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An Estimation of the Sediment Budget in the Laptev Sea during the Last 5000 Years

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Summary: This article presents a mass balance calculation of the sediment sources and sinks of the Laptev Sea. Sediment input into three regional sectors calculated on the basis of fluvial sediment discharge and coastal erosion sediment supply is compared with sediment output as estimated from sedimentation rates of well-dated marine sediment cores and data on sediment export to the central Arctic Ocean by sea ice and through bottom currents.

Within the uncertainties of the calculations, input and output are very well balanced. The calculation reveals that the sediment budget of the Laptev Sea is mainly controlled by fluvial and coastal sediment input. The major fraction of the material is simply deposited on the Laptev Sea shelf. However, for the western Laptev Sea, where sedimentation rates are low due to the absence of large rivers, export by sea ice is the main output factor.

Zusammenfassung: In diesem Artikel wird eine Bilanzierung des Sedimenthaushaltes der Laptewsee vorgestellt. Der Sedimenteintrag in drei regionale Sektoren, welcher auf dem Flusseintrag und dem Eintrag durch Küstenerosion basiert, wird mit dem Sedimentaustrag durch Sedimentation auf dem Laptewsee-Schelf und Export in den Arktischen Ozean durch Meereis und Tiefenströmungen verglichen.

Innerhalb des Ungenauigkeiten der Berechnung konnten Sedimenteintrag und –austrag sehr gut bilanziert werden. Die Bilanzierung zeigt, dass der Sedimenthaushalt der Laptewsee hauptsächlich durch den Eintrag durch Flüsse und Küstenerosion gesteuert wird. Der größte Teil davon sedimentiert auf dem Laptewsee-Schelf. In der westlichen Laptewsee allerdings, wo die Sedimentationsraten durch das Fehlen großer Flüsse wesentlich geringer sind, bildet der Sedimentexport durch Meereis den bedeutendsten Austragsmechanismus.

INTRODUCTION

Numerous recent studies have pointed out that the Laptev Sea plays a central role for sediment input, sea ice formation and oceanographic circulation patterns of the Arctic Ocean due to its geographical position within the source region of the Transpolar Ice Drift (KASSENS et al. 1998). In the present article the sediment budget of the Laptev Sea is quantitatively assessed by comparing sediment input and output. Figure 1 summarizes sediment sources and sinks that are considered:

(1) Large amounts of suspended sediments are imported through the Siberian rivers, mainly the Lena River (GORDEEV et al. 1996). However, a portion of these riverine sediments may be stored in the river deltas and, thus, does not contribute to the Laptev Sea sediment budget (ALABYAN et al. 1995).
(2) Recent studies showed that the amount of sediments originating from the erosion of permafrost coastlines in the Laptev Sea is similar to or even larger than the river sediment input (RACHOLD et al. 2000).
(3) The entrainment of shelf surface deposits into newly forming sea ice has been widely proven (DETHLEFF et al. 2000). At present, rafting of sediments by sea ice is a major mode of particulate sediment transport in the Arctic Ocean (DETHLEFF submitted, EICKEN et al. 2000).
(4) Downslope bottom sediment transport to the central Arctic Ocean and sediment export/import to and from the East Siberian and Kara seas have to be considered.

The net input of sediments to the Laptev Sea, which can be computed based on these estimates, will be compared with the sediment accumulation as documented in marine sediment cores.

METHODS AND DATA SOURCES

The modern Laptev Sea is characterized by strong regional differences, which have been mainly attributed to the positions of the river mouths (THIEDE et al. 1999 and references herein). Today high sedimentation rates are observed in the proximity of the Lena/Yana outflow, whereas in the western Laptev Sea sediment accumulation is significantly lower due to geography and seafloor topography (BAUCH et al. 1999, STEIN & FAHL 2000). For that reason, in the following we divide the Laptev Sea into three equally sized sectors as shown in Figure 2. The western sector, which is bounded by the Taymyr Peninsula in the west and the mouth region of the Olenyok River in the east, includes the sediment discharge of the Khatanga, Anabar and Olenyok rivers. The central sector mainly comprises the Lena Delta coastline and includes the Lena and Omoloy rivers. Its eastern border is defined at Cape Buor-Khaya (Fig. 2). The eastern sector includes the Yana River, its eastern boundary is formed by the western coastlines of the New Siberian Islands.

Fluvial Sediment Supply

Regular hydrological measurements in the Laptev Sea drainage area commenced in the period from 1925-1935. Today 340 hydrometeorological stations, which are randomly scattered over the drainage area, are in operation. At several of these stations, water discharge and in part also suspended load are measured daily. The data are available through publications of the St. Petersburg (formerly Leningrad) Hydrometeo-

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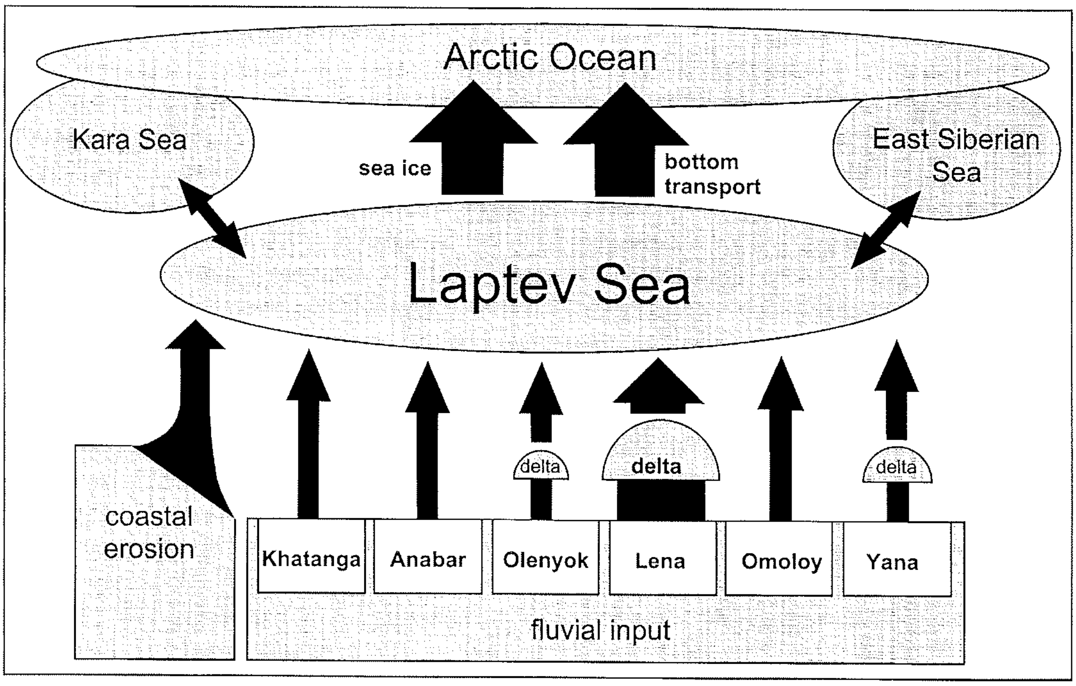

Fig. 1: Scheme of the Laptev Sea sediment budget.

Abb. 1: Schematische Darstellung des Sedimentbudgets der Laptewsee.

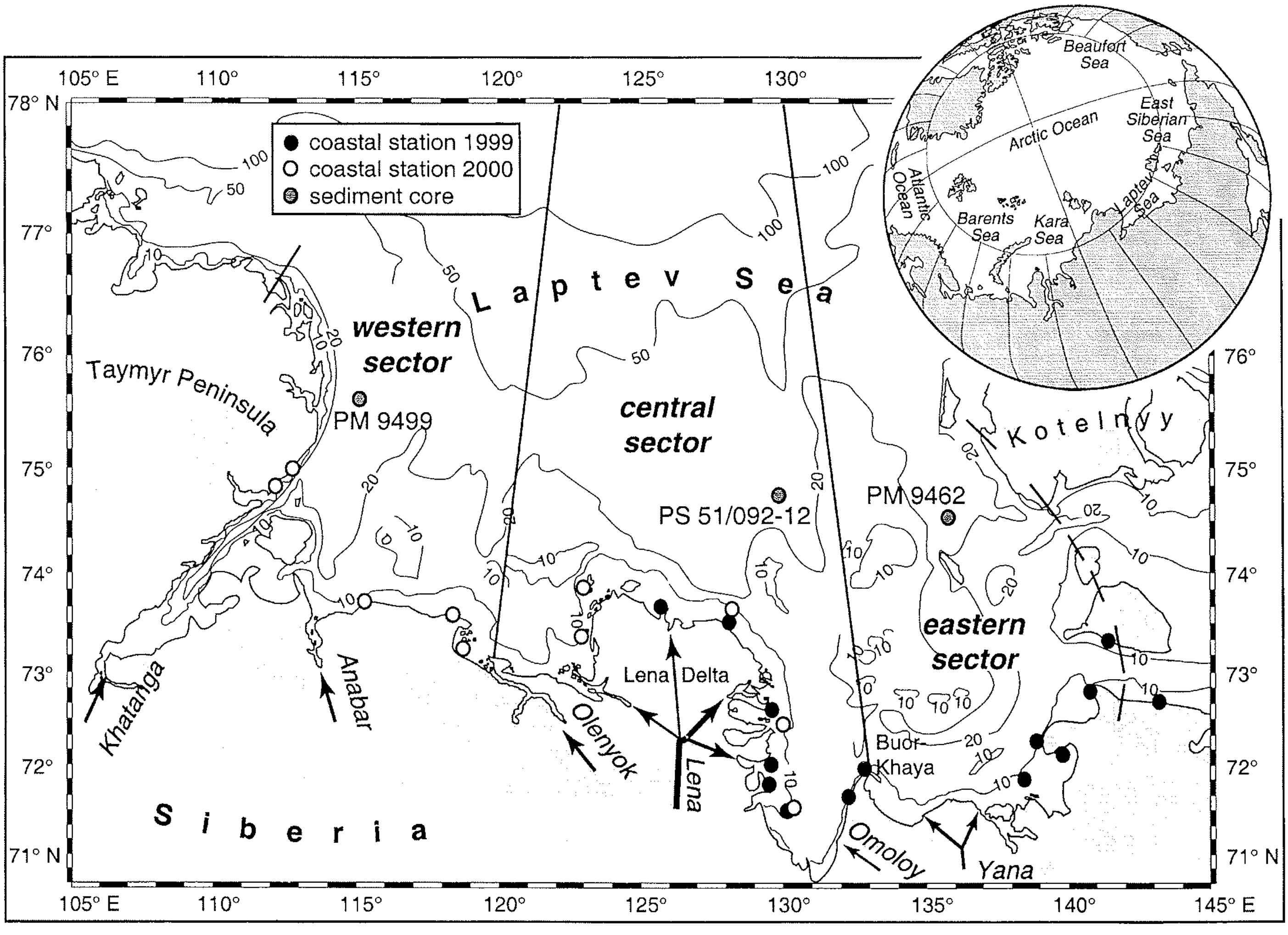

Fig. 2: Location map of the Laptev Sea. Positions of the sediment cores and coastal key sites are indicated. Black lines indicate the borders of the defined sectors.

Abb. 2: Übersichtskarte der Laptewsee. Die Positionen der Sedimentkerne und der Küstenlokalitäten sind eingezeichnet. Die schwarzen Linien kennzeichnen die Grenzen der definierten Sektoren.

rological Service. Several articles on the water and sediment discharge, which are based on these data, have been presented (ALABYAN et al. 1995, GORDEEV et al. 1996, RACHOLD et al. 1996). These data refer to the sediment discharge in the upper reaches of the rivers several kilometers upstream from the deltas/estuaries. Furthermore, the data only consider the suspended load; data on bedload of the Siberian rivers are not available. Only one publication (GORDEEV et al. 1996) lists all of the rivers draining to the Laptev Sea. Other articles have not taken into account some of the smaller rivers. For that reason our estimates on riverine sediment input are based on the data presented by GORDEEV et al. (1996).

Several studies conducted in different river systems during the last decade present evidence for a significant loss of sediment load on subaerial parts of deltas before reaching the sea (ALABYAN et al. 1995 for the Lena Delta). However, new investigations clearly show that fine-grained sediments are not deposited in the Lena Delta but flushed out to sea during spring floods. The delta acts as a filter for the sand and gravel fraction but does not store considerable amounts of river suspended material (RACHOLD et al. 2000). This statement is based on several observations discussed by RACHOLD et al. (2000) in detail:

(1) As pointed out by ARE & REIMNITZ (2000), the delta front is advancing only along relatively short segments. Considerable regions appear to be either stable or are even retreating. Therefore, progradation does not act as a sediment sink.
(2) A zone of sandy islands 400-1000 years old and 3 m above sea level characterizes the rather flat, interdistributary parts of the active delta. The modern pattern of smaller distributaries between these islands is very similar to that seen on topographic maps prepared from air photos about 45 years earlier. The island surfaces are, therefore, over 50 years, perhaps several hundred years old and show little change indicating that deposition of fines is not occurring on subaerial parts of the delta.
(3) The channel floors of Lena Delta are composed mainly of sand, locally of gravel, and flow velocities are generally too high for the deposition of mud.

Therefore, it can be concluded that most of the Lena river suspended sediments are supplied to the sea. Thus, the data presented by GORDEEV et al. (1996) represent the amount of sediment that is actually supplied to the Laptev Sea by rivers.

According to the position of the river mouths, the fluvial sediment discharge is attributed to one of the sectors defined above. It has to be noted that due to the positions of the main channels of the Lena Delta the modern sediment discharge of the Lena River is directed both to the north and to the northeast. According to the distribution of water discharge in the Lena Delta (ALABYAN et al. 1995) in our following calculation we, therefore, assume that 80 % of the Lena sediment enters the central and 20 % the eastern sector.

Coastal Erosion Sediment Input

The data on the sediment input by coastal erosion into the Laptev Sea are based on

(1) long-term monitoring of coastal dynamics on key sites;
(2) one-time or one-season field measurements of shorelines on key sites;
(3) comparison of shorelines and cliff tops for a time-series of topographic maps, satellite images and aerial photographs, and
(4) comparison of the present-day field measurements with remote sensing information.

At a number of key sites along the Laptev Sea observations of coastal retreat rates were conducted almost annually. During the field seasons 1999 and 2000 all these sites have been revisited. Figure 2 shows the position of the coastal sites studied during the expeditions Lena 99 (RACHOLD & GRIGORIEV 2000) and Lena 2000 (RACHOLD & GRIGORIEV 2001).

Coastal retreat rates have been quantified for all these sites. Based on cliff morphology, ice content and density of the sediments the sediment mass supplied to the sea by coastal cliff erosion can be calculated. A more detailed description of the methodology is presented in RACHOLD et al. (2000). The total amount of coastal erosion sediment input is computed for the three sectors defined above.

Sea Ice Sediment Export

Sea ice can be an important carrier for sediment export from the Laptev Sea to the central Arctic Ocean. The total ice-bound sediment export for an entrainment event documented in 1994/1995 by EICKEN et al. (2000) accounted for $18.5/10^6$ t, which is of the same order of magnitude as annual Lena river sediment supply. However, the source area of this entrainment event has been identified north and northeast of the New Siberian Islands and, thus, the Laptev Sea budget is not affected. Rafting of sediments by sea ice has been observed in the Laptev Sea as well (LINDEMANN et al. 1999). EICKEN et al. (1997) calculated that $2\text{-}11/10^6$ t y^{-1} are entrained into sea ice during fall freeze-up. In addition $17\text{-}20/10^6$ t y^{-1} may be exported by lead ice (DETHLEFF submitted). The sum amounts to $19\text{-}31/10^6$ t y^{-1} and for our budget calculation we consider an average value of $25/10^6$ t y^{-1} for sea ice sediment export. Because information on the regional variability is not available we assume that each of the Laptev Sea sectors defined above contributes one third to the sea ice sediment export.

Bottom Sediment Transport and Sediment Exchange with the East Siberian and Kara Seas

The Holocene sedimentary record of the Siberian continental margin is characterized by very low sedimentation rates and hiatuses (MÜLLER & STEIN 2000) except for those regions located north of the Lena and Yana submarine valleys (KLEIBER & NIESSEN 2000). Compared to the sediment accumulation in the Laptev Sea (29-230 g cm^{-2} 5 ky^{-1}), the mass flux to the Eurasian part of the Arctic Ocean ranging from 1 to 5 g cm^{-2} 5 ky^{-1} (NØRGAARD-PEDERSEN et al. 1998) is 1-2 orders of magnitude lower. For our budget calculation we use an estimate of 6.2 10^6 t y^{-1} for the bottom sediment export published by EICKEN et al. (1997). Again we assume that each sector contributes one third to the total bottom sediment export. Data on sediment exchange with the East Siberian and Kara seas are not available. However, we assume that this process is of minor importance.

Sediment Accumulation on the Laptev Sea Shelf

In the Laptev Sea regional trends in sediment accumulation rates are not only seen in the west-east transect but also in the south-north transect. According the STEIN & FAHL (2000) the bulk accumulation rates decrease from 132 cm ky^{-1} in the region off the Lena Delta to 39 cm ky^{-1} on the outer shelf at 50-200 m water depth and 4.9 cm ky^{-1} on the lower continental slope at water depth of 2000-3000 m). Table 1 shows average accumulation rates for the Laptev Sea shelf and continental slope. It has to be noted that the shelf data refer to a transect north of the Lena Delta corresponding to our central and/or eastern Laptev Sea sector.

Based on the accumulation rates published by STEIN & FAHL (2000) and considering the area of the individual region an average accumulation rate of 36 cm ky^{-1} for the Laptev Sea shelf can be calculated (Tab. 1). This value refers to an area of 200,000 km^2 where water depths are larger than 20 m. STEIN & FAHL (2000) argue that the shallow coastal region (water depth 0-20 m), which has an area of 260,000 km^2, is characterized by erosion and re-deposition and, therefore, does not contribute to the sediment accumulation on the Laptev Sea shelf. This statement is supported by new investigations of ARE et al. (2002), who point out that in the Laptev Sea the shallow coastal regions with a water depth of less than 10 m (shoreface) are undergoing erosion.

Region	bulk sed. rate cm ky^{-1}	area km^2
Laptev Sea Shelf (a)		
coastal region (0-20 m WD)	0 (*)	260000
off Lena	132	20000
inner shelf (20-50 m WD)	15	100000
outer shelf (50-200 m WD)	39	80000
shelf average	36	200000
Continental Slope (a)		
upper slope (200-1000 m WD)	34	50000
mid slope (1000-2000 m WD)	15	50000
lower slope (2000-3000 m WD)	4.9	50000
Sediment Cores (b)		
PM 9462 (eastern LS, 27 m WD)	46	
PS 51/092-12 (central LS, 32 m WD)	40	
PM 9499 (western LS, 48 m WD)	5.9	

Tab. 1: Geometric parameters of the investigated profiles.

Tab. 1: Geometrische Parameter der untersuchten Profile.

In order to establish average sediment accumulation rates for the three Laptev Sea sectors defined above we selected three well-dated marine sediment cores (PM 9499 from the western Laptev Sea at 48 m water depth; PS 51/092-12 from the central Laptev Sea at 32 m water depth, and PM 9462 from the eastern Laptev Sea at 27 m water depth). The age/depth models of the cores are presented in Figure 3.

Previous studies indicated that in the Laptev Sea rather stable environmental conditions similar to the modern situation have prevailed since c. 5-6 ky BP when sea-level reached its modern level (BAUCH et al. 2001a). BAUCH et al. (2001b) state that both temporal development and magnitude of the post-glacial sea-level rise in the Laptev Sea are similar to the global sea-level record (FAIRBANKS 1989).

Terrestrial paleoclimate reconstructions of the region mainly derived from pollen records also suggest rather constant climatic conditions since c. 5 ky BP. Results obtained from a sediment core drilled in a thermokarst lake of the western Lena Delta document that after the Holocene climatic optimum around 7 ky BP, and a climate deterioration which followed, conditions similar to the modern situation were established c. 5 ky BP (SCHWAMBORN et al. 2002).

The sediment cores selected for the assessment of the sediment budget (Fig. 3) show more or less constant sedimentation rates during the last 5 ky as well. As seen from Table 1 the average accumulation rates for the two cores located in the central (PS 51/092-12, 40 cm ky^{-1}) and eastern Laptev Sea (PM 9462, 46 cm ky^{-1}) are very similar to the average accumulation rate calculated for the Laptev Sea shelf based on the 36 cm ky^{-1} given by STEIN & FAHL (2000), which refers to the central/eastern Laptev Sea as well. We, therefore, conclude that the selected sediment cores are representative for the three sectors. To calculate the sediment accumulation we use the average sedimentation rates of the last 5000 years for each sediment core. Based on these data and on the average dry bulk density of the sediments the amount of material deposited in each sector during the last 5000 years can be quantified. In accordance with STEIN & FAHL (2000) we only consider regions with water depths larger than 20 m. Thus, the area of each sector amounts to one third of the 200,000 km^2.

RESULTS AND DISCUSSION

The results of our calculation are shown in Table 2. In all three Laptev Sea sectors sediment input and output are very well balanced, the difference between input and output does not exceed 15 %. In the western Laptev Sea sector we calculate a sediment input of 0.66×10^{11} t 5 ky^{-1} and an output of 0.71×10^{11} t 5 ky^{-1}, in the central sector 1.63×10^{11} t 5 ky^{-1} and 1.84×10^{11} t 5 ky^{-1} and in the eastern sector 1.81×10^{11} t 5 ky^{-1} and 2.05×10^{11} t 5 ky^{-1}. In all three sectors coastal erosion is the main source of sediments, the river input is significantly smaller. In the central and eastern sector sedimentation constitutes the main output, whereas in the western sector, where sedimentation rates are significantly lower due to the absence of large river

	Area (km²)	Western LS 6.67E+04 (*)	Central LS 6.67E+04 (*)	Eastern LS 6.67E+04 (*)
SEDIMENT INPUT				
1. Rivers (a)				
	t y^{-1}	1.70E+06 Khatanga	1.41E+07 Lena (#)	3.52E+06 Lena (#)
	t y^{-1}	1.00E+05 Anabar	1.30E+05 Omoloy	3.50E+06 Yana
		1.10E+06 Olenyok		
Sum	t y^{-1}	2.90E+06	1.42E+07	7.15E+06
Total Riverine Input	t 5ky^{-1}	0.15E+11	0.71E+11	0.36E+11
2. Coastal Erosion (b)				
	t y^{-1}	1.02E+07	1.83E+07	2.90E+07
Total Coastal Input	t 5ky^{-1}	0.51E+11	0.92E+11	1.45E+11
Total Input	t 5ky^{-1}	0.66E+11	1.63E+11	1.81E+11
SEDIMENT OUTPUT				
1. Sedimentation (b)				
Sediment Core		PM 9499	PS 51/092-12	PM 9462
Age Interval	ky	0-5	0-5	0-5
Dry Density	g cm^{-3}	1.05	0.81	0.92
Sedimentation Rate	cm ky^{-1}	5.6	49	50
Accumulation Rate	g cm^{-2} ky^{-1}	5.9	40	46
Accumulation	g cm^{-2} 5ky^{-1}	29	200	230
Total Sedimentation	t 5 ky^{-1}	0.19E+11	1.32E+11	1.53E+11
2. Sea-Ice Export (c,d)				
	t y^{-1}	8.30E+06	8.30E+06	8.30E+06
Total Sea-Ice Export	t 5ky^{-1}	0.42E+11	0.42E+11	0.42E+11
3. Bottom Export (d)				
	t y^{-1}	2.07E+06	2.07E+06	2.07E+06
Total Bottom Export	t 5ky^{-1}	0.10E+11	0.10E+11	0.10E+11
Total Output	t 5ky^{-1}	0.71E+11	1.84E+11	2.05E+11
Sediment Budget				
Input - Output	t 5ky^{-1}	-0.06E+11	-0.22E+11	-0.24E+11
Rel. Difference	%	-9	-13	-14

Tab. 2: Sediment budget of the Laptev Sea. (a): GORDEEV et al. (1996), (b): this study, (c): DETHLEFF (submitted), (d): EICKEN et al. (1997); (#) area with water depth ≥20 m, see text for explanation, (#) 80 % of total Lena River sediment discharge are assumed to enter the central, 20 % the eastern Laptev Sea sector.

Tab. 2: Das Sedimentbudget der Laptewsee. (a): GORDEEV et al. (1996), (b): diese Arbeit, (c): DETHLEFF (eingereicht), (d): EICKEN et al. (1997), (#) Gebiete mit Wassertiefen ≥20 m, s. Text, (#) 80 % des gesamten Sedimenteintrages der Lena erreichen den zentralen, 20 % den östlichen Laptewsee-Sektor.

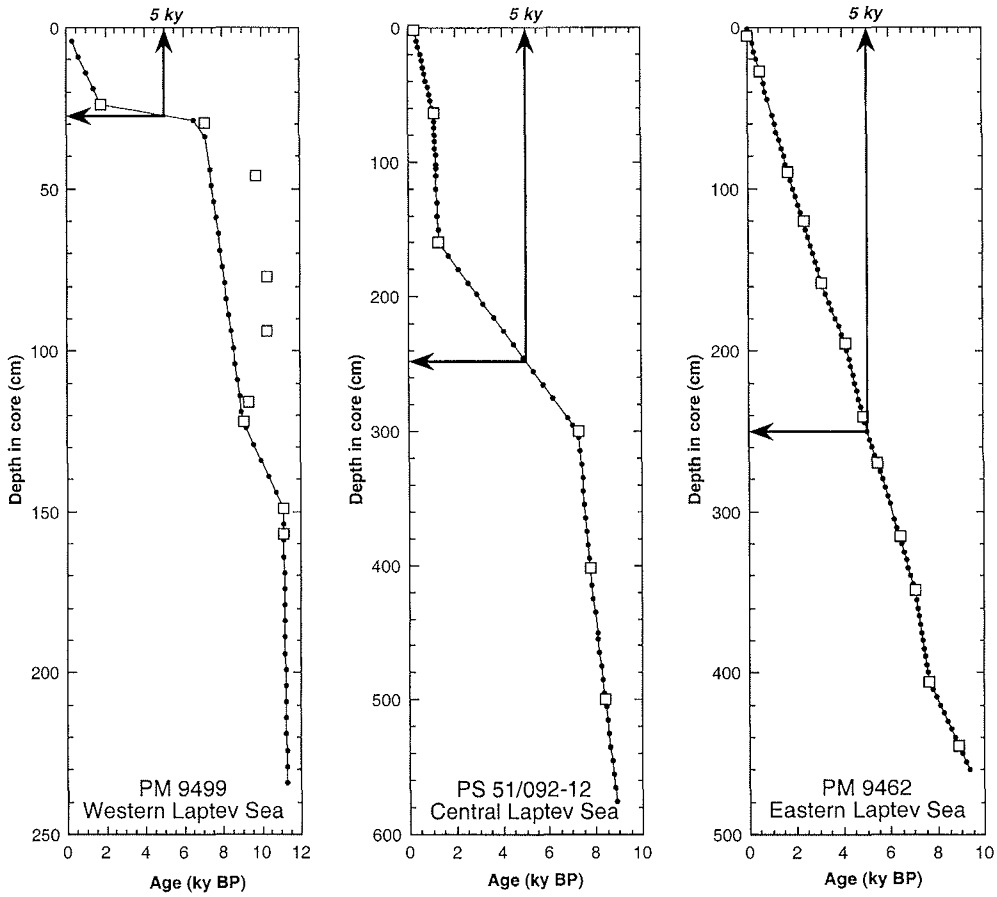

Fig. 3: Age models of Laptev Sea sediment cores (BAUCH et al. 2001b). Open squares represent radiocarbon dates.

Abb. 3: Altersmodell der Sedimentkerne aus der Laptewsee (BAUCH et al. 2001b). Die weißen Quadrate repräsentieren ^{14}C-Datierungen.

systems, sediment export by sea ice exceeds sedimentation by a factor of about 2.

The total sedimentation in the Laptev Sea amounts to 3.04×10^{11} t 5 ky^{-1}, which is in good agreement with the estimate of STEIN (pers. comm.) of 3.25×10^{11} t 5 ky^{-1}.

In general, sediment output is slightly higher than sediment input in all three sectors. A possible explanation for this discrepancy lies in the shallow coastal regions (<20 m water depth). As noted above, for the budget calculation these shallow regions were not regarded as sedimentation areas. The assumption was that they are characterized by a neutral sediment balance due to erosion and re-deposition. However, ARE et al. (2002) pointed out that the shoreface (<10 m water depth for the Laptev Sea), which is undergoing erosion, is an additional source for the sediment input to the Laptev Sea. ARE et al. (2002) suggest that the subsea erosion of the shoreface may transfer as much sediments to the sea as the subaerial erosion of the cliff. However, at the moment the information available on shoreface erosion is still insufficient to be included into the sediment input calculations, and this will be a future task.

In summary, it can be stated that regarding the uncertainties of our estimates, sediment sources and sinks are well balanced. The sediment budget of the Laptev Sea is mainly controlled by fluvial and coastal sediment input. Except for the western Laptev Sea, where sediment export by sea ice is the main output factor, the major fraction of the material is simply deposited on the Laptev Sea shelf.

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References

Alabyan, A.M., Chalov, R.S., Korotaev, V.N., Sidorchuk, A.Y. & Zaitsev, A.A. (1995): Natural and technogenic water and sediment supply to the Laptev Sea.- Rep. Polar Res. 176: 265-271.

Are, F.E., Grigoriev, M.N., Hubberten, H.-W., Rachold, V., Razumov, S. & Schneider, W. (2002): Comparative shoreface evolution along the Laptev Sea coast.- Polarforschung 70: 135-150.

Are, F.E. & Reimnitz, E. (2000): An overview of the Lena River Delta setting: Geology, tectonics, geomorphology and hydrology.- J. Coastal Res. 16 (4): 1083-1093.

Bauch, H.A., Kassens, H., Erlenkeuser, H., Grootes, P., Dehn, J., Peregovich, B. & Thiede, J. (1999): Changes in sea-level and sedimentation on the western Laptev Sea shelf (Arctic Siberia) during the Holocene.- Boreas 28: 194-204.

Bauch, H.A., Kassens, H., Naidina, O.D., Kunz-Pirrung, M. & Thiede, J. (2001a): Composition and flux of Holocene sediments on the eastern Laptev Sea shelf, Arctic Siberia.- Quat. Res. 55: 344-351.

Bauch, H.A., Mueller-Lupp, T., Spielhagen, R.F., Taldenkova, E., Kassens, H., Grootes, P.M., Thiede, J., Heinemeier, J., Petryashov, V.V. (2001b): Chronology of the Holocene transgression at the northern Siberia margin.- Global Planet. Change. 31:125-139.

Dethleff, D., Rachold, V., Tintelnot, M. & Antonow, A. (2000): Modern sea-ice transport of riverine sediments from the Laptev Sea to the Fram Strait based on clay mineral studies.- Intern. Journ. Earth Sci. 89: 496-502.

Dethleff, D. (submitted): Entrainment and export of Laptev Sea ice sediments.- J. Sed. Petrol.

Eicken, H., Reimnitz, E., Alexandrov, V., Martin, T., Kassens, H. and Viehoff, T. (1997): Sea-ice processes in the Laptev Sea and their importance for sediment export.- Cont. Shelf Res. 17: 205-233.

Eicken, H., Kolatschek, J., Freitag, J., Lindemann, F., Kassens, H. & Dmitrenko, I. (2000): A key source area and constraints on entrainment for basin-scale sediment transport by Arctic sea ice.- Geoph. Res. Lett. 27: 1919-1922.

Fairbanks, R.G. (1989): A 17,000 year glacio-eustatic sea-level record: influence of glacial melting on the Younger Dryas event and deep-ocean circulation.- Nature 342: 637-642.

Gordeev, V.V., Martin, J.M., Sidorov, I.S. & Sidorova, M.V. (1996): A reassessment of the Eurasian river input of water, sediment, major elements, and nutrients to the Arctic Ocean.- Amer. J. Sci. 296: 664-691.

Kassens, H., Dmitrenko, I., Rachold, V., Thiede, J. & Timokhov, L. (1998): Four years of German-Russian cooperation in the Laptev Sea unravel an Arctic climate system.- EOS 79: 317,322-323.

Kleiber, H.P. & Niessen, F. (2000): Variations of continental discharge pattern in space and time: implications from the Laptev Sea continental margin, Arctic Siberia.- Intern. Journ. Earth Sci. 89: 605-616.

Lindemann, F., Hölemann, J.A., Korablev, A. & Zachek, A. (1999): Particle entrainment into newly forming sea ice - freeze-up studies in October 1995.- In: H. KASSENS, H.A. BAUCH, I. DMITRENKO, H. EICKEN, H.-W. HUBBERTEN, M. MELLES, J. THIEDE & L. TIMOKHOV (eds.), Land-ocean systems in the Siberian Arctic: dynamics and history, Berlin: Springer: 113-123.

Müller, C. & Stein, R. (2000): Variability of fluvial sediment supply to the Laptev Sea continental margin during Late Weichselian to Holocene times: implications from clay-mineral records.- Intern. Journ. Earth Sci. 89: 592-604.

Nørgaard-Pedersen, N., Spielhagen, R.F., Thiede, J. & Kassens, H. (1998): Central Arctic surface ocean environment during the last 80,000 years.- Paleoceanography 13: 193-204.

Rachold, V., Alabyan, A.M., Hubberten, H.-W., Korotaev, V.N. & Zaitsev, A.A. (1996): Sediment transport to the Laptev Sea - hydrology and geochemistry of the Lena River.- Polar Research 15: 183-196.

Rachold, V. & Grigoriev, M.N. (2000): Russian-German Cooperation System Laptev Sea 2000: The Expedition LENA 1999.- In: V. RACHOLD (ed.), Expeditions in Sibiria in 1999, Rep. Polar Res. 354: 1-269.

Rachold, V., Grigoryev, M.N., Are, F.E., Solomon, S., Reimnitz, E., Kassens, H. & Antonow, A. (2000): Coastal erosion vs. riverine sediment discharge in the Arctic shelf seas.- Intern. Journ. Earth Sci. 89: 450-460.

Rachold, V. & Grigoriev, M.N. (2001): Russian-German Cooperation System Laptev Sea 2000: The Expedition LENA 2000.- Rep. Polar Res. 388.

Schwamborn, G., Andreev, A., Rachold, V., Hubberten, H.-W., Grigoriev, M.N., Tumskoy, V., Pavlova, E.Yu. & Dorozhkina, M.V. (2002): Evolution of Lake Nikolay, Arga Island, western Lena River delta, during Late Pleistocene and Holocene time.– Polarforschung 70: 69-82.

Stein, R. & Fahl, K. (2000): Holocene accumulation of organic carbon at the Laptev Sea continental margin (Arctic Ocean): sources, pathways, and sinks.- Geo-Marine Letters 20: 27-36.

Thiede, J., Timokhov, L., Bauch, H.A., Bolshiyanov, D.Y., Dmitrenko, I., Eicken, H., Fahl, K., Gukov, A., Hölemann, J., Hubberten, H.-W., Juterzenka, K.v., Kassens, H., Melles, M., Petryashov, V., Pivovarov, S., Priamikov, S., Rachold, V., Schmid, M., Siegert, C., Spindler, M., Stein, R. & Scientific Party (1999): Dynamics and history of the Laptev Sea and its continental hinterland: a summary.- In: H. KASSENS, H.A. BAUCH, I. DMITRENKO, H. EICKEN, H.-W. HUBBERTEN, M. MELLES, J. THIEDE & L. TIMOKHOV (eds.), Land-ocean systems in the Siberian Arctic: dynamics and history, Berlin: Springer: 695-711.