyen, 1913) (Fig. 1). In December the same year, another well-preserved vertebra (Fig. 3) was found approximately 2 m south of the find location of the first, at the same depth and in the same type of sediment. This find was also identified by Winge as musk ox, this time a first thoracic vertebrae (Øyen, 1916). The proximity of the find locations, the anatomical proximity of the two bones, the identification of both as belonging to a large male due to their size (according to Winge) strongly indicates that they are from the

same individual. They are the only sub-fossil musk ox bones ever found in Norway and they have been stored at the Paleontological Museum in Oslo from shortly after their discovery, under the registration numbers 74259 and 169.284, respectively.

A re-examination of the bones by the first author confirms that both bones are of musk ox and, as Reusch (1913) already noticed for the first find, that the preservation conditions were excellent. Furthermore, Winge's identification of cervical and thoracic vertebrae as well as their size as consistent with large adult individuals, probably male is confirmed. The diagnostic morphological criteria important for separating the fourth and fifth vertebra; the transverse processes, is absent. However, based on the shape of the vertebral foramen, it is likely that it is the fourth rather than, as suggested by Winge, the fifth cervical vertebra. The thoracic vertebra is also somewhat incomplete as the end of the spinous process is missing. Examination of the photograph presented in Øyen (1913) suggests that the damage occurred before this visual record was created. We acknowledge Winge's osteological identification skills and agree that the bone is a thoracic vertebra; however, due to the broken spinous process as well as other smaller breakages and cracks, we cannot confirm that it is the first.

These two vertebrae were found in fluvial layers and the pristine condition of the bone indicates rapid deposition and covering by sediments after the death of the musk ox. If the vertebra had been exposed on the surface for any length of time, evidence of degradation by weathering would have been visible, however, the absence of weathering does not necessarily mean that they are found in situ at the place of death. The bones may have been fluvially transported, for example from the northwest along the valley presently occupied by the river Orkla in Orkdalen. Reusch (1913) reports that all waterlain sediments in sub-till positions seen in the profile are sloping to the east, suggesting that they have been deposited from the west to the east (Fig. 1).

According to Behrensmeier (1975), who studied the disarticulation and dispersal of a skeleton in a fluvial medium, vertebrae belong to the group of bones (Voorhies) that are the first to be disarticulated and removed from the skeleton and have the highest possibility of being transported some distance from the site of death. Therefore, whilst we concur that these two bones may have been transported some distance from the site of death, their fluvial relocation to Innset, north of Dovre, implies that this area was ice-free at that time.

## 3. Radiocarbon dating

All new radiocarbon dates reported in this paper were calibrated using OxCal version 4.2.4 (Bronk Ramsey et al., 2013); r5 IntCal13 atmospheric curve (Reimer et al., 2013) with 1950 as zero yr B.P. age after Stuiver and Polach (1977). Radiocarbon dates are expressed as yr/kyr B.P. whereas calibrated calendar dates are expressed as cal yr/kyr B.P.

The cervical vertebra (museum number 74259) was AMS dated by The National Laboratory of Age Determination at the Norwegian University of Science and Technology in Trondheim in 2011 and the thoracic vertebra (museum number 169.284) at Oxford Radiocarbon Accelerator Unit (ORAU) in 2015 (Table 1).

A sample of 2.3 g of bone was carefully removed from the cervical vertebra (Fig. 2) and 2.5 g of bone from the thoracic vertebrae. For the latter, to preserve as much morphology as possible, a fragment that had already started to crack was sampled. Furthermore, to get a clean, unpolluted sample the surface of the bone was removed before submitting 2.39 g for radiocarbon dating, of which 0.61 g was used by ORAU for dating. Some small red spots, probably remnants from cast production, were visible at the surface of the bone but there were no visible spots at the bone that was sampled for radiocarbon dating. To be sure, however, that all contamination was removed, according to ORAU, a solvent extraction was performed prior to the collagen being extracted from the bone powder.

The pretreatment of the two samples before dating was slightly





Fig. 2. The cervical vertebra of musk ox (museum number 74259) from Innset, with the sample used for radiocarbon dating included. Photo: Tore Fredriksen.

different: For the cervical vertebrae bone (museum no. 74259) all organic components were removed, using diluted hydrochloric acid under pressure. To remove humic acids, the solution was treated with a sodium hydroxide solution. The collagen was then extracted with warm, distilled water and dried. The routine at ORAU (museum no. 169.284) involves an acid (HCl), base (NaOH) and then acid (HCl) treatment, followed by gelatinization, ultrafiltration and freeze-drying (Brock et al., 2010). For both dates isotopic fractionation has been corrected for, using the measured  $\delta^{13}\text{C}$  values.

At the Trondheim Dating Laboratory coal is used to correct for contamination, whereas ORAU uses very old bone. This leads to a higher value for “the  $^{14}\text{C}$  activity of the background” – and thus an older  $^{14}\text{C}$  age. The thoracic vertebra was dated at ORAU (OxA-32611) to  $35,650 \pm 700$  yr B.P.,  $\delta^{13}\text{C}$ -19.1‰ (Table 1). The calibrated ages are: 41,060–39,570 cal yr B.P. (68.3% probability) and 41,650–38,850 cal yr B.P. (95.4% probability). The cervical vertebra was dated at the Trondheim Dating Laboratory to  $32,465 \pm 925$  yr B.P.,  $\delta^{13}\text{C}$  -16.2‰ (TRa-2935). Typically, the difference between a coal background and a bone one is 0.3–0.4 pMC (% modern carbon). Thus, a recalculation of TRa-2935 with the additional bone background value produces, according to Marie-Josée Nadeau at Trondheim Dating Laboratory, a  $^{14}\text{C}$  age at  $34,000 \pm 1200$  yr B.P., calibrated to 39,670–36,800 cal yr B.P. (68.3% probability) and 40,980–35,620 cal yr B.P. (95.4% probability). This dating result is statistically identical to the results obtained at ORAU with 1.2 sigma difference.

A study by Huels et al. (2017) shows variation between radiocarbon laboratories in dating protocols and consequently in the  $^{14}\text{C}$  results of the same samples. The study concludes that a more detailed examination of background effects: measurements of background material, procedures for correction and evaluation of the suitability of a given set of materials is needed.

Whilst we argue that the two bones are from the same individual, the two bones have produced  $\delta^{13}\text{C}$  values that diverge by 2.8‰. We are not able to find an explanation for these differences but suggest a number of possibilities; including the use of different preparation protocols by the two laboratories, contamination and taphonomy or, may be less likely, within differences in the skeletal elements of the musk ox. It can also not be excluded that the two bones are from different individuals. We find, however, this less likely due to the fact that the dates of the two bones are almost identical, they are both from the fore part of the vertebral column, and that they have been found only 2 m apart. Both bones then support the idea of the existence of musk ox from late MIS3 in Norway, during the time interval ~41–35 kyr B.P. It is important to remember that radiocarbon dating of ancient bone is challenging, because of the impact of even trace contaminants upon accuracy beyond ~30,000 yr B.P. (see Higham, 2011). Work on dating single amino acids, which remove all organic and museum contaminants, is one promising way forward (see Deviese et al., 2018). If one were to test these finite dates further, extracting hydroxyproline for AMS dating would be one way forward.



**Fig. 3.** The thoracic vertebra of musk ox (museum number 169.284 from Innset).  
Photo: Finn Audun Grøndahl.

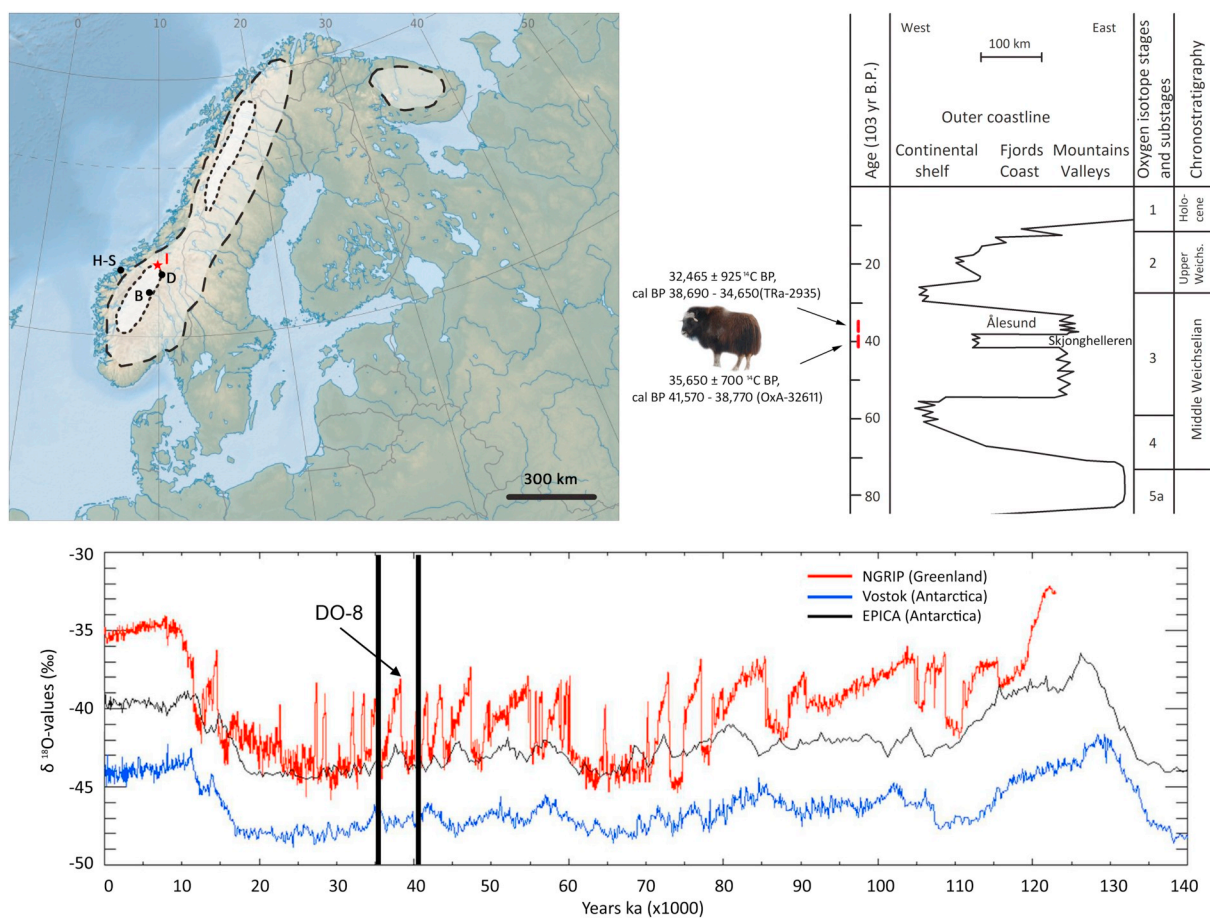
**Table 1**

Radiocarbon dating results and  $\delta^{13}\text{C}$  values of the two musk ox bones from Innset, Sør-Trøndelag county, Norway. Analytical data concerning the preparation of the TRa-2935 sample is not available, but is shown for OxA-32611.

Museum no	Site	Species	Bone	Lab. no	Radiocarbon age cal yr BP	$\delta^{13}\text{C}$ ‰
74259	Innset	<i>Ovibos moschatus</i>	Cervical vertebra	TRa-2935	32,465 ± 925	−16.2
169.284	Innset	<i>Ovibos moschatus</i>	Thoracic vertebra	OxA-32611	35,650 ± 700	−19.1

#### 4. Discussion

The presence of large terrestrial herbivore mammals in late MIS3 in Fennoscandia has been documented from several locations. In Sweden, five radiocarbon dates of mammoth material, three from north central Sweden and two from central Sweden yielded ages of 36–28 cal kyr B.P. (Ukkonen et al., 2007). The two northernmost were located approximately one latitudinal degree north of the Innset finds. Three of eight radiocarbon dates on mammoth material from Finland also fall into the same time window. The specimens were, however, dated in different laboratories over a period of time, including both AMS and conventional dating. Furthermore, the methods used for pre-treatment vary



**Fig. 4.** Left: Environmental reconstruction of Scandinavia during the Ålesund Interstadial ~35,000–28,000 B.P., adapted from Fig. 5a in Hughes et al. (2016). The maximum extent of the ice cap (scenario 1) and the minimum extent (scenario 2) are illustrated. The figure and locations mentioned in the text [Hamnsundhelleren (H), Skjonghelleren (S), Bukkehåmårtjønne (B), Djupdalsbekken (D) and Innset (I)] are indicated. Right: A schematic glaciation curve for the south western flank of the Scandinavian Ice Sheet throughout the Weichselian, adapted from Fig. 22.4 in Mangerud et al. (2011). The radiocarbon dates for the two musk ox bones are shown on the time scale. Below: Oxygen isotope records from the Vostok and EPICA (Antarctica) and NGRIP (Greenland) ice cores during the last 140 kyr. ( $\delta^{18}\text{O}$  is a proxy for temperature; more negative values mean lower temperatures.) The high-frequency and high-amplitude Dansgaard-Oeschger (DO) events are clearly visible in the NGRIP core. The black, vertical bars indicate the time period 41–35 ka BP when musk ox lived in southern Norway, apparently during DO-8 (Centre for Ice and Climate, Denmark). NGRIP data from North Greenland Ice Core Project members (2004). [<ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/ngrip/isotopes/ngrip-d18o-50yr.txt> (ss09sea timescale)]. EPICA data from Jouzel et al. (2004). [[ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica\\_domec/edc\\_dd.txt](ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc_dd.txt) (EDC2 timescale)]. Vostok data from Petit et al. (2001). (<ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/deutnat.txt>).

and this adds an element of uncertainty in comparing the dates (Ukkonen et al., 2011). Finally, there is a radiocarbon date of  $32,000 \pm 1100$  yr B.P. (Ua 2866) for a musk ox tibia from Bohuslän, SW Sweden (reported in Bennike and Liljegren, 2014) and two reindeer bones from the NW coast of Norway indirectly dated to the Ålesund interstadial (Hufthammer, 2001) (Fig. 4).

The find of musk ox at Innset, north of the Dovre Mountains in southern Norway, presented in this paper and dated to 38,970–34,720 and 41,650–38,850 cal yr B.P. adds to this dataset. According to the reconstruction of the environmental conditions in Scandinavia throughout the Weichselian (Mangerud et al., 2011), the Innset area lay immediately north of the ice cap covering the central and inland areas of Scandinavia during the Ålesund Interstadial (Fig. 4, scenario 2). However, radiocarbon dates of sub-till sediments from Bukkehåmårtjønne of  $37,600 \pm 1060$  yr B.P. (43,460–39,880 cal yr B.P.) and  $32,100 \pm 580$  yr B.P. (37,660–34,780 cal yr B.P.) (Lie and Sandvold, 1997) and the Djupdalsbekken ravine, ~50 miles east of Innset, have been dated to  $30,810 \pm 370$  yr B.P. (36,190–34,880 cal yr B.P.) (Table 2, Paus et al., 2011). The dated material from Djupdalsbekken consists of *Betula nana* catkin scale, *Salix* budscale, seeds/megaspores of *Empetrum*, *Silene dioica* and *Selaginella* and probably reflect a shrub tundra and polar desert vegetation (Paus et al., 2011). These data

indicate a vegetation cover in the area and consequently that the ice sheet may have been even smaller than suggested by Mangerud et al. (2011). In order to put the musk ox dates (41–35 kyr B.P.) from Norway into a wider perspective, the time frame was compared with ice-core records from NGRIP (Greenland). Data from North Greenland Ice Core Project members (2004). [<ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/ngrip/isotopes/ngrip-d18o-50yr.txt> (ss09sea timescale)] as well as EPICA data from Jouzel et al. (2004).

[[ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica\\_domec/edc\\_dd.txt](ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc_dd.txt) (EDC2 timescale)] and Vostok data (both from Antarctica) from Petit et al. (2001). (<ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/deutnat.txt>.) The dates fall within the mild Dansgaard-Oeschger event no. 8 (Fig. 4).

It is established that Reindeer and Ovibos are genera adapted to periglacial conditions and that musk ox in particular correlates to the coldest and driest periods of the Pleistocene (Raufuss and von Koeningswald, 1999). There is no modern analogue to the Pleistocene Tundra-Steppe biome of Europe (Kowalski, 1977) and the knowledge of past fauna and vegetation that can be linked to the presence of musk ox is insufficient. It has, however, been shown that Ovibos have been identified in association with a temperate fauna in Spain, and Ovibos and Rangifer have been found in a moist prairie-park biotope in France



(Crégut-Bonnaure, 1984). Therefore it can be questioned if the presence of musk ox at Innset indicates a particular dry and cold climate in the region 41–35 cal kyr B.P. or if the climate was more temperate. The presence of plant remains (Paus et al., 2011) that indicate the existence of a low or middle alpine vegetation type in the region in late MIS3 may point to the latter.

## 5. Conclusions

The presence of musk ox bones provides strong support for the presence of a herbivore fauna in Central Southern Norway ~41–35 cal kyr B.P. The existence of the species may also indicate dry and cold conditions with sparse snow cover during the winter seasons. The musk ox bones as well as the existence of sub-till sediments suggests ice-free conditions and the existence of only a small ice cap restricted to the high mountain areas.

Furthermore, the radiocarbon dates demonstrates that the musk ox was present in the region during a time period that correlates with the older Austnes Interstadial or the Ålesund Interstadial. This indicates that the ice-free conditions that have been documented at the Norwegian West coast at those time periods also reached far inland.

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