Late Weichselian glacial history and postglacial emergence of Phippsøya, Sjuøyane, northern Svalbard: a comparison of modelled and empirical estimates of a glacial-rebound hinge line

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Field research on Phippsøya, the largest island in the Sjuøyane archipelago, defines the course and timing of postglacial emergence, documents past-glacier movements, and reinterprets deglacial sedimentary sequences. Previously described tills were not identified in sections exposed along the northeast shore of Phippsøya, but instead sublittoral sediments with rock-fall concentrations derived from the adjacent slope. A glacio-isostatically higher sea level >40 ka deposited sublittoral sediment and is possibly correlative to a deglacial event in oxygen isotope stage 4 or 5 identified at other sites on Svalbard. The postglacial marine limit is 22 ± 1 m aht and occurs as an escarpment or washing limit into a stony drift. This drift contains granite and quartzite erratics from Nordaustlandet that indicate coverage by a northward flowing ice sheet during the Late Weichselian. Datable material on the raised-beach sequence was rare and a ^{14}C age of *c.* 9.2 ka on an articulated *Balanus balanus* from 10 m aht provides a minimum constraining age on the marine limit. A mild transgression occurred by 6.2 ka, with sea level falling close to present levels by *c.* 5.0 ka. The zone of zero emergence (hinge line) lies 10 to 20 km north of Sjuøyane and is approximately coincident with the last glacial maximum limit on the continental shelf. There is an approximately 75 to100 km offset between observed and modelled zone of zero emergence, indicating a need to refine earth rheology-based ice-sheet models.

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There is clear evidence from marine geologic studies for an ice sheet grounded over much, if not all, of the Barents Sea shelf during the Late Weichselian (Elverhøi & Solheim 1983; Solheim *et al*. 1990; Gataullin *et al*. 1993; Polyak *et al.* 1995). This ice sheet expanded across Spitsbergen, with flow concentrated into fjords and sounds, with some margins reaching to the continental shelf edge (Forman 1989; Lehman & Forman 1992; Mangerud *et al*. 1992; Svendsen *et al*. 1992; Andersen *et al*. 1996; Lubinski *et al*. 1996; Polyak *et al*. 1997; Landvik *et al*. 1998). Previous studies of postglacial emergence on Svalbard place maximum ice-sheet loads over Kong Karls Land and eastern Svalbard (Salvigsen 1981; Forman 1990; Bondevik *et al*. 1995). Large-scale glacial folding of sediments on Kongsøya indicates ice-sheet flow from the east, off the Barents Sea (Ingølfsson *et al*. 1995). Recent studies of raised-beach sequences on Frans Josef Land and Novaya Zemlya further constrain maximum glacio-isostatic compensation to the Barents Sea shelf, rather than the surrounding archipelagos (Forman *et al*. 1997, 1999). This pattern of postglacial emergence within prescribed glacier limits coupled with refinements in modelling mantle rheology is the basis of reconstructing a 2+ km thick ice sheet over the central Barents Sea (Lambeck 1995; Peltier 1996).

Recent marine geologic investigations place retreat of the Barents Sea ice sheet from the >500-m-deep Franz Victoria and Saint Anna troughs, which border the northern Barents Sea shelf, by *c.* 13 ka (Polyak & Solheim 1994; Lubinski *et al*. 1996), and >13.3 ka (Polyak *et al*. 1997), respectively. Deglaciation of the shelf north of Franz Josef Land initiated also >13 ka (Herlihy 1996). Sediment cores from the continental slope northwest of Sjuøyane place final retreat of a grounded ice sheet front at ≈400 m water depth between 14.8 and 13.5 ka (Leirdal 1997). Oxygen isotope records for sediment cores from the central Arctic Ocean exhibit a strong negative excursion at *c.* 15.7 ka, possibly associated with an even earlier retreat of the northern margin of the Barents Sea ice sheet (Stein *et al*. 1994). Glaciers retreated from coastal areas surrounding northern Nordaustlandet by 10.6 to 10.0 ka indicated by the cessation of glacial marine sedimentation (Leirdal 1997). In contrast, assessments of postglacial emergence on northeastern Nordaustlandet show deglaciation of some coastal forelands by at least 11.2 ka (Blake 1981). Outlet glaciers for the western Nordaustlandet ice cap (Vestfonna) were at or behind present margins by *c.* 9.5 ka, or earlier (Blake 1989). Whereas, some forelands on north and west Spitsbergen were possibly unglaciated in the past *c.* 40 ka (Salvigsen

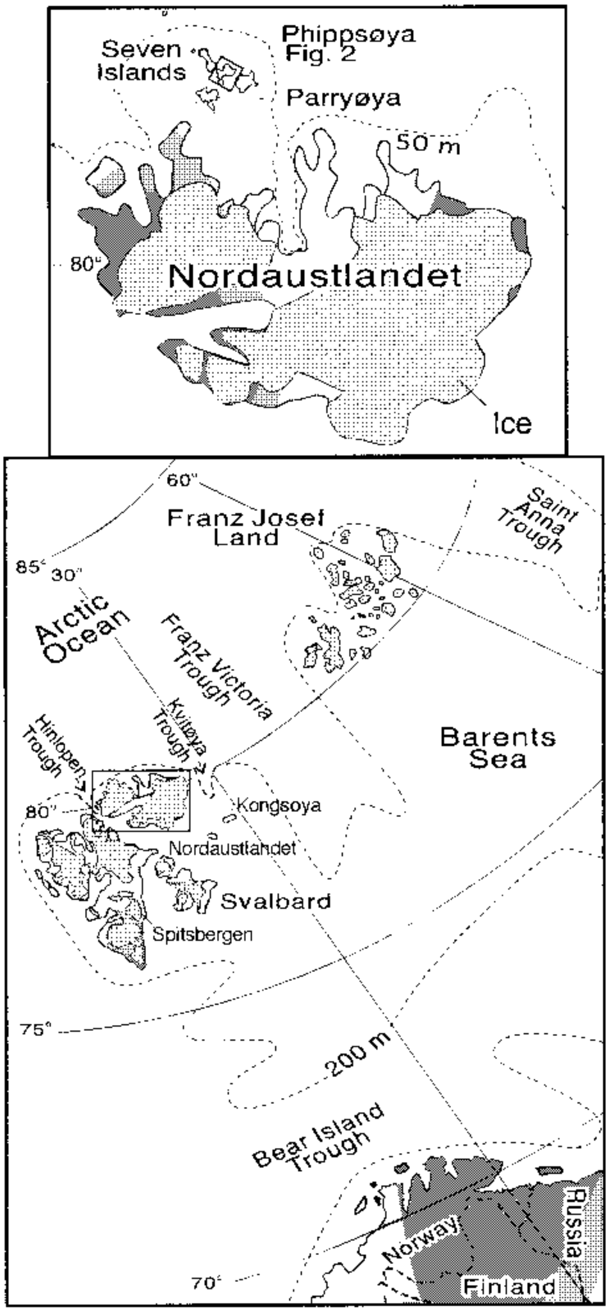

Fig. 1. Svalbard and the Sjuøyane archipelago, north of Nordaustlandet.

& Österholm 1982; Forman 1989; Lehman 1989; 1982; Landvik *et al.* 1998; Andersson *et al.* 1999).

Field research on Phippsøya, the largest island in the Sjuøyane archipelago (Figs 1, 2), was initiated in order further to evaluate the geometry and activity of the northern margin of the Barents Sea ice sheet. The only previous study of Sjuøyane identified an anomalously low marine limit (22 m aht [metres above high tide]), compared to adjacent Nordaustlandet (60 to 100 m aht), and a rich stratigraphic record of glacial and sea-level events, the earliest dated at >40 ka (Salvigsen & Nydal 1981). Our field research concentrated on temporally constraining the raised-beach record, documenting past glacier movements and re-evaluating a previously described stratigraphic section on the west coast of Phippsøya (Salvigsen & Nydal 1981; Fig. 2).

Determining elevation and age of raised marine landforms

The Sevens Islands are separated by a shallow (<50 m deep) continental shelf from Nordaustlandet, 40 km to the south. The maximum elevation on Phippsøya is 465 m and this island does not currently support cirque glaciers. Gneiss, schist and migmatite dominate the bedrock of the archipelago (Wisnes 1988).

Field research was undertaken for 15 days in August 1996 on Phippsøya (Figs 1, 2), where ice-free forelands contain abundant raised marine and glacial features (Salvigsen & Nydal 1981). The calibration datum for measuring the altitude of raised beaches and other landforms is the high-tide swash mark. The measured tidal range on Sjuøyane during July 1996 was between 0.5 and 1.0 m. The modern storm beach on southern Phippsøya reaches up to about 3 m aht. The elevation of raised beaches and finds of datable materials was measured by an AIR-HB-1L altimeter, with an analytical precision of 0.1 m. The altitude of a landform was usually measured multiple times and these measurements agree within 1 m. The maximum estimated error in determining the altitude of a landform is ±2 m.

Age constraint on deglaciation and marine inundation is provided by ^{14}C dating of whalebone and shell from raised littoral sediments (Tables 1, 2). Whalebone was sectioned by saw and an internal, well-preserved dense part of the bone was submitted for ^{14}C dating. To evaluate the veracity of ages, the collagen-dominated gelatin extract and apatite fraction from each bone was dated. Previous studies show that ^{14}C ages on gelatin extracts from whalebones preserved in Arctic environment are consistent with ^{14}C ages on driftwood from the same raised beach (Forman 1990; Bondevik *et al.* 1995; Forman *et al.* 1997). In contrast, the apatite fraction is more susceptible to contamination and can yield younger ages (Stafford *et al.* 1990). However, if apatite and gelatin ages agree (within two sigma) there is added confidence in the veracity of ^{14}C ages on bone, which is the case for the two dated whalebones from Sjuøyane (Table 1). Three AMS radiocarbon ages were obtained on *in situ* subfossil shells collected from excavations in clear stratigraphic context to past sea levels. Radiocarbon ages on whalebones and shells are corrected for fractionation of carbon isotopes by normalizing to a δ^{13}C of -25%, and compensated for the marine

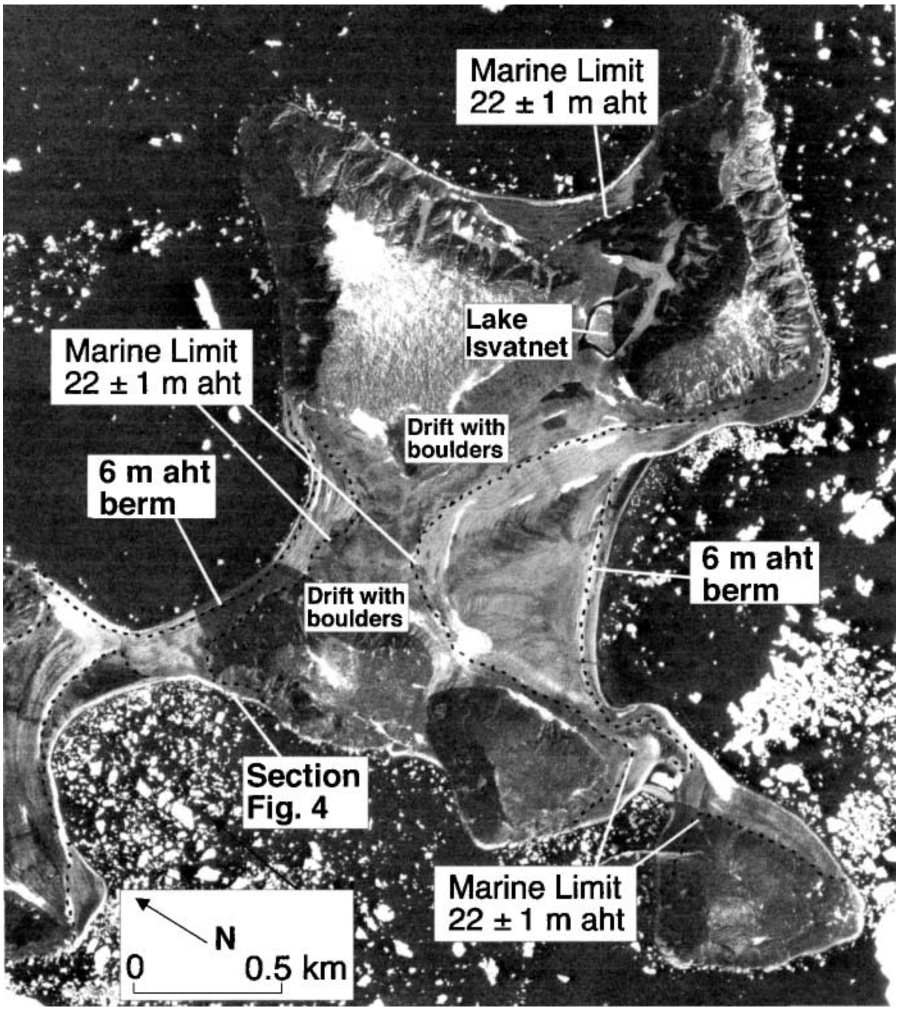

Fig. 2. Enlargment of Norwegian Polar Institute aerial photograph S69 3269 of southern Phippsøya. The marine limit at 22 ± 1 m aht and areas of glacial drift above the marine limit are shown.

reservoir effect by subtracting 440 years from the ^{14}C ages (Olsson 1980).

Evidence for glaciation

The morphology of Sjuøyane, and Phippsøya reflects in particular largely glacial sculpturing. On Phippsøya there are a series of asymmetric low mountains (≈230–465 m high), connected by lower plains, where south-facing sides are generally more moulded and north-facing sides steepened, reflecting glacial overriding from a southerly direction. Schistose-bedrock outcrops are exfoliated extensively with surfaces covered by regolith, obscuring small-scale glacial sculpture or striae. Lake Isvatnet on southern Phippsøya (Fig. 2) occupies the floor of a small cirque or nivation hollow, developed below the craggy north facing slope of Mt. Trollenykjen (200 m). Perennial snowfields in north- and east-facing niches on Phippsøya and Parryøya at <100 m aht demonstrate that the equilibrium line altitude on Sjuøyane is low today.

A drift of glacial origin covers the lower plains above the marine limit (22 m aht) and gently sloping mountain sides. This drift is rich in angular to subangular cobbles and boulders (Fig. 3). The silty-clayey matrix of the drift contains abundant shell fragments, which are most evident eroding out of fine-centres of sorted polygons and stripes. The local bedrock is mostly composed of gneiss, schist and migmatite (Wisnes 1988) belonging to the Hecla Hoek complex (Hjelle & Lauritsen 1982; Hjelle 1993), but erratics of granites and quartzites, originating from Nordaustlandet occur frequently in the drift (Fig. 3). These foreign erratics were traced up to 120 m on the mountains of Phippsøya (Salvigsen & Nydal 1981) and bear witness to glacier overriding from the south. Shell fragments from silty-clayey outcrops in the drift, 10+ m above the postglacial marine limit, gave radiocarbon ages of *c.* 38 to 39 ka, which provide a maximum estimate for emplacement of the drift (Table 1). The shells probably originate from marine sediments eroded by glaciers advancing onto Sjuøyane from Nordaustlandet and were incorporated into the glacial drift.

Table 1. Radiocarbon ages on driftwood, whalebone, and shell from raised-beach deposits and glacial drift on Phippsøya, Sjuøyane, Svalbard.

Material dated	Shoreline altitude (m aht)	Laboratory ^{14}C age or reservoir corrected age *(yrs BP)	$\delta^{13}C$	Laboratory number or reference¥
>0.75 m log embedded in raised-beach berm	3	5725 ± 115	–24.3	GX-22381
Cranium bone from whale skull	4	5485 ± 110	–19.3	GX-22380-G
		5280 ± 95	–14.9	GX-22380- A
Paired *Hiatella arctica* from littoral gravels	5	8970 ± 60	+1.3	GX-22387-AMS
3.5 m long log embedded in raised-beach berm	6	6225 ± 115	–24.8	GX-22382
Whale earbone from partially buried skull	6	9380 ± 140	–17.5	GX-22379-G
		8750 ± 180	–13.8	GX-22379-A
Mya truncata shells from raised beach	6	9410 ± 60		Salvigsen & Nydal 1981
Articulated *Balanus balanus*	10	9210 ± 60	+1.9	GX-22386-AMS
Hiatella arctica fragment from glacial drift	35	39 260 ± 1100	+0.7	GX-22385-AMS
Mya truncata shells from glacial drift	36/38	38 400 + 1960/−1300		Salvigsen & Nydal 1981

*440 years are subtracted from ^{14}C ages on marine subfossils to compensate for the ^{14}C oceanic reservoir effect.
¥A and G indicate radiocarbon age on the apatite and gelatin extracts, respectively.

Table 2. Amino acid racemization ratios and associated radiocarbon ages for molluscs from stratigraphic sections on Phippsøya, Sjuøyane, Svalbard.

Material and field no.	Altitude (m aht)	Laboratory no.	D/L amino acid racemization ratio* Free	D/L amino acid racemization ratio* Total	Radiocarbon age (yrs BP) and laboratory number or reference
Valves of *H. arctica*	8	AAL-8257	0.23 ± 0.01(6)	0.033 ± 0.006(6)	47 460 ± 2900 (GX-22388-AMS)
Fragments of *M. truncata*	9	AAL-8256	0.30 ± 0.07(5)	0.034 ± 0.008(5)	
M. truncata (Sa-76–69)	14	AAL-1239	0.18	0.022	42 000 + 3200/−2300 (Salvigsen & Nydal 1981)
		AAL-1240	0.19	0.021	45 100 + 1700/−1400 (Salvigsen & Nydal 1981)
H. arctica (Sa-76–66)	6.5	AAL-1233	0.35	0.037	38 100 + 1600/−1400 (Salvigsen & Nydal 1981)
M. truncata (Sa-76–66)	6.5	AAL-1234	0.34	0.036	42 200 + 1300/−1200 (Salvigsen & Nydal 1981)
H. arctica (Sa-78–71)	8	AAL-1242	0.36	0.037	41 200 + 3100/−2200 (Salvigsen & Nydal 1981)

* Ratio of D-alloisoleucine to L-isoleucine in the free amino acid fraction and after acid hydrolysis to yield total fraction. Analyses completed at the Amino Acid Geochronology Laboratory at INSTAAR, University of Colorado, Boulder.

Salvigsen & Nydal (1981; Fig. 2) described a stratigraphic section on the western side of Phippsøya, where they recognized two till-units below a shell-bearing littoral sand. Radiocarbon dating of shells from the sand and the upper till unit gave ages of >40 ka, and amino-acid determinations indicated that the shells originated from two populations of different ages. U-Th dating of shells from the Phippsøya section yielded minimum limiting ages of *c*. 37.7 to 45.1 ka (Salvigsen & Nydal 1981; Table 1).

We reinvestigated the stratigraphy on the west coast of Phippsøya (Fig. 2) by locating a section previously reported by Salvigsen & Nydal (1981). However, we could not confirm the occurrence of tills in the section (Fig. 4). The lowermost bouldery diamicton contains angular clasts of gneiss and schist, all of local provenance and none striated or faceted. Granite or quartzite erratics, which occur frequently in the glacial drift that blankets the island above the marine limit, were not found. These clasts were within a matrix of well-sorted, massive-to-centimetre-scale laminated, medium sand. This sand contains fragments of bivalves, including *Mya truncata* and *Hiatella arctica*. Silt laminae and one noticeable interbed of clayey silt with whole and fragmented bivalves also occur within the sand. Shells from this sand yielded ^{14}C ages between 38.1 and 47.5 ka, which are probably minimum limiting ages (Table 2). We conclude that the lowermost diamicton is rockfall debris, deposited by mass movements into a sublittoral environment, below the steep west-facing cliffs at the site. Finer-grained beds and lenses with angular shell fragments and valves reflect turbidite deposition, associated with mass movements from the adjacent slope, when relative sea level was higher. This process is highly active today, and the raised-beach terrace at approximately 12 m aht and the modern shoreface is littered with large, angular boulders from the adjacent cliff.

Relative sea-level record

The elevational limit of marine influence is clearly demarked as an erosional notch or a washing limit into glacial drift at 22 ± 1 m aht (Figs 2, 5), identical to previous measurements by Salvigsen & Nydal (1981). Below the marine limit to 5 m aht is a series of well-

Fig. 3. Granite erratic on drift surface at 35 m a.s.l. on southern Phippsøya. The shotgun is approximately 1 m long.

preserved regressional strandlines composed of coarse gravels and boulders.

The age of the marine limit is difficult to constrain because there is a noticeable paucity of driftage on raised beaches on Phippsøya. Driftage was not found at or within 12 m below the marine limit, despite a concentrated search over six days. The highest retrieved subfossil is an articulated *Balanus balanus* found in a cliff section, associated with sandy, littoral foreset beds that grade to a prominent raised beach at 10 ± 1 m aht; a

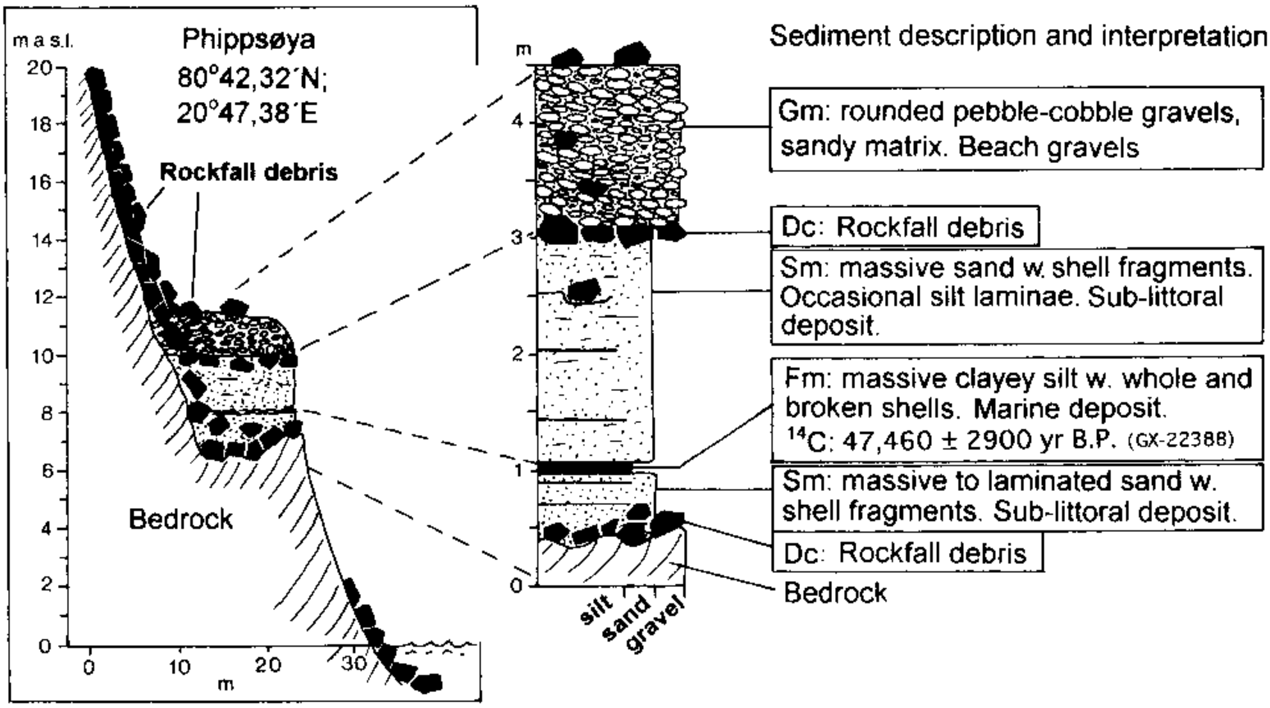

Fig. 4. Lithofacies and stratigraphic relations on the west coast of Phippsøya. No till was identified, only rockfall debris from the adjacent steep slope.

Fig. 5. Person (1.6 m tall) standing on marine limit at 22 ± 1 m aht on southern Phippsøya, demarcated as a washing limit into cobbly drift.

plate yielded the ^{14}C age of 9210 ± 60 BP (GX-22386-AMS). An earbone from a stranded whale skull at 6 m aht, retrieved on a low gradient strandflat approximately 0.5 km inland, yielded the ^{14}C age of 9380 ± 140 BP (GX-22379-G). The age for this whalebone is similar to a previously reported conventional ^{14}C age of 9410 ± 60 BP on bivalves of *Mya truncata* from littoral gravels at 6 m aht (Salvigsen & Nydal 1981). A paired bivalve of *Hiatiella arctica* from gravel forset beds associated with a raised beach at 5 m aht yielded ^{14}C age of 8970 ± 60 BP (GX-22387-AMS).

At 5 to 6 m aht there is a noticeable discontinuity in the raised-beach sequence, with a constructional berm that truncates previously deposited raised beaches with ages of *c*. >9.2 ka (Fig. 2). Driftwood from the crest of this berm gave the ^{14}C age of 6225 ± 115 BP (GX-22382). Discrete strandlines occur below 5 m aht to 2 to 3 m aht, where the modern storm beach ridge truncates raised beaches. A whale skull bone and a log from regressional strands at 4 and 3 m aht yield the respective ^{14}C ages of 5485 ± 110 BP (GX-22380-G) and 5725 ± 115 BP (GX-22381).

The deglaciation of Phippsøya and subsequent marine inundation occurred well before *c*. 9.4 ka ago, the oldest ages from primary regressional strand deposits (Fig. 6). Radiocarbon ages between *c*. 9.4 and 9.0 for driftage from raised beaches between 10 and 5 m aht overlap at two sigma, indicating rapid emergence (within *c*. 280 ^{14}C years) for these regressional strands. Sea level fell below or attained the current level sometime between *c*. 9 and 7 ka. A mild transgression occurred *c*. 6.2 ka, building a prominent constructional berm at 6 m aht, which truncates older (>9 ka) raised beaches (Figs 2, 6). Sea level then fell from the constructed berm by 5.7 to 5.5 ka. A similar mid-Holocene transgression is documented on other areas of Svalbard (e.g. Forman 1990) and may be associated with the highest occurrence of pumice on raised beaches in central Spitsbergen (Salvigsen 1984) and Nordaustlandet (Schytt *et al*. 1968; Salvigsen 1978).

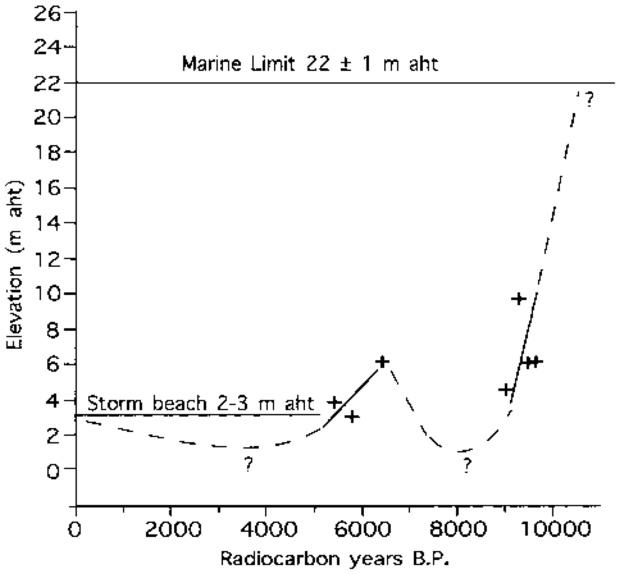

Fig. 6. Height–age relation for raised beaches on southern Phippsøya. The size of the plotting symbol approximates errors in determining altitude of approximately 1 m and ^{14}C age determination error of approximately 100 years.

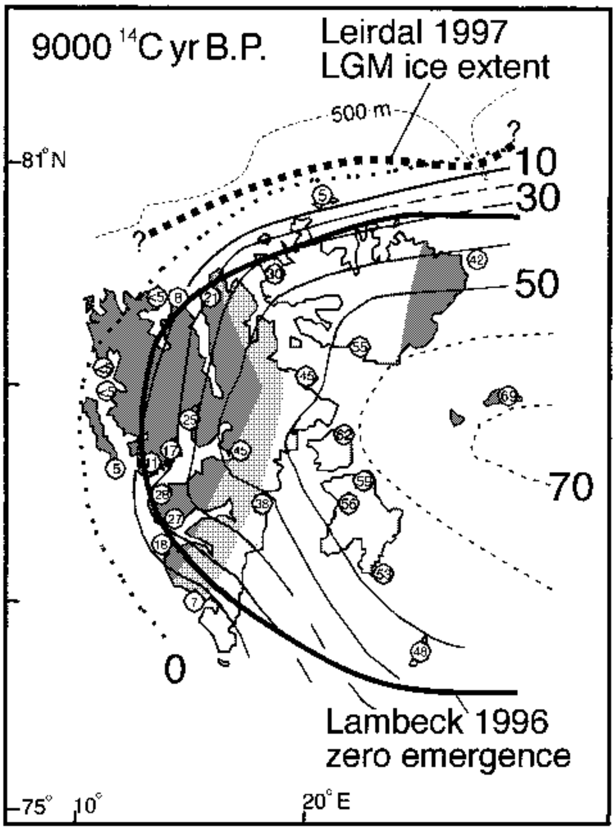

Fig. 7. Estimated emergence isobases since 9000 ^{14}C yr for Svalbard, with a new data point (5 m) for Phippsøya, Sjuøyane (modified from Forman *et al.* 1997). Also Shown is the zero line of emergence, derived from the rheological model of the last ice sheet over Svalbard and the Barents Sea (Lambeck 1996). Note the discrepancy between the empirically inferred and modelled zone of zero emergence. The inferred zero line of emergence corresponds approximately to the Last Glacial Maximum (LGM) limit of Leirdal (1997). See also the 500 m bathymetric contour for the continental shelf north of Svalbard.

Discussion

The section studied on the west coast of Phippsøya exhibits clear evidence for a pre-Late Weichselian glacio-isostatically induced higher sea level, presumably associated with a regional glaciation of Svalbard of similar or greater magnitude as the Late Weichselian. This sedimentary sequence contains sublittoral and deltaic sediments presently at *c*. 10 m aht, which yielded ^{14}C ages >40 ka and total and free amino acid epimerization ratios of 0.033 and 0.23/0.30, respectively. Correlation of this deglacial sequence on Phippsøya to other localities on Svalbard is problematic because of uncertainties in site-specific thermal histories. Stratigraphic localities on Kongsøya with corresponding amino acid ratios are assigned an early Weichselian or Eemian age (Ingólfsson *et al.* 1995). Deglacial strata from a number of sites along west Spitsbergen with total amino ratios of 0.026 to 0.031 yielded luminescence ages between 50 to 70 ka (Mangerud *et al.* 1998); an additional luminescence dating study favours an older age of *c*. 70 ka for this deglacial event (Forman 1999). Contrary to previous efforts (Salvigsen & Nydal 1981), we found no evidence for glacial diamictons, but sublittoral sediments contain locally derived angular clasts and boulders from the adjacent steep 50+ m high cliff.

The occurrence of foreign erratics from Nordaustlandet and a ubiquitous shelly drift, above the marine limit to 120 m aht is positive evidence for over-riding of Sjuøyane by a northerly flowing glacier, largely based in the Barents Sea during the Late Weichselian. The lack of pre-Late Weichselian raised beaches, often recognized along the west and north coasts of Spitsbergen (Salvigsen & Österholm 1982; Forman 1989; Lehman 1989; Andersson *et al.* 1999), is consistent with the passage of a wet-based, erosive glacier across Sjuøyane, which incorporated older marine sediments into the diamicton, from which shells yielded ^{14}C ages of >40 ka.

Acoustic records from the shelf immediately west and north of Sjuøyane identified a moraine system at a maximum water depth of ≈400 m (Leirdal 1997). This moraine system is traced up to 10 km across the shelf to the lower flanks of the Hinlopen Trough. The 400-m bathymetric limit of morainal forms and deeper distribution of Svalbard-distinct, pink glacial-marine sediments in the adjacent continental slope and shelf indicates that the Barents Sea ice sheet terminated 15 to 20 km north of Sjuøyane. This ice sheet advanced to about 400 m water depth as a calving margin, with grounded ice streams occupying the adjacent Hinlopen and Kvitøya troughs (Leirdal 1997). Radiocarbon dating of *in situ* foraminifera fauna from glacial marine sediments from the shelf and slope north of Sjuøyane place expansion of the Barents Sea ice sheet across the continental shelf at between *c*. 24 and 21.5 ka and retreat from the morainal bank north of Sjuøyane by 14.8 to 13.5 ka. Thus, the advance and retreat of the Barents Sea ice sheet across the shelf north of Sjuøyane spanned a maximum of *c*. 10 ka (^{14}C), with a reconstructed ice-sheet thickness of at least 500 m over Sjuøyane (Leirdal 1997; Landvik *et al.* 1998).

The relative sea-level curve for Phippsøya exhibits an initial period of rapid regressive followed by a mild transgression and then regression (Fig. 6). Previous geophysical models categorize this pattern of emergence (transition zones 1–2) as characteristic for areas at or close to an ice-sheet margin (Clark *et al.* 1978). However, marine and glacial geologic studies concur that Sjuøyane sustained at least a 500-m-thick ice-sheet load, within 15 to 20 km of the inferred margin on the outer continental shelf (Leirdal 1997 and this study). The relatively diminutive isostatic response on Phippsøya may reflect non-equilibrium ice-sheet loading conditions, with rapid expansion and retreat (within 2 to 6 ka) of the Barents Sea ice sheet across Sjuøyane.

Such relatively rapid (<5000 years) ice-sheet marginal movements over Sjuøyane are permissible with the available chronologic control (Leirdal 1997). The uplift half-life for Svalbard is approximately 2000 to 2500 years (Forman *et al*. 1997), and assuming a similar response during the ice-sheet loading interval, a glacial-deglacial cycle of *c*. 5000 years would result in a 75% or lower isostatic response than equilibrium load conditions.

A record on postglacial emergence on Phippsøya provides needed data to constrain emergence isobases for northernmost Svalbard (Fig. 7). Relative sea-level data from Phippsøya are particularly important for further constraining the 'zero line' or 'hinge line', which demarks the boundary between postglacial emergence and submergence. Submergence reflects postglacial collapse of the forebulge, with back redistribution of glacio-isostatically displaced mantle material toward the centre of ice-sheet loading. The area of zero emergence during deglaciation reflects a balance between glacio-isostatic submergence associated with forebulge collapse and rising global sea level largely from the demise of Northern Hemisphere continental ice sheets.

Earth rheology-based models of the Fennoscandinavian and Barents Sea ice sheets reconstruct a 'zero line' of emergence that is relatively stationary during early postglacial emergence (15 to 9 ka) that occurs *c*. 50-to-70 km *landward* of the glacial maximum position (Fig. 7; Fjeldskaar 1994). However, the low net emergence of ≈5 m since 9 ka on Sjuøyane, shows that the zone of zero emergence lies immediately northwest and 20-to-30 km *seaward* of Sjuøyane and corresponds closely to the inferred glacial maximum position (Fig. 7). This 75–100 km discrepancy between the location of the observed and modelled line of zero emergence indicates that rheological-based ice-sheet models need further refinement. The model underestimation of postglacial emergence at the margin of the Barents Sea ice-sheet margin may reflect insufficient ice-sheet thicknesses within prescribed limits, overly high mantle and asthenosphere viscosities, overestimates on lithosphere thickness (65 km), insufficient flexural rigidity, or some combination of the these factors. However, changing model parameters to fit marginal records of postglacial emergence may lead to discordancy in well-constrained records near the centre of ice loading and less plausible earth rheology (Peltier 1996). Spatially variable lithosphere thickness, rigidity and mantle viscosity with changes in geologic province may yield more realistic ice-sheet configurations.

Alternatively, this disagreement between modelled and actual emergence may reflect an intrinsic limitation of rheological-based ice-sheet models. The 50–100 km^2 grid resolution of ice-sheet models provides an insensitive representation of marginal processes. The single dome geometry prescribed by rheologically based models over the central Barents Sea may not accurately represent ice-sheet geometry and flow, particularly in coastal areas with mountains, such as on the western and northern coasts of Svalbard. Coastal satelitic ice caps, with diameters greater than lithosphere thickness (>50 km), would produce locally greater loads and more reactive margins that could rapidly advance and retreat across the shallow shelf; similar to coastal areas along the present margin of the east Antarctic ice sheet.

Conclusions

1. We confirm observations by Salvigsen & Nydal (1981) that the postglacial marine limit on Phippsøya, Sjuøyane is 22 ± 1 m aht. This limit was recognized as an escarpment or washing limit into a stony drift. A ^{14}C age of *c*. 9.2 ka on an articulated *Balanus balanus* from 10 m aht provides a minimum constraining age on the marine limit. A mild transgression occurred by 6.2 ka, with sea level falling close to present levels by *c*. 5.0 ka.

2. Erratics of granites and quartzites originating from Nordaustlandet occur frequently in the drift. These foreign erratics are traced up to 120 m on the mountains of Phippsøya (Salvigsen & Nydal 1981) and bear witness to glacier overriding from the south. Shell fragments from silty-clayey outcrops in the drift, 10+ m above the postglacial marine limit, gave radiocarbon ages of *c*. 40 to 47 ka, which we consider to be maximum limiting estimates on glacier advance. A recent marine geologic study indicates that the Barents Sea ice sheet advanced across the continental shelf between 24 and 21. 5 ka and retreated from a morainal bank north of Sjuøyane by 14.8 to 13.5 ka (Leirdal 1997).

3. A section studied on the west coast of Phippsøya exhibits clear evidence for a pre-Late Weichselian glacio-isostatically induced higher sea level, presumably associated with regional glaciation of Svalbard of similar or greater magnitude as the Late Weichselian. This sedimentary sequence contains sublittoral and deltaic sediments presently at *c*. 20 m aht, which yielded ^{14}C ages >40 ka and total and free amino acid epimerization ratios of 0.033 and 0.23/0.30, respectively. This deglacial sequence may correspond to Middle or Early Weichselian or Eemian strata on other localities on Svalbard. Contrary to previous efforts, we found no evidence of a glacial diamicton, but sublittoral sediments contain locally derived angular clasts and boulders from the adjacent steep 50+ m high cliff.

4. The 9 ka 'zero line' of emergence on northern Svalbard is 20–30 km offshore of Sjuøyane, close to the inferred glacial maximum limit. However, earth rheological-based ice-sheet models place the zero line at 50–70 km inland. This discrepancy between the observed and modelled zone of zero emergence, indicates that rheological-based ice-sheet models need further refine-

ment. Future models of the Barents Sea ice sheet need to incorporate complex processes such as calving, ice-stream development and interactions with coastal satelitic ice caps to better understand the dynamics of the last glaciation.

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