Ruediger Stein
Alfred-Wegener-Institut, Bremerhaven

Terrigenous sediment supply in the Holocene Kara Sea: Sources, burial, variability and paleoenvironment

In order to study in detail the freshwater discharge, its influence on biological, geochemical, and geological processes in the Kara Sea (Arctic Ocean) (Fig. 1), and its variability in space and time, a joint German-Russian multidisciplinary research project on "Siberian River Run-off (SIRRO)" has been initiated. Within this project, three main expeditions with RV "Akademik Boris Petrov" were carried out in 1999, 2000, and 2001. Background information, methodology, and detailed results of the SIRRO studies are published in Stein et al. (2003b).

Carbon supply

The modern terrigenous sediment supply into the Kara Sea strongly depends on the river discharge. The annual discharge of total suspended sediments by the rivers Ob and Yenisei is 15.5 * 10^6 tons and 4.7 * 10^6 tons, respectively (Rachold et al. 2003 and further references therein). Particulate organic carbon supply by the same rivers is estimated to reach about 0.3 * 10^6 and 0.2 * 10^6 tons per year. Most of the suspended matter is already trapped in the estuaries where freshwater and salt water mix (salinities of about 2 to 10) and rapid accumulation (precipitation) of fine-grained suspension occurs due to coagulation processes. According to Lisitzin (1995), more than 90% of the suspended matter probably accumulates within this so-called "marginal filter". This results in thick sequences of young (Holocene) soft sediments overlying the pre-Holocene basement in the Ob and Yenisei estuaries (Dittmers et al. 2003; Stein et al. 2003a). In the Yenisei area north of about 73°30´ N, the thickness of the Holocene sedimentary cover is approaching almost zero (Fig. 1). Concerning the total sediment input into the Kara Sea, coastal erosion is the other most important sediment source. Romankevich and Vetrov (2001) give an estimate of 109 * 10^6 t y^{-1} of total sediment annually supplied by coastal erosion. Based on this number, the input of total organic carbon is estimated to reach about 1 * 10^6 t y^{-1}. Most of this organic matter is probably particulate matter (Stein and Fahl 2003).

There are important differences in the sediment sources of the suspended matter supplied by the Ob and Yenisei rivers. Whereas the Ob River is draining Quaternary Siberian lowland deposits, a major source of the suspended matter of the Yenisei River is the widespread Triassic plateau basalts and tuff deposits of the Putoran Massif (Fig. 1; Duzhikov and Strunin, 1992). Basalts and their weathering products are generally characterized by high magnetic susceptibility (MS) values (Thompson and Oldfield 1986). The relationship between riverine input from basaltic source areas and MS values is clearly reflected in surface sediments

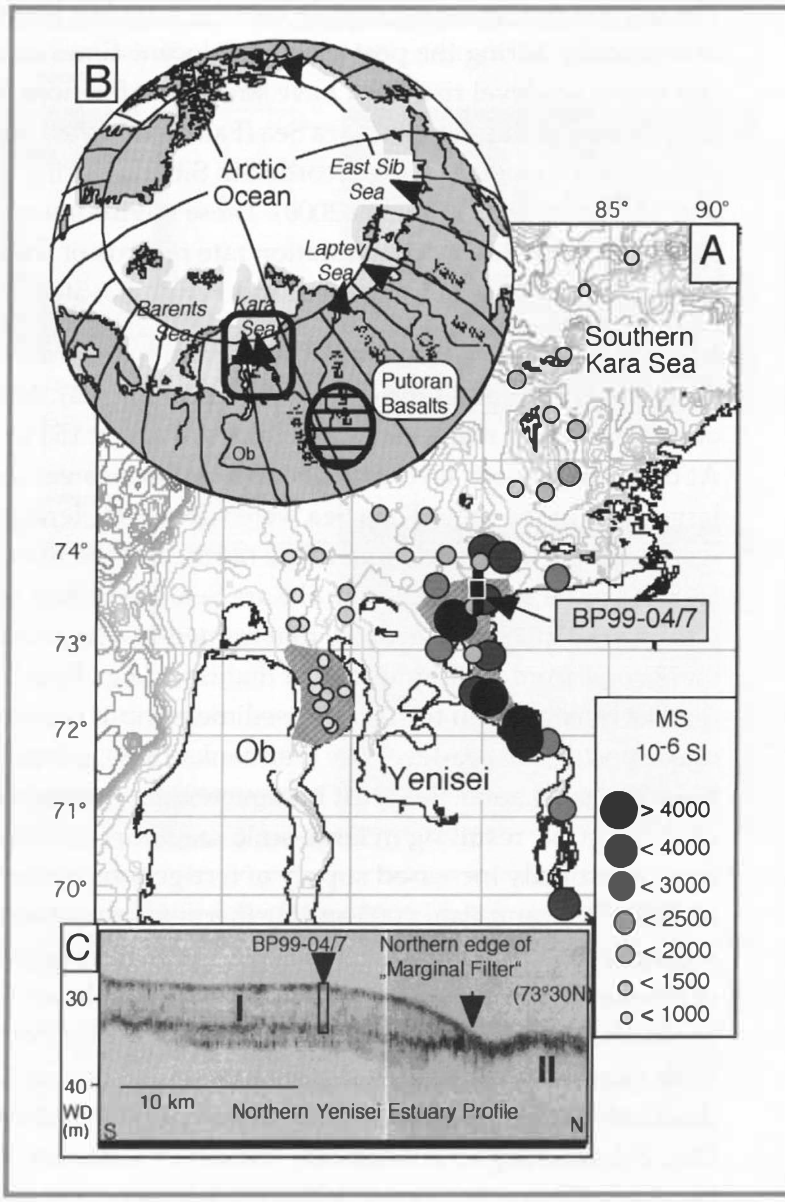

Fig. 1 Porosity-corrected magnetic susceptibility (MS) values (10^{-6} SI) which are a measure for the amount of MS carrying grains, in surface sediments (A). Hatched areas indicate the "marginal filter" zone in the Ob and Yenisei estuaries. Location of sediment core BP99-04/7 (cf. Fig. 3) and location of the sediment echograph profile (black bar) are indicated. For details see Dittmers et al. (2003). (B) Overview map of northern Eurasia and adjacent the Arctic Ocean indicating the major Eurasian rivers (black triangles) draining into the Arctic Ocean. The study area as well as the occurrence of Putoran basalts, the main source of the Yenisei suspended matter, are marked. (C) Sediment echograph profile through the northern end of the Yenisei "marginal filter" zone. The young (Holocene) sediments, i.e., Unit I, are overlying the pre-Holocene "basement" (Unit II). North of the "marginal filter" Holocene sedimentation decreases to zero. The location of Core BP99-04/7 is indicated.

from the Kara Sea. The Yenisei-influenced sediments have very high MS values whereas the sediments supplied by the river Ob are characterized by very low MS values (Fig. 1; Dittmers et al. 2003.). Thus, high MS values determined in the sediment cores may give information about the input of suspended matter by the Yenisei River into the southern Kara Sea.

Holocene sediment accumulation

The terrigenous sediment supply into the Kara Sea should have changed dramatically during the post-glacial-Holocene times as (1) the post-glacial global sea-level rise must have strongly influenced the land-ocean distribution in the shallow Kara Sea (Fairbanks 1989), and (2) distinct paleoclimatic changes were recorded in Siberia during that time interval (e.g., Andreev and Klimanov 2000). These environmental changes are clearly reflected in the accumulation rate records of the investigated sediment cores (for details see Stein and Fahl 2003; Stein et al. 2003a).

In the earliest Holocene (10 - 11 Cal. kyrs.BP), maximum accumulation rates were recorded in the central Kara Sea (Fig. 2a). Accumulation rates of total sediment reach very high values of about 150 to >300 g cm^{-2} ky^{-1}. At that time, the sea level was about 40 to 50 m lower than today and large parts of the inner Kara Sea were sub-aerial. Terrigenous sediments were transported much more to the north, and the main depocenter was situated more toward the central Kara Sea. Maximum accumulation rates were contemporaneously determined in a large number of sediment cores from the Laptev Sea at that time (e.g., Bauch et al. 2001). This distinct maximum in terrigenous sediment input occurred at a time of a major postglacial sea-level rise (Fairbanks 1989), when the shallow inner Kara Sea and Laptev Sea shelf became widely flooded for the first time after the LGM, resulting in large-scale sea floor/coastal erosion and, thus, a distinctly increased supply of terrigenous matter (e.g., Bauch et al. 2001; Stein and Fahl 2003 and further references therein). The river discharge probably increased at the same time, transporting large amounts of riverine material towards the core locations. Near 9 Cal. kyrs. BP, accumulation rates distinctly decreased on the central/outer shelf (Fig. 2a). With increasing sea level, sedimentation in the central Kara Sea became drastically reduced, and the main depocenter shifted towards the south (Fig. 2b), reaching approximately "modern" condition during the last 6 Cal. kyrs. BP (see Stein et al. 2003a for details).

Sediment budget

Based on Holocene sediment thickness charts, sediment echograph profiling results and sediment core data, Stein and Fahl (2003) estimate an average Holocene accumulation of 194 * 10^6 t y^{-1} of total sediment and 2.1 * 10^6 t y^{-1} of total organic carbon for the entire Kara Sea. For the late Holocene time interval (0 – 6 Cal. kyrs. BP), a mass balance for total sediments implies that about 123 * 10^6 t y^{-1} (82% of the initial input) is accumulating on the Kara Sea shelf and about 27 * 10^6 t y^{-1} (or 18% of the input) are exported by currents and sea ice towards the interior ocean (see Stein and Fahl 2003 for details).

Short-term variability

As outlined above, the Yenisei discharge is characterized by high magnetic susceptibility (MS) values. Looking at the MS record of Core BP99-04/7 for the time interval of the last about 9 Cal. kyrs. BP in detail, a distinct cyclicity is obvious (Fig. 3; Stein et al. 2003a), which may support short-term Holocene climate variability. Maxima in MS may be in-

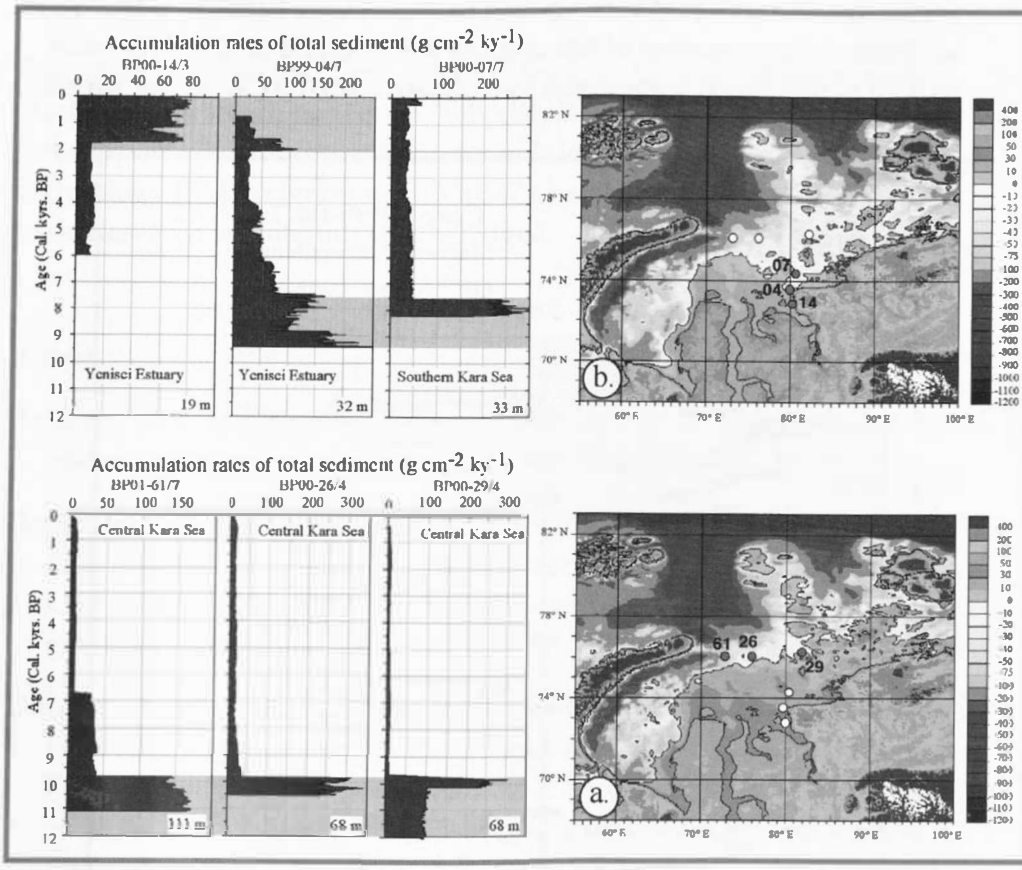

Fig. 2 Accumulation rate records of bulk (siliciclastic) sediments from the AMS-^{14}C dated sediment cores. (a) Records from cores BP00-26, BP00-29, and BP01-61; (b) records from cores BP99-04, BP00-07, and BP01-14. In addition, land/sea distribution maps in the Kara Sea at times of lowered global sea level (according to Fairbanks 1989) and core locations are shown. The maps have been constructed simply by using the -50m ((a) about 11 Cal. kyrs. BP) and -30m ((b) about 9 Cal. kyrs. BP) isolines of the modern bathymetry (assuming no or negligible isostatic rebound). Maps were drawn based on the IBCAO data set (I. Harms, Institute of Oceanography, Hamburg University).

terpreted as periods of increased discharge of suspended matter from the Putoran Massif. Elevated temperature and precipitation values probably resulted in enhanced weathering and erosion and, thus, increased supply of MS-rich basaltic weathering products. In general, maxima/minima occur at a frequency of about 200 to 700 years during the last about 7 Cal. kyrs. BP. In addition to the short-term centennial variability, a lower-frequency millennial variability of minima and maxima in MS seems to be obvious (Fig. 3). On this scale, maxima centred around 8.9, 7.5, 5.4, and 2.5-3.5 Cal. kyrs. BP.

Paleaoclimate

The major decrease in MS values starting near 2.5 Cal. kyrs. BP and being more pronounced during the last about 2 Cal. Kyrs. BP, may be related to the "Subatlantic cooling" characterized by a significant drop in air temperature and mean annual precipitation, as indicated in pollen records from Taymyr Peninsula (Andreev and Klimonov 2000). During the last 2 Cal. kyrs. BP, most unfavourable climatic conditions and modern vegetation zones in the coastal area and in the hinterland of the Kara Sea region are also reflected in the pollen record of Core BP99-04/7 (Kraus et al. 2003). A large number of MS minima and maxima on the centennial as well as millennial scale seems to correlate with the Greenland ice core (Fig. 3; Grootes et al. 1993).

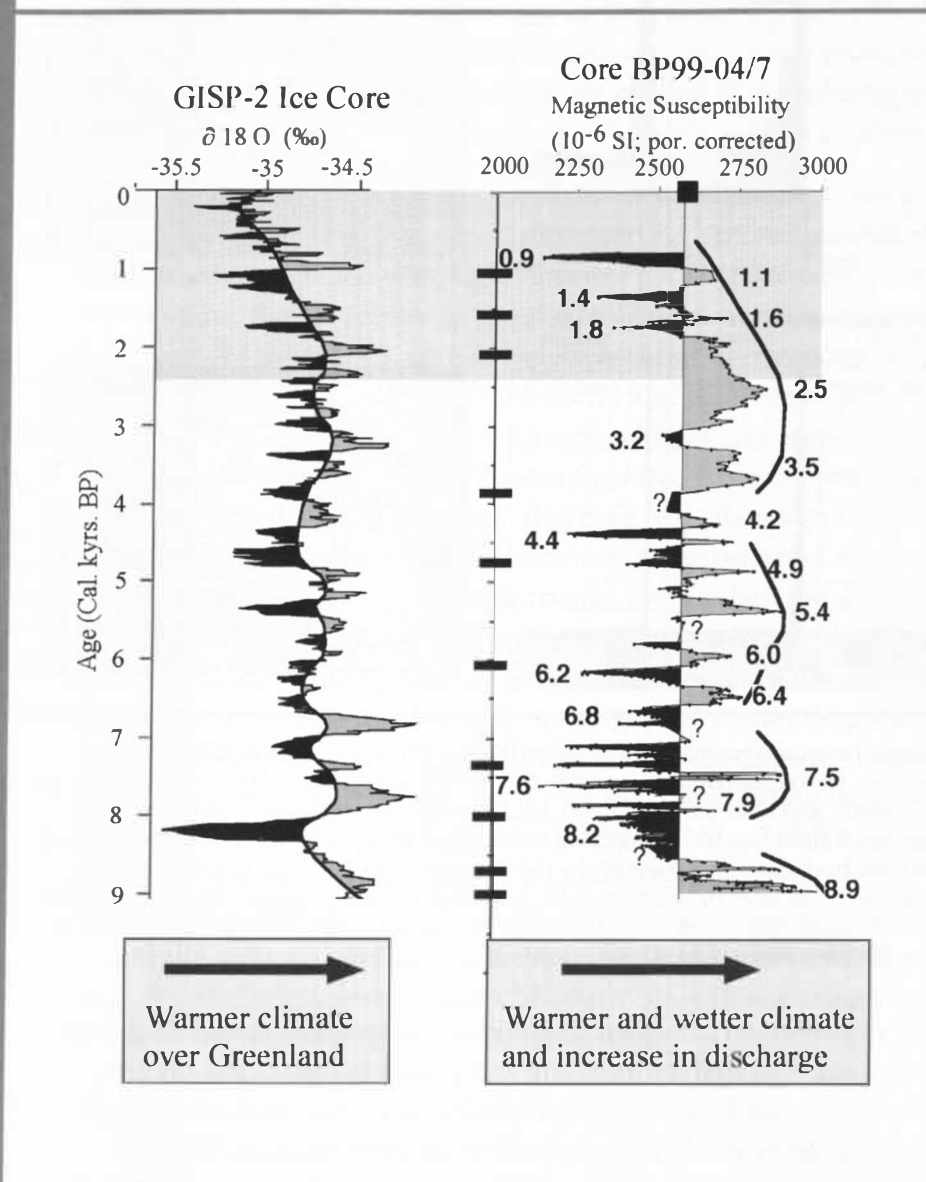

Fig. 3 High-resolution record of porosity-corrected magnetic susceptibility (10^{-5} SI) of Core BP99-04/7 for the last about 9 Cal. kyrs. BP and its paleoclimatic interpretation. Black square marks susceptibility value determined in surface sediments from this area. Numbers close to the MS minima and maxima are ages in Cal. kyrs. BP. Question marks in the MS record indicate data gaps between the measured 1m core sections. The BP99-04/7 record is compared with the $d^{18}O$ record of the GISP-2 ice core (Grootes et al., 1993). Location of $AMS^{14}C$ datings in the BP04/7 record are shown as black bars. For further details see Stein et al. (2003a).

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