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Unraveling Sediment Transport Along Glaciated Margins (the Northwestern Nordic Seas) Using Quantitative X-Ray Diffraction of Bulk (< 2mm) Sediment

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1. Introduction

In most environments, sediment transport is controlled by the density and velocity of the transporting medium, and the grain-size of the sediment. Thus in a very simplistic sense, transport by wind and/or water results in a settling of grains and invariably sediments become more fine-grained along the transport path. Major exceptions to this rule are those areas where sediment is entrained and transported by sea ice or icebergs. In these polar and sub-polar areas the normal rules of sediment transport do not apply. Hence, coarse-grained sediments can be, and have been, transported 100's to 1000's of kilometers beyond their point of entrainment in sea ice or a glacier/ice stream. However, a critical but frequently overlooked aspect of sediment transport is that of provenance. On-land, the sources of sediment delivered to a stream channel are essentially known as they are delimited and restricted mineralogically to the bedrock that outcrops within the drainage basin (Eberl, 2004). The marine environment, and especially the glacial marine environment, is much more open, so that abrupt changes in sediment transport from different bedrock outcrops are not uncommon. An obvious example is that of the major changes in sediment provenance associated with the North Atlantic Heinrich (H-) events of the last glacial cycle, which involved massive discharges of melt-water and icebergs transported from the Hudson Strait ice stream of the Laurentide Ice Sheet (Heinrich, 1988; Andrews and Tedesco, 1992; Bond et al., 1992; MacAyeal, 1993; Dowdeswell et al., 1995; Hesse, 1995; Andrews, 1998; Hemming, 2004). These large-scale glaciological events resulted in the transport of massive amounts of glacially derived detrital carbonate into the North Atlantic, which were then transported as far east as the margins of Portugal and the British Isles (Lebreiro et al., 1996; Peck et al., 2007).

A variety of methods have been used to distinguish changes in the transport and provenance of glacial marine sediments. These have included studies of the mineralogy and characteristics of the sand-size fraction (Bond et al., 1997), radiogenic isotopic signatures that allow identification of the probable bedrock outcrops (Grousset et al., 1993, 2001; Farmer et al., 2003; Verplanck et al., 2009), argon ages which allow a source identification (Hemming et al., 2002a; 2002b), magnetic properties (Pirrung et al., 2002; Andrews and Hardardottir, 2009), sediment reflectance (Ortiz, 2009), and quantitative X-ray diffraction (qXRD) of the bulk sediment (Moros et al., 2004; Andrews and Eberl, 2007). It is the purpose of this paper to show how qXRD is a relatively cheap, simple, but powerful approach to determine changes in sediment provenance, hence sediment transport, along the glaciated margin of E/NE Greenland and across the Denmark Strait to Iceland.

2. Background

The area of Denmark Strait is a contact zone between southward flowing Polar/Arctic water masses sourced from the Arctic Ocean (East Greenland Current and East Iceland Current) and warmer, more saline northward flowing Atlantic Water (Irminger and North Iceland Irminger Current) (Stefansson, 1962; Malmberg, 1985; Hopkins, 1991) (Fig. 1). Sea ice is pervasive on the East Greenland shelf and in many years also extends onto the NW and N Iceland shelf (Fig. 1), but only during extreme years does the ice wrap around Iceland and impact the E/SW coasts (Gray, 1881a; Ogilvie, 1996). This SW-NE pattern of sea ice extent in the Nordic Seas (Fig. 1) also appears as a feature of the LGM (Li et al., 2010). Ocean fronts form at the contact between the Polar and Atlantic water masses and define the North Iceland Front and the Polar Front (Fig. 2). These fronts are often areas of high marine productivity (Jennings et al., 2011) and they also mark boundaries between low to higher rates of drift ice melt, hence sites of enhanced sediment deposition.

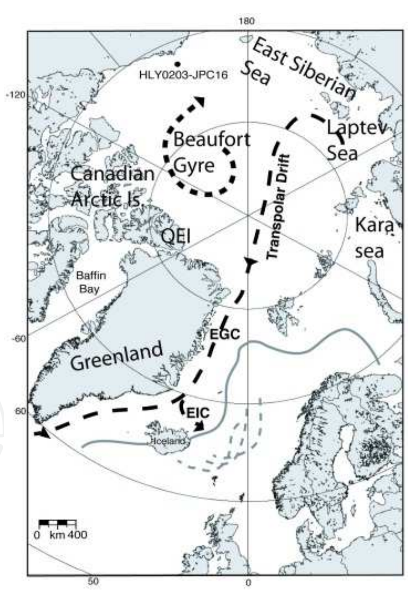


Fig. 1. Location of research area showing the major surface currents---TransPolar Drift, East Greenlany.

Icebergs calved from tidewater margins of E/NE Greenland ice streams (Fig. 3) are frequently retained within the fjords for months to years because of the presence of sikkussuaq and land-fast sea ice (Dwyer, 1995; Syvitski et al., 1996; Reeh et al., 2001). Thus during summers, when there is little or no removal of the land-fast sea ice, iceberg sediment transport is severely curtailed and the bulk of the deposition will take place within the fjord

(Reeh et al., 1999; Mugford and Dowdeswell, 2010). Conversely, during warmer periods when the barriers to transport are removed, icebergs can exit the fjords onto the shelf and still retain a sediment load.

Mafic-rich Tertiary and Quaternary flood basalts crop-out on either side of Denmark Strait (Larsen, 1983). On the Greenland side the outcrop extends from the south shore of Scoresby Sund southward to Kangerlussuaq Fjord; it also extends offshore (Larsen, 1983; Brooks, 1990). To the north of Scoresby Sund, the geology is complex (Henriksen, 2008) but the bedrock is dominated by igneous and metamorphic rocks, with some Paleozoic sandstones (red beds) (Pirrung et al., 2002) and carbonates. Offshore sediments are rich in quartz and k-feldspars, thus they present a clear mineralogical contrast with similar processes affecting the basalts of East Greenland and Iceland (Andrews et al., 2010).

3. Sediment loads and transport

A key question, and one that is difficult to answer in absolute terms, is the magnitude of the sediment load that is transported in the icebergs and sea ice, and which is thus available to melt-out and be deposited on the seafloor (Hebbein, 2000; Dethleff, 2005; Dethleff and Kuhlmann, 2009, 2010). In glacial marine environments there is another reworking and transport mechanism, which is the impact of large icebergs on the seafloor, and which causes sediment reworking and resuspension (Dowdeswell et al., 1994, 2010; Syvitski et al., 2001). The flux of water in the East Greenland Current through Fram Strait (EGC) is of the order of 3000-5000 km^3/yr (Foldvik et al., 1988), compared with an annual iceberg flux north of Kangerlussuaq Trough of ~100 km^3 (Bigg, 1999) and a sea ice flux in the range of ~700 km^3/yr (Kwok, 2009). The magnitude of the iceberg sediment load along the East Greenland margin is essentially unknown, however, there are some critical observations that need to be considered. In fast-flowing tidewater ice streams the sediment is usually held within the lowermost 1-10 m (Dowdeswell, 1986), although, if there is a pronounced sill, considerable thickness of sediment can be added through the freezing on of super-cooled basal melt-water (Alley et al., 1997, 1998; Lawson et al., 1998). A key consideration is that along the E/NE Greenland margin, icebergs are restricted in moving out of the fjords and onto the shelf by the presence of land-fast sea ice and/or the sikkussuaq (a mélange of sea ice, bergy bits, and icebergs) (Syvitski et al., 1996; Reeh et al., 1999, 2001). Thus the icebergs suffer significant mass loss during their "enforced captivity, " hence most probably lose a considerable fraction of their sediment. An order of magnitude estimate of the sediment load in icebergs (100 km^3 of ice calved (Bigg, 1999), average iceberg thickness of 200 m (Dowdeswell et al., 1992), hence 500 km^2 area coverage, a 2 m sediment thickness) is 2600×10^{9} kg, or a mass accumulation rate (MAR) ~0.5mg/cm^2/yr if distributed evenly over the 500,000 km^2 shelf of NE Greenland, north of 68°N. Melting of the margin of the Greenland Ice Sheet below the Equilibrium Line produces ca 273 Gt (km^3) of melt-water per year (van den Broeke et al., 2009), probably < ¼ of this from NE Greenland. However, from a sediment transport viewpoint, the flux of sediment entrained in the melt-water plumes decreases exponentially away from the ice front (Andrews and Syvistki, 1994; Syvitski et al., 1996; Mugford and Dowdeswell, in press) with a half-distance transport length of 10's of km, thus resulting in massive deposition within the fjords (Smith and Andrews, 2000) but with relatively little impact on the mid- and outer shelf.

Darby, D. A. and Bischoff, J. F., 1996: A statistical approach to source determination of lithic and Fe oxide grains: An example from the Alpha Ridge, Arctic Ocean. *Journal of Sedimentology Research,* 66: 599-607.

Darby, D. A., 2003: Sources of sediment found in the sea ice from the western Arctic Ocean, new insights into processes of entrainment and drift patterns. *Journal of Geophysical Research,* 108: 13-11 to 13-10. doi: 10, 1111029/1112002JC1001350, 1112003.

Darby, D. A. and Bischof, J., 2004: A Holocene record of changing Arctic Ocean ice drift analogous to the effects of the Arctic Oscilation. *Palaeoceanography,* 19: 1 of 9. doi: 10.1029/2003PA000961, 002004.

Darby, D. A., Ortiz, J., Polyak, L., Lund, S., Jakobsson, M., and Woodgate, R. A., 2009: The role of currents and sea ice in both slowly deposited central Arctic and rapidly deposited Chukchi-Alaskan margin sediments. *Global Planetary Change.,* 68: 58-72, doi:10.1016/j.gloplacha.2009.1002.1007.

Dethleff, D., 2005: Entrainment and export of Laptev Sea ice sediments, Siberian Arctic (vol 110, art no C07009, 2005). *Journal of Geophysical Research-Oceans,* 110.

Dethleff, D. and Kuhlmann, G., 2009: Entrainment of fine-grained surface deposits into new ice in the southwestern Kara Sea, Siberian Arctic. *Continental Shelf Research,* 29: 691-701.

Dethleff, D. and Kuhlmann, G., 2010: Fram Strait sea-ice sediment provenance based on silt and clay compositions identify Siberian and Kara and Laptev sxeas as main source reegions. *Polar Research,* 29: 265-282.

Divine, D. V. and Dick, C., 2006: Historical variability of the sea ice edge position in the Nordic Seas. *Journal of Geophysical Research,* 111: 1 of 14, doi:10.1029/2004JC002851.

Dowdeswell, J. A., 1986: The Distribution and Character of Sediments in a Tidewater Glacier, Southern Baffin Island, N.W.T., Canada. *Arctic and Alpine Research,* 18: 45-46.

Dowdeswell, J. A., Whittington, R. J., and Hodgkins, R., 1992: The sizes, frequencies, and freeboards of East Greenland icebergs observed using ship radar and sextant. *Journal Geophysical Research,* 97: 3515-3528.

Dowdeswell, J. A., Whittington, R. J., and Marienfeld, P., 1994: The origin of massive diamicton facies by iceberg rafting and scouring, Scorsby Sund, East Greenland. *Sedimentology,* 41: 21-35.

Dowdeswell, J. A., Maslin, M. A., Andrews, J. T., and McCave, I. N., 1995: Iceberg production, debris rafting, and the extent and thickness of Heinrich layers (H-1, H-2) in North Atlantic sediments. *Geology,* 23: 301-304.

Dowdeswell, J. A., Evans, J., and Cofaigh, C. O., 2010: Submarine landforms and shallow acoustic stratigraphy of a 400 km-long fjord-shelf-slope transect, Kangerlussuaq margin, East Greenland. *Quaternary Science Reviews,* 29: 3359-3369.

Dwyer, J. L., 1993: Monitoring Characteristics of Glaciation in the Kangerdlugssuaq Fjord Region, East Greenland, Using Digital LANDSAT MSS and TM Data. MSc, University of Colorado, Boulder. 238 pp.

Dwyer, J. L., 1995: Mapping tide-water glacier dynamics in East Greenland using Landsat data. *Journal of Glaciology,* 41: 584-596.

Dyke, A. S., England, J., Reimnitz, E., and Jette, H., 1997: Changes in Driftwood Delivery to the Canadian Arctic Archipelago: The Hypothesis of Postglacial Oscillations of the Transpolar Drift. *Arctic,* 50: 1-16.

Eberl, D. D., 2003: *User guide to RockJock: A program for determining quantitative mineralogy from X-ray diffraction data*. United States Geological Survey, Open File Report 03-78, 40 pp, Washington, DC.

Eberl, D. D., 2004: Quantitative mineralogy of the Yukon River system: Variations with reach and season, and determining sediment provenance. *American Mineralogist,* 89: 1784-1794.

Eggertsson, O., 1993: Origin of the driftwood on the coasts of Iceland: A dendrochronological study. *Jokull,* 43: 15-32.

Eiriksson, J., Knudsen, K. L., Haflidason, H., and Henriksen, P., 2000: Late-glacial and Holocene paleoceanography of the North Iceland Shelf. *Journal of Quaternary Science,* 15: 23-42.

Evans, J., Dowdeswell, J. A., Grobe, H., Niessen, F., Stein, R., Hubberten, H.-W., and Whittington, R. J., 2002: Late Quaternary sedimentation in Kejser Joseph Fjord and the contiental margin of East Greenland. *In* Dowdeswell, J. A. and O'Cofaigh (eds.), *Glacier-influenced sedimentation on High-Latitude conintental margins*. London: Geological Society 149-179.

Farmer, G. L., Barber, D. C., and Andrews, J. T., 2003: Provenance of Late Quaternary ice-proximal sediments in the North Atlantic: Nd, Sr and Pd isotopic evidence. *Earth and Planetary Science Letters,* 209: 227-243.

Foldvik, A., Aagaard, K., and Torresen, T., 1988: On the velocity field of the East Greenland Current. *Deep Sea Research,* 35: 1335-1354.

Geirsdottir, A., Miller, G. H., Axford, Y., and Olafsdottir, S., 2009: Holocene and latest Pleistocene climate and glacier fluctuations in Iceland. *Quaternary Science Reviews,* 28: 2107-2118.

Ghil, M., Allen, M. R., Dettinger, M. D., Ide, K., Kondrashov, D., Mann, M. E., Roberston, A. W., Saunders, A., Tian, Y., Varadi, F., and Yiou, P., 2002: Advanced spectral methods for climatic time series. *Reviews of Geophysics,* 40: 3-1 to 3-41 1003, doi:1029/2000RG000092.

Giraudeau, J., Jennings, A. E., and Andrews, J. T., 2004: Timing and mechanisms of surface and intermediate water circulation changes in the Nordic Sea over the last 10,000 cal years: a view from the North Iceland shelf. *Quaternary Science Reviews,* 23: 2127-2139.

Gray, D., 1881a: Ice chart of the Arctic Ocean between Greenland and Spitsbergen. From observations by Capt. David Gray: Royal Geographical Society, Control # 503747. Scale 503741:503746,503750,503000.

Gray, D., 1881b: The recent advance of the Polar ice in the Greenland and Spitzbergen Sea. *Proceedings of the Royal Geographiocal Society and monthly record of Geography,* 3: 740-741.

Grousset, F. E., Labeyrie, L., Sinko, J. A., Cremer, M., Bond, G., Duprat, J., Cortijo, E., and Huon, S., 1993: Patterns of ice-rafted detritus in the glacial North Atlantic (40-55°N). *Paleoceanography,* 8: 175-192.

Grousset, F. E., Pujol, C., Labeyrie, L., Auffret, G., and Boelaert, A., 2000: Were the North Atlantic Heinrich events triggered by the behavior of the European ice sheets. *Geology,* 28: 123-126.

Grousset, F. E., Cortijo, E., Huon, S., Herve, L., Richter, T., Burdloff, D., Duprat, J., and Weber, O., 2001: Zooming in on Heinrich layers. *Paleoceanography,* 16: 240-259.

Hebbein, D., 2000: Flux of ice-rafted detritus from sea ice in the Fram Strait. *Deep-Sea Research II,* 47: 1773-1790.

Heinrich, H., 1988: Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years. *Quat. Res.,* 29: 143-152.

Hemming, S., Vorren, T., and Kleman, J., 2002a: Provinciality of ice rafting in the North Atlantic: application of 40Ar/39Ar dating of individual ice rafted hornblende grains. *Quaternary International,* 95-96: 75-85.

Hemming, S. R., Hall, C. M., Biscaye, P. E., Higgins, S. M., Bond, G. C., McManus, J. F., Barber, D. C., Andrews, J. T., and Broecker, W. S., 2002b: 40Ar/39Ar ages and 40Ar concentrations of Fine-Grained Sediment Fractions from North Atlantic Heinrich Layers. *Chemical Geology,* 182: 583-603.

Hemming, S. R., 2004: Heinrich Events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint. *Reviews of Geophysics,* 42: RG1005/2004.

Henriksen, H., 2008: *Geological history of Greenland.* Copenhagen: Geological Survey of Denmark and Greenland, 272 pp.

Hesse, R., 1995: Continental slope and basin sedimentation adjacent to an ice-margin: a continous sleeve-gun profile across the Labrador Slope, Rise and Basin. *In* Pickering, K. T. e. a. (ed.), *Atlas of Deep Water Environments Architectural style in turbidite sytems*, 14-17.

Hopkins, T. S., 1991: The GIN Sea- A synthesis of its physical oceanography and literature review 1972-1985. *Earth Science Reviews,* 30: 175-318.

Howat, I. M., Joughin, I., Fahnestock, M., Smith, B. E., and Scambos, T. A., 2008: Synchronous retreat and acceleration of southeast Greenland outlet glaciers 2000-06: ice dynamics and coupling to climate. *Journal of Glaciology,* 54: 646-660.

Jennings, A. E. and Weiner, N. J., 1996: Environmental change on eastern Greenland during the last 1300 years: Evidence from Foraminifera and Lithofacies in Nansen Fjord, 68°N. *The Holocene,* 6: 179-191.

Jennings, A. E., Gronvold, K., Hilberman, R., Smith, M., and Hald, M., 2002: High resolution study of Icelandic tephras in the Kangerlussuaq Trough, southeast Greenland, during the last deglaciation. *Journal of Quaternary Science,* 17: 747-757.

Jennings, A. E., Andrews, J. T., and Wilson, L., 2011: Holocene environmental evolution of th SE Greenland Shelt north and south of the Denmark Strait: Irminger and East Greenland current interactions. *Quaternary Science Reviews*.

Kelly, M. A. and Lowell, T. V., 2009: Fluctuations of local glaciers in Greenland during the latest Pleistocene and Holocene time. *Quaternary Science Reviews,* 28: 2088-2106.

Koch, L., 1945: The East Greenland Ice. *Meddelelser om Gronland,* 130 (3): 346.

Kolla, V., Biscaye, P. E., and Hanley, A. F., 1979: Distribution of quartz in Late Quaternary sediments in relation to climate. *Quaternary Research,* 11: 261-277.

Kristjansdottir, G. B., Stoner, J. S., Gronvold, K., Andrews, J. T., and Jennings, A. E., 2007: Geochemistry of Holocene cryptotephras from the North Iceland Shelf (MD99-2269): Intercalibration with radiocarbon and paleomagnetic chronostratigraphies. *The Holocene,* 17: 155-176.

Kwok, R., 2009: Outflow of Arctic Ocean Sea Ice into the Greenland and Barents Seas: 1979-2007. *Journal of Climate,* 22: 2438-2457.

Larsen, B., 1983: Geology of the Greenland-Iceland Ridge in the Denmark Strait. *In* Bott, M. H. P., Saxov, S., Talwani, M., and Thiede, J. (eds.), *Structure and Development of the Greenland-Scotland Ridge*. London: Plenum Publishing Corp., 425-444.

Lawson, D. E., Strasser, J. C., Evenson, E. B., Alley, R. B., Larson, G. J., and Arcone, S. A., 1998: Glaciohydraulic supercooling: a freeze-on mechanism to create stratified, debris-rich basal ice: I. Field Evidence. *Journal of Glaciology,* 44: 547-562.

Lebreiro, S. M., Moreno, J. C., McCave, I. N., and Weaver, P. P. E., 1996: Evidence for Heinrich layers off Portugal (Tore Seamount: 39N, 12W). *Marine Geology,* 131: 47-56.

Li, C., Battisti, D. S., and Bitz, C. M., 2010: Can North Atlantic Sea Ice Anomalies Account for Dansgaard-Oeschger Climate Signals? *Journal of Climate,* 23: 5457-5475.

MacAyeal, D. R., 1993: Binge/purge oscillations of the Laurentide Ice Sheet as a cause of North Atlantic's Heinrich events. *Paleoceanography,* 8: 775-784.

Malmberg, S.-A., 1985: The water masses between Iceland and Greenland. *Journal Marine Research Institute,* 9: 127-140.

Mann, M. E. and Lees, J. M., 1996: Robust estimation of background noise and signal detection in climatic time series. *Climatic Change,* 33: 409-445.

Marko, J. R., Fissel, D. B., Wadhams, P., Kelly, P. M., and Brown, R. D., 1994: Iceberg severity off Eastern North America---its relationship to sea-ice variability and climate change. *Journal of Climate,* 7: 1335-1351.

McCarty, D. K., 2002: Quantitative mineral analysis of clay-bearing mixtures: The "Reynolds Cup" contest. *Innternational Union of Crystallography, Newsletter,* No. 27: 12-16.

Miller, J. D. and Hotzel, I. S., 1984: Iceberg flux estimation in the Labrador Sea. International Offshore Mechanics and Arctic Engineering Symposium, 3rd, New Orleans, Louisiana, Feb. 12-17, 1984, 3: 298-304.

Moros, M., McManus, J., Rasmussen, T., Kuijpers, A., Dokken, T., Snowball, I., Nielsen, T., and Jansen, E., 2004: Quartz content and the quartz-to-plagioclase ratio determined by X-ray diffraction: a proxy for ice rafting in the northern North Atlantic? *Earth and Planetary Science Letters,* 218: 389-401.

Moros, M., Andrews, J. T., Eberl, D. D., and Jansen, E., 2006: The Holocene history of drift ice in the northern North Atlantic: Evidence for different spatial and temporal modes. *Palaeoceanography,* 21: 1 of 10. doi:10.1029/2005PA001214.

Mugford, R. I. and Dowdeswell, J. A., 2010: Modeling iceberg-rafted sedimentation in high-latitude fjord environments. *Journal of Geophysical Research-Earth Surface,* 115.

Mugford, R. I. and Dowdeswell, J. A., in press: Modeling glacial meltwater plume dynamics and sedimentation in high-latitude fjords. *Journal of Geophysical Research*.

Ogilvie, A. E. J., 1996: Sea-ice conditions off rhe coasts of Iceland A.D. 1601-1850 with special reference to part of the Maunder Minimum period (1675-1715). *North European climate data in the latter part of the Maunder Minimum period A.D. 1675-1715*, AmS-Varia 25: 9-12.

Ogilvie, A. E. J. and Jonsdottir, I., 2000: Sea ice, climate, amd Icelandic fisheries in the eighteenth and nineteenth centuries. *Arctic,* 53: 383-394.

Ortiz, J. D., Polyak, L., Grebmeier, J. M., Darby, D., Eberl, D. D., Naidu, S., and Nof, D., 2009: Provenance of Holocene sediment on the Chukchi-Alaskan margin based on combined diffuse spectral reflectance and quantitative X-Ray Diffraction analysis. *Global and Planetary Change,* 68: 71-84.

Paillard, D., Labeyrie, L., and Yiou, P., 1996: Macintosh Program Performs Time-Series Analysis. *EOS,* 77: 379.

Parkinson, C. L., 2000: recent trend reversals in Arctic sea ice extents: possible connection to the North Atlantic oscillation. *Polar Geography,* 24: 1-12.

Parkinson, C. L., Rind, D., Healy, R. J., and Martinson, D. G., 2001: The impact of sea ice concentration accuracies on climate model simulations with the GISS GCM. *Journal of Climate,* 14: 2606-2623.

Peck, V. L., Hall, I. R., Zahn, R., Grousset, F. E., Hemming, S. R., and Scourse, J. D., 2007: The relationship between Heinrich events and their European precursors over the past 60 ka BP: a mulit-proxy ice-rafted debris provenance study in the North East Atlantic. *Quaternary Science Reviews,* 26: 862-875.

Pirrung, M., Futtere, D., Grobe, H., Matthiessen, J., and Niessen, F., 2002: Magnetic susceptibility and ice-rafted debris in surface sediments of the Nordic Seas: Implications for Isotope Stage 3 oscillations. *Geo-Marine Letters,* 22: 1-11.

Principato, S. M., 2003: The late Quaternary history of eastern Vestfirdir, NW Iceland. PhD, Geological Sciences, University of Colorado, Boulder. 258 pp.

Reeh, N., Mayer, C., Miller, H., Thomsen, H. H., and Weidick, A., 1999: Present and past climate control on fjord glaciations in Greenland: Implications for IRD-deposition in the sea. *Geophysical Research Letters,* 26: 1039-1042.

Reeh, N., Thomsen, H. H., Higgins, A. K., and Weidick, A., 2001: Sea ice and the stability of north and northeast Greenland floating glaciers. *In* Jeffries, M. O. and Eicken, H. (eds.), *Annals of Glaciology,* 33, 474-480.

Reimnitz, E., Barnes, P. W., and Kempema, E. W., 1987: Anchor Ice, Seabed Freezing, and Sediment Dynamics in Shallow Arctic Seas. *Journal of Geophysical Research,* 92: 14, 671-614, 678.

Rogers, J. C., Yang, L., and Li, L., 2005: The role of Fram Strait winter cyclones on sea ice flux and on Spistbergen air temperatures. *Geophysical Research Letters,* 32: 1 of 4, doi:10.1029/2004GL022262.

Schmith, T. and Hanssen, C., 2003: Fram Strait ice export during the nineteenth and twentieth centuries reconstructed from a multiyear sea ice index from Southwestern Greenland. *Journal of Climate,* 16: 2782-2791.

Sigurdsson, F. H., 1969: Report on Sea Ice off the Icelandic Coasts October 1967 to September 1968. *Jokull,* 19: 77-93.

Smith, L. M. and Andrews, J. T., 2000: Sediment characteristics in iceberg dominated fjords, Kangerlussuaq region. East Greenland. *Sedimentary Geology,* 130: 11-25.

Smith, L. M., Alexander, C., and Jennings, A. E., 2002: Accumulation in East Greenland Fjords and on the continental shelves adjacent to the Denmark Strait over the last century based on 210Pb geochronology. *Arctic,* 55: 109-122.

Stefansson, U., 1962: North Icelandic Waters. *Rit Fiskideildar,* III. Bind, Vol 3, 269 pp.

Stein, R., Dittmers, K., Fahl, K., Kraus, M., Matthiessen, J., Niessen, F., Pirrung, M., Polyakova, Y., Schoster, F., Steinke, T., and Futterer, D. K., 2004: Arctic (palaeo) river discharge and environmental change: evidence from the Holocene Kara Sea sedimentary record. *Quaternary Science Reviews,* 23: 1485-1511.

Stoner, J. S., Jennings, A. E., Kristjansdottir, G. B., Andrews, J. T., Dunhill, G., and Hardardottir, J., 2007: A paleomagnetic approach toward refining Holocene radiocarbon based chronostratigraphies: Paleoceanographic records from North

Iceland (MD99-2269) and East Greenland (MD99-2322) margins. *Palaeoceanography,* 22: 1 0f 23. PA1209, doi:1210:1029/2006PA001285, 002007.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Hughen, K. A., Kromer, B., McCormack, F. G., v.d. Plicht, J., and Spurk, M., 1998: INTCAL98 Radiocarbon age calibration 24,000-0 cal BP. *Radiocarbon,* 40: 1041-1083.

Syvitski, J. P. M., Andrews, J. T., and Dowdeswell, J. A., 1996: Sediment deposition in an iceberg-dominated Glacimarine Environment, East Greenland: Basin Fill Implications. *Global and Planetary Change,* 12: 251-270.

Syvitski, J. P. M., Stein, A., Andrews, J. T., and Milliman, J. D., 2001: Icebergs and seafloor of the East Greenland (Kangerlussuaq) continental margin. *Arctic, Antarctic and Alpine Research,* 33: 52-61.

Thompson, D. W. J. and Wallace, J. M., 1998: The Arctic oscillation signature in wintertime geopotential height and temperature fields. *Geophysical Research Letters,* 25: 1297-1300.

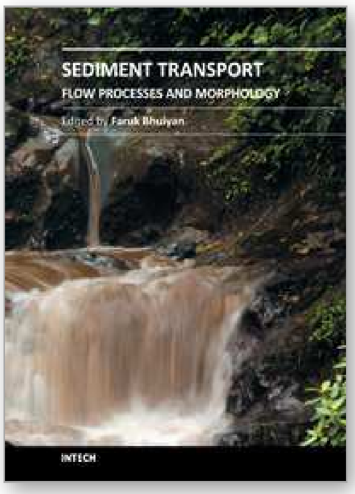
Tremblay, L. B., Mysak, L. A., and Dyke, A. S., 1997: Evidence from driftwood records for century-to-millennial scale variations of the high latitude atmospheric circulation during the Holocene. *Geophysical Research Letters,* 24: 2027-2030.

van den Broeke, M., Bamber, J., Ettema, J., Rignot, E., Schrama, E., van de Berg, W. J., van Meijgaard, E., Velicogna, I., and Wouters, B., 2009: Partitioning Recent Greenland Mass Loss. *Science,* 326: 984-986.

Verplanck, E. P., Farmer, G. L., Andrews, J., Dunhill, G., and Millo, C., 2009: Provenance of Quaternary glacial and glacimarine sediments along the southeast Greenland margin. *Earth and Planetary Science Letters,* 286: 52-62.

Wallevik, J. E. and Sigurjonsson, H., 1998: *The Koch index: Formulation, corrections and extension.* Icelandic Meteorological Office Report

Ward, C. R., Taylor, J. C., and Cohen, D. R., 1999: Quantitative mineraology of sandstones by X-ray diffractometry and normative analysis. *Journal Sedimentary Research,* 69: 1050-1062.



Sediment Transport - Flow and Morphological Processes

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The purpose of this book is to put together recent developments on sediment transport and morphological processes. There are twelve chapters in this book contributed by different authors who are currently involved in relevant research. First three chapters provide information on basic and advanced flow mechanisms including turbulence and movement of particles in water. Examples of computational procedures for sediment transport and morphological changes are given in the next five chapters. These include empirical predictions and numerical computations. Chapters nine and ten present some insights on environmental concerns with sediment transport. Last two contributions deal with two large-scale case studies related to changes in the transport and provenance of glacial marine sediments, and processes involving land slides.