Middle and Late Weichselian high relative sea levels in Norway : implications for glacial isostasy and ice-retreat rates

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Highly uplifted Middle Weichselian marine sediments at Høgjæren, SW Norway, have previously been explained by tectonic movements, glacial isostasy or a combination of these factors, whereas most recent studies seem to favour a model based on glacial isostasy. New evidence of uplifted Middle and Late Weichselian marine sediments in coastal areas of central and northern Norway, as well as from inland areas of central and southeastern Norway, strongly suggests a glacio-isostatic cause for the high-altitude location of most of these occurrences. The positions of these sediments also indicate a frequently fluctuating ice sheet during the interval 18-50 ka BP. Repeated rapid ice retreat following heavy ice loading seems to be the most likely way to get marine sediments of both the same and different age intervals in such uplifted positions over such a wide geographical area. Significant deviations in the general glacial rebound trends of postglacial shoreline displacement in any of the areas discussed here have not been reported earlier. Hence, a tectonic cause for the land uplift of any of these locations is considered to be quite unlikely.

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Introduction

The coast of Norway and the Norwegian fjord valleys reaching far inland have been exposed to major climatic, sea-level and glacial changes during the Quaternary. Evidence of high relative sea levels (marine sediments, marine erosion of coastal caves, etc.) from ice-free intervals during the last glaciation have been known for a long time from coastal sites in western Norway (Bjørlykke 1908, Grimnes 1910, Holtedahl 1955, Andersen 1964, Feyling-Hanssen 1966, Andersen et al. 1987, 1991, Janocko et al. 1998). At Høgjæren, SW Norway (Fig. 1), uplifted (above the late-/postglacial marine limit) Middle Weichselian *in situ* marine sediments > 200 m a.s.l. have been explained by tectonic movements (e.g. Feyling-Hanssen 1966, Fugelli & Riis 1992), glacial isostasy (e.g. Andersen et al. 1987, Sejrup et al. 1998) or a combination of tectonic and glacio-isostatic uplift (Andersen et al. 1991). The main problem for the glacial rebound theory has been to explain why such a model, while successfully explaining the uplifted position of the Middle Weichselian clays, has failed to explain the altitude of the late-/postglacial marine limit at Jæren, which is generally low (< 25 m a.s.l.). In a comprehensive study of sea levels, sedimentation and erosion at Jæren, Larsen et al. (in press) review this debate and provide new evidence which seems to explain both high Middle Weichselian clays and the low lateglacial marine limit with glacial rebound and differences in ice-retreat history. To reach a better understanding of this problem, more regional data should also be considered.

In spite of comprehensive studies, proper evidence of marine influence at pre-lateglacial sites located far inland have been difficult to find. Except for one find of marine shells at Lillehammer (Fig. 2), no marine fossils of pre-Late Weichselian age in such locations have previously been reported. However, high relative sea levels of Middle to Early Weichselian age, based on geomorphological and sedimentological evidence, have been suggested for the Gudbrandsdalen - Mjøsa region in southeastern Norway (Bergersen 1964, Olsen 1979, 1985a, Bergersen & Garnes 1981, Rokoen-

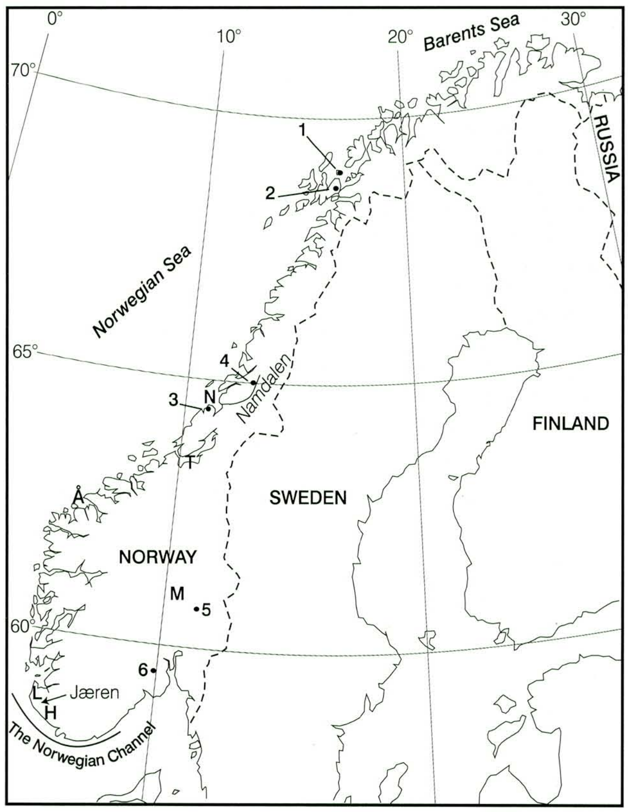

Fig. 1. Map with all sites and names of the most central places and areas discussed in this paper. 1- Storelva, Grytøya; 2- Mågelva II, Hinnøya; 3- Sitter; 4- Namsen; 5- Rokoberget; and 6- Rundhaugen, Herlandsdalen. N - Namsfjorden, T - Trondheimsfjorden, L - Lågjæren, H - Høgjæren, M - Mjøsa, Å - Ålesund area.

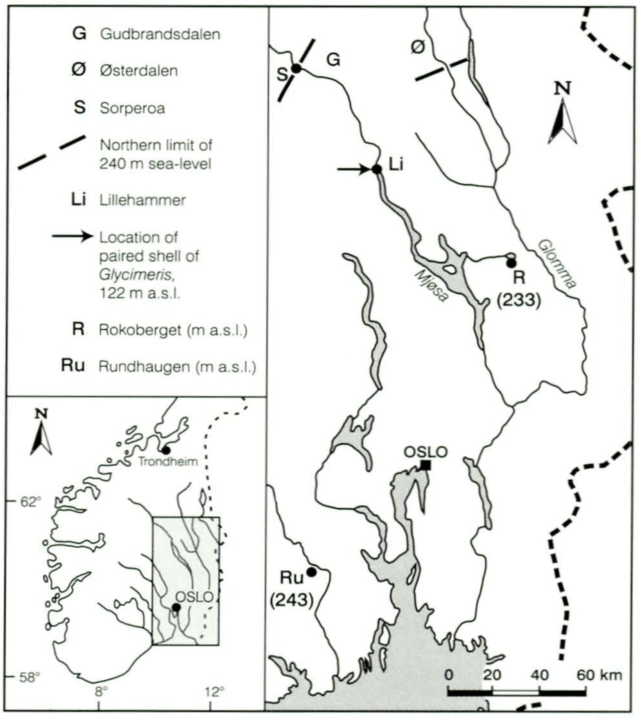

Fig. 2. Location map, southeastern Norway, modified from Rokoengen et al. (1993a). During at least one Middle Weichselian interval, with a sea level reaching c. 240 m a.s.l. (at least 233 m a.s.l. at Rokoberget), the sea covered a wide area of SE Norway, with the southern parts of Gudbrandsdalen and Østerdalen probably occurring as narrow fjords, in which possible beach terraces were developed in tills.

gen et al. 1993a). The uplifted position of the locations of these relative sea levels inferred from the inland area has simply been explained by glacial loading and unloading.

The aim of this paper is to present preliminary data from localities with Middle to early Late Weichselian marine fossils (shells, dinoflagellates) in uplifted positions in Norway. The record includes three coastal sites and two inland sites, which have been used, together with other relevant data, to discuss the most probable cause of land uplift and the consequences for the glacial conditions during the interval 18-50 ka BP.

Setting and background

The Quaternary geology of Norway has been investigated by the Geological Survey of Norway (NGU) and the Norwegian universities in several mapping programmes comprising regional surficial mapping (e.g. Olsen et al. 1996b, Bergstrøm et al. 1997, Sveian et al. 1997) and mapping of the Quaternary stratigraphy at selected localities (e.g. Roaldset 1980, Bergersen & Garnes 1981, Vorren et al. 1981, Andreassen et al. 1985, Olsen 1985b, 1993, 1995, 1997, in prep., Andersen et al. 1987, 1991, Landvik & Hamborg 1987, Larsen & Ward 1992, Rokoengen et al. 1993a, Janocko et al. 1998, Olsen et al., in prep. a, b, c). In all these sources, which together cover both coastal and inland areas, uplifted Weichselian interstadial sediments of possible marine character occur. The uplifted position of some of the marine sediments, or sediments with marine mollusc shells at the coast, have been explained by glacial transportation (e.g. Vorren et al. 1981). Such data cannot easily be used to reconstruct previous sea levels, whereas other data, for example the uplifted *in situ* marine sediments at Høgjæren (Fig. 1), may have a potential as a sea-level indicator, if the absolute and relative magnitude of the tectonic movements and the glacial isostasy can be sorted out.

The hypothesis of a possible marine influence in the inland locations has not previously been confirmed by finds of marine fossils, except for one site at Lillehammer in the northern Mjøsa district, SE Norway, but is based on various secondary evidence. These include lanthanide distribution with typical marine Ce deficiency (e.g. Roaldset 1980, Olsen et al., in prep. b), pollen content indicating vegetation with a sea-shore affiliation (e.g. Rokoengen et al. 1993a), sea-level reconstructions from accumulation/erosion level of deltaic and other glaciofluvial sediments in subtill positions (e.g. Bergersen & Garnes 1981), and sub-surface terraces resembling beach terraces developed by erosion in tills of Mid-Weichselian age (e.g. Bergersen 1964, Olsen 1979, 1985a).

A find of paired shells of the low boreal marine species *Glycimeris* redeposited from pre-Holocene sediments in the delta at the outlet of the Gausdal and Gudbrandsdalen valleys in lake Mjøsa at Lillehammer (Figs. 2 and 5A), indicates the occurrence of a pre-Late Weichsel maximum interval with a relative sea level of more than 122 m a.s.l. (Olsen, unpublished material). Pollen of spruce (*Picea*) found in a calcareous concretion filling the paired shell (S. Funder, pers. comm. 1990) may indicate a pre-Middle Weichselian age for the shell because spruce is not supposed to have grown north of Germany in any Weichselian interstadial younger than the Early Weichselian (Mangerud 1991). The precise age of the mollusc shell, however, is not known, but the shell has to derive from a warm interval, i.e. a warm interstadial or perhaps most likely an interglacial, e.g. the Eemian. If the uplifted position of the shell site is caused mainly by glacio-isostasy, this implies that the mollusc lived in an early part of an ice-free interval. Theoretically, the uplifted position could be caused by tectonic movements, but there are no other data which might suggest a significant tectonic component during the Late Pleistocene or the Holocene in this area. This is different from the situation in northern central Fennoscandia where postglacial faults with vertical displacements of 7.5-30 m have been recorded (e.g. Lundquist & Lagerbäck 1976, Olesen 1988, Olsen et al. 1999), and in SW Norway where possible active fault zones in northern Jæren may have caused significant uplift of the eastern landblock (e.g. Feyling-Hanssen 1966, Fugelli & Riis 1992, Jorde et al. 1995). Moreover, litho-isostatic subsidence still seems to be occurring in the southern Jæren – Egersund area (Bakkelid & Skjøthaug 1984, Anundsen & Gabrielsen 1990).

Stratigraphy, marine fossils and chronology

Coastal sites

Fragments of marine mollusc shells have been found in the lower part of a 1.5 m-thick sandy gravel which is overlying

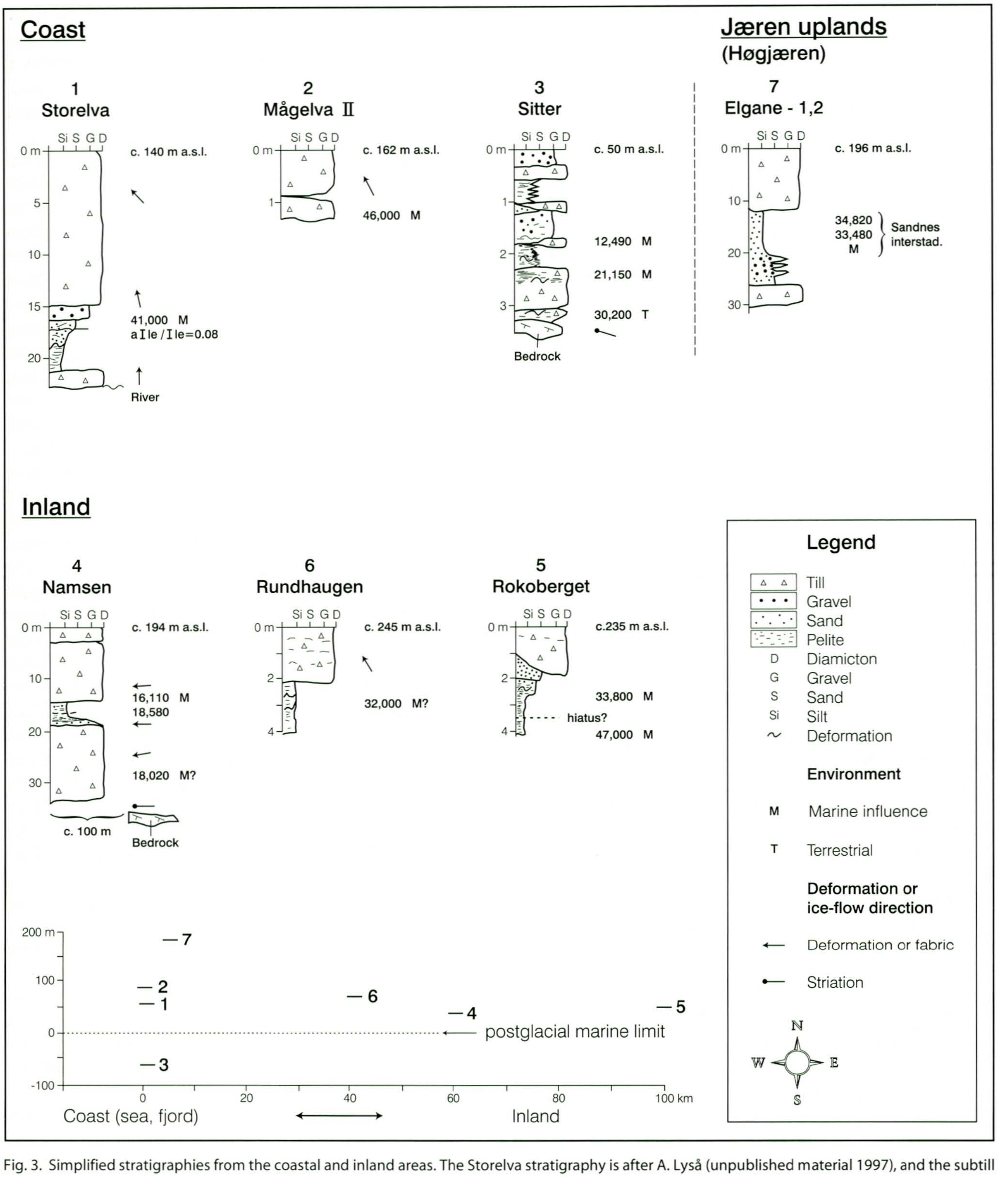

Fig. 3. Simplified stratigraphies from the coastal and inland areas. The Storelva stratigraphy is after A. Lyså (unpublished material 1997), and the subtill sediments at Rundhaugen and Rokoberget are previously published by Roaldset (1980) and Rokoengen et al. (1993a), respectively. Coring data from Elgane at Jæren (Høgjæren) are included for comparison (after Janocko et al. 1998, Sejrup et al. 1998). Comparison between minimum sea levels represented by the marine sediments from the different sites and the postglacial marine limit (defined by the 0-level) is also indicated.

5m-thick laminated sediments at Storelva c. 125 m a.s.l. on the island Grytøya, northern Norway (Figs. 1, 3 & 4). The waterlain sediments, which are intercalated between tills, have a general coarsening upwards trend and are inferred to represent an *in situ* marine succession of prograding or regressive character (A. Lyså, pers.comm. 1997, Olsen et al. in prep.c). One fragment of *Arctica islandica* from the gravel has been ^{14}C-AMS dated to c. 41,000 yr BP (Olsen et al., in prep. a, c), whereas another fragment from the same species gave alle/Ile ratios of 0.081 (HYD) and 0.289 (FREE) from amino acid

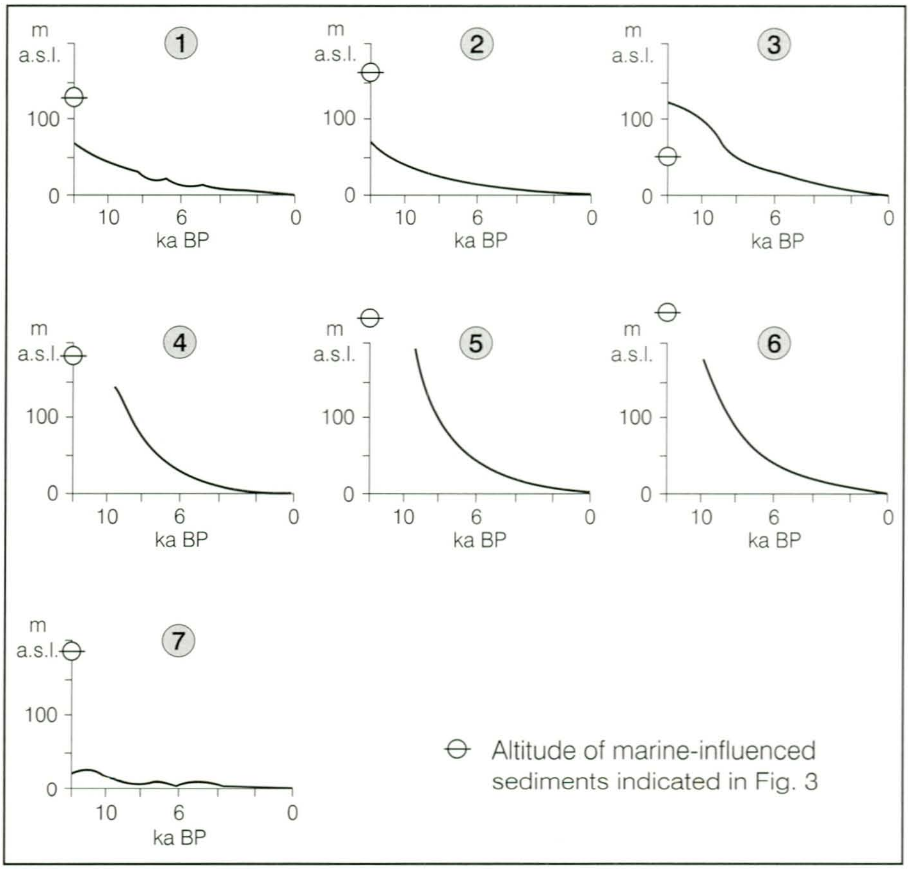

Fig. 4. Simplified late-/postglacial shoreline displacement curves from each area discussed in the text. The altitude of each site with subtill sediments of pre-lateglacial age and possible marine origin, as shown in Fig. 3, is indicated in each diagram. The shoreline data are modified from Andersen (1968) (*1 & 2*), Ramfjord (1982) and Kjemperud (1986) (*3*), Sveian & Olsen (1984) (*4*), Hafsten (1956) (*5*), Bergstrøm (1988) (*6*), and Hafsten (1983) (*7*). All the curves are strongly generalised.

analysis, which also indicates a Middle Weichselian age (H.P. Sejrup, pers. comm. 1998).

One fragment of *Mya truncata* from a till at Mågelva c. 160 m a.s.l. on the island Hinnøya (Figs. 1, 3 & 4) has been ^{14}C-AMS dated to c. 46,000 yr BP (Olsen et al., in prep. a, c). The lateglacial marine limit (ML) is c. 70 m a.s.l. in the Grytøya-Hinnøya area, which indicates a considerably lower uplift than indicated by the highly raised positions of the Middle Weichselian shell finds. However, the shell in this till may have been glacially transported from lower ground 6-7 km from the Mågelva site in the 'upstream' direction of the regional ice movement.

At a third coastal site, at Sitter in central Norway, dinoflagellate cysts have been recorded in reworked sediments in a till c. 50 m a.s.l., which is 60-70 m below the lateglacial ML in this area (Figs.1, 3, 4 & 5B-E). According to ^{14}C-AMS dating of the insoluble (INS) fraction of one bulk sample from these sediments, the age of the interval that most likely include a phase with a high relative sea level (> 50 m a.s.l.) is c. 21,000 yr BP (Table 1). Underlying the dinocyst-bearing till there is

Table 1. Record of highly uplifted Norwegian sites with Middle and early Late Weichselian sediments, including marine fossils and ^{14}C-AMS dates from the same stratigraphical levels.
Note that the sediment dates are from sediments with a generally low content of organic material (total organic carbon 1 - 2 % or less). Possible contamination of such sediments by young or old carbon is discussed by Olsen et al. (in prep. a).

Marine fossils	**1. Grytøya* 125 m a.s.l.**	**2. Hinnøya** 160 m a.s.l.**	**3. Sitter 50 m a.s.l.**	**4. Namsen 179 m a.s.l.**	**5.Rokoberget 233 m a.s.l.**	**5.Rokoberget 231 m a.s.l.**	**6.Rundhaugen 243 m a.s.l.**
Mollusc shells	XX	X					
Dinoflagellates			XX	X	X	X	
Possible diatoms (marine)							X
^{14}C-AMS age, yr BP; dated material	41,660 +/- 1500 *Artica islandica*	45,560 +/- 2400 *Mya truncata*	21,150 +/- 130 INS fraction, sed.	18,580 +/- 140*** INS fraction, sed.	33,800+ 800/-700 INS fraction, sed.	47,000 +/- 4000 INS fraction, sed.	32,000 +/- 300 INS fraction, sed.

*) Loc. Storelva (A. Lyså, unpublished); **) Loc. Mågelva II (Olsen et al., in prep. c); ***) Dating of the hexane extracted fraction: 16,110 +/- 120 yr BP from the same unit, and of the INS fraction: 18,020 +/- 170 yr BP from the underlying unit. x = some; xx = abundant.

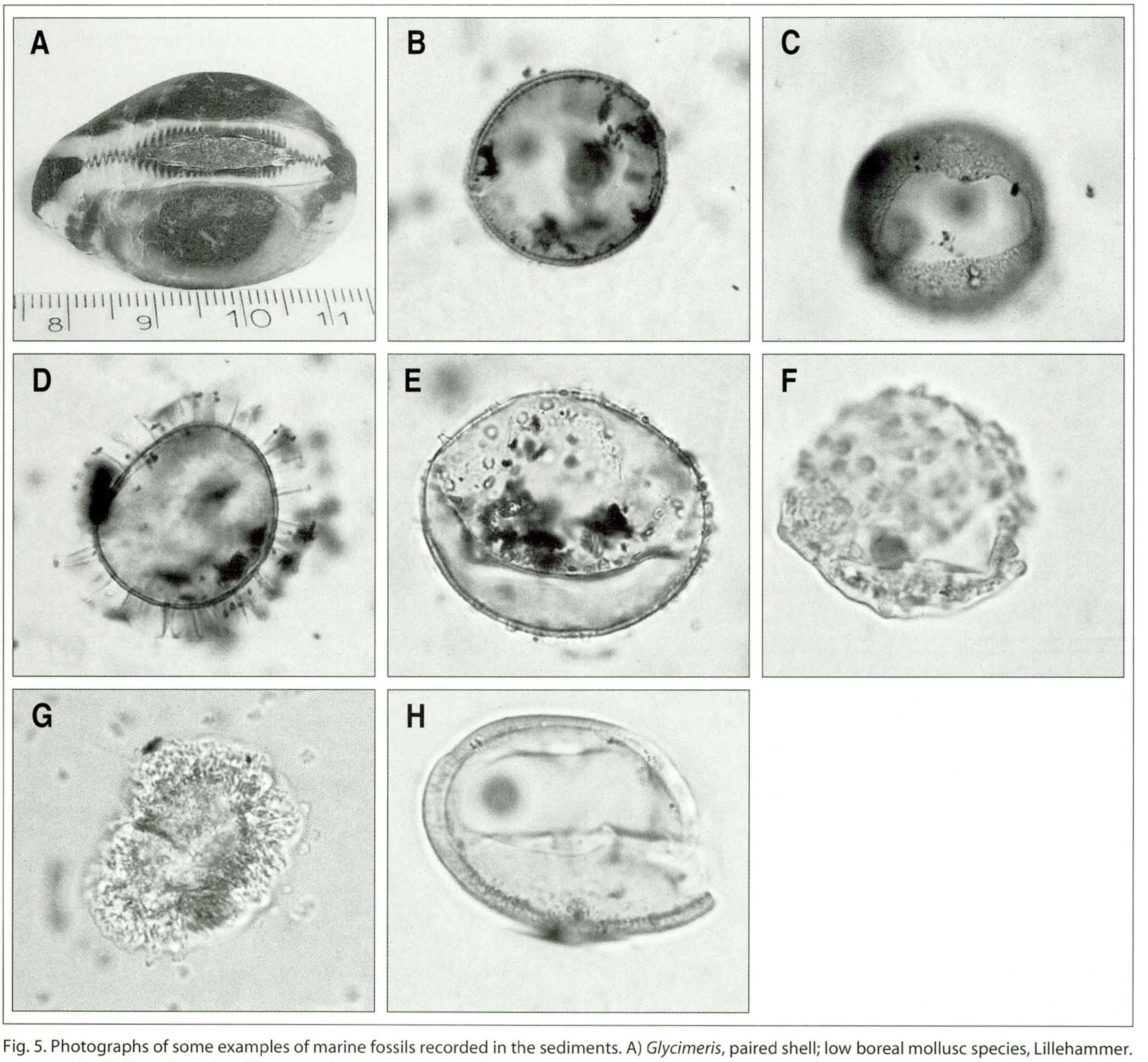

Fig. 5. Photographs of some examples of marine fossils recorded in the sediments. A) *Glycimeris*, paired shell; low boreal mollusc species, Lillehammer. Age: > 74 ka BP(?). Collected by Thor Nordahl, 1989. B – H) Dinoflagellate cysts, bright field. All given sizes of the cysts refer to the long axis of the cyst body. Preparation followed standard palynological methods, using cold HCl and HF to remove carbonate and silicate particles (Rochon & de Vernal 1994). The dinocyst nomenclature follows that of Rochon et al. (1999) and Lentin & Williams (1993). Figs. B, C & H. *Bitectatodinium tepikiense*. B, C: Sitter, N.-Flatanger. Sample id. 950557. Age: c. 21 ka BP. B: Optical section showing wall structure, cyst body diameter: 47.5 microns. C: Dorsal view, high focus, showing the archeopyle (the opening in the cyst wall through which the protoplast emerges during excystment) formed by loss of two precingular paraplates, cyst body diameter: 49 microns. H: Rokoberget, sample id. 4-11/3-90, 4 m depth. Age: c. 47 ka BP. Cyst body diameter: 37.5 microns, optical section. Figs. D-G: *Operculodinium centrocarpum*. D, E: Sitter, N.-Flatanger. Sample id. 950557. D: Cyst body diameter: 42.5 microns. E: Specimen with short processes. F: Rokoberget, sample id. 2-27/9-91, 2.5 m depth. Age: c. 34 ka BP. Specimen with short processes; cyst body diameter: 35 microns. G: Namsen, sample id. 2-10/10-95, 18 m depth. Age: c. 18 ka BP. A strongly oxidised specimen classified as *Operculodinium centrocarpum*.

another till, which overlies a thin (0.1- 0.3 m) diamictic silt. This unit is inferred to be of glaciolacustrine or glaciomarine origin. It contains no marine fossils, but terrestrial organic plant residue suggests deposition above sea level and implies a corresponding sea level below 50 m a.s.l. A ^{14}C-AMS dating of the INS-fraction of a bulk sample from the silt indicates that this may have happened c. 30,200 yr BP (Fig. 3; Olsen et al., in prep. a, c). The sediments with the dinocysts at Sitter may be slightly dislocated, but in that case they were probably transported from higher ground in accordance with the ice-movement direction from east to west (Fig. 3; Olsen, unpublished material).

Inland sites

Dinocysts are also recorded in subtill laminated sediments at two inland sites, at Namsen near the village of Trones in central Norway and at Rokoberget in southeastern Norway (Figs. 1, 2, 3, 4 & Table 1). The sediments may therefore be of shallow-marine origin. The Namsen sediments are intercalated between tills and located c. 179 m a.s.l., which is some 37 m above the postglacial ML in this area. The sediments at Rokoberget are situated c. 233 m a.s.l., which is more than 40 m above the early Holocene ML (190 m a.s.l.) in the Mjøsa area (Fig. 2). All the dinocysts from the Namsen and Rokoberget sites are badly preserved and difficult to identify. Hence, the dinocysts recorded from these sites refer to unidentified species, except for those which are illustrated in Figs. 5F-H, where names of inferred species types are included.

Three ^{14}C-AMS dates of extracted fractions from bulk samples of the Namsen sediments and reworked clayey silt in the underlying till give ages of c. 16,000-18,500 yr BP (Table 1), which together with the sediments at Sitter indicate a major ice retreat and ice-margin oscillations in the Namsfjorden-Namdalen area, and thus the entire Trondheimsfjorden area, during the interval 16,000-21,000 yr BP.

Dinocysts are recorded at two stratigraphical levels at Rokoberget (Figs. 3 & 5F, H; Table 1). ^{14}C-AMS dates of the INS fraction of bulk samples of the sediments from these two stratigraphical levels yield ages of c. 34,000 and 47,000 yr BP, respectively (Rokoengen et al. 1993a). Vegetation with a seashore affiliation, reflected in the pollen content, is thought to be represented at both stratigraphical levels (Rokoengen et al. 1993a). The boundary zone in the sediments between these stratigraphical levels is not observed in detail. A hiatus or unconformity, corresponding to the regional ice advance which is known to have occurred in other parts of Norway c. 40,000 yr BP (Larsen et al. 1987, Olsen et al. 1996a), and in the Norwegian Channel (Longva & Thorsnes 1997, Sejrup et al. 1998), may well be represented.

At Rundhaugen in Herlandsdalen, SE Norway (Figs. 1, 2, 3 & 4), glaciotectonised sub-till clay located c. 243 m a.s.l. has been studied by Roaldset (1980). Based on a Ce-deficiency in the sediments typical of marine conditions, she concluded that the clay was most likely of marine origin. She also suggested a correlation with the Sandnes interstadial clays (30-40 ka BP) based on general considerations and particularly on their similarly highly uplifted positions.

The Geological Survey of Norway has recently reinvestigated the sub-till sediments in the Herlandsdalen valley, and a Middle Weichselian age has been confirmed by two ^{14}C-AMS dates of c. 28,000 and 32,000 yr BP (Bergstrøm 1999, Olsen et al., in prep. a, c). The sub-till sediments at Rundhaugen contain some microfossils (possible diatoms) which have not yet been identified.

Contrary to the coastal area of SW Norway, there are no published records of anomalous postglacial shore displacements or other data which suggest that active fault zones, with significant vertical displacement of landblocks, exist in any of the coastal or inland regions discussed here.

Discussion and conclusions

The results presented here demonstrate the existence of ice-free conditions with a marine influence both at coastal and inland sites in Norway at around 41,000-47,000 yr BP, 32,000-34,000 yr BP, and 16,000-21,000 yr BP. The uplifted positions of the sediments imply most likely a glacial isostatic cause, which unfortunately and erroneously was printed as a 'glaciotectonic' cause by Olsen (1997, p.55), whereas the context, with many different uplifted sites distributed over a wide region, indicates clearly that it was the term 'glacioisostatic' which was meant to be used. Theoretically, tectonic movements could have explained the uplifted position of these sites, but we find it most unlikely that repeated and alternating downward and upward tectonic movements could bring these sediments to comparable high altitudes at such different locations during the same time interval (e.g. Sitter vs. Namsen, Grytøya and Hinnøya vs. Rokoberget), or to the same altitude and location during different time intervals (e.g. Rokoberget).

A glacio-isostatic explanation for the inferred uplift of the presented locations seems evident based on general considerations. The consequence for the glacial development must therefore include a dynamically unstable ice-sheet with repeated intervals of rapid ice advance alternating with rapid ice retreat. If the tectonic factor is negligible, as we think it is for the sites discussed here, then such high relative sea levels can only occur in connection with rapid ice retreat. The glacio-isostatic component seems to have been even more important if we include the possible shoreline which was developed over a wide area as a roughly formed, elongated terrace in tills c. 240-260 m a.s.l. in the southern part of the Gudbrandsdalen valley, and along the borders of the Mjøsa drainage basin (Fig. 2). The terrace has previously been explained primarily as a result of glacial and glaciofluvial erosion (Bergersen 1964, Olsen 1979, 1985a), but its extensive and partially almost horizontal character suggests that it should rather be considered to reflect a previous shoreline. However, a better description of this landform would probably be a previous temporary fluvial and colluvial erosion – accumulation basis. This possible 'shoreline' seems to be of complex origin as it was probably developed both prior to and after deposition of the fine-grained, bluish-grey Jørstad till, which is younger than 31,000-36,000 yr BP according to three ^{14}C-AMS dates from laminated sediments underlying this till at Lillehammer (Olsen 1985b, 1995). The older part of the 'shoreline' corresponds roughly with the lateral distribution of the Jørstad till in the main valleys, and with the accumulation level of the younger part of the subtill sediments in the main Gudbrandsdalen valley (Bergersen & Garnes 1981). This part of the 'shoreline' may well roughly correlate with the Sorperoa interstadial, which is represented by wind-blown sediments, TL-dated to c. 35,000-40,000 yr BP, and described from the mid-Gudbrandsdalen valley (Bergersen et al. 1991). The younger part of the 'shoreline' is less distinct and less known. It is not yet proven that this part reflects a real shoreline, because the zone is represented mainly as an erosion level on top of the Jørstad till along the valley sides around Lillehammer. Small envelopes of sorted sediments occur in places along this zone between the Jørstad till and the overlying tills, but these have not been studied in detail. Moreover, it has not been demonstrated that the area around Lillehammer was completely ice-free and exposed to direct influence by the sea in any interval between the deposition of the Jørstad till and the last deglaciation period.

The marine influence, reaching far inland and up to at least 233 m a.s.l. around 34,000 yr BP, is proven from the site Rokoberget in the southeastern part of the Mjøsa region. Given that there were ice-free conditions, the sea must therefore have reached much farther in central southeastern Norway, including the southern part of the Gudbrandsdalen and Østerdalen valleys (Figs. 2, 3 & Table 1). A marine influence in the interval somewhere between the last deglaciation and 31,000 yr BP is not yet proven for the Mjøsa region, but seems quite likely. This supposition is based on the well-known glacio-isostatic depression during the Late Weichselian maximum (LWM) at around 22,000-24,000 yr BP, and the subsequent (c. 18,000-21,000 yr BP), extremely rapid, ice retreat even far inland in southeastern Norway (Olsen 1993, 1997, 1998, Olsen et al., in prep. a, b, c). A possible marine influence around Mjøsa during ice retreat subsequent to the LWM is supported by the suggested marine influence at Namsen, central Norway, around 16,000-18,500 yr BP (Figs. 1, 3 & Table 1).

Olsen (1997) and Olsen et al. (in prep. a, b, c) have found a semi-cyclicity of 5-7 ka in glacier variation during the interval 15-45 ka BP. If glacial isostasy is the only significant cause of uplift for the highly uplifted 'marine' localities discussed here, the requirement of ice loading, and therefore duration of the ice-growth interval, should match with this semi-cyclicity. We will try to show that this is possible, using the following general approach. The highest levels of uplifted marine-influenced sediments are c. 260 m a.s.l. This requires a minimum load of ice which equals an average ice thickness of 260 m x 3= 780 m, where the factor 3 is the average ratio between specific weights of rock and ice (Paterson 1994). With a net accumulation rate of 0.1 m/yr, which is similar to the average Holocene net accumulation rate for the Greenland ice sheet, and an ice-growth interval of 7800 yr, an ice sheet with a thickness of 780 m could be developed. However, this approach starts from equilibrium, which means ice growth in a context where the rebound each time has been completed. A more realistic context would be a situation where the land-blocks were, to some extent, glacial-isostatically depressed constantly during the interval 15-18 to 45-50 ka BP. In the areas we discuss here, an average depression of minimum 50 m seems reasonable. With this adjustment as a starting level, the same approach as outlined above gives an ice-growth interval of 6300 yr, which seems to match the semi-cyclicity of 5000-7000 yr of glacier variation very well.

The glacio-isostatic cause which seems to explain the uplifted position of all the marine influenced sediments discussed here, suggests a similar cause for the highly uplifted Middle Weichselian marine sediments at Høgjæren, SW Norway (Fig.1). This accords well with most of the recent reports which discuss the uplift history of these sediments. For example, Sejrup et al. (1998) explain the uplifted position of the Middle Weichselian clays at Høgjæren by rebound after unloading of the big ice-load formed by a major ice stream c. 40 ka BP in the Norwegian Channel adjacent to the coast of SW Norway. It is well established that a major ice stream developed in the Norwegian Channel also during the LWM (24-22 ka BP) and during the Tampen readvance (18-15 ka BP) as well (Sejrup et al. 1996, King et al. 1998, Sejrup et al. 1998), which therefore should give generally high lateglacial marine limits in the Jæren region. This is not the case, as all reports of lateglacial MLs in this area indicate low ML altitudes. The highest of these is that of 20-25 m a.s.l. in the northern part of Jæren (Thomsen 1981, Andersen et al. 1987). Hence, to explain these differences in sea levels and glacial conditions Sejrup et al. (1998) suggested the presence of different deglaciation mechanisms and eustatic conditions between the pre-LWM interstadials and the last ice-retreat interval. Larsen et al. (in press) refine this model and conclude that the low ML at Jæren can be explained by glacial rebound, but in that case the ice sheet covering Jæren during the Late Weichselian must have been thin, in accordance with the model presented by Nesje et al. (1988) and Nesje & Sejrup (1988).

The inferred 'low' (< 50 m a.s.l.) sea level at Sitter c. 30,200 yr BP (Figs. 1 & 3) may correspond with the low (lower than the present) sea level at c. 30,000 yr BP reported from the North Sea Plateau southwest to west of Ålesund (e.g. Rokoengen et al. 1993b). It would also seem to be in accordance with the sea level at c. 29,000 – 34,000 yr BP (the Ålesund interstadial) in the Ålesund area, which never exceeded the postglacial marine limit in that area (Larsen et al., in press). The altitudes well above the postglacial marine limit of the sea levels during the supposed correlative intervals at Rokoberget (c. 33,800 yr BP) and Rundhaugen (c. 32,000 yr BP) may, however, indicate a different trend (Fig. 3). Alternatively, this apparent discrepancy may simply be caused by an earlier stage of glacial recovery at these sites.

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