NOAH
North Sea Observation and Assessment of Habitats

Permeability of Marine Sediments

GENERAL OVERVIEW	
Dataset name: *Sediment grain size data were taken to assess sediment permeability (Kp)*	
Project: *North Sea – Observation and Assessment of Habitats (NOAH)*	
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DATASET SPECIFICATIONS	
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Date(s) available: --	
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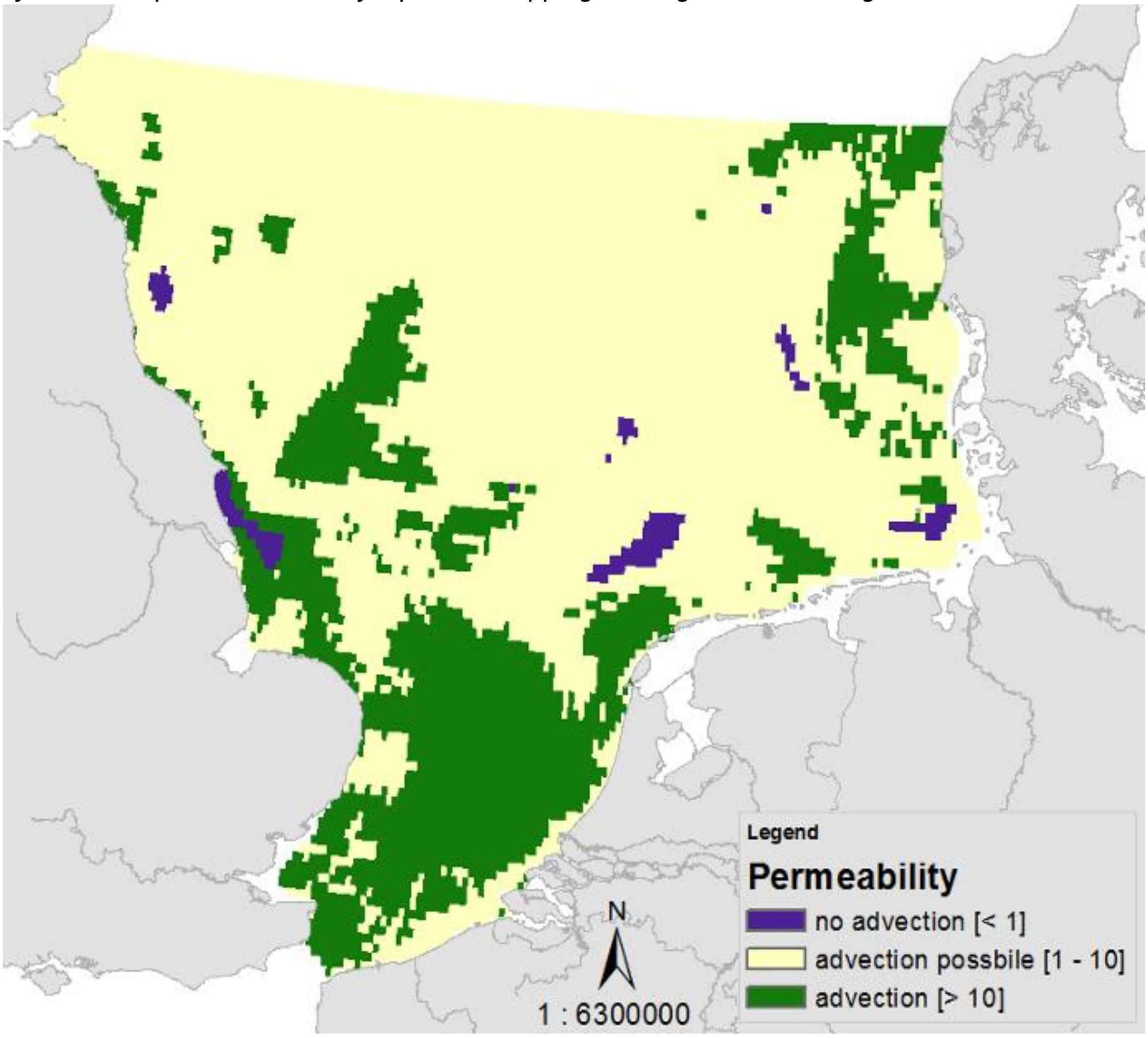
DATASET DETAILS

Abstract

Sediment grain size data were taken to assess sediment permeability (Kp) and spatially classify the sea bed of the North Sea accordingly into the three groups "no advection", "advection potentially possible" and "advection definitely possible". Information on permeability helps to unravel the role of North Sea permeable sands for particle trapping and organic matter degradation.



In a porous medium as a sand bed, water can flow within the sand bed in response to an external pressure gradient. The flow velocity depends on the permeability of the sand bed.

The map shows the spatial distribution of the specific sediment permeability K_P (in m^2) of surface sediments in the southern North Sea. The permeability map originates from an area-covering map of D15, the 15th percentile sediment grain-size.

The sea bed is classified into sediments with (a) a permeability of less than $1 \cdot 10^{-12}$ m^2 where advection in the sediment bed is expected to be absent, (b) a permeability between $1 \cdot 10^{-12}$ m^2 and $10 \cdot 10^{-12}$ m^2 where advection is possible to a certain extent and (c) a permeability above $10 \cdot 10^{-12}$ m^2 where advection definitely takes place.

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Acquisition and Processing Description:

Acquisition:

The sediment permeability is calculated from D15, the 15th percentile sediment grain-size. The D15 data consists of more than 50,000 individual sample values. Only samples from the sediment surface (maximum sub-bottom depth 10 cm) were taken into account. The grain-size data were collected from more than 10 institutions and databases. The oldest data were measured during the fifties. All collected data are united into the same data set, disregarding the date of sampling.

Processing Description:

The specific permeability K_P of sediment is calculated by a formula given in Soulsby (1997), section 2.4:

$$K_P = 0.0011 * D15^2$$

In this formula, K_P is in m^2 and D15 is the 15th percentile sediment grain-size in meters. The formula is originally valid for sediments with uniform grain-size D, and it is applicable to grains smaller than 1.2 mm. For mixed (i.e. natural) sediment, Soulsby recommends to replace D by D15.

An area-covering permeability map of the southern North Sea is generated as follows: First the 15th percentile grain-size D15 of each individual sediment sample is obtained from a Tauber fit of the sample's grain-size distribution.

Next the D15 values of individual samples are interpolated into grid nodes. The generation of a map covering the North Sea area of interest is done by Co-Kriging using the R-routine "krige" (R-library "gstat"). The values of the primary variable (D15 of individual samples) are provided at the original sample locations. The values of the secondary variable are provided at the target grid nodes. The secondary variable (log-converted %mud) is known at all the target grid nodes. The result of Co-Kriging is a full-coverage estimation of the primary variable at the target grid nodes. Co-Kriging tends to produce a smoothed image. Along with the estimate of the primary variable ("kriging mean"), kriging gives an estimate of the estimation error ("kriging variance") at every target grid node.

Finally K_P is calculated at each grid node with

$$K_P = \frac{0.0011 * D15^2}{1.36 * 2.6}$$

The two factors below the fraction bar have resulted from:

(1) Forster et al. (2003) measured the permeability of bottom sediment in the Baltic Sea. They compared their measured results with the permeabilities calculated by a formula of Krumbein and Monk (1943). The Krumbein-Monk formula includes the median grain-size and the sorting. The result of the comparison was: the Krumbein-Monk formula "… overestimates the measured permeabilities on average by a factor 2.6 …".

(2) The grain-size data set of BSH (more than 20 000 samples) was used to compare the permeabilities of the Krumbein-Monk formula with the permeabilities of the Soulsby formula $K_P = 0.0011 * D15^2$. For each BSH sample, median grain-size D50, sorting and D15 were determined by Tauber fit. The comparison of the two calculated permeability data sets shows: the Soulsby formula overestimates the results of the Krumbein-Monk formula on average by a factor 1.36.

*Altogether the Soulsby formula $K_P = 0.0011 * D15^2$ overestimates the measured data of Forster et al. (2003) by a factor of 1.36 * 2.6. This is compensated for by reducing the Soulsby permeability by the same factor.*

The advantage of the Soulsby permeability formula is that it is less subject to constraints than other formulas. In particular, a lower limit is not given for D15. This means that small *permeabilities $K_P < 10^{-12}$ m^2 are calculated for D15 < 57µm. This, however, is misleading. In such fine sediments advective transport does not happen. Instead, there is diffusive transport only. Forster et al. (2003) assume the "threshold for permeability effects" at $K_P = 2.5\ 10^{-12}$ m^2. Janssen et al. (2005) state that "… all studies agree that permeabilities between 10^{-11} and 10^{-12} m^2 are the minimum requirement for a significant effect of advection …"*

Notes and Limitations:

Data Quality:

The quality of the permeability map depends (a) on the quality of the D15 and (b) on the quality of the permeability formula of Soulsby (1997).

Results of the Soulsby formula were compared with results of two other permeability formulas.

Error Estimation:

For individual samples an estimate of the median grain-size error can be obtained from data of CEFAS Lowestoft (2012). At a muddy site (Farnes Deep) the mean and standard deviation of median grain-size (12 sediment surface samples, taken between 1999 and 2010 at the same position) is 3.91 ± 0.06 (φ-scale). At a sandy site (off East Anglia) the mean and standard deviation of median grain-size (11 sediment surface samples between 2000 and 2010) is 1.57 ± 0.25 (φ-scale). The samples were taken at sites where "it is expected there will not be changes in sediment type at these sites over time".

The standard deviation of D15 predicted by Co-Kriging is in the order of 0.68 and thus much higher than the above given errors of individual samples. The spatial distribution of the Kriging standard deviation is very uniform. The error is slightly larger where the density of samples is low, e.g. north of 56° latitude.

Data Sources

The data for the generation of sediment maps were obtained from the following institutions:

NAVAL OFFICES and RESEARCH INSTITUTES:
Forschungs- und Technologiezentrum Büsum, Germany
Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg, Germany
Senckenberg Institut Wilhelmshaven, Germany
Helmholtz Zentrum Geesthacht, Germany
Bioconsult Schuchardt & Scholle GbR, Bremen, Germany
Deltares, Utrecht, The Netherlands
British Geological Survey, Marine Information Project, Edinburgh, UK
Marine Scotland, Marine Laboratory, Aberdeen, UK
Universität Hamburg, Institut für Geologie und Paläontologie, Hamburg, Germany
Royal Netherlands Institute for Sea Research (NIOZ), Texel, The Netherlands
Geological Survey of the Netherlands (TNO), Utrecht, The Netherlands
School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, UK
CEFAS, Lowestoft, UK
Geological Survey of Norway (NGU), Trondheim, Norway
Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
Bureau de Recherches Géologiques et Minières (brgm), Orléans, France

PROJECTS:
Management, Research and Budgeting of Aggregates in Shelf Seas related to End-users (MAREBASSE, 2002-2006), Ghent University, Belgium
North Sea Benthos Survey 1987
North Sea Benthos Project 2000
Zirkulation und Schadstoffumsatz in der Nordsee (ZISCH, 1984-1989), Universität Hamburg

Biogeochemistry and Distribution of Suspended Matter in the North Sea and Implications to Fisheries Biology (TOSCH, 1984-1988), Universität Hamburg
Geopotenzial Deutsche Nordsee (GPDN, 2009-2013), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Hannover, Landesamt für Bergbau, Energie und Geologie (LBEG) Hannover, Bundesamt für Seeschifffahrt und Hydrographie (BSH) Hamburg, Germany

DATABASES:
Flanders Marine Institute (VLIZ) Data Centre, Ostend, Belgium
Management Unit of the North Sea Mathematical Models (MUMM), Brussels, Belgium
International Council for the Exploration of the Sea (ICES), Copenhagen, Denmark
Publishing Network for Geoscientific & Environmental Data (PANGAEA), Alfred-Wegener-Intitut (AWI), Bremerhaven, Germany