DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 1997/59

Raw Materials in the Femer Bælt area

A summary report

Jørn Bo Jensen

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MINISTRY OF ENVIRONMENT AND ENERGY

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1. Preface

This technical report has been prepared as part of the Environmental Impact studies of the Fehmarn Belt Link Feasibility Study, Phase 1, on behalf of the Fehmarn Belt Project Organisation, comprising the "Trafikministeriet", Denmark and "Bundesministerium für Verker", Germany.

The report is a summary of a confidential report (Råstofgeologiske og Geologiske undersøgelser i Østersøen. Femer Bælt, område 564) prepared by GEUS (Jensen 1996) on behalf of the Danish National Forest and Nature Agency.
In addition, investigations on sand resources in Fehmarn Belt undertaken by the "Bundesanstalt für Wasserbau" in 1965 are included (Bundesanstalt für Wasserbau 1965).

A general evaluation is presented of sand and gravel raw materials in the German and Danish sector of Femer Bælt as potential resources for a Fehmarn Belt Link project.

The main results are based on mapping and research made by GEUS in co-operation with the German research institute "Institut für Ostseeforschung Warnemünde".

The detailed geological interpretation of seismic and lithological data is not included in this report, but has been and will be published in scientific papers (Jensen, J.B., Kuijpers, A. & Lemke, W. 1996, Jensen, J .B., Bennnike, O., Witkowski, A. Lemke, W. & Kuijpers, A. accepted, Lemke, W., Jensen, J.B., Bennike, O. & Witkowski, A. accepted).

The contents of the report can be subdivided in 3 main parts, i.e. 1) an introductory methods and geological part, 2) description of seabed sediments and seabed dynamics and finally 3) the raw material evaluation.

Although for the geologically skilled person it is important to understand the depositional history of the raw materials and the actual seabed dynamics, other readers may confine them selves with the chapters dealing specifically with the raw materials.

2. Summary

On basis of marinegeological studies it has been possible to describe the Late- and Postglacial depositional evolution in the Femer Bælt area.
In relation with the final deglaciation of the Femer Bælt area, subglacial lodgement till and proglacial marginal flow till and esker deposits were deposited. Continued deglaciation lead to deposition of icelake sediments, which can be related to the initial phase of the Baltic Ice Lake. After the complete deglaciation, changes in water levels resulted in establishment of different lake phases (The Baltic Ice Lake and The Ancylus Lake), which resulted in deposition of coastal deposits in the Femer Bælt area. Finally the Littorina Sea transgression caused deposition of marine coastal deposits at different levels, before the total area was submerged.
The above described geological evolution has resulted in a characteristic distribution of seabed sediments (see enclosed Late Quaternary sediments map in scale 1 : 200 000), as also is reflected in the distribution of raw materials (see Fig. 2 and enclosed Femer Bælt Resource areas map in scale 1 : 200000).
In addition the seabed sediment distribution, the occurence of dynamical bedforms and man made marks gives information of the present bottom current pattern and intensity as well as human impact on the seafloor. These aspects are of major importance as basis for assessing the effects of future human activity on the seafloor.

The raw materials mapped by GEUS in the Femer Bælt area consisted of 20 sand and gravel resource areas with a total resource volume of 285 mill m^3 . Of these 75 mill m^3 are situated in German waters.

The resource areas are classified in 3 main depositional environments.

Submerged coastal deposits.
These sediments were deposited in relation with water level changes in the Femer Bælt.
Supposed 15 mill m^3 fine - medium grained sand and 3 mill m^3 medium - coarse sand are freshwater coastal sediments deposited along the Ancylus Lake paleo coastline.
The majority of the sandy coastal sediments was deposited in connection with the Littorina Sea transgression, partly as spit progradations and as ordinary beach deposits. Some of these deposits has been redeposited, but in the order of 150 mill m^3 must be related to coastal deposits of which about 40 mill m^3 are located in German waters. The grain sizes are from fine to coarse sand, but medium sand is dominating.

Current-induced deposits.
In many places the paleo coastal deposits have been heavily modified by subrecent to recent current activity. It is to be expected that about 120 mill m^3 sand belong to this category of medium sand. About 35 mill m^3 of the sand are found in German waters.

Glacial meltwater deposits.
In the central part of Femer Bælt elongated esker deposits are found. These deposits are supposed to contain sandy sediments. Because of lack of information the raw material quality can not be evaluated.

Reported extraction activities in The Femer Bælt area in the period 1990 - 1994 have been evaluated.
The period 1990 - 93 is characterised by limited activity with a focus on Gedser Rev, where about 35.000 m^3 of gravel was extracted.
In 1994 a pronounced change is seen, as in excess of 12.000 m^3 of gravel and pebbles at Gedser Rev and about 104.000 m^3 of sand was extracted south-west of Gedser. This remarkable change is ascribed to increasing demands from the German marked.

On basis of few samples the sediment characteristics (primarily grain size distribution) in some of the resource areas, mapped by GEUS, have been evaluated in relation to probable demands for sand fill and sand aggregates for concrete. Criteria stipulated in the Great Belt Link project and the Øresund Link Project have been take into account.

Concerning sand fill specific demands have been stipulated to average grain size (D50 >0.25 mm) and uniformity coefficient (U >2.0). In general the resource areas contain sand with too low D50 and U values, in other words too fine-grained sand. But the coarse grained sandwave part of resource areas 564012 and 564014 possibly can fulfil the demands.
The ideal grain size composition of sand aggregates for concrete is a very strong criteria and the only resource areas that possibly can fulfil the demands are 564012 and 564014.
The total volume of the coarse grained sandwave part of the resource areas 564012 and 564014 is 20 - 25 mill m^3 .

Additional information from the Bundesanstalt für Wasserbau report show that it is likewise expected that 5 - 8 mill m^3 sand is available in the north-western part of resource area 564016 and it may be suggested that about 1 mill m^3 sand is available at Sagas Bank .

3. Data background

The geological mapping of marine raw materials in the Femer Bælt (Fig. 1) is mainly based on a total shallow reflectionseismic track length of about 1000 km and on 41 vibrationcorings carried out in April 1993 (Fig. 1).

The reflectionseismic investigation is documented in a cruise report DGU datadokumentation nr. 19 - 1992 (Jensen 1992b) and detailed results on grain size analysis, carbonate content and organic content are reported in a confidential report Råstofgeologiske og Geologiske undersøgelser i Østersøen. Femer Bælt, område 564 (Jensen 1996). Additional reflectionsesimic data and vibrocorings were sampled in a scientific project in co-operation with the Baltic Sea Research Institute in Warnemünde, Germany and University of Gdansk in Poland.

These scientific investigations include investigations of sedimentology, macroplants, diatoms and radiocarbon ages. The results from various investigations have been incorporated in sequence-stratigraphical analysis as a basis for evaluation of paleo water level changes and related paleocoastal deposits as possible raw material resources.

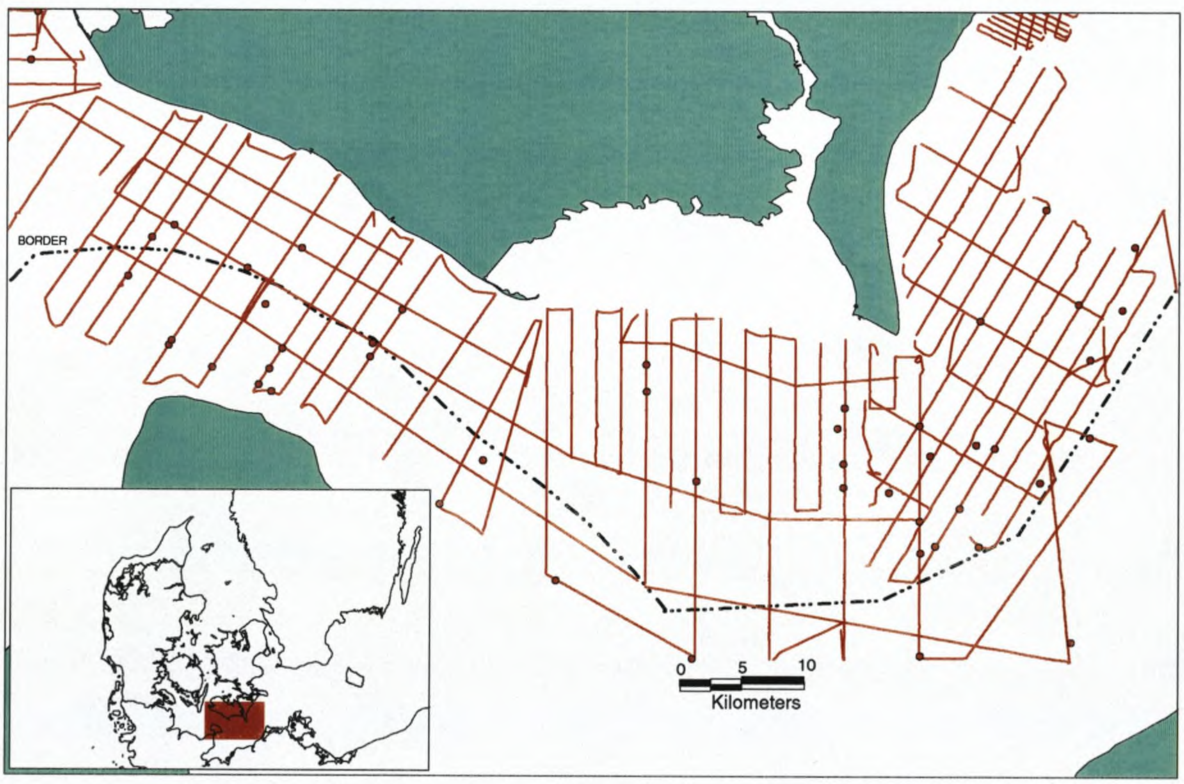

Fig. 1 GEUS shallow seismic grid and vibrocorings in Femer Bælt.

4. Methods

4.1. Shallow seismics

Shallow seismic data were collected using an Elac 30 kHz echosounder, an ORE 3.5 kHz pinger system, an Uniboom (0.8-16 kHz) and an Edo Western and EG&G 100 kHz side scan sonar. The total track length is about 1000 km. The data were analogue recorded on an EPC, respectively, Klein graphic printer and stored either on analogue tape or in digital form.
Positioning was done using differential GPS and the Sercel Syledis precision navigational system with an accuracy of within 10 m.
The echosounder information was used for determination of the water depth, whereas interpretation of the data from the subbottom profiler and Uniboom systems enabled establishing a regional seismostratigraphic model. This was done following seismo- stratigraphic principles introduced by Vail et al. (1977). These principles have previously been shown to be an useful tool in connection with the exploration of marine raw materials
(Jensen 1992a). When applying these seismostratigraphic analyses, depositional sequences are being defined by unconformities as they are cutting off the various reflectors. In addition, the internal reflector pattern of the sequences has been described.
A characterisation of the depositional environment was inferred from the seismic information and used for the selection of the coring sites.

4.2. Sediment investigations

A lithological description of 41 vibrocores was made, whereas selected cores were subsampled for the purpose of grain size determination, loss on ignition and determination of carbonate content. Moreover, a larger number of cores was subsampled at selected subbottom levels for ^{14}C-dating and the study of macroflora remains in order to obtain further information on the age and depositional environment of the cores. Selection of these samples was done by Ole Bennike, GEUS. The samples were dated either by conventional ^{14}C-dating at the Dating Laboratory of the National Museum and GEUS, or by Accelerator Mass Spectrometry (AMS) ^{14}C-dating at the Institute of Physics, Aarhus University, following the method described by Heinemeier and Andersen (1983). The stratigraphy used is based on these dating results. Further and more detailed information on the ^{14}C-dating is beyond the scope of this report.

5. Geological setting

The Femer Bælt and western Arkona Basin have had a complex postglacial geological history.
The Femer Bælt is situated south of the isostatic 0-line (Mörner 1983), which implies that some isostatic subsidence of the area could be expected. Investigations by Winn et al. (1986) indicate, however, that during the Holocene there has been virtually no difference in the rate of subsidence between Kieler Bucht and the Mecklenburger Bucht. By contrast, on a more local scale subsidence can occur due to salt tectonics. Water level changes in the area dealt with can thus mainly be ascribed to a combination of eustatic and more local and episodic processes.
When comparing the newly collected data with the existing information so far published, we can make a number of conclusions with regard to the Late- and Postglacial development and paleogeography of the area. The final deglaciation during which the Belt Sea advance („Fehmarn-Mecklenburg Vorstoss") occurred, resulted in the formation of various typically regressive ice marginal features (Kolp 1965). Our present investigations support these conclusions, since we observed a glacial deformed ground moraine in the western Femer Bælt, which most likely had subsequently become part of a marginal moraine formed along an ice lobe. Northwest of this moraine a relatively soft moraine deposit has been found apparently formed as a flow till in front of the retreating ice margin. The further ice melting resulted in the formation of an (ice-)dammed lake immediately in front of the ice margin. During this initial stage of the Baltic Ice Lake large-scale drainage systems in the form of „Urstromtäler" were developed. These were running more or less parallel with the ice margin and caused the deposition of proximal sediments in parts of our study area. Immediately north-east of the Gedser Rev - Darsser Schwelle a large sand delta prograded in a NE direction apparently due to meltwater discharge from a late glacial Warnow river system draining the area around Rostock and further inland. In the more distal parts of the Femer Bælt and Arkona Basin more fine-grained and typically laminated ice lake sediments as well as layered diamict deposits accumulated. Deposition of the latter type of sediments can be related to slumping processes. The end of this episode occurred after the ice had retreated from the area, and is marked by a significant lowering of the lake level.
A large-scale transgression of the Baltic Ice Lake occurred at the end of the late glacial period in the south-western part of the Baltic Basin, during which a connection with the open sea was formed through the Sound (Björck 1995). In the Femer Bælt and western Arkona Basin this transgressive stage is represented by varved clay and silt deposits. Also during this stage the late glacial Warnow river system transported sediments into the Baltic Ice Lake.
This is demonstrated by the presence of a relatively small sand delta in the southern part of the Mecklenburger Bucht and renewed progradation of the prograding system in the Arkona Basin NE of the Darsser Schwelle. The prograding systems reveal that the transgression ended with a highstand period characterised by a relatively constant water level, before a relative lake level lowering. The dating of flora remains from the delta deposits in the Mecklenburger Bucht shows an age of about 10.500 ^{14}C yrs BP (Lemke et al., in press), which corresponds to the time immediately prior to the final drainage of the Baltic Ice Lake as reported by Björck (1995). Our study shows, that the relative lake level during the high stand period reached about 20 m below present sea level (mbsl). This implies, that on a smaller scale outflow through the Great Belt may have occurred, as is suggested in studies made in that area by Rørbeck (1995). The drainage at Mount Billingen in central Sweden caused a lowering of the relative lake level in the central Baltic of about 25 m (Svensson 1989). A regression of about the same magnitude is observed in the Arkona Basin, where fossil coastal deposits are found at 40 mbsl. By contrast, a threshold at 23-24 mbsl at the Darsser Schwelle north-east of Gedser Rev resulted in the formation of a local lake in the Femer Bælt area at around 10.000 ^{14}C yrs BP. During this period when lowstand conditions prevailed in the Arkona Basin a lowstand wedge deposit was formed in front of the late glacial outbuilding system. The formation of the lowstand wedge is dated at about 9.600 ^{14}C yrs BP.
The connections through the Belt and Sound were also interrupted due to the drainage through central Sweden.
Associated with a further isostatic rebound, the connection at Mount Billingen was interrupted as well and a new episode of lake level rise (Ancylus Lake) occurred in the Baltic basin (Björck 1995). The highstand maximum of the Ancylus Lake in the south-western Baltic was reached at about 9.200 ^{14}C yrs BP. During the

highstand the Ancylus Lake has generally been considered to have had its westernmost limit at the western margin of the Arkona Basin.

By contrast, our investigations in the Femer Bælt area demonstrate that the Ancylus Lake during this period extended much more to the west, i.e. as far as into the Kieler Bucht, with a highstand maximum in this area of about 19 mbsl. Studies performed along the Swedish east coast have shown that after the Ancylus highstand period an episode of a few hundred years occurred with drainage of the lake and a lowering of the relative water level by about 9 m (Svensson 1989, Björck 1995). The observations in the Femer Bælt indicate a simultaneous lowering of the water level of not more than 5 m. This difference can be ascribed to the effects of the threshold north-east of Gedser Rev - Darsser Schwelle. Thus, conditions around 8.900 ^{14}C yrs BP were characterised by continuous sedimentation in the deeper parts of the Femer Bælt and Arkona Basin, during which the water level in the Femer Bælt area was higher than in the Arkona Basin. This lowstand situation has been a matter of a major debate, since previous studies suggest a possible discharge of the Ancylus Lake through the Great Belt (Björck 1995).

If the lowering of the Ancylus Lake indeed was considerably more than 5 m, another drainage passage must have existed, for example, through central Sweden. A further eustatic global sea level rise meanwhile resulted in increasing salinities in the Great Belt and Femer Bælt area, where waters became brackish (Mastogloia Sea) and undisturbed sedimentation continued in the deeper parts of this basin. A situation with intermittent overflow of the threshold east of Gedser Rev favoured the accumulation of sandy sediments filling the previously existing channel system found here. After the marine transgression had reached 20 mbsl at around 7200 ^{14}C yrs BP, hydrodynamic conditions at the Darsser Schwelle drastically changed due to a rapid and marked increase of the crossection of this passage. As a result, current intensities strongly increased. Sedimentation continued in the deeper basins, but coastal processes in the near-shore areas resulted in increased erosion and long-shore transport favouring the formation of coastal barriers and associated bar systems. The continuing transgression was associated by onshore stepping of the coastline, which thus migrated further inland. The former coastal deposits were inundated, being no longer directly affected by active coastal processes. Their remains are presently found mainly in the form of inactive larger sand deposits.

The water exchange regime between the North Sea and Baltic developed since the Littorina Transgression is characterised by a non-tidal current system in which strong currents are triggered by gale-force winds or, more generally, by differences in sea level between the south-western Baltic and Kattegat. Maximum current velocities in the inflowing saline water masses at greater depth and those reached in the outflowing low-salinity Baltic water at the surface are well above the critical speed required for sediment erosion. For example, the fossil sandy coastal deposits clearly illustrate the erosional capability of this current system by often displaying a characteristic pattern of megaripples. Ripple formation in upstream direction can be ascribed to erosion of the coastal deposits, whereas bedforms in downstream direction are positive accumulation forms.

6. Seabed sediments

The seabed of the Femer Bælt and western part of the Arkona Basin consists of Late Quaternary sediments. These sediments were mapped (Late Quaternary sediments map enclosed, scale 1 : 200 000) within the framework of the Danish program for mapping of offshore sand and gravel resources, which since 1990 was carried out in this area in close co-operation with the „Institut für Ostseeforschung" (IOW) in Warnemünde. Due to limitation of seismic resolution, characterisation of the seabed sediments applies to the sediment type found at about 0.5 m subbottom depth. It is stressed that the seabed map not only provides lithological information, but also illustrates the regional Late quaternary stratigraphy with a ^{14}C-based chronology and it includes information on the depositional environment as well. Various surveying techniques could not be applied at water depths of less than about 4 m, which implies that information from the coastal zone is not included in the map.
The actual bathymetry shows water depths of up to more than 40 m in the Arkona Basin and around 30 m in large parts of the Femer Bælt and Mecklenburger Bucht. A threshold, i.e. the Darsser Schwelle, separates the two basins for the largest part. A connection between the deeper basins is formed by the Kadet Channel with a maximum water depth of about 30 m. This erosional feature extends in a NE-SW direction just south of Gedser Rev. The prevailing water depth elsewhere in the Darsser Schwelle area is less than 20 m.
During deglaciation ground moraines were formed, whereas also flow tills and esker ice marginal deposits were left behind by the retreating ice. Ice lake deposits accumulated in front of the melting ice masses. These deposits can be related to the earliest stage of the Baltic Ice Lake. After further retreat of the ice, changes of the lake water level resulted in various episodes (Baltic Ice Lake, Ancylus Lake) during which, amongst others, a series of littoral sediments and coastal deposits were formed in the area. Finally, the Littorina transgression occurred and marine conditions were established. In course of this transgression, another series of (marine) coastal deposits was formed.
The development described here has resulted in the typical sediment distribution as can be observed on the seabed map. Sediments found include glacial till mostly with a thin cover of sandy or gravely lag sediments, late glacial freshwater clay, silt or sand, Holocene freshwater and brackish (muddy) sand and sandy mud, and Holocene marine sand and mud.
The occurrence and areal distribution of current-induced bedforms reflects actual sediment transport and bottom current conditions. A direct human impact on the seabed is seen e.g. by virtue of trawl marks. Information of this map thus may help to distinguish between erosional-, non-depositional and sediment accumulation areas, whereas it also gives an indication on bottom current transport directions.
Notwithstanding the restrictions referred to above, the data presented in this report may significantly add to knowledge of the seabed conditions in the Femer Bælt and western Arkona Basin.

6.1. Moraine - Glacial till.

The oldest deposits exposed in the area are moraine deposits dominating along the basin margins, where water depth is less than 15-20 m. Two different moraine deposits can be distinguished, i.e. a consolidated ground moraine generally with a rough surface topography and an unconsolidated flow till with a smooth surface topography. Both moraine deposits are being characterised by the occurrence of a thin (approx. 0.10 m) layer of lag sediments of mainly gravel and coarser material.

6.2. Late glacial freshwater clay - sand.

The late glacial deposits consist of ice lake sediments exposed in the central part of Femer Bælt, along the northern and eastern margin of Mecklenburger Bucht, and in large parts of the area between the Darsser Schwelle and Arkona Basin. Clayey and typically varved distal ice lake deposits are the most widespread late glacial surface sediments found in the Femer Bælt and in the area immediately south-east of Møn. Late glacial sandy deposits predominate, however, in the area south of Gedser Rev and along the south-western margin of the Arkona Basin. These sandy deposits reflect sediment input from a late glacial Warnow river system discharging in this area.

6.3. Holocene freshwater-brackish (muddy) sand and sandy mud.

During the early Holocene organic-rich fine-grained sediments were deposited in the deeper parts of the Femer Bælt area. These sediments were deposited during the development of the Ancylus Lake and partly also during the following beginning marine transgression (Mastogloia Sea). The sandy littoral facies of these sediments in the northern part of Femer Bælt has been eroded in a narrow zone around 20 m water depth. The Ancylus sediments were also deposited south and north-east of Gedser Rev filling the older channel system and deeper parts of this area. Erosional remnants of these deposits are locally exposed on the seafloor here.

6.4. Holocene marine sand.

Marine sand overlying moraine deposits is locally found at water depths of less than 20 m.
This sand originates for a large part from former coastal deposits formed during the Littorina Transgression. Subsequently, reworking of the sandy deposits may locally have occurred.
Furthermore, at the Darsser Schwelle, in the vicinity of Gedser Rev and more to the east larger areas are found, covered by an up to 4 m thick layer of sand. Water depth in these areas is around 20 m. The thickness of the sand layer gradually decreases in an easterly direction.

6.5 Holocene marine mud.

Areas where marine mud has been accumulating are found in the central part of the Mecklenburger Bucht, in the Arkona Basin and in the south-western part of Femer Bælt. In addition, a smaller mud basin is present immediately east of Møn. A characteristic feature of the mud depositional area in the Femer Bælt is the evidence of erosion found in the northern and western part of this area. This is indicated by an erosional unconformity and the occurrence of sediment waves. Thus, a record of continuous accumulation of recent sediments can be expected to be found only in the central parts of the Mecklenburger Bucht and Arkona Basin.
However, large-scale reworking of recent sediments may still occur here, as is suggested by the widespread occurrence of trawling marks in these areas.

7. Current-induced bedforms

The actual circulation pattern of the Femer Bælt is responsible for modifying older deposits and for the generation of specific current-induced bedforms. As outlined before, the non-tidal current system in this area is controlled by the large-scale weather pattern over NW Europe, and more in particular, by wind-induced sea level changes in the Kattegat and Baltic. Another factor to be taken into consideration is the layering of the water column with generally inflow of saline waters in the lower part of the water column and outflow of low-salinity Baltic water at the surface. The effect of the earth rotation (Coriolis force) further complicates this two-layer flow pattern.
A general conclusion is that the seabed in the southern part of the investigated area is mainly affected by inflowing saline waters from the Great Belt and Kattegat, whereas Baltic outflow affects the seafloor at shallower (< 15 m) depth in the northern part of the area.

7.1. Sandwaves and megaripples.

These transverse bedforms clearly indicate current-induced sediment transport. Sandwave and megaripple fields occur in various parts of the investigated area and are often found in relation with fossil sandy coastal deposits. In such areas they originate from erosional processes affecting the fossil deposits upstream, whereas downstream they form by accumulation processes.
Investigations have previously been made of a sandwave field found between 12 and 22 m water depth north of the island of Fehmarn (Werner and Newton 1970; Werner and Wolf 1974). The wavelength of these sandwaves is between 40 and 70 m, their height is 1-2 m, and they consist of medium to coarse sand (Werner and Wolf 1974). The sandwaves have a markedly asymmetric appearance with the steep sides facing east, which is indicative of an easterly current direction. The current speed required for the formation of such sand waves is in the range between 0.70 and 1.00 m/s (Rubin and McCulloch 1980; Kuijpers 1980). Current measurements demonstrate that in the area of investigation bottom current velocities normally are below this critical range; extreme bottom current events with the speed required for megaripple generation occur at a time-scale of months or years (Wyrtki 1953, 1954; Kuijpers 1980). This is supported by seabed observations showing that the top of the sandwaves can be covered by small-scale current marks and a Mya arenaria fauna indicative of long-term stable conditions with a largely inactive sand bed in the troughs in between the sandwaves (Werner and Wolf 1974).
Investigations of the Gedser Rev area (Lemke et al. 1995) have shown the occurrence of sandwaves indicative both of inflow and outflow. Moreover, repeated observations indicated a change of bedform configurations in this area, i.e. a reversal of large sandwaves as well as the disappearance of a megaripple field (Kuijpers 1991). The present study shows that sandwave fields also occur in the north-western part of Femer Bælt. These sandwaves are mainly found at water depths in excess of 15 m, which corresponds to the depth range of the sandwave field present in the vicinity of the island of Fehmarn.

7.2. Isolated sediment (sand-silt) waves.

The seismic data demonstrate the presence of isolated sediment waves of presumably sand or silt in the central parts of the Femer Bælt at water depths in excess of 20 m.
These features are transverse bedforms and appear as NE-SW striking ridges of considerable length. The distance between the individual sediment waves is up to 500 m. Their height is 0.5 - 1.0 m, whereas they are about 50 m wide. The single occurrence of these bedforms is ascribed to sparse sediment supply preventing a more widespread occurrence. A characteristic feature is that they occur on various substrates ranging from late glacial clay in the western part of the Femer Bælt to Holocene marine mud in the eastern part of this strait. In contrast to the sandwaves referred to above, these isolated sediment waves do not display a clear asymmetry or preferred orientation with regard to bottom current directions.

7.3. Comet marks.

These longitudinal structures have been defined as obstacle marks characterised by a downstream erosional area of which the length is much larger than its width (Werner and Newton 1974). In the Femer Bælt they are preferably formed in areas where moraine deposits are locally covered by a thin layer of fine sand. Erratics from the moraine provide the obstacles required to form these erosional features developed in the fine sand layer. Often, however, a minor sand shadow is present downstream immediately behind the obstacle. The comet marks can be classified into various types depending on the hydrodynamic environment in which they form (Werner et al. 1980). The comet marks observed in the Femer Bælt mostly have a parabolic appearance typically reflecting bottom current conditions comparable to those required for the formation of sandwaves. The areas with comet marks are found in the northern sector of the Femer Bælt and, more generally, along the northern margin of the deeper parts of the strait at water depths between 15 and 20 m. Without exception, they all display an easterly tail direction indicative of the inflow of saline bottom water from the Great Belt.

7.4. Sand ribbons.

Small sand ribbons are widespread at shallow (< 15 m) depth over the entire area in the northern part of the Femer Bælt. Only in a few cases it was possible to determine the current direction from these longitudinal bedforms.

8. Bottom current conditions

Initially, the deeper parts of the Femer Bælt and Mecklenburger Bucht had been covered by freshwater and marine deposits from the earlier part of the Holocene. After the marine transgression of the Darsser Schwelle, current intensities increased and erosion started to prevail in particular in the western narrow part of the Femer Bælt. Presently, late glacial ice lake clay deposits are widespread exposed on the seabed in this area. Remnants from the Holocene freshwater and marine deposits referred to above still occur, however, locally along the margin of the Femer Bælt. Generally, erosion is less towards the Mecklenburger Bucht. Current-induced erosion is probably negligible only in the central parts of this bay.

The occurrence of strong bottom currents is not only evident from widespread erosion as described above, but is also demonstrated by the various current-induced bedform types observed in the area. Both the occurrence of sandwave fields and comet marks correspondingly indicate a prevailing easterly bottom current with maximum speeds of up to 1.0 m/s. These extreme current events are concluded to be relatively rare, normally occurring at a time scale of months or years (Wyrtki 1954, Kuijpers 1980). Also the isolated sediment waves in the deepest part of Femer Bælt suggest a relatively high-energy hydrodynamic environment. Thus it can be shown that bottom currents at water depths in excess of 15 m reach their maximum speed during inflow conditions. An easterly sediment transport direction is also found north-east of Gedser Rev in the area characterised by the presence of an up to 4 m thick marine sand layer getting thinner towards the east.

A more complicated bottom current pattern is observed around Gedser Rev, where both inflow- and outflow-induced bedforms occur. Previous investigations by Lemke et al. (1995) demonstrate that inflow of saline bottom water prevails in the Kadet Channel and in the area to the south, whereas outflow affects the seabed at water depths of less than 15 m north of the Kadet Channel. The bedform pattern around Gedser Rev suggest that in a situation of strong outflow an anticyclonic gyre will develop at the (western) lee side of Gedser Rev.

Finally, it can be concluded that generally outflow is the dominating sediment transport agent at shallow (< 15 m) depth in the northern sector of the Femer Bælt off Lolland as well as in the coastal zone of Falster just north of Gedser Rev.

9. Resource areas mapped in surveys made by GEUS.

On basis of the geological model presented it is possible to identify a number of resource areas in the survey areas 564 Femer Bælt (Jensen 1996) and 560 Gedser Rev (Kuijpers 1991) in the Danish sector. In the central Femer Bælt area the Danish surveys also cover some resource areas in the German sector.
The rather open seismic grid and the limited number of vibrocorings (Fig. 1) means that the evaluation of the size of resource areas, calculation of raw material volumes and raw material quality must be regarded as approximately values.
The raw material quality evaluations are made on basis of grain size analysis, loss on ignition and determination of carbonate content carried out on samples from the vibrocorings.

The mapped resource areas can be classified in accordance to depositional environment (Larsen 1994) including the following 3 classes:

1. Submerged coastal deposits.
    a. Freshwater beach deposits
    b. Marine spit deposits
    c. Marine beach deposits

2. Current-induced bedforms
    a. Channel bedforms

3. Glacial meltwater deposits
    a. Esker deposits

9.1. Submerged coastal deposits

The dominating depositional environment of the resource areas can be classified as submerged coastal deposits. The reason for this is the dramatic water level changes in the Baltic since the last ice age. In the western part of the Femer Bælt, the resource areas 564012 and 564015 are interpreted as Ancylus Lake coastal deposits. The majority of the paleocoastal deposits are classified as marine beach deposits (564001, 564009, 564011, 564014, 564016, 564017) from which a few can be identified as spit deposits (564010, 564013).
Previous investigations of fossil coastal deposits in the inner Danish waters by Nielsen et al. (1988) and Jensen and Stecher (1992) show, like the present investigation that coastal deposits in the vicinity of coarse grained source areas contain gravel and stones, while the majority of the deposits consist of well sorted sand often with a varying content of shells. Transgressive overflow of spit deposits means that sand resources may cover submerged organic and possible muddy lagoon sediments and wetland.

9.2. Current-induced bedforms

Some of the submerged coastal deposits are modified by recent current activity. Examples are sandwave fields in the western part of Femer Bælt, dominated by inflowing saline bottom currents (564010, 564014, 564015) and combined in- and outflow in the Gedser Rev area (560007, 564001, 564002).
The recent processes imply that the submerged coastal deposits have been exposed to an extra sorting, concentrating medium and coarse sand in the sandwave fields (Werner and Wolf 1974, Lemke et al. 1995)

9.3. Glacial meltwater deposits

In the central part of Femer Bælt an elongated ridge is interpreted as a possible esker, probably containing sandy sediments.

9.4. Description of resource areas

In the following paragraphs the individual resource areas shown in Fig. 2 (Femer Bælt Resource areas map in scale 1 : 200000 is enclosed) are described.

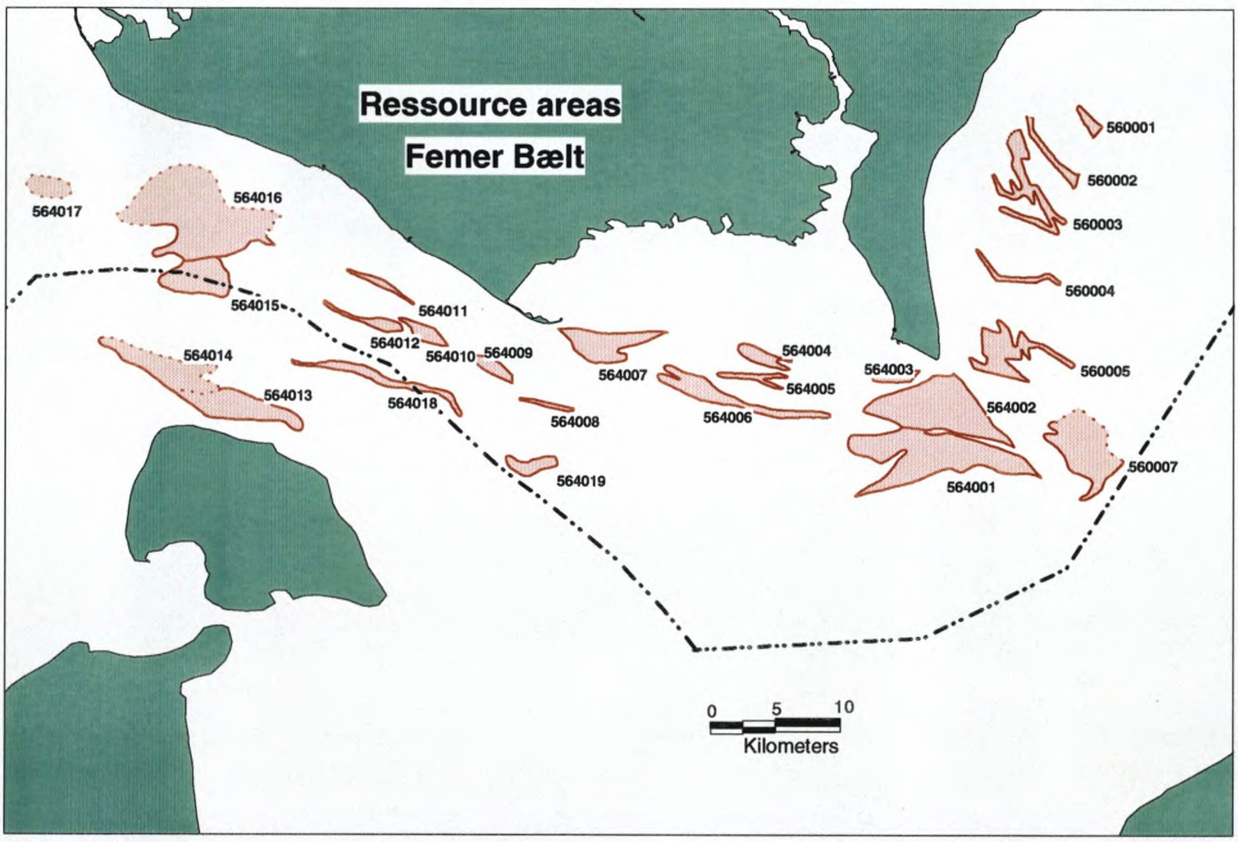

Fig. 2 Resource areas mapped by GEUS in the Femer Bælt area.

Depositional environment and raw material quality is outlined and in addition information is given on volumes (Table I) and quality of extracted raw materials

RESOURCE AREA	VOLUME	MEAN THICKNESS	WATER-DEPTH
	mill m^3	m	m
560007	25 - 30	3	9 - 15
564001	35 - 40	2	10 - 20
564002	30	1	6 - 10
564003	2	1	6 - 8
564004	3	1	4 - 6
564005	2	1	6 - 8
564006	11	1 - 2	6 - 8
564007	15	2	4 - 10
564008	2	1 - 2	12 - 18
564009	4	1 - 2	12 - 18
564010	5	1 - 3	12 - 18
564011	4	1 - 2	12 - 18
564012	3	1 - 2	18 - 22
564013	30	3	7 - 15
564014	45	3	15 - 25
564015	15	2	18 - 24
564016	50	2	8 - 18
564017	4	1	15
564018	?	2 - 3	25 - 30
564019	?	2 - 3	25 - 30
IN TOTAL	285		

Table I. Resource volumes mapped by GEUS in the Femer Bælt area.

9.4.1. Resource area 560007.

The resource area covers an area of 6 x 4 km along the north-eastern margin of Gedser Rev (Fig. 2). The area originally was formed as Littorina Sea coastal deposits, for a major part mobilised by (sub)recent current-induced processes with redeposition in a sandwave field. The well sorted medium grained sand resource is to be found at water depths between 9 and 15 m. The resource covers till deposits in the margin of the reef and mainly lateglacial deposits north-east of the reef.

Detailed studies of the sandwave field (Kuijpers 1991) shows, a dynamic environment with the uppermost part of the seabed being exposed to periodical redeposition. The thickness of the resource varies strongly from less than 1 m to more than 5 m with an average of about 3 m. A tentativ estimation on the resource volume is 25 to 30 mill m^3 (Table I).

Data on extraction in the period 1990 - 1994 (Table II) show, that mainly gravel and pebbles were extracted from resource area 560007. The extraction has taken place in the south-western part of the resource area margined by the Gedser Rev till area. This area can be referred to as the source area for the fossil coastal deposits.

	1990 - 91	1992	1993	1994	TOTAL
	m^3	m^3	m^3	m^3	m^3
1 SAND	0	0	5.780	0	5.780
2 GRAVEL	33.985	0	1.030	4.760	39.775
3 PEBBLES	1.750	820	1.700	7.745	12.015
4 FILLSAND	0	0	4.850	0	4.850
TOTAL	35.735	820	13.360	12.505	62.420

Table II. Extracted raw materials on Gedser Rev (resource area 560007) in the period 1990 - 1994.

9.4.2. Resource area 564001

The resource is situated on the western margin of Gedser Reef at water depths of 10 - 20 m covering an area of 13 x 4 km (Fig. 2). This resource is for some part described by Kuijpers (1991) in relation with the raw material mapping of the area 560 Gedser. Resources consists of Postglacial marine sandy sediments, that partly may have been deposited as coastal deposits in relation with the Littorina Sea transgression. However the main part is deposited as a lee deposit of Gedser Rev. Core evidence show, that it is fin - medium sand with a thickness of 0.5 - 5 m. The volume of the resource is estimated to be 35 - 40 mill m^3 . Particularly at deeper water the sediment must be expected to be rather fine-grained. Before 1994 only a single shipload of pebbles was registrated, but in 1994 a massive extraction of sand started summing up to 104.326 m^3 (Table III). This is double as much as the total extraction from the Gedser Rev in the period 1990 - 1994 (Table II). Much points to that this expansion is due to the new German marked in Rostock .

	1990 - 91	1992	1993	1994	TOTAL
	m^3	m^3	m^3	m^3	m^3
1 SAND	0	0	0	104.326	104.326
2 GRAVEL	0	0	0	0	0
3 PEBBLES	1.200	0	0	0	1.200
4 FILLSAND	0	0	0	0	0
TOTAL	1.200	0	0	104.326	105.526

Table III. Resource area “Gedser” (resource area 564001) in the period 1990 - 1994.

9.4.3. Resource area 564002.

This resource lies on the western margin of the Gedser Rev as well, but at water depths of 6 - 10 m and covers an area of about 10 x 4 km (Fig. 2). It is a very dynamic area with north-eastern and south-western currents forming sandwaves. No samples have been taken in the area, but general knowledge from the sandwaves in Femer Bælt combined with sediment data from a nearby vibrocore implies coarse sand with some content of gravel. The resource thickness is very inconsistent from less than 1 m to about 4 m. A general evaluation of the resource volume indicates about 30 mill m^3 (Table I).
No extraction activity is registrated in the resource area 564002.

9.4.4. Resource areas 564003, 564004, 564005 and 564006.

These four resource areas are discussed together because they represent limited areas and belong to the same type of resources. The resource areas 564003 - 564004 cover areas in the order of 4 x 1 km, while the resource area 564005 is somewhat larger, i.e.13 x 2 km (Fig. 2). A common feature is, however, that they are found at water depths of 4 - 8 m, made of sandy fossil marine coastal deposits and that that the areas are modified by currents and waves. Most probable it is fine to medium sand in volumes of 2 mill m^3 in the small areas and about 11 mill m^3 in resource area 564006 (Table I).
No extraction activity is registrated.

9.4.5. Resource area 564007.

Eastward of the present spit development (Hyllekrog) south of Lolland, the resource area 564007 covers an area of 7 x 2 km at water depths of 4 - 10 m (Fig. 2). The location of the area, the seismic reflection pattern and the sediment composition reveal a local paleo-marine lagoon covered by marine upward coarsening coastal deposits, formed as a result of the Littorina Sea transgression. The sandy part reaches a thickness of 1 - 4 m with an average of 2 m. A volume of about 15 mill m^3 fine - medium sand is to be expected (Table I). Presumably no previous extraction has taken place.

9.4.6. Resource areas 564008, 564009, 564010 and 564011.

These four resource areas are all situated in the north-eastern part of the Femer Bælt at water depths of 12 - 18 m. The areas are rather uniform in size each covering about 4 x 0.5 - 1 km (Fig. 2). Originally the resource areas were formed as sandy marine coastal deposits possibly in connection with stagnation's during the Littorina Sea transgression. Present current-induced mobilisation and redeposition has (especially in resource area 564010) formed a sandwave field showing sediment transport from west. Core evidence document the existence of medium to coarse sand of 1 - 3 m thickness. The total resource volume is about 15 mill m^3 distributed with 3 - 5 mill m^3 in each resource area (Table I).
Extraction is only registrated in resource area 564010. In the northern part of this area 520 m^3 gravel was extracted in 1990 (Table IV). It is however to be expected that the resource mainly consists of medium to coarse sand with some contents of gravel.

	1990 - 91	1992	1993	1994	TOTAL
	m^3	m^3	m^3	m^3	m^3
1 SAND	0	0	0	0	0
2 GRAVEL	520	0	0	0	520
3 PEBBLES	0	0	0	0	0
4 FILLSAND	4.420	0	0	0	4.420
TOTAL	4.940	0	0	0	4.940

Table IV. Extraction "Østersøen Vest" (resource areas 564010 og 564012) in the period 1990 - 1994.

9.4.7. Resource area 564012.

This area can be compared with the surrounding resource areas in size, but a clear difference is that it is placed at water depths of 18 - 22 m (Fig. 2). In addition, the resource area is assumed to consist of freshwater coastal sediments deposited along the Ancylus Lake shoreline. The resource is believed to be 1 - 2 m thick and consists of medium to coarse sand. The resource volume is about 3 mill m^3 (Table I).

In the eastern part of the resource area 4.420 m^3 of fillsand was extracted in the period 1990 - 1992 (Table IV).

9.4.8. Resource area 564013.

In German waters, North of the Fehmarn island a resource area with a size of 10 x 2 km north-west south-east elongated is found at water depths of 7 - 15 m (Fig. 2). It is a drowned spit complex deposited during the Littorina Sea transgression, comparable to the present spit complex situated at the north coast of the island of Fehmarn. Seismic profiles crossing the paleospit complex show the wedge shaped resource reaching a thickness of 2 - 5 m. Internal dipping reflectors indicate a northern prograding of the system. Coring evidence is basis for concluding that the spitsystem mainly consists of fine to medium sand. The volume of the spit complex is estimated to be about 30 mill m^3.
No extraction activity is registrated in the area, which is supported by the seismic data.

9.4.9. Resource area 564014.

In the north-western prolongation of resource area 564013 (still in German waters) resource area 564014 is mapped as a north-west - south-east elongated area with dimensions of about 10 x 2 km, situated at water depths of 15 - 25 m (Fig. 2).
The resource area is dominated by a present active sandwave field previously described by Werner and Wolf (1974) and Kaufholdt (1995). The sandwave field is developed in areas where paleo sand deposits exist (explanation in chapter 7.1). In this case Littorina Sea paleo coastal deposits are the main source for the development of the sandwave field. But also at deeper water freshwater sandy deposits from the Ancylus Lake coastal zone may be the source. The surface layer of sandwaves mainly consist of medium to coarse sand in a thickness of about 2m, while the fossil coastal deposits apparently consist of about 2 m of fine to medium sand. The total resource volume is about 45 mill m^3 of which one half is the coarse grained sandwave field partly covering the fine to medium grained fossil coastal sand.
No signs of extraction are observed in the area.

9.4.10. Resource areas 564015 and 564016.

These resource areas are described together because of the common location in the "bay" north and east of the small reef Øjet and their close genetic affinity.
The resource area 564015 covers an area of about 5 x 3 km in the immediate vicinity west of Øjet and at water depths of 18 - 24 m, while the resource area 564016 covers an area of about 6 x 10 km north of Øjet at water depths of 8 - 18 m (Fig. 2).
Deposition of sediments in the "bay" originally was caused by coastal processes as probably can be related to the Ancylus Lake transgression (resource area 564015) and the Littorina Sea transgression (resource area 564016). In the western part bordered by till deposits both resource areas are partly marked by eastward sediment transport and redeposition in 1 - 3 m thick sandwave fields mainly consisting of medium grained sand.
In the eastern part of the resource areas an about 2 m thick "sheet" of marine fine grained sand is formed. This sand sheet merges with coastal progradation in the north-western part of resource area 564016. The coastal deposits are situated in the borderzone to the till deposits. The resource volume is about 15 mill m^3 in resource area 564015 and 50 mill m^3 in resource area 564016 (Fig. 3). Most likely the main part of the area consists of fine sand. In the sandwave field areas, however, medium to coarse sand must be expected in a volume of 5 - 8 mill m^3 and the coastal deposits in the north-western part contain 3 - 5 mill m^3.
Lithological data still are missing in the resource areas 564015 and 564016 due to anchoring and fishing restrictions in the area. This means that the evaluation of resource quality is very uncertain.
The only activity registrated in the area is extraction of gravel in the north-western part of resource area 564016 (Table V).

	1990 - 91	1992	1993	1994	TOTAL
	m^3	m^3	m^3	m^3	m^3
1 SAND	0	0	0	0	0
2 GRAVEL	2268	560	150	190	3168
3 PEBBLES	0	0	0	0	0
4 FILLSAND	150	0	0	0	0
TOTAL	2418	560	150	190	3168

Table V. Extraction "Vindeholm" (resource area 564016) in the period 1990 - 1994.

9.4.11. Resource area 564017.

The north-western most resource area mapped in Femer Bælt is of limited size (3.5 x 1,5 km) (Fig. 2). It probably consists of current-induced sand deposits situated at water depths of about 15 m. The resource thickness is about 1 m and the resource volume is about 4 mill m^3 (Table I).
No extraction activity is registrated in the area.

9.4.12. Resource areas 564018 and 564019.

In the central part of Femer Bælt two elongated resource areas are registrated. The dimensions of the areas are 13 x 1 km (564018) and 3 x 1 km (564019). They are located at water depths of 25 - 30 m (Fig. 2) and are partly covered by Lateglacial varvic clay. The resource areas are interpreted as approximately 3 m thick esker deposits with a diverse lithology. Evidence from one core shows alternating clay and sand lamina. Because of the overburden the resources are very difficult to exploit. Furthermore additional coring is necessary to be able to evaluate volumes and raw material quality.

9.5. Resource evaluation of the GEUS mapped raw materials in the Femer Bælt area.

In the Femer Bælt area the total resource volume of sand and gravel mapped by GEUS is about 285 mill m^3. The resource volume is split up in 20 resource areas (Table I); 11 of these areas are very small each containing less than 5 mill m^3 of raw material and from this aspect they are of only limited interest.
In the Danish waters of Femer Bælt it is especially the resource areas in the vicinity of Gedser Rev 8560007, 564001 and 564002) (Fig. 2) looking promising. These 3 areas contain a total volume of 90 mill m^3 sand and gravel.
The areas 564015 and 564016 in the western part of Femer Bælt (Fig. 2) are likewise major resource areas (in total 65 mill m^3), but the main part probably is fine grained sand. In the German waters in Femer Bælt GEUS has mapped two important resource areas (564013 and 564014) (Fig. 2) with a total volume of 75 mill m^3 sand. Both areas are interesting because a major part of the resources are interpreted as medium to coarse sand.
In the period 1990 - 1993 only a limited volume of raw material was extracted from the Femer Bælt area. From the Gedser Rev area extraction of about 35.000 m^3 of gravel is registrated and in addition small amounts of fillsand (4.420 m^3 in resource area 564012) south of Rødby and gravel (2.978 m^3 in resource area 564016) in the north-western part of Femer Bælt. In 1994 a remarkable boom occurred for the extraction of raw material in the Gedser Rev area. In this area about 12.000 m^3 gravel and pebbles was previously extracted, but a significant change happened in resource area 564001 south of Gedser, as 104.000 m^3 sand

was extracted in 1994. The reason for this must be expansion in the building industry in Germany especially in the Rostock area.

9.6. Sediment characteristics of resource areas mapped by GEUS in relation to probable demands.

In connection with the Great Belt Link project and the Øresund Link Project a set of criteria has been stipulated regarding grain size distribution, loss on ignition and uniformity for sand fill and sand aggregates for concrete. In order to make a preliminary quality assessment, the resource criteria for the Great Belt Link and Øresund Link are tested on the sand resources in Femer Bælt.

9.6.1. Preliminary quality assessment of Femer Bælt sand fill.

The following criteria for sand fill have been stipulated by the Øresundskonsortiet.

Average Grain Size (D50)	>0.25 mm
Uniformity coefficient (U)	>2,0
Material < 0.074 mm	<10%
Material < 32 mm	>95%
Loss on ignition	<2%

Grain size analysis from the Femer Bælt is based on samples from few corings in some of the mapped resource areas.

Concerning the upper and lower limits of grain size and loss on ignition it is in general no problem to meet the stipulated criteria.

It is more problematic to fulfil the criteria for D50 and U. This can be observed from grain size data obtained in some of the resource areas in the Femer Bælt (Fig. 3). Data from the resource areas 564012 and 564014 show, that these areas can be regarded as probable resources for sand fill, while resource area 564013 hardly can be used. The resource areas 564001 and 564006 are rather inhomogeneous and it can not be excluded that subareas may contain acceptable sand fill.
It is estimated that the coarse grained part of the resource areas 564012 and 564014 amounts to 20 - 25 mill m^3.
It must be stressed that the presented data only can give a hint on the resource quality and that detailed investigations must be carried out to specify the quality of the resource areas.

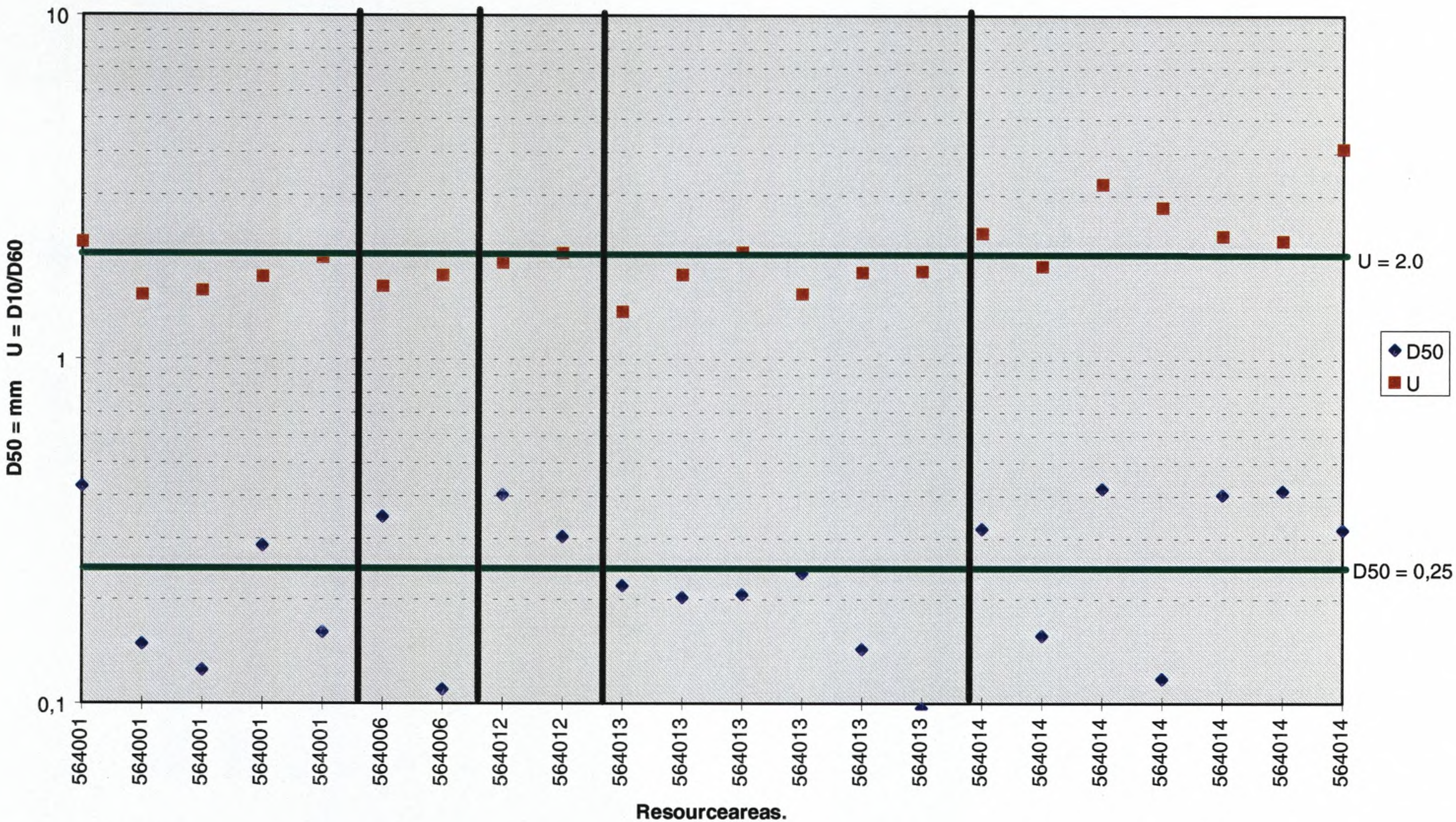

Fig. 3 Evaluation of Average Grain Size (D50) and Uniformity coefficient (U) of Femer Bælt resource areas in relation to stipulated criteria D50 >0.25 mm and U >2.0.

9.6.2. Preliminary quality assessment of Femer Bælt sand aggregates for concrete.

A number of criteria has been stipulated regarding sand aggregates for concrete in the Great Belt project. In this report only grain size data are evaluated to give a rough idea of the probability of finding sand aggregates for concrete in the Femer Bælt resource areas. More sophisticated analysis like petrography must be carried out in a later phase of the investigations.

The ideal grain size composition for sand aggregates in the Great Belt project has the following specifications:

Sieve mesh size	run through weight %
2 mm	96 - 97 %
1 mm	84 - 87 %
0.5 mm	65 - 72 %
0.25 mm	17 - 20 %
0.125 mm	0 - 2 %

A graphical presentation of the ideal grain size interval (Fig. 4) shows that very strong grain size criteria have been stipulated. In the Femer Bælt area the only resource areas that possibly can meet the grain size criteria are 564012 and 564014. While the rest of the resource areas with known grain size data all are too fine grained.
The relevant coarse grained part of the resource areas 564012 and 564014 contains 20 - 25 mill m^3 coarse sand.

Again it must be stressed that detailed investigations must be carried out to specify the quality of the resource areas.

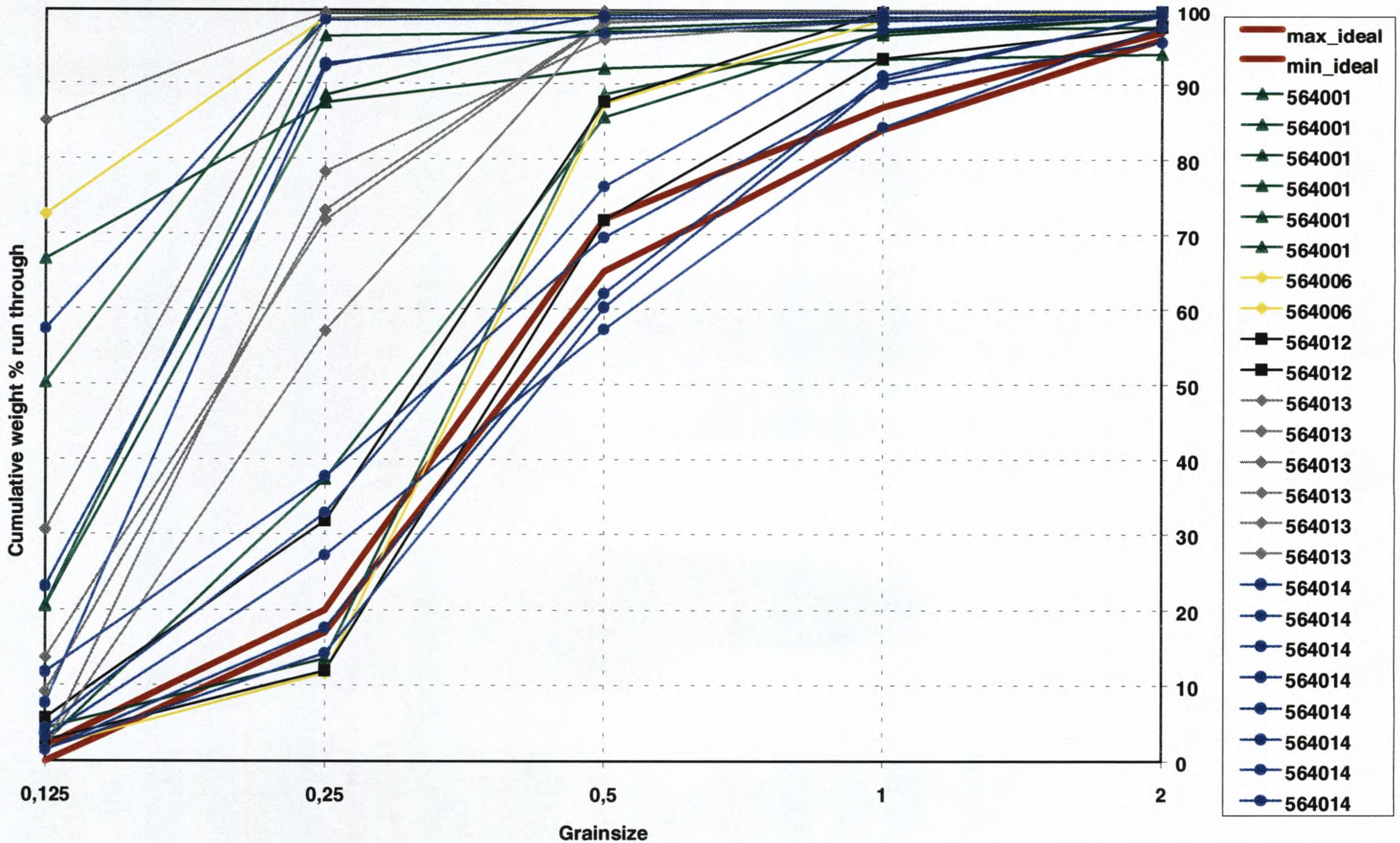

Fig. 4 Maximum and minimum values of ideal grain size distribution of sand aggregates for concrete related to data from resource areas in the Femer Bælt area.

10. Resource areas outlined by Bundesanstalt für Wasserbau.

Enquiries in Germany lead to “Bundesanstalt für Wasserbau”, from where it was informed, that one German report exists dealing with evaluation of possible raw material areas in the Femer Belt area (Bundesanstalt für Wasserbau 1965). This report was produced in 1965 when the first serious ideas about a Femer Bælt link was introduced.

Information was collected from the archives at the Bundesanstalt für Wasserbau as basis for shallow corings in 4 selected areas named Rödby-sand, Puttgarden-Riff, Sagas-Bank and Westlichen Teil des Fehmarn Belts. In addition to these areas Gjedser-Riff was evaluated on basis of general knowledge from extraction in the area (Fig. 5 and enclosed Femer Bælt resource areas map in scale 1 : 200000).

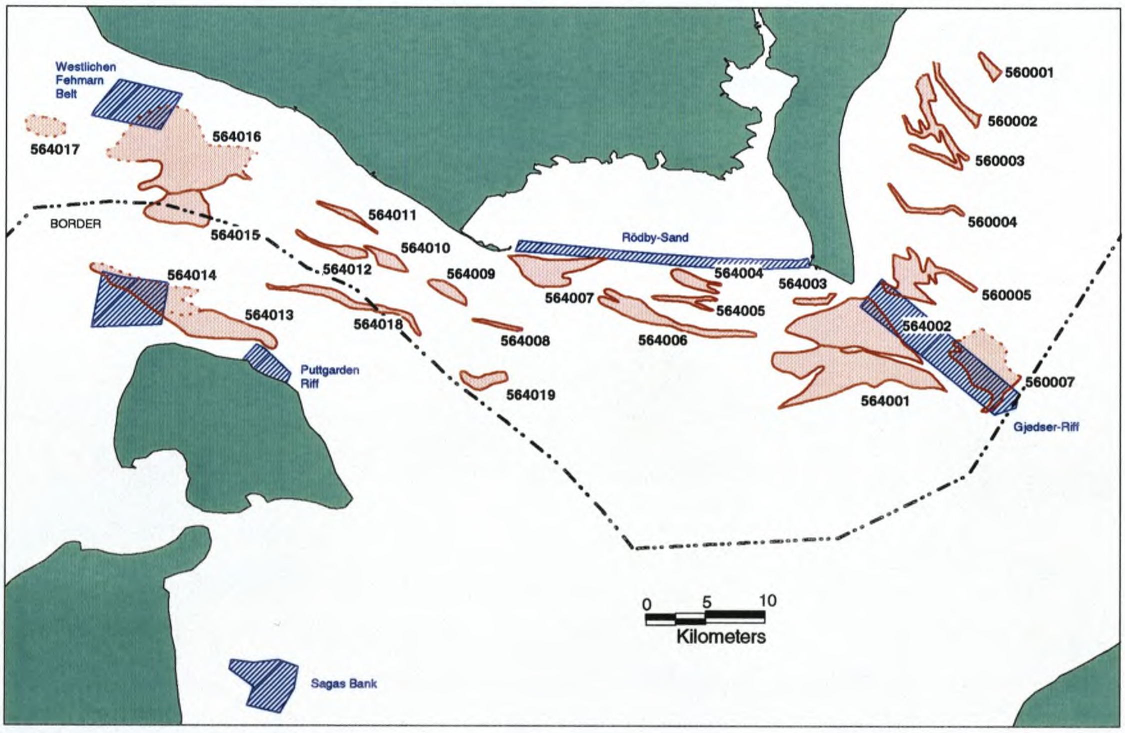

Fig. 5 Mapped resource areas. Red areas mapped by GEUS and blue areas outlined by Bundesanstalt für Wasserbau.

10.1 Rödby-sand.

A number of corings were carried out in this narrow sandbar, where in general fine to medium sand was found in a maximum thicknes of 6 m. The volume is evaluated to about 10 mill m^3 . Grain size analysis show, that it may be possible to find sand acceptable for sand fill and sand aggregates for concrete.
It must however be stressed, that Rödby Sand not will be acceptable as resource area because this area is protected as a bird protection area under the EU directive on conservation of wild life.

10.2 Puttgarden-Riff.

In the shallow waters north-west of Puttgarden coring results showed very fine sand - fine sand in a volume evaluated to about 3 mill m^3 . Grain size analyses reveal, that it is not acceptable for sand fill and sand aggregates for concrete. At deeper waters north-west of the Fehmar island a resource area is marked, but no information about this area is outlined.

10.3 Sagas Bank.

In the western part of Mecklenburger Bucht Sagas-Bank is positioned at water-depths of about 10 m. Corings in this area show fine - coarse sand with a grain size distribution, that possibly makes it acceptable for sand fill and sand aggregates for concrete. The volume is evaluated to about 1 mill m^3 .

10.4 Westlichen Teil des Fehmarn Belts.

In the north-western part of Femer Bælt at water-depths between 6 and 16 m medium to coarse sand is found in a volume estimated to 4 mill m^3 . The grain size distributions possibly makes it acceptable for sand fill and sand aggregates for concrete.

10.5 Gjedser-Riff.

n the Gjedser Riff area no information is available but on basis of experiences by extraction it is estimated that sand of good quality is available in a volume of about 3 mill m3 .

10.6 Comparison of the resource areas mapped by GEUS and the areas outlined by Bundesanstalt für Wasserbau.

A comparison of the areas mapped by GEUS and the areas outlined by Bundesanstalt für Wasserbau (BW) shows, that some additional information can be obtained from the Bundesanstalt für Wasserbau data (Fig. 5 and enclosed Femer Bælt resource areas map in scale 1 : 200000).

- The Rödby-Sand area lies outside the GEUS survey area, but is not available due to an EU directive on conservation of wild life.
- The Puttgarden-Riff area is for the shallowest part positioned outside the GEUS survey area but is too finegrained. The resource area at deeper waters north-west of the Fehmar island is covered by the GEUS mapping and no information is available in the BW report.
- Sagas Bank is positioned outside the GEUS mapping area and the BW report makes it probale that about 1 mill m^3 sand is available.
- In the north-western part of the Femer Bælt the BW resource area overlaps the GEUS resource area 564016. Grain size analyses from the BW report gives additional information on the coastal deposits

mapped in resource area 564016 (discussed in chapter 9.4.10.). On Basis of this it may be expected that 5 - 8 mill m^3 usable sand is available in the north-western part of resource area 564016.

- The Gjedser Riff outlined resource area gives no additional information to the GEUS mapping results.

11. Conclusions

Investigations carried out by the "Bundesanstalt für Wasserbau" (Bundesanstalt für Wasserbau 1996) and by GEUS (Jensen 1996) are basic data for evaluation of potential resource areas in the Femer Bælt area.
In spite of the data reported by "Bundesanstalt für Wasserbau" and comprehensive studies carried out by GEUS, only rough estimates of quality and volumes can be presented.

The geological evolution is reflected in the distribution of seabed sediments and hereby the distribution of raw materials. Furthermore, the bedforms yield evidence on recent in- and outflow bottom current patterns and of human impact on the seafloor. These aspects are of grate importance for the raw material quality assessment and evaluation of effects of human activity.

The Femer Bælt investigations show that while submerged Ancylus Lake and Littorina Sea coastal deposits are potential resource areas, lateglacial esker deposits are of only limited value.
The most promising resource areas are developed in paleocoastal deposits exposed to (sub)recent erosion and redeposition. This additional sorting proces has removed fine grained material and favoured coarse graines in associated sand wave fields.

Great Belt Link project and Øresund Link Project criteria for fillsand and sand aggregates for concrete previously have demanded relatively coarse grained sand. Grain size analysis shows that probably some of the sandwave areas in Femer Bælt (564012 and 564014) can fulfil these demands. The expected resource volume for these deposits is about 25 mill m^3 . Likewise it is expected that 5 - 8 mill m^3 sand is available in the north-western part of resource area 564016 and it may be suggested that about 1 mill m^3 sand is available at Sagas Bank (Table VI).

RESOURCE AREA	**VOLUME**	**MEAN THICKNESS**	**WATER-DEPTH**
	mill m^3	m	m
564012	3	1 - 2	18 - 22
564014	20 -25	3	15 - 25
564016	5 - 8	2	8 - 15
Sagas Bank	1	2 - 3	8 - 15
IN TOTAL	29 - 37		

Table VI. Estimated resource volumes that fulfils the probable criteria for fillsand and sand aggregates for concrete.

In the Femer Bælt area limited extraction of sand and gravel is registrated in the period 1990 - 1993. In 1994 a pronounced increase in sand extraction is ascribed to increasing demands from the German marked.

In addition to raw material aspects the results from our investigations are useful as a basis for environmental and archaeological studies. For instance surface sediment distribution and current induced bedforms yield important information for understanding of the bottom flow pattern in the Femer Bælt area. Paleogeographical maps illustrate the distribution of coastal deposits through time since the melting of the iceshield, which is of interest of archeological studies.

On basis of the existing data it must be concluded that more detailed investigations must be carried out for attaining a more complete and detailed overview of Femer Bælt resources and seabed characteristics.

12. Supplementary investigations and information

On basis of the existing data at GEUS some additional investigations and information might be relevant and needed to further improve the raw material assesment presented here:

- GEUS has the capasity to carry out additional raw material analysis (e.g. petrographical analysis, grain size analysis) on existing cores located at the GEUS core store.

- On basis of existing data at GEUS it is possible to carry out resource assesments of potential resource areas positioned outside the Femer Bælt area.

- The mapped seabed sediments and resource areas are available in digital format in all current formats used in GIS systems. This might be valuable for planning purposes.

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13.3. Maps

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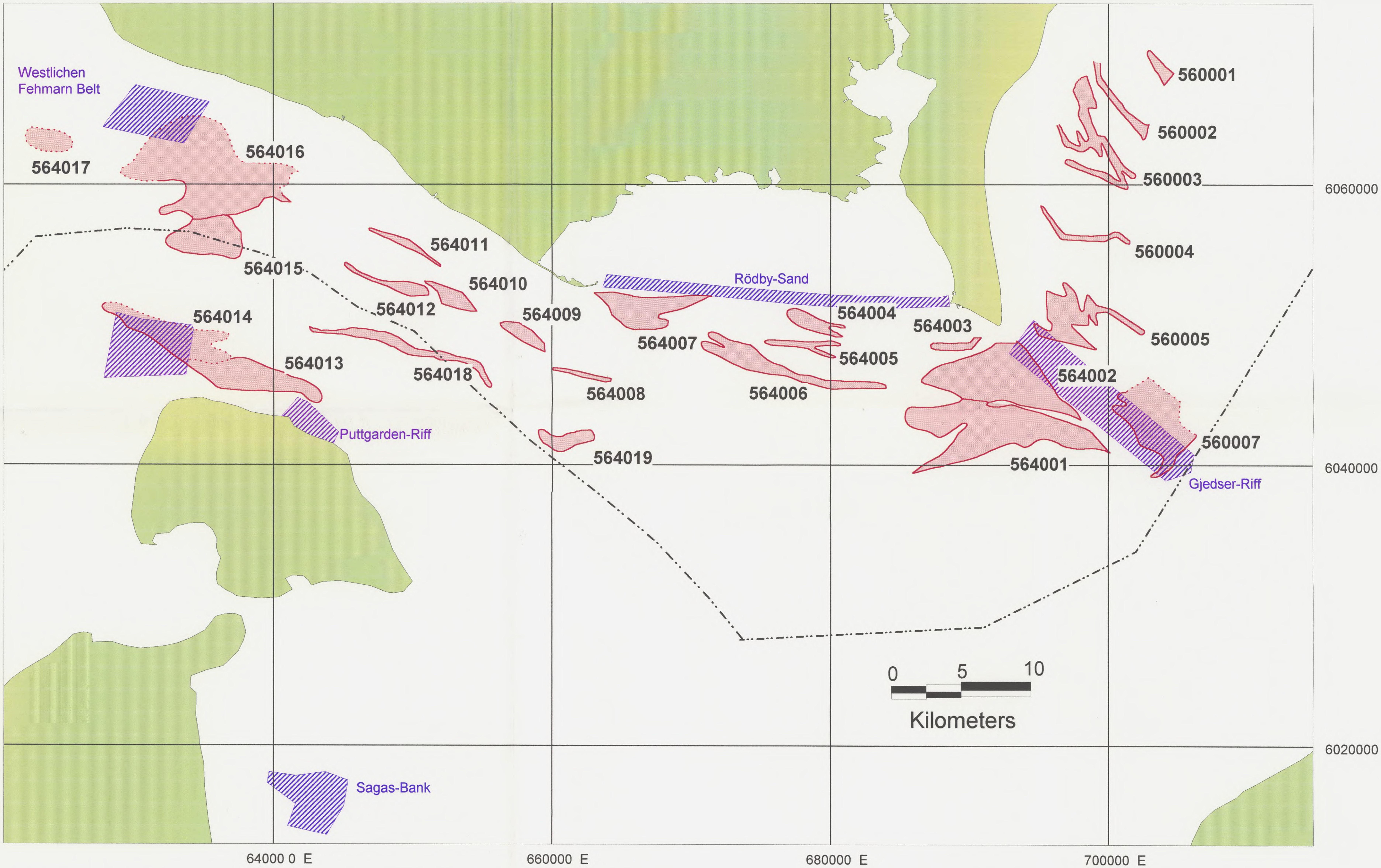
14. Figures

15. Tables.

16. Maps.

- Late Quaternary sediments map in scale 1 : 200 000
- Femer Bælt Resource areas map in scale 1 : 200 000



FEMER BÆLT

RESOURCE AREAS

UTM ZONE 32

SCALE 1 : 200 000

RESOURCE AREA BUNDESANSTALT FÜR WASSERBAU

RESOURCE AREA MAPPED BY GEUS

564001 RESOURCE NUMBER

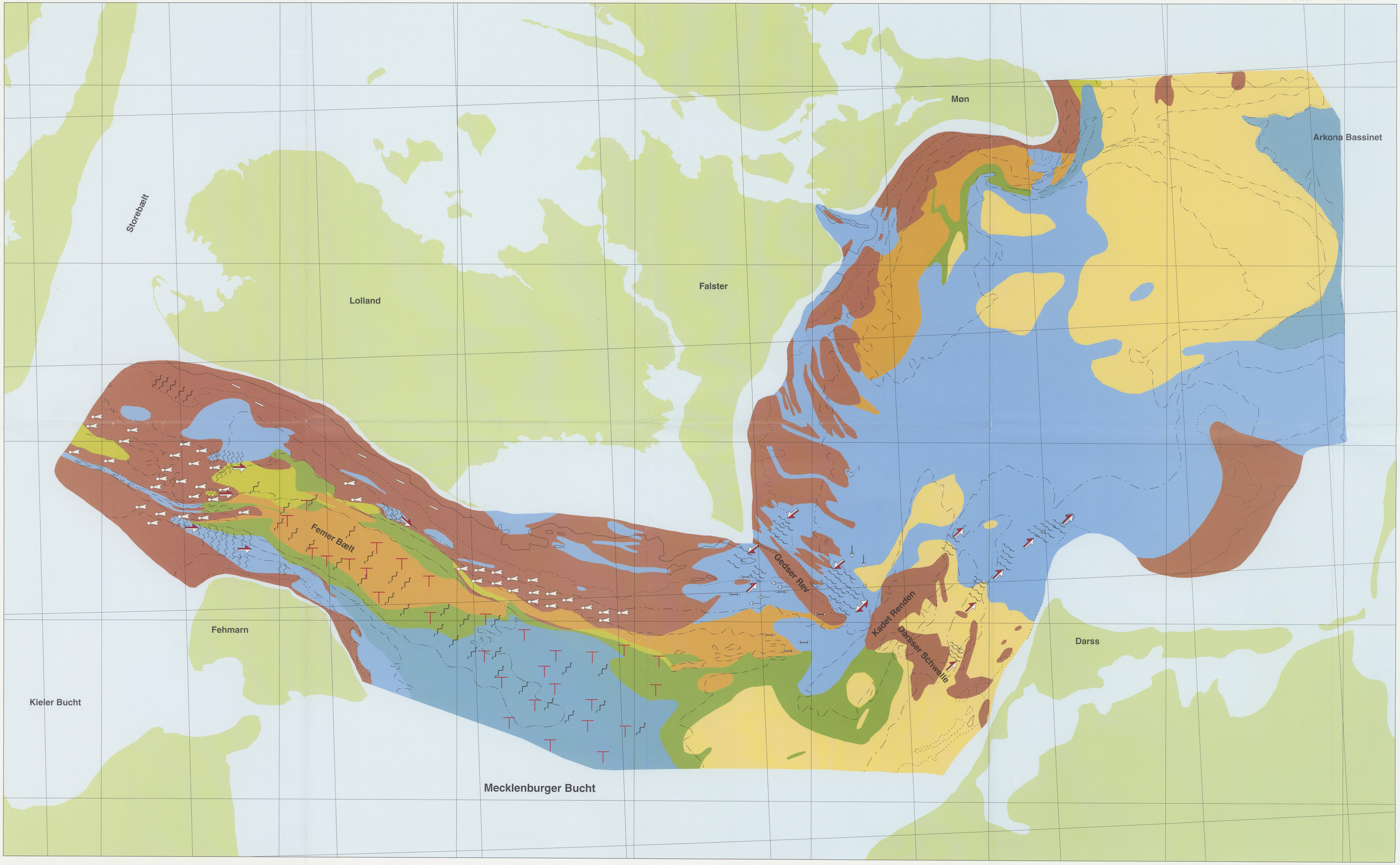
RESOURCE BOUNDARY (CERTAIN)

RESOURCE BOUNDARY (UNCERTAIN)

Geologisk kort over Femer Bælt - Arkona Bassinet *Map sheet Femer Bælt - Arkona Basin / Blatt Fehmarn Belt - Arkonabecken*

Sen-kvartære sedimenter *Late Quaternary sediments / Spätquartäre Sedimente*

DGU Kortserie nr.52 / DGU Map Series no. 52



Oversigtskort *Location map / Übersichtskarte*

Signaturforklaring *Legend / Legende*

Holocæn *Holocene Holozän*		Marint sand *Marine sand Mariner Sand*
Holocæn *Holocene Holozän*		Marint dynd *Marine mud Mariner Schlick*
Holocæn *Holocene Holozän*		Ferskvands-brakvands sand *Freshwater/Brackish sand Süsswasser/Brackischer Sand*
Holocæn *Holocene Holozän*		Ferskvands/brakvands ler/sand *Freshwater/Brackish clay/sand Süsswasser/Brackischer Ton/Sand*
Senglacial *Late Glacial Spätglazial*		Ferskvands sand *Freshwater sand Süsswassersand*
Senglacial *Late Glacial Spätglazial*		Ferskvands ler *Freshwater clay Süsswasserton*
Glacial *Glacial Glazial*		Moræne *Till Geschiebemergel*

Strøm Strukturer *Current Structures / Strömungsbedingte Sedimentmarken*

Transverse *Transverse / Transverse*

- Sandbølge felt *Megaripple field Megaripple Feld*
- Sandbølge enkelt *Single megaripple or sandwave Einzelne Megarippeln*

Longitudinale *Longitudinal / Longitudinalstrukturen*

- Kometmærke (strømretning mod øst) *Comet mark (Eastern current direction) Komet marke (Östliche Strömungsrichtung)*
- Sandstriber *Sand Ribbons Sand Streifen*
- Sandstriber (strømretning angivet) *Sand Ribbons (current direction indicated) Sand Streifen (mit Strömungsrichtung)*

Andre signaturer *Other signatures / Andere Signaturen*

- Generelle transportretning *General transportdirection / Generelle Transportrichtung*
- Trawlmærker *Trawl marks / Schleppspuren*

Dybdekurver *Depth contours / Tiefenlinien*

6 m, 10 m, 15 m, 20 m, 25 m, 30 m, 35 m

0 2 4 6 8 10 km

1:200 000

Sammenstillet af / Compiled by / Zusammengestellt von: J. B. Jensen, A. Kuijpers & W. Lemke

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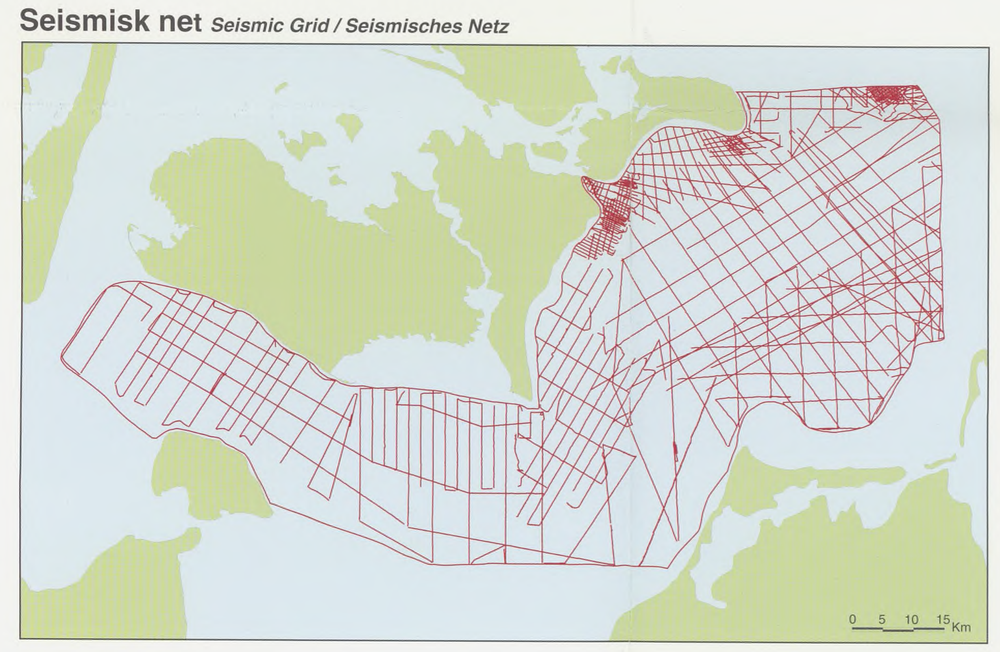
IOW

Seismisk net *Seismic Grid / Seismisches Netz*



Borepositioner *Core Positions / Probenpositionen*