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A high-resolution, 800-year glaciomarine record from Russkaya Gavan', a Novaya Zemlya fjord, eastern Barents Sea

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Abstract: Sediment core ASV-987 from Russkaya Gavan', a tidewater fjord on the northwestern coast of Novaya Zemlya, provides the first multicentury record of sedimentary and hydrographic glaciomarine environments in Russian Arctic with a century-scale resolution. Age is constrained by seven ^{14}C ages securing an especially robust control for the period between *c.* AD 1370 and 1600. Based on sediment structure, grain size, depositional rates, foraminiferal assemblages and stable isotopes in foraminiferal tests, we reconstruct the changes in fjord sedimentation and circulation in relation to the history of a tidewater glacier connected to the main Novaya Zemlya ice complex. We conclude that a noticeable glacier advance occurred *c.* AD 1400, contemporaneous with a change in North Atlantic atmospheric circulation inferred from GISP-2 ion-contents data. A major glacier retreat from Russkaya Gavan' occurred by *c.* AD 1600, succeeded by low sedimentary inputs. Intervals with depleted stable isotopic values, including the core top, may indicate intensified glacier melting. Stronger melting in the 1900s is consistent with an increase in sedimentation rates.

Key words: Last millennium, glaciomarine, sedimentary record, tidewater fjord, Novaya Zemlya, Barents Sea, late Holocene.

Introduction

Dramatic changes in climate, hydrography and sea-ice conditions were observed in the Arctic over the last two decades (e.g., Parkinson *et al.*, 1999; Rigor *et al.*, 2000). These changes prompt detailed investigation of the Arctic natural variability to evaluate the effect of global warming. Instrumental data covering the period of 125 years indicate strong variability in atmospheric and oceanic processes in the Arctic on a multidecadal scale (Polyakov and Johnson, 2000; Polyakov *et al.*, 2002), consistent with modelled and proxy results for the Northern Hemisphere, which emphasize the role of the North Atlantic in shaping the multidecadal variability (Delworth and Mann, 2000). However, the evaluation of long-term changes and the identification of feedbacks involved is limited by a short period of instrumental observations and requires multicentury, high-resolution proxy records. This task is complicated in the Arctic by various factors, notably the paucity of biogenic remains that could be used as palaeoenvironmental proxies, as well as logistical constraints.

An important source of long-term, high-resolution sedimentary archives constitute glaciated fjords that combine high sedimentation rates with sensitivity to both glacial and oceanographic histories (e.g., Gilbert, 2000, and references therein). Meanwhile, fjords in Eurasian Arctic except for its western fringe are virtually unexplored. Notably, the indented coasts of Novaya Zemlya (Figure 1) yield extensive glacimarine archives of climatic changes in the Barents Sea region that is characterized by pronounced atmospheric and oceanographic gradients. In this paper, we present the first detailed palaeoclimatic time series from the eastern Barents Sea for the past *c.* 800 years, developed on a sediment core from Russkya Gavan', a glacier-influenced fjord on the northwest Novaya Zemlya coast (Figure 1).

Physiographic and oceanographic setting

Russkaya Gavan' is a unique study site as it provides one of the few meteorological archives (>60 years) for the eastern Barents Sea. Moreover, the regime of Shokal'ski Glacier, which drains into Russkaya Gavan' and connects to the main Novaya Zemlya ice complex, has been repeatedly studied since 1933 (Chizhov *et al.*, 1968; Mikhaliov and Chizhov, 1970). The ELA for this $>500\,km^2$ glacier is at $\sim$400 m a.s.l., encom-

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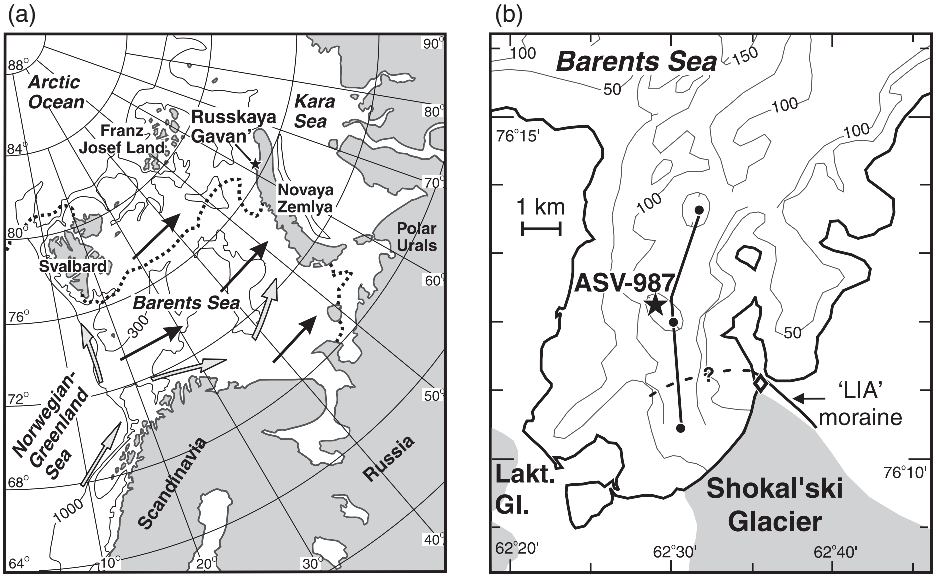

Figure 1 (a) Map of the Barents Sea with 300 m and 1000 m isobaths, minimal winter sea-ice margin (dotted line) and direction of Atlantic water flows (grey arrows) and winter cyclones (black arrows). (b) Index map of Russkaya Gavan' with bathymetry in 50 m intervals. Diamond north of glacier shows location of ^{14}C age from the moraine (Zeeberg, 2001). Lakt. Gl. = Loktionov Glacier. Thick line along the fjord and superimposed filled circles show location of sonar transect and hydrocast stations (Figure 2).

passing the 9 km length of the 100 m thick and 3 km wide outlet to Russkaya Gavan'. The outlet is rich in morainic debris and the estimated ice-flow speed near the front reaches 150 m/yr. A second large glacier (Laktionov Glacier) terminates close to, but not reaching, the fjord coast. Approximately 80% of glacier mass loss in Russkaya Gavan' is estimated to be from melting and the remainder from iceberg production. Most of meltwater presumably enters the fjord from subglacial channels. Summer temperature has a strong control on glacier melting. In turn, snow/ice accumulation is strongly connected with winter temperature, as winter precipitation on Novaya Zemlya occurs predominantly at the fronts of warm North Atlantic cyclones (Chizhov *et al.*, 1968; Serreze *et al.*, 1993). Observational data imply that net mass balance of Shokal'ski Glacier is approximately equally dependent on winter precipitation and summer melting. This conclusion is consistent with indications that most Novaya Zemlya glaciers did not experience significant changes in ice mass or in the position of margins during the last century as present warming enhances both winter accumulation and summer melting (Chizhov *et al.*, 1968; Zeeberg and Forman, 2000). Prior glacial advances are indicated by the subbottom record of fjord sediments (Figure 2). A fresh-looking moraine north of the outlet glacier marks its latest advance beyond the present position (Figure 1). A ^{14}C age obtained on a transported bivalve shell from this moraine constrains its maximal age to AD 1300–1400 (Zeeberg, 2001). Given the morainic configuration, we infer that the glacier front (grounded or floating) extended into the fjord by several kilometres.

Winter temperatures at the western Novaya Zemlya coast covary with inputs of Atlantic water that are largely controlled by atmospheric circulation, notably the strength of the Icelandic Low (Blindheim *et al.*, 2000; Zeeberg and Forman, 2000). In contrast, summer temperatures on Novaya Zemlya do not show any clear relationship with the Atlantic influence, reflecting a more complex climatic pattern. Atlantic inputs and related sea-ice condition strongly affect the hydrographic regime in Russkaya Gavan', as illustrated by a correlation of sea-ice melting time in the fjord with winter air temperatures (Mikhaliov and Chizhov, 1970). The fjord hydrography in summer is largely controlled by meltwater discharge. Hydrocast data show high sediment load in meltwater over- and underflows within >5 km from the glacier terminus (Figure 2). This, together with an increase in glaciomarine sediment thickness towards the glacier, as indicated by subbottom sonar data (Figure 2), demonstrates that sedimentation in the fjord is largely controlled by glacial inputs.

Materials and methods

Geological sampling, geophysical profiling and oceanographic measurements were performed in Russkaya Gavan' in September 1997 and 1998 by R/Vs *Akademik Sergei Vavilov*

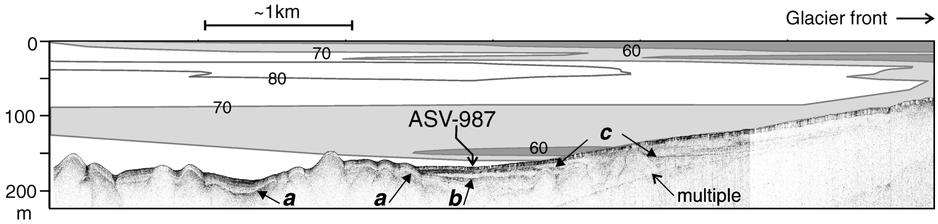

Figure 2 Transect along Russkaya Gavan' showing light transmissivity in water-column and 8.8 kHz subbottom sonar data (R/V *Ivan Petrov*, 1998) (Figure 1 for location). Light transmissivity (%, interpolated between the hydrocast profiles) is inversely proportional to suspended sediment load. Reflector a on the sonar profile separates Holocene glacimarine sediments from older (last glacial maximum?) glacigenic deposits. The ice-proximal glacimarine sedimentary wedge consists of three units separated by reflectors b and c, which may reflect the two major ice-front readvances, possibly including the event recorded in ASV-987 (reflector c).

Table 1 AMS (accelerator mass spectrometry) ages. ^{14}C ages were converted to calendar years using the CALIB 4.3 program, with $\Delta R = 85$ (see text) (AA = Arizona AMS Facility; GX = Geochron Laboratories)

Lab. no.	Depth in core (cm)	Material	Reported ^{14}C age BP	Calibrated age AD (1σ)	Med. prob. age AD
AA34305	41–44	*Thyasira* sp., *Yoldiella* sp.	post-bomb		
AA35039	175–180	*Nuculana tenuis*	795 ± 40	1538–1651	1592
AA39567	304–306	*Thyasira* sp., shell detr.	919 ± 40	1440–1527	1488
AA35038	399–401	*Macoma* sp.	990 ± 45	1394–1485	1434
AA39568	474–476	*Macoma* sp.	1068 ± 40	1333–1420	1377
GX-24917	559–561	*Macoma* sp.	1260 ± 40	1184–1291	1229
AA39569	584–586	shell detr.	1301 ± 40	1133–1263	1190

(ASV) and *Ivan Petrov*, respectively. A 6 m long gravity core ASV-987 was collected from a silled basin in the central part of the fjord (water depth 170 m) (Figure 1). The core was described immediately after raising and sampled at 5 cm intervals. Analytical studies included measurements of density and water content, magnetic susceptibility, grain size, total organic carbon and carbonate contents, foraminifers, stable isotopes in foraminiferal calcite, and clay minerals. Age control was provided by seven AMS ^{14}C datings on mollusc shells (Table 1). Lithological and foraminiferal analyses were performed at the Shirshov Institute of Oceanology; stable isotopes were measured at the Woods Hole Oceanographic Institution.

The content of coarse fractions ($>50\,\mu m$) was determined in all samples by washing and sieving. The distribution of finer fractions was analysed at 10–20 cm intervals applying combined pipette and decantation method. Fraction >1 mm was semi-quantitatively examined for rock fragments and macrofaunal remains. Foraminifers were counted in the size fraction 0.1–1 mm. Compositions of oxygen and carbon stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) were simultaneously measured on a Finnigan MAT-252 mass spectrometer in tests of benthic foraminifer *Elphidium excavatum* forma *clavata*.

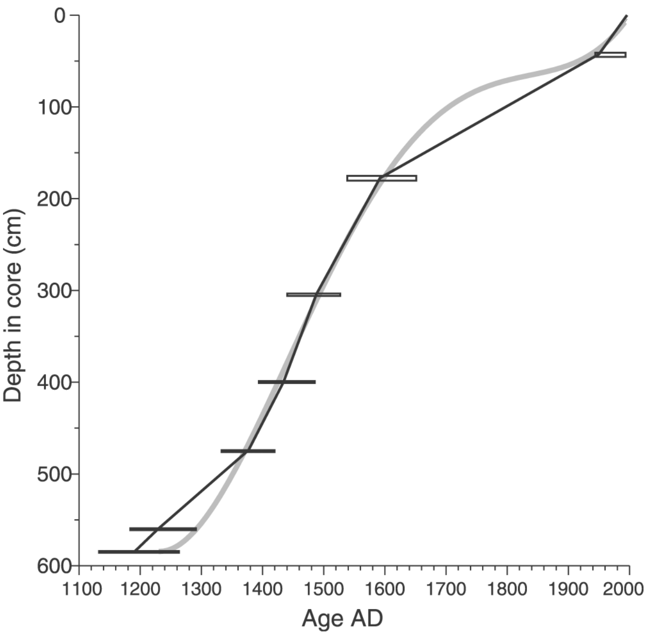

Figure 3 Calibrated ^{14}C ages plotted against depth in ASV-987 (Table 1). Bars show 1σ calibrated age ranges. Black line shows linear interpolation between dated points (median probability cal. ages), grey line shows fourth-order polynomial fit. Post-bomb age is plotted as AD 1950.

Results

Chronostratigraphy

Mollusc shells measured for ^{14}C belong to epifaunally feeding species, which implies that they are unlikely to yield an abnormally high reservoir age of 800+ years that was demonstrated for an infaunal genus *Portlandia* in Arctic fjords (Forman and Polyak, 1997). However, the reservoir effect in glaciated fjords may still exceed that in the open sea due to circulation impeded by meltwater and to possible inputs of old CO_2. We tentatively use an apparent local reservoir correction (ΔR) of 85 years obtained on an epibenthic mollusc from another northern Novaya Zemlya fjord, Krestovaya Bay (Forman and Polyak, 1997). We note that ASV-987 may require a higher correction, because of a modern presence of tidewater glacier in Russkaya Gavan' as opposed to Krestovaya Bay. In this case, corrected ages used in the paper should be considered as maximal.

Calibrated ^{14}C ages are spaced at 50 to 350 years and yield 1σ ranges of *c.* 100 years (Table 1; Figure 3). This data provides a broad chronological control for ASV-987 on a century scale. Obtaining a time series for the entire core may require fitting the age-depth model; however, in glacier proximal areas, where sedimentation rates are very changeable, it may be more reasonable just to use linear interpolation between the dating points (Andrews *et al.*, 1999). In Figure 3 we compare linear interpolation with a fourth-order polynomial model, which was shown to be appropriate for sediment cores with an amount of dates similar to ASV-987 and relatively even sedimentation rates (Andrews and Giraudeau, 2003). This comparison shows that the two approaches give similar results between 175 and 475 cm (calibrated ages *c.* AD 1380 to 1600), but differ noticeably near the core ends. Given the high probability of variable sedimentation rates in a glaciated fjord with fluctuating ice-front position, we use the linear interpolation model, deeming it reliable for the middle part of the record, but more tentative for the younger and the older parts. The largest uncertainty is with the youngest, *c.* 400-yr section that encompasses two lithological units. Unfortunately, this sediment contains very little calcareous material suitable for ^{14}C dating. The age for this section is tentatively estimated by interpolation between the dating of AD 1592, a post-bomb age (AD 1950 as a maximal estimate), and a year of collection 1997 at the top. Resulting sedimentation rate at the core top is consistent with estimates based on excess ^{210}Pb and ^{137}Cs data that were obtained on a hermetically sealed short core collected <1 km from the ASV-987 site (Zeeberg, 2001).

Lithology

Sediment in ASV-987 generally consists of olive-grey clayey mud with variable amounts of black iron-monosulphide mottles and interbeds. Bioturbation (mottling and homogeneous beds) and various laminations occur throughout the core in variable proportions. Based on the degree of lamination versus bioturbation, combined with the contents of coarse grain-size fractions, we identify four major sedimentary units, I–IV (Figure 4). Unit III, between 440 and 180 cm (estimated *c.* AD 1400–1600), is distinguished from the rest of the core by distinct to diffuse, millimetre- to centimetre-scale lamination due to alternating blackish and olive-grey laminae and high deposition rates of $\sim 2-3\,g/cm^2/yr$. Sediment below and above this unit may have diffuse lamination partially or completely disturbed by bioturbation. The lower part of unit III (440–330 cm, *c.* AD 1400–1470), is coarsely laminated with distinct black (0.5–5 cm) and grey (1–10 cm) interbeds. A second-order, thin, convolute lamination resembling bacterial mats occurs further up-unit within some dark interbeds, especially common between 280 and 235 cm (*c.* AD 1500–1550).

Fine-silt to clay sediment fractions (< 0.005 mm) predominate throughout the core, ranging between 67 and 84%, with finest pelites (< 0.001 mm) constituting 40–60%. Unit III generally has somewhat lower contents of fine fractions, 67–75%, and elevated contents of silts (0.005–0.05 mm). Except for several levels, coarser grains (> 0.05 mm) do not comprise more than 2%. Their numbers are generally higher in unit III between 380 and 180 cm (Figure 4). Notably, the distinctly laminated sediment (380–330 cm) is relatively enriched in the coarse-silt to fine-sand fractions (0.05–0.1 mm) rising to 5% near its top. Another characteristic feature of this interval is that coarse clasts (> 1 mm) are largely represented here by clay pellets. The overlying sediment of unit III (330–180 cm) contains layers with the highest contents of > 0.1 mm fractions. Coarse clasts, mostly angular to subangular rock fragments reaching 13 mm, are especially abundant in the upper part of this interval. Further upcore coarse clasts are less numerous and rarely exceed 2 mm size.

Fossils

Unit IV shows frequent occurrence of macrobenthic remains (mollusc shells and chitinous polychaete tubes). Their amounts are noticeably lower and more variable in unit III, whereas unit II is practically devoid of them and unit I contains variable, mostly low numbers.

Benthic foraminifera in the core are almost exclusively represented by calcareous tests with variable preservation and numbers mostly below 10–20 per gram. Higher abundances occur in unit IV and at some levels in unit III. Further upcore foraminiferal numbers are very low in unit II and somewhat increase in unit I. Foraminiferal assemblages throughout the core are low–diverse, predominated by *Elphidium excavatum* forma *clavata* and *Cassidulina reniforme*, comprising together > 80% in most samples. These are common species for Arctic continental shelves, including glaciated fjords (e.g., Hald and Korsun, 1997; Korsun and Hald, 1998). Patterns of their relative dominance are not well understood. Among other species, *Nonion labradoricum* and *Cibicides lobatulus* show interesting patterns with elevated frequencies in units IV and II–I, respectively (Figure 4). Planktonic foraminifera occur discontinuously in low numbers, most frequently in unit IV. We assume that they were mostly occasionally imported from the open sea by undercurrents (cf. Elverhøi *et al.*, 1980).

Stable isotopes

The $\delta^{18}O$ and $\delta^{13}C$ values in *E.excavatum* f. *clavata* tests closely covary throughout the core (Figure 4), which indicates the likelihood of a common control. Equilibrium calcite $\delta^{18}O$ composition calculated from measured September water $\delta^{18}O$ and temperatures shows consistent values of 4.3‰ (versus PDB) for bottom water and as low as near 1‰ at the surface

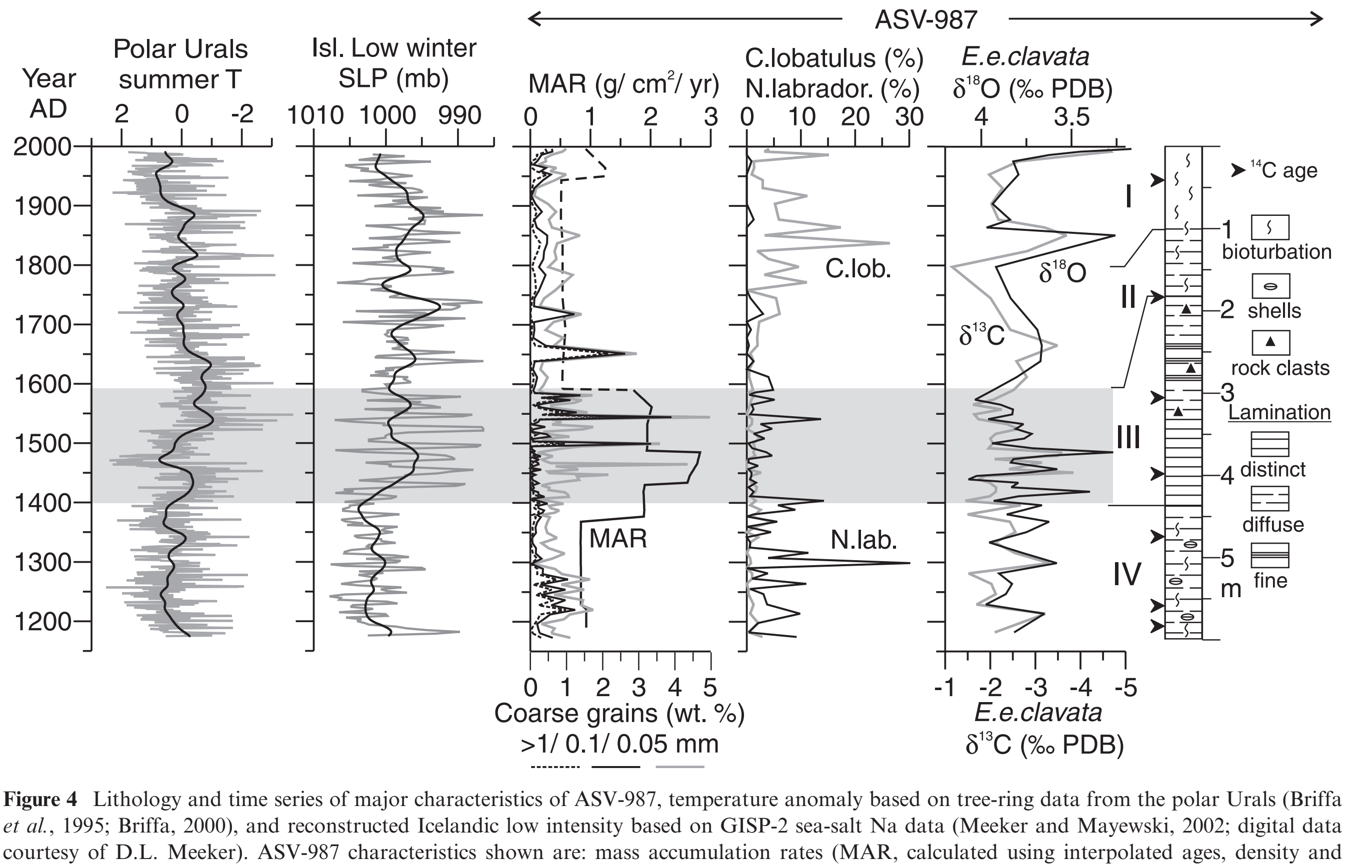

Figure 4 Lithology and time series of major characteristics of ASV-987, temperature anomaly based on tree-ring data from the polar Urals (Briffa *et al.*, 1995; Briffa, 2000), and reconstructed Icelandic low intensity based on GISP-2 sea-salt Na data (Meeker and Mayewski, 2002; digital data courtesy of D.L. Meeker). ASV-987 characteristics shown are: mass accumulation rates (MAR, calculated using interpolated ages, density and water contents), coarse grain-size fractions, percentage of selected foraminiferal species, and stable isotopes. MAR is shown as dashed line for the insufficiently age-constrained interval. An outlier $\delta^{18}O$ value of 2.21‰ at *c.* AD 1825 is omitted. Stratigraphic unit numbers, IV–I, are shown left of the lithology column and unit boundaries are connected to the timescale. Age interval for unit III is highlighted.

in the fjord interior. This depletion obviously results from high meltwater component. The $\delta^{13}C$ composition of dissolved inorganic carbon in glacial meltwater is also expected to be depleted (Anderson *et al.*, 1983). Therefore, we assume that the concerted depletion in stable isotopic values in the sedimentary record primarily indicates enhanced glacial water inputs to the fjord. Another factor affecting benthic stable isotopic signature can be the intensity of brines, which help deliver surface water to the bottom. Units IV and III are distinguished by highly variable stable isotopic values, depleted in both $\delta^{18}O$ and $\delta^{13}C$ at several levels between 440 and 300 cm (*c.* AD 1400–1500). The upper units shows three distinct depletions including the core top.

Discussion

Sedimentary environments

Unit IV (estimated *c.* AD 1170–1400) is characterized by relatively low sedimentation rates, moderate bioturbation, generally low contents of coarse grain-size fractions, and abundant foraminifers and macrofaunal remains. Foraminiferal assemblages have elevated frequencies of *Nonion labradoricum* indicative of relatively high primary productivity (e.g., Korsun and Hald, 1998). We infer that these features indicate a minimal influence of the tidewater glacier on sedimentation in the fjord (cf., for example, Elverhøi *et al.*, 1980; Ó Cofaigh and Dowdeswell, 2001), except for the middle interval that has somewhat higher contents of coarse fractions including grains >1 mm.

Sedimentation rates increased at least twofold sometime between *c.* AD 1380 and 1435. We assume that this change coincided with the commencement of distinct lamination and the drop in abundance of macrofaunal remains at 440 cm (transition to unit III). The combination of these changes probably signifies an abrupt advance of the glacier front into the fjord. This interpretation is corroborated by the ^{14}C date from the lateral moraine of the Shockal'ski Glacier (Figure 1), that constrains the maximal age of the last major glacial expansion to AD 1300–1400. It is possible that Laktionov Glacier also extended to the fjord, which would have augmented sediment inputs. The advancing glacier typically destabilizes the underlying sediment and generates gravity and turbidity flows (e.g., Powell, 1990). This process may be indicated by the coarse lamination of the lower interval of unit III (*c.* AD 1400–1470), co-occurring with common clay pellets in >1 mm fractions. The approaching glacier front is also reflected in the upsection increase of silt to fine-sand fractions (0.05–0.1 mm) within this interval, indicating a more ice-proximal sedimentation from over/underflows (e.g., Elverhøi *et al.*, 1980). The concurrent decline in macrofaunal remains could be related to excessive sediment fluxes and/or to a destructive effect of near-bottom turbidity flows on benthic biota (Ó Cofaigh and Dowdeswell, 2001). The coarsening of grain size is also reported for a broadly correlative interval in two more sediment cores collected in Russkaya Gavan' in 1998 (Zeeberg, 2001).

Overlying sediments of unit III have more diffuse, finer lamination, somewhat more abundant macrofaunal remains and considerable amounts of coarse grains including rock fragments >10 mm in the upper part of the unit. We infer that these features indicate a stabilization of the advanced, possibly floating, ice front and its subsequent retreat with significant iceberg calving. The lower part of this sediment, until *c.* AD 1500, is characterized by predominantly depleted stable isotopic values indicating a strong effect of glacial meltwater. The interval between *c.* AD 1500 and 1550 is distinguished by bacterial-mat type lamination and an increased content of *N. labradoricum*. These characteristics possibly indicate enhanced primary productivity, which may have been triggered by a retreat of glacier front and/or reduced sea-ice cover.

The transition to unit II is marked by a weakening of lamination and a drop in coarse-fraction contents. It is reasonable to assume that the major decrease in sedimentation rates also occurred at this boundary, dated to *c.* AD 1600. The drop in overall sedimentation rates and in coarse fractions probably indicates a major retreat of glacier front from the fjord (e.g., Elverhøi *et al.*, 1980; Powell, 1990). Isolated coarse-grain spikes in unit II may reflect temporary readvances or periods of intensified iceberg calving. However, we do not see any persistent grain-size change that would signify a second major glacier advance into the fjord, as suggested by Zeeberg *et al.* (unpublished data). The unit III/II transition also features a decline in macrobenthic remains combined with very low foraminiferal numbers. This might indicate deteriorated ecologic environments, such as prolonged sea-ice coverage. Alternatively, diminished abundances of faunal remains may largely result from taphonomic losses (decay and dissolution), which typically intensify with decreasing sedimentation rates and thus enhanced oxidation. The faunal remains become more abundant in unit I, consistent with the estimated raise in sedimentation rates towards the core top. Starting from the middle of unit II foraminiferal assemblages feature elevated percentages of *Cibicides lobatulus*, an epibenthic species characteristic for agile, well-aerated water with low sediment fluxes (e.g., Hald and Korsun, 1997). This change may indicate reduced sediment inputs and/or an improved water exchange with the open sea. Stable isotope values are depleted at three intervals in units II–I, probably reflecting the intensity of glacier melting and/or formation of brines. Depleted foraminiferal $\delta^{18}O$ values at the core top appear to be incompatible with normal-marine $\delta^{18}O$ composition measured in bottom water in September 1998. A possible explanation of this discrepancy is that the formation of foraminiferal calcite is affected by brines that transport surficial, $\delta^{18}O$-depleted water to the fjord floor later in the fall. We note that interpretation of sedimentary environments in units II–I is impeded by a lack of detailed age control. It is possible that the transition to unit I occurred at the time of a pronounced climatic change at the turn of the twentieth century (e.g., Briffa *et al.*, 1995; Jones *et al.*, 2001). In this case, sedimentation rates were elevated throughout unit I, thus indicating enhanced glacier melting.

Palaeoclimatic inferences

Palaeoclimatic and palaeoceanographic records from the Barents Sea and glacier fluctuations on adjacent islands appear to show similarities in the timing and magnitude of changes during the Holocene (e.g., Svendsen and Mangerud, 1997; Forman *et al.*, 1999; Lubinski *et al.*, 1999). The largest recent glacier advances in the Barents Sea region and in Scandinavia occurred within the last millennium and broadly coincided with the widespread 'Little Ice Age' (LIA) cooling between *c.* AD 1500 and 1900 (e.g., Matthews, 1991; Lubinski *et al.*, 1999). This cooling is reflected in a 2+ °C summer temperature drop indicated by a tree-ring record from polar Urals southeast of the Barents Sea (Briffa *et al.*, 1995) and in extreme southward migrations of sea ice documented in historical records (Vinje, 1997). Subsequent recession characterized many Arctic glaciers including those in the Barents Sea region in the twentieth century and was probably controlled by a summer temperature rise (Dowdeswell *et al.*, 1997; Zeeberg and Forman, 2000; Henderson, 2002).

The apparently weak effect of tidewater glacier on Russkaya Gavan' prior to *c.* AD 1400 is in agreement with relatively mild climate in the Northern Hemisphere at this time, known as the 'Mediaeval Warm Period' (e.g., Jones *et al.*, 2001). The subsequent expansion of glaciers on Novaya Zemlya could be caused by the intensification of North Atlantic winter cyclones (precipitation increase) and/or cooler summers (melting decrease) (Chizhov *et al.*, 1968; Zeeberg and Forman, 2000). We cannot conclude on the relative importance of these controls but, as there are no indications of dramatically decreasing summer temperatures around AD 1400 neither locally (Figure 4; Briffa *et al.*, 1995) nor hemispherically (Jones *et al.*, 2001), we believe that winter circulation was at least partially responsible for glacier advance in Russkaya Gavan'. This inference is in line with a sharp change in ion contents in GISP-2 ice-core record at *c.* AD 1400 indicating a stronger winter Icelandic Low (Figure 4; Meeker and Mayewski, 2002). Glacier advances/surges occurred at about the same time on Svalbard (Hald *et al.*, 2001), in Franz Josef Land (Lubinski *et al.*, 1999) and in Scandinavia (Matthews, 1991), evidencing a wide effect of atmospheric circulation changes on glacier mass balance in the region.

Based on our interpretation of ASV-987 data, the glacier front extended into Russkaya Gavan' to a maximal position by *c.* AD 1470 and retreated close to *c.* AD 1600. The timing of an advanced glacier position, generally corresponding to the older portion of LIA, was marked by a significant lowering of summer temperatures in the region, with minimal values between *c.* AD 1520 and 1630 (Figure 4; Briffa *et al.*, 1995). ASV-987 data do not bear any evidence of major glacial response to the late-LIA cooling in the 1800s (Figure 4; Briffa *et al.*, 1995). However, very low sedimentation rates and meagre faunal remains in unit II may indicate severe sea-ice conditions during this time. Elevated sedimentation rates and depleted stable isotope signatures near the core top indicate the enhanced melting of Shokal'ski Glacier in recent times. This is consistent with data on negative glacial mass balance and elevated temperatures in the Barents Sea region in the twentieth century (Dowdeswell *et al.*, 1997; Zeeberg and Forman, 2000; Henderson, 2002).

Conclusions

Core ASV-987 provides a detailed 800+-year record of sedimentary environments in Russkaya Gavan' fjord on the northwestern coast of Novaya Zemlya. The record has a century-scale resolution, well constrained between *c.* AD 1370 and 1600 and with a more tentative age model for the older and younger parts. The middle section of the core, dated to *c.* AD 1400–1600, stands out by high sedimentation rates, consistent presence of laminated structures, and elevated contents of coarse-grain fractions. It is interpreted to reflect an expansion of the outlet glacier that feeds the fjord, consistent with the dating of a correlative moraine on land. The likelihood of a region-wide expansion of glaciers around AD 1400 is corroborated by contemporaneous multiple glacier advances around the Barents Sea. We conclude that this event was at least partially caused by the intensification of winter atmospheric inputs from the North Atlantic. The glacier front retreated from Russkaya Gavan' interior by *c.* AD 1600. The overlying sediment is characterized by very low sedimentation rates and meagre faunal remains, possibly reflecting prolonged sea-ice coverage. The post-1600 AD section of the core features three intervals with depleted benthic stable isotopic signature, including the core top. These events probably reflect intensified glacier melting and/or formation of brines in the fjord. Together with the apparent increase in sedimentation rates, the topmost stable isotopic depletion possibly demonstrates the enhanced modern glacier melting. Our data exemplify the sensitivity of Novaya Zemlya glaciers to climatic changes in the Barents Sea region located at the crossroads of Arctic–Atlantic interactions, and prompt further research of palaeoclimate and palaeoceanographic records along the western Novaya Zemlya coast.

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