Investigation of a modern glacimarine sedimentary environment in the fjord Kuannersuit Sulluat, Disko, West Greenland

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Abstract

A 56 cm long sediment core from Kuannersuit Sulluat, a fjord on the island Disko, West Greenland is used to infer modern sedimentation rates and describe the sedimentary environment. The fjord abuts a catchment area dominated by a recently surging glacier (1995-1999). Analyses of the core included magnetic susceptibility, x-radiographs and grain size analysis. From these analyses it is concluded that deposition takes place both through sediment settling from the water column and by gravity flows. Modern sedimentation rates in the fjord appear to be more than 10 times higher than average annual rates (3-5 mm/a) during the Holocene. This is due to changes in melt-water discharge and shorter distance to the sediment source caused by the glacier surge. Episodic gravity flows may result in a deposition of 12 cm sediment and thereby strongly influence long-term average sedimentation rates.

Keywords

Arctic, fjord, glacimarine sedimentation, sedimentation rates, gravity core, West Greenland.

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The fjords at Disko have been the subject of a number of different studies during the last years (Gilbert et al., 1998; Nielsen et al., 1998; Desloges et al., 2001), as a part of intensified recent studies of arctic fjords in general (e.g. Syvitski & Shaw, 1995). The investigations in the Disko area have mainly focused on the sedimentary record and sedimentation rates. Gilbert (2000) suggests that investigations of the sedimentary record of high latitude fjords will be of great potential in answering global change questions in the future.

Measurements of sedimentation rates in the Arctic are rare, mainly because of difficulties in the dating process due to lack of material containing carbon (Andrews et al., 1994). In arctic fjords annual laminations, varves, are unfortunately not as abundant as in lacustrine environments. However, varves do occur in few sedimentary records from temperate fjords (Gilbert, 2000). Cowan et al. (1999) found rhythmically laminated sediment in a core from a temperate fjord in Alaska and linked it to melt-water discharge, tides and marine productivity. Based on grain size analysis and measurements of magnetic susceptibility (MS) they were able to identify annual layers. Sedimentation rates are therefore often estimated by dividing the sediment thickness measured with acoustics by the time elapsed since deglaciation. Gilbert et al. (1998) used this method in the present study area, Kuannersuit Sulluat. The average sedimentation rate in the fjord since deglaciation (8.4 ka B.P.) has been calculated to 5 mm/a closest to the delta, descending to a minimum of 0.8 mm/a at the confluence with Kangikerlak, the fjord arm to the south, and with a sedimentation rate of 3 mm/a near the core site (Nielsen et al., 1998). This rate is an average for Holocene sedimentation, and not necessarily similar to the modern sedimentation rate.

Øhlenschlæger (2000) has investigated a 5 m long piston core recovered in 1997 in the fjord for the presence of for-aminiferas. Foraminiferal numbers were very low, and were present in only the deepest part of the core. This indicates a high sedimentation rate (Øhlenschlæger, 2000). Other investigations in the area show that accumulation rates are strongly variable (Desloges et al., 2001).

The sediment, deriving primarily from glacial melt-water, is most likely deposited by settling or gravity flow processes (Desloges et al., 2001). Due to the recent changes in melt water discharge (Nielsen et al., 1998; Naturgeografisk Hovedfagskursus, 1999), probably associated with a glacier surge in the catchment area starting in 1995, present sedimentation rates are expected to differ from the Holocene average.

During the summer of 1999 traps for settling of suspended matter were placed in the fjord. Only a few of the traps were recovered, but those recovered suggested a much higher sedimentation rate than the maximum of 5 mm/a (Naturgeografisk Hovedfagskursus, 1999). Preliminary results from traps placed in the fjord in the summer 2000 also indicate a sedimentation rate significantly higher than Holocene average mean.

A number of gravity-cores were collected from the fjord floor in the summer 1999. One of these is the main subject of the analyses presented in this article. The core is 56 cm long; assuming an average Holocene sedimentation rate of 3 mm/a the core should represent nearly 200 years of sedimentation. The objective of this paper is to describe the present sedimentary environment, to infer a sedimentation rate for recent years and to investigate possible changes in the sedimentation rate caused by the glacier surge.

Physiographic setting

The island Disko (8600 km^2) is located in central West Greenland. Disko has a polar maritime climate, and climatic data from Qeqertarsuaq on southern Disko show a mean annual temperature and precipitation of respectively – 4°C and 450 mm water equivalent. The island geology is characterised by Tertiary plateau basalts dissected by a number of fjords and valleys (Humlum et al., 1995).

The fjord, Kuannersuit Sulluat, forms the innermost part of the Kangerluk (Disko Fjord) system located on the west side of Disko (Figure 1). The fjord drains a 531 km^2 catchment, with 68% glacier cover (Nielsen et al., 1998, Desloges et al, 2001).

A recently surging glacier draining the central icecap, Sermerssuaq, dominates the valley. Investigations of satellite images show that the surge began around April 1995 and lasted until the summer of 1999 (Naturgeografisk Hovedfagskursus, 1999). In 1995 the glacier was situated 22 km from the fjord head. The current location of the glacier front is only 12 km up the valley. The advanced parts of the glacier constitute a mass of ice equivalent to 2 km^3 water equivalents. One major stream, Kuannersuit Kuussuat, drains the glacier and the valley. In 1997, a single measurement of the discharge from the stream gave 36 m^3/s with a suspended sediment concentration of 4230 mg/l (Nielsen et al., 1998). In 1999, the discharge measured at one occasion was 100 m^3/s with a suspended sediment concentration of 4071 mg/l (Naturgeografisk Hovedfagskursus, 1999). The sandur and the stream of this braided river end in an extensive delta in Kuannersuit Sulluat (Figure 2). Interpretation of aerial photos as well as GPS-measurements show that the delta has advanced at least 500 m in the period 1985-1999 (Naturgeografisk Hovedfagskursus, 1999). Upon discharge to the fjord, the fresh water forms a 1-2 m thick plume with high temperature, low salinity and high sediment concentration that may extend several kilometres out in the fjord (Naturgeografisk Hovedfagskursus, 1999 and Møller unpubl. data).

Kuannersuit Sulluat is about 20 km long from the fjord head to the confluence with Kangikerlak fjord to the south,

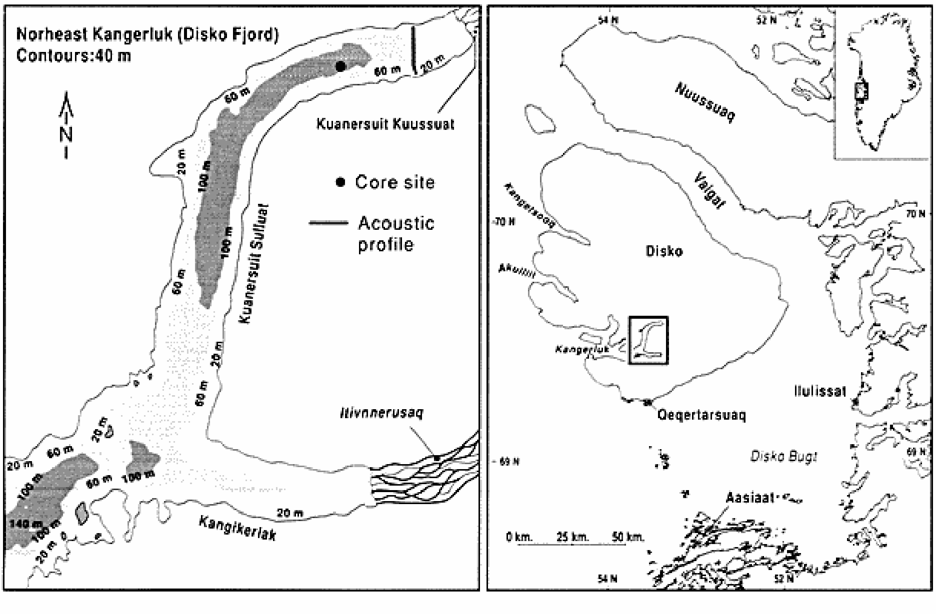

Figure 1: Location of Kuannersuit Sulluat on Disko. Core site (●) and location of the acoustic profile are shown.

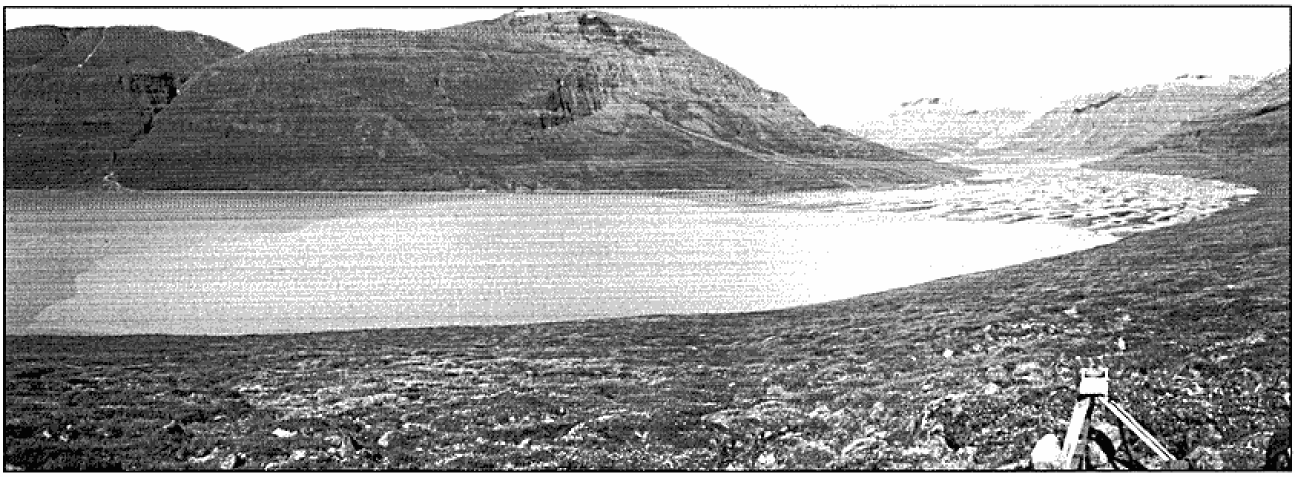

Figure 2: View from the southern fjord side showing the braided river Kuannersuit Kuussuat with the extensive delta and the freshwater plume in the fjord. In the lower right hand corner a digital camera is visible. Photo: N. Nielsen.

and it is c. 2 km wide. Maximum depth is 120 m with two sills at 70 and 80 m water depths just up fjord from the confluence with Kangikerlak. In the inner part of the fjord the bottom is irregular (Figure 3) (Naturgeografisk Hovedfagskursus, 1999). These morphological features can be interpreted as subaqueous channels and levees, resulting from slope failures on the delta leading to gravity flows strong enough to erode the fjord floor (Syvitski et al., 1987).

4-5 km from the fjord head the bottom becomes more regular due to settling of suspended sediment (Gilbert et al., 1998) in addition to a lower frequency of strong gravity flows. At the confluence with Kangikerlak the fjord bottom is irregular with only a thin layer of glacimarine sediment overlying the bedrock surface (Gilbert et al., 1998).

The tide is semi-diurnal with a maximum range of 2.5 m. The fetch in Kuannersuit Sulluat is limited due to protection from bends and high valley sides. Kuannersuit Sulluat is normally covered by sea ice from December until May or June. In the summer of 1999 the ice broke up in early June. Only a few small icebergs enter the western fjords of Disko (Gilbert et al., 1998), and probably none reaches the inner part of the fjord system, including Kuannersuit Sulluat.

Methods

The core discussed was taken on 16 July 1999, approximately 4.5 km from the delta in the middle of the fjord (Figure 1). The depth of the fjord at this site is 93 m. The core was collected from R/V Porsild using a gravity corer, as one of several cores collected that summer. The length of the

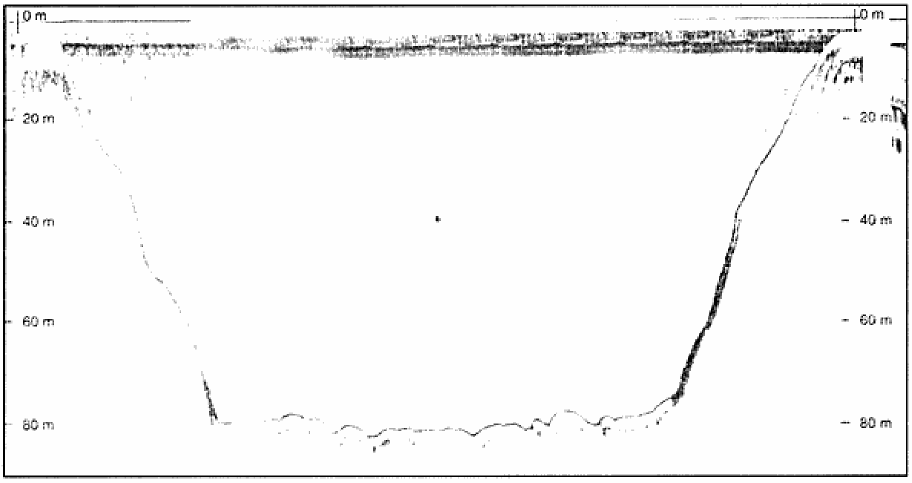

Figure 3: Acoustic profile measured with a Furuno Fe-400. Profile length is 1729 m. View is down fjord. Location of profile is shown in Figure 1.

core is 56 cm, and the inner diameter is 45 mm. Before splitting the core, magnetic susceptibility (MS) (SI-units) was measured in 2-cm intervals, using a Bartington MS2C. Its bulk or volume MS was not corrected for density.

After splitting the core it was x-rayed and photographed. The core was logged for texture and colour using a Munsell Soil Color Chart. Sedimentary structure and lamination were analysed from the X-radiograph according to an ichnofabric classification suggested by Droser & Bottjer (1986).

The core was frozen to facilitate preparation of thin slices. After freezing, the core was removed from the plastic tube and cut in to 57 slices 1 cm thick. Preparation of 0.5 cm thick slices proved impossible due to thawing of the core. The 57 samples were treated with 0.01 M $Na_2P_2O_7 \times 10$ H_2O, dispersed for 2 minutes and wet sieved using a 63 µm sieve.

Sediment coarser than 63 µm (4) was dried and weighed. The sediment finer than 63 µm (4Φ) was kept in the 0.01 M $Na_2P_2O_7 \times 10\ H_2O$ solution. Concentration in the solution was determined and the sediment was dispersed again for 2 minutes just before particle size analysis.

Particle size analysis was perfromed using a SediGraph 5100, and a Malvern Mastersizer/E. A break down of the SediGraph 5100 necessitated the use of two machines. Sedigraph 5100 measures the equivalent-settling diameter based on Stokes law, while the Malvern Mastersizer/E measures the true nominal diameter based on forward light scattering of a laser beam. The equivalent-settling diameter is generally known to be smaller than the true nominal diameter. Konert & Vandenbergh (1997) found that the grain size limit for clay < 2 µm (9Φ), defined by methods based on settling, correspond with a grain size of 8 µm (7Φ) defined by methods based on laser diffraction. According to this, the limit between clay and silt is determined as 2 µm (9Φ) using SediGraph 5100, and 8 µm (7Φ) for analyses on the Malvern Mastersize/E. For comparison six of the samples were analysed on both machines. The results were generally comparable considering the observations by Konert & Vandenbergh (1997). Mean deviation for the median diameter between the two analyse methods were +/- 1.4 µm.

Skewness was calculated using the moment method (Boggs, 1995). These statistical calculations are only possible for data from the Malvern Mastersize/E analyses and have only been made for samples with less than 5% sand. Skewness indicates the excess of fine or coarse material in a non-symmetrical distribution, thereby indicating deposition (fine skewed) or erosion (coarse skewed) (Boggs, 1995). The median diameter D_{50}, which is the midpoint of the grain-size distribution, has been calculated for all samples excluding the sandfraction.

Results

Visual description

The photograph is shown in Figure 4a. There are no shells or shell fragments, nor any particle above 2 mm. Evidence of bioturbation is absent. There are signs of slight deformation in the top of the core that probably occurred during recovery. The core consists of a very dark greyish brown (10YR 3/2) top layer (0-8cm) with a silty texture. The next part of the core is dark yellowish brown (10 YR 3 /4) and apparently more muddy. The middle of the core (19-32 cm) is slightly darker (10 YR 3/3) and more homogenous with a coarser texture. Below 32 cm the core is dark yellowish brown (10 YR 3 /4) with horizontal black (10 YR 2/1) l ayers, both multiple thin layers (e.g. 33 and 35 cm), and single layers with a thickness of 0.5 to 1 cm (47 and 51 cm).

X-ray description

The X-radiograph (Fig 4b) is a positive image: light areas indicate greater exposure resulting from low bulk density and vice versa. In the very top of the core some deformation is visible, but lamination is intact between 0 and 20 cm. Lamination occurs in two patterns: fine lamination (on the mm scale) at 14 cm and 18-19 cm and lamination at larger scale with 4 to 5 cm spacing between dark sub-horizontal layers at 7, 12 and 17 cm. Below 20 cm the X-radiograph is dark without lamination, and shows no significant structure. The lower boundary of the unlaminated zone is sharp and nearly horizontal. Below this unlaminated zone significant lamination occurs again at 32 cm. The spacing is 1-2 cm between the dark horizontal layers. At least 10 dark layers are visible between 32 and 45 cm. At 47 cm and 51 cm there are more massive dark sub-horizontal layers. At 17, 36 and 42 cm it is possible to distinguish millimetre-scale lamination within these layers.

Magnetic susceptibility and grain size distribution

Figs. 5a and 5b show the results of the analysis including values of bulk MS, the ichnofabric classification (Droser and Bottjer, 1986), and the distribution of sand, silt and clay, respectively. Median diameters and skewness for samples with less than 5% sand are shown in Figs. 5c and 5d.

Between 19 and 32 cm a thick sandy layer with more than 30% sand is present. Four further sandy layers are found at

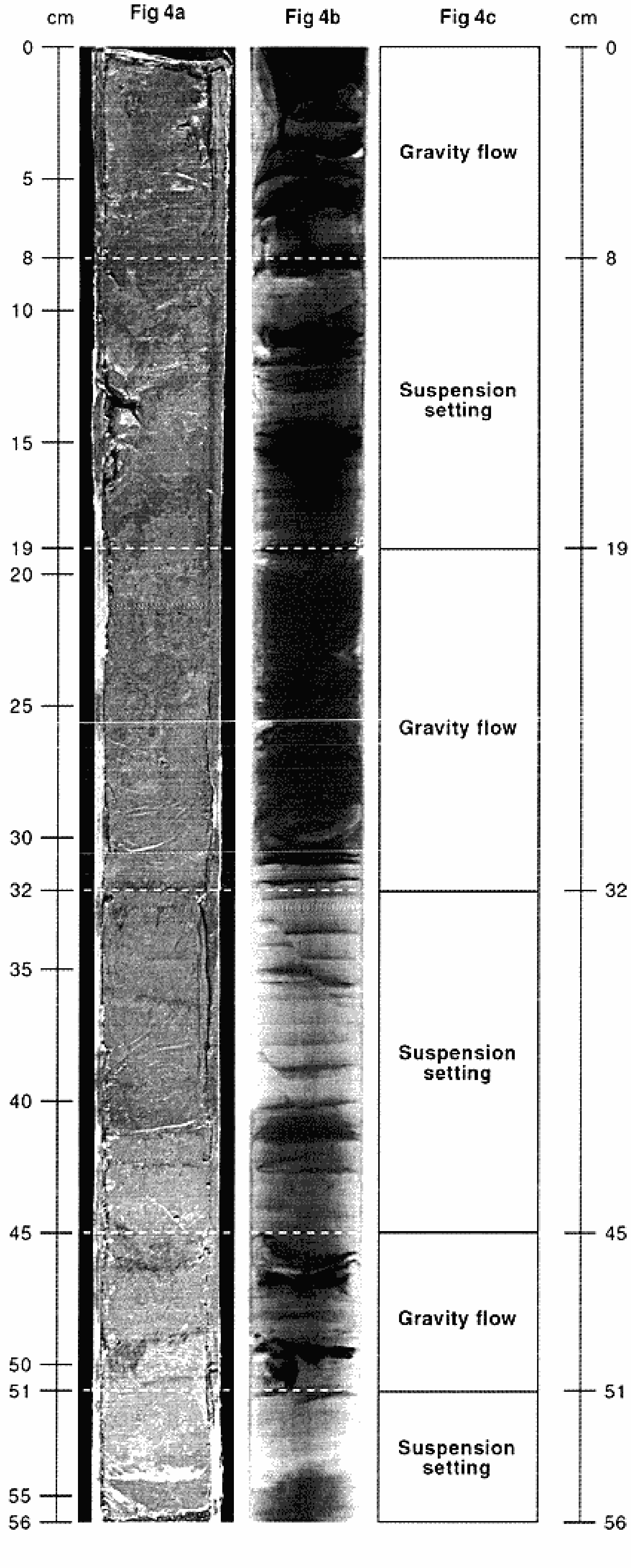

Figure 4: *Photograph (a), positive X-radiograph (b), interpretative log (c). Note that the photograph and the X-radiograph both are mosaics of 3 separate pictures, thus differences in the lightness may occur.*

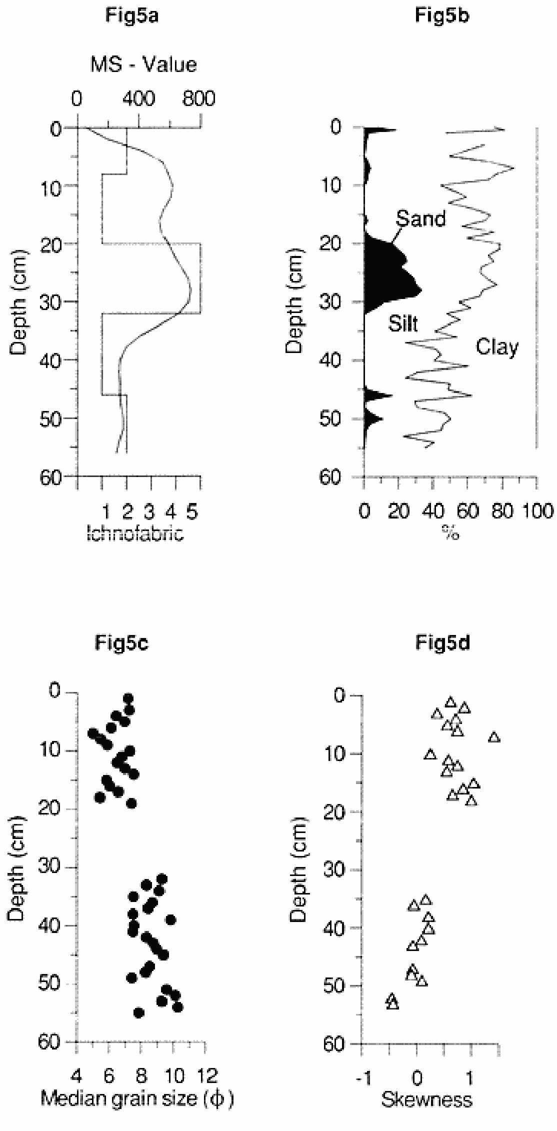

Figure 5: *Magnetic susceptibility (SI-units) ichnofabric classification (a), and physical properties of the core (b-d). Median grain size and skewness are calculated for samples with less than 5 % sand. Key for ichnofabric classification: 1 - Strongly laminated, 2 - Moderately laminated, 3 -Faintly laminated, 4 - Weakly laminated, 5 - Unlaminated.*

0-2 cm, 5-8 cm, 47cm and 51 cm with up to 15-20% sand content. The amount of clay differs above and below the thick sandy layer. Above there is around 40% clay while below there is around 60% clay. Fluctuations in the clay content are superimposed on this general difference in clay content, but are not found to be significantly coherent with the laminations in the X-ray. Median grain size is 6-7Φ above the sandy layer and 8-9Φ below 32 cm (Figure 5c). There is also a distinct difference in skewness between samples in the top of the core and samples in the lower part of the core. The top samples all exhibit strong fine, positive skewness (skewness >0.30). In the lower part of the core the samples are nearly symmetrical; they are marginally positive skewed or negatively skewed. High values of bulk MS correlate to layers with high amounts of sand (Figures. 5a and 5b). According to Cowan et al. (1999), this reflects an enhancement of the MS-signal due to the high amount of ferromagnetic minerals contained in the sand and the coarse silt.

Based on the visual and x-radiograph description, grain size data and the MS values two different facies of sediment structures can be defined; Laminated intervals, with both well defined and moderate lamination consisting mainly of clay and silt, and an unlaminated unit with a significant content of sand.

Discussion

Two different sediment types dominate the core's lithology. Laminated mud can be interpreted as deposition from suspension, while unlaminated sediment with sand reads as deposition from either turbidity currents or gravity flows, triggered by slope failures on the delta as reported by e.g. Cowan et al. (1997). A single thick sandy layer (19-32 cm) indicates the importance of gravity flow as a deposition process. Several smaller layers with sand (5-8 cm, 47 cm, 51cm) are concluded to originate from minor gravity flows. The sandy layers are deposited at irregular intervals and represent episodic events. Between these layers laminated fine sediments dominate. Under steady, uniform dynamic conditions sediment settling from the fresh water plume will result in an unlaminated sediment structure. Laminations in sediment deposited from suspension are a result of changes in the dynamic conditions on a daily, monthly or seasonal basis (cf. Cowan et al., 1999; Gilbert, 2000). The lamination is preserved at the coring site due to lack of bioturbation and strong bottom currents during deposition.

The presence of sand, the different patterns in lamination and varying MS-values allow the core to be divided into units in which the two different sedimentation processes have dominated (Figure 4c and Table 1).

This subdivision shows that the amount of sediment deposited by gravity flow is approximately the same as deposition from settling of suspended material. The signal is not clear in the top of the core probably due to deformation. The importance of the different sedimentation processes will depend on the distance to the delta (Syvitski et al., 1987 and Gilbert et al., 1993). In the inner part of the fjord sediment from gravity flows will deposit together with sediment from settling processes. Spatial variability in the deposition from gravity flow and turbidity currents will be large due to the delta morphology and the relief close to the delta (Figure 3). Further away from the delta only the strongest gravity flows will be able to deposit sediment, and settling of suspended material will dominate the sedimentary environment. In the very distal part of the fjord the latter process will clearly prevail (Gilbert et al., 1998).

The interpretation of sedimentation processes from this core is a single point measurement and spatial variability in the sedimentation process cannot be interpreted from this study. Nonetheless previous studies from the area indicate that variability does occur (Gilbert et al., 1998; Desloges et al., 2001).

The lamination in the muddy part of the core is rhythmic with a spacing of roughly 4-5 cm above 19 cm and 1-2 cm below 32 cm. This could be annual lamination. Fine laminations on mm scale within the coarser lamination are interpreted to result from variations in the dynamic conditions on a shorter time scale, e.g. monthly or daily, and such

	Deposition by suspension settling	Deposition by gravity flow
Sand (%)	very low	high
Ichnofabric class	high	low
MS value	low	high

***Table 1:** Physical characteristics for deposition of suspended sediment and gravity flows based on the present investigation.*

Table2: Values for specific suspended sediment load, sediment discharge and water discharge for Kuannersuit Sulluat drainage basin and mean, standard deviation values for 9 rivers on western Disko (Nielsen et al., 1998; Rasch et al., 2001).

	Surging glacier drainage basin	Mean for 9 rivers on western Disko ($\bar{x}_{9\ rivers}$)	Standard deviation for 9 rivers on western Disko ($SD_{9\ rivers}$)
Specific suspended sediment load (kg/s/km^2)	2728	588	880
Suspended sediment discharge (kg/s)	145	27	48
Water discharge (l/s/km^2)	651	689	200

changes can originate from variation in the tide or melt-water discharge. Changes in the dynamic conditions are also concluded to be responsible for the changes in median grain size in the core. Above the sandy layer (19 cm) median grain sizes have lower phi-values than below the layer. The shift in grain size from the lower to the upper part of the core corresponds with a change in skewness for the samples (Figs. 5c and 5d). This change may be caused by the glacier surge in the catchment area which halved the distance from the fjord head to the glacier front to 12 km. The surge precipitated an increase in melt-water discharge and suspended sediment load. In August 1997 spot measurements of river water and sediment discharge from 9 major rivers on western Disko were carried out (Nielsen et al., 1998). This investigation gave very high values of the specific suspended sediment load and the suspended sediment discharge from the surging glacier drainage basin in spite of average values for runoff (Table 2). The high specific suspended sediment load (c. 4243 t/km^2/y in 1997 with a runoff period of 6 months) is due to the erosive effect of the glacier surge, while the close to average runoff value probably is due to the fact that the glacier surge in itself only involves a very small area (c. 5%) of the total glaciated part of the drainage basin (in August most river water is melt water from the glaciers). Peak suspended sediment discharge in the rivers results from snow melt in the beginning of the run-off period, and occurs during heavy rainfall episodes where a threefold rise in water discharge may be associated with a thirty fold rise in suspended matter discharge (Rasch et al., 2000). No measurements of river water discharge from the surging glacier drainage basin have been carried out before the glacier surge began in 1995.

Massive deposition by a single gravity flow could correlate to the glacier surge beginning in 1995. The appearance of large-scale lamination structures with a spacing of 4-5 cm in the top 18 cm of the core would reflect the sediment accumulated during the period of 1995-1999. This would imply a sedimentation rate of nearly 5 cm/y during this period, not including the large gravity flow. This hypothesis is supported by preliminary results from sediment traps deployed in 2000 away from the delta front (Table 3). The traps at 4 km from the delta front nearby the coring position showed near bottom settling fluxes of 2.9 mm/day in June and July and 0.3 mm/day during July to September indicating a yearly settling flux of about 14 cm. Allowing for compaction on the bottom of the settled material and eventual resuspension, these results thus indicate abnormally high sedimentation rates in line with the core results.

Below the massive deposition from the gravity flow (19-32 cm) laminations on both the x-radiograph and the photographs interpreted as varves indicate annual sedimentation rates of 1-2 cm. The black laminae visually observed in the lower part of the core may be similar to rhythmically interbedded monosulphide layers observed in sediment cores from fjords on Spitsbergen (Elverhøj et al., 1980). Elverhøj et al. report that these layers originate from decay of organic

Period	Height above bottom (m)	1 km from deltafront	4 km from deltafront	7 km from deltafront
10. June - 23. July	5	4	2.9	0.7
	10	2.4	2.3	0.2
	40	1.4	1.4	0.3
24. July - 9. September	5	7.8	0.3	0.1
	10	7.3	0.6	0.05
	40	5.3	0.7	0.07

***Table 3:** Preliminary trap results of settling fluxes (mm/day) at three heights above the bottom as function of distance away from the delta front.*

matter that produces H_2S and results in in situ reactions with Fe^{3+} (Figure 4a). Melt-water rivers on Disko generally show an inverse relation between suspended sediment discharge and organic matter content in the suspended matter. Rivers with high discharge of suspended sediment such as Kuannersuit Kuussuat have low organic matter content in the particulate matter (Rasch et al. 200?). Therefore, to produce a discrete black layer on the seabed in front of the delta, it is suggested that before the melt-water season spring plankton blooms strongly contribute to the organic matter deposition on the fjord floor. Smith and Andrews (2000) made similar observation. This process allows the black horizon to remain relatively unmixed with non-organic sediment from land. By this interpretation the black laminae may be used as a seasonal spring indicator. Primary production in the fjord by phytoplankton during summer is low and generally confined to the upper 5 m of the water column because of summer turbidity accompanying the meltwater outflow (Andersen, 1981). These observations support the suggested sedimentation rates.

Knowledge of sediment transport in proglacial rivers in Greenland is poor. Because of the short observation periods (due to difficulties of maintaining measurements during the winter season), measurements of seasonal variations in transport are limited. Hasholt (1996) offers a review of the present knowledge. Suspended sediment yields from non-glaciated areas range between 1 and 56 t/km^2/y whereas the yield from glaciated areas in Greenland have been estimated to range between 84 and 1500 t/km^2/y (Hasholt, 1996). It has, however, been observed that part of the glacially eroded material may be retained in the pro-glacial valley which acts as a sink for the coarsest part of the transported material (Busskamp & Hasholt, 1996). Rivers from both glaciated and non-glaciated areas may also lose some of their load in lacustrine sediment sinks (Hasholt et al., 2000). Trap efficiencies of up to 80% have been reported for lakes (Hasholt and Thomsen, 1980). Therefore, very high glacimarine sedimentation rates are likely to depend on the up-valley distance to the glacier front and extremely high rates (>2 m/a) are mostly found in front of calving tidewater glaciers (Powell & Cowan, 1987). The shorter distance to the glacier front due to the surge may thus help explain the higher sedimentation rates since the inferred 1995 gravity flow deposits in the core.

Compared to East Greenland, glacimarine environments in West Greenland generally experience more sedimentation from meltwater sources due to the warmer West Greenland current and less severe climate (Desloges et al., 2001). The mean Holocene sedimentation rate (based on total Holocene sediment accumulations measured on seismic records) in Kuannersuit Sulluat is comparable to rates in other fjords elsewhere in the Arctic (Gilbert et al., 1998). However, during the past few years the sedimentation rate in the fjord is possibly among the highest ever measured in a proglacial environment in the Arctic. This is due to the influence of the surging glacier. Similar glacier surges have occurred in the drainage basin in historical time. Several post Little Ice Age (relative dating based on lichenometric observations) terminal moraine systems occur in front of the glacier (unpublished data), and a glacier surge terminating in 1920-30 is documented on topographic maps from the area (Geodætisk Insitut, 1956). It is therefore concluded that long periods of average sedimentation rates alter-nating with short periods of extreme sedimentation rates charecterise the sedimentary regime of Kuannersuit Sul-luat.

Conclusion

Detailed study of a sediment core from Kuannersuit Sulluat shows that the main sedimentary processes at the coring site are settling of suspended matter from the fresh water overflow and sedimentation through gravity flows triggered on the delta. The presence of a thick sandy layer deposited by gravity flow demonstrates that this kind of deposition is significant. Holocene average rates of sedimentation calculated from sediment thickness must be considered with caution as a single gravity flow can deposit 12 cm of sediment.

Analysis of grain size indicates long-term (years) changes in the dynamic conditions as a result of a glacier surge. Correlating the massive sandy layer to the surge of the valley glacier, yearly sedimentation rates for the period 1995 to 1999 are estimated to be as high as 4-5 cm. This is corroborated by trap results, the laminations on the x-radiograph and the black laminae on the photograph which could be varves. If these are varves, they indicate an annual sedimentation rate of 1-2 cm before 1995. The inferred sedimentation rates are thus magnitudes higher than the Holocene average sedimentation rate of maximum 5 mm/a determined by Gilbert et al. (1998).

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matter that produces H_2S and results in in situ reactions with Fe^{3+} (Figure 4a). Melt-water rivers on Disko generally show an inverse relation between suspended sediment discharge and organic matter content in the suspended matter. Rivers with high discharge of suspended sediment such as Kuannersuit Kuussuat have low organic matter content in the particulate matter (Rasch et al. 200?). Therefore, to produce a discrete black layer on the seabed in front of the delta, it is suggested that before the melt-water season spring plankton blooms strongly contribute to the organic matter deposition on the fjord floor. Smith and Andrews (2000) made similar observation. This process allows the black horizon to remain relatively unmixed with non-organic sediment from land. By this interpretation the black laminae may be used as a seasonal spring indicator. Primary production in the fjord by phytoplankton during summer is low and generally confined to the upper 5 m of the water column because of summer turbidity accompanying the meltwater outflow (Andersen, 1981). These observations support the suggested sedimentation rates.

Knowledge of sediment transport in proglacial rivers in Greenland is poor. Because of the short observation periods (due to difficulties of maintaining measurements during the winter season), measurements of seasonal variations in transport are limited. Hasholt (1996) offers a review of the present knowledge. Suspended sediment yields from non-glaciated areas range between 1 and 56 t/km^2/y whereas the yield from glaciated areas in Greenland have been estimated to range between 84 and 1500 t/km^2/y (Hasholt , 1996). It has, however, been observed that part of the glacially eroded material may be retained in the pro-glacial valley which acts as a sink for the coarsest part of the transported material (Busskamp & Hasholt, 1996). Rivers from both glaciated and non-glaciated areas may also lose some of their load in lacustrine sediment sinks (Hasholt et al., 2000). Trap efficiencies of up to 80% have been reported for lakes (Hasholt and Thomsen, 1980). Therefore, very high glacimarine sedimentation rates are likely to depend on the up-valley distance to the glacier front and extremely high rates (>2 m/a) are mostly found in front of calving tidewater glaciers (Powell & Cowan, 1987). The shorter distance to the glacier front due to the surge may thus help explain the higher sedimentation rates since the inferred 1995 gravity flow deposits in the core.

Compared to East Greenland, glacimarine environments in West Greenland generally experience more sedimentation from meltwater sources due to the warmer West Greenland current and less severe climate (Desloges et al., 2001). The mean Holocene sedimentation rate (based on total Holocene sediment accumulations measured on seismic records) in Kuannersuit Sulluat is comparable to rates in other fjords elsewhere in the Arctic (Gilbert et al., 1998). However, during the past few years the sedimentation rate in the fjord is possibly among the highest ever measured in a proglacial environment in the Arctic. This is due to the influence of the surging glacier. Similar glacier surges have occurred in the drainage basin in historical time. Several post Little Ice Age (relative dating based on lichenometric observations) terminal moraine systems occur in front of the glacier (unpublished data), and a glacier surge terminating in 1920-30 is documented on topographic maps from the area (Geodætisk Insitut, 1956). It is therefore concluded that long periods of average sedimentation rates alter-nating with short periods of extreme sedimentation rates charecterise the sedimentary regime of Kuannersuit Sul-luat.

Conclusion

Detailed study of a sediment core from Kuannersuit Sulluat shows that the main sedimentary processes at the coring site are settling of suspended matter from the fresh water overflow and sedimentation through gravity flows triggered on the delta. The presence of a thick sandy layer deposited by gravity flow demonstrates that this kind of deposition is significant. Holocene average rates of sedimentation calculated from sediment thickness must be considered with caution as a single gravity flow can deposit 12 cm of sediment.

Analysis of grain size indicates long-term (years) changes in the dynamic conditions as a result of a glacier surge. Correlating the massive sandy layer to the surge of the valley glacier, yearly sedimentation rates for the period 1995 to 1999 are estimated to be as high as 4-5 cm. This is corroborated by trap results, the laminations on the x-radiograph and the black laminae on the photograph which could be varves. If these are varves, they indicate an annual sedimentation rate of 1-2 cm before 1995. The inferred sedimentation rates are thus magnitudes higher than the Holocene average sedimentation rate of maximum 5 mm/a determined by Gilbert et al. (1998).

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