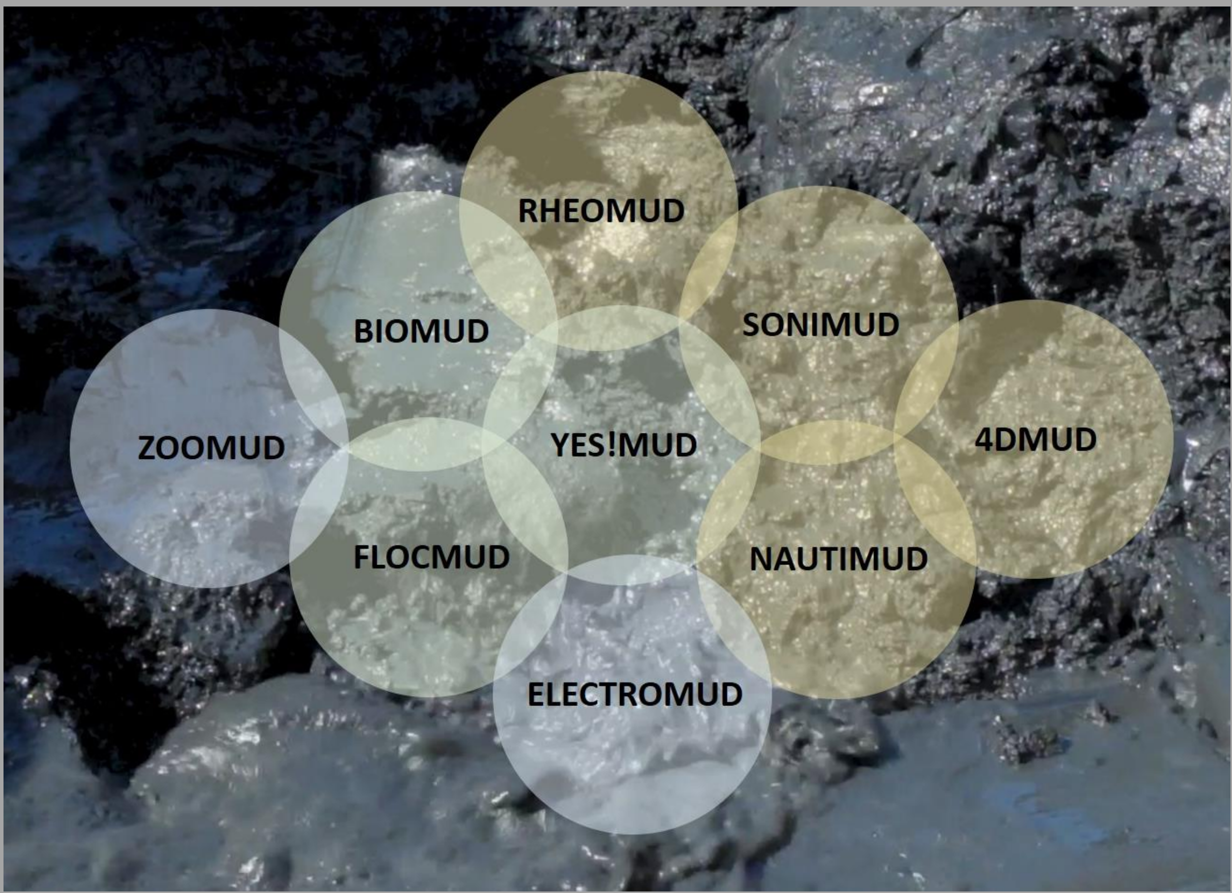
MUDNET
Annual Report
2020



MUDNET Foundation

With particular thanks to Ahmad Shakeel and Claire Chassagne for the great work they did in designing the present report

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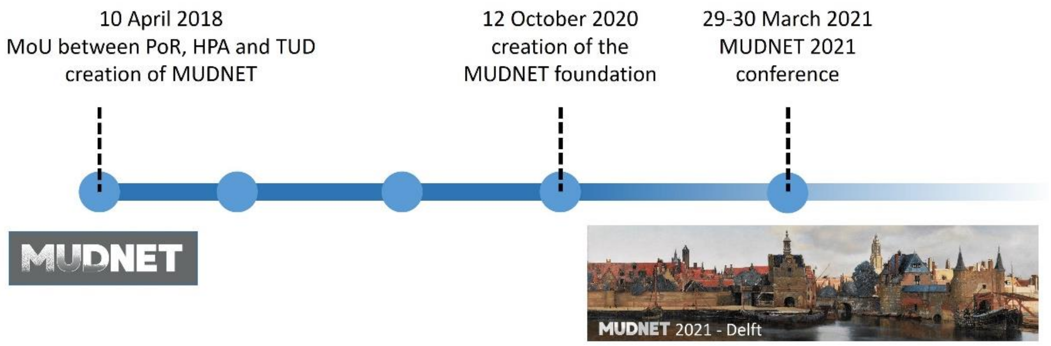
1. Introduction

In 2015, a group of scientists from TU Delft decided to fund the academic platform MUDNET in order to centralize the multidisciplinary knowledge around fine-grained (clayey-silty) sediments (mud). The aims of MUDNET are:

- to promote interaction between different scientific disciplines in order to develop the understanding of complex mud-related systems, from suspended sediment in water to soil
- to facilitate exchange of knowledge between science and applications and offer a platform where the research findings are centralized
- to provide new solutions to stakeholders for optimizing sediment management as well as developing new port and waterways maintenance strategies

The MUDNET team works on different research topics, spanning from theoretical to applied science, from microscale to macroscale, from laboratory experiments to in-situ monitoring.



Helping the world to make use of mud in a safe and predictive way

We work in close collaboration with industrial partners on sediment and mud related issues, to improve sediment managements in ports and waterways, and provide healthy ecosystems in clay-dominated environments. Our partners and ourselves aim at changing the view of mud from waste to resource. To this end, it is important to develop predictive models and protocols, based on in-situ monitoring and complementary lab analysis. We have hence initiated several lines of research in view of practical applications to get a proper understanding of the complex processes playing a key role in the changes in mud over space and time.
End users hereby provide valuable input, as they share with us their knowledge of the field and facilitate in situ monitoring.

Exchanging and making knowledge available

In our work, we make use of a large range of techniques and expertise and we value sharing our results with the scientific community and all stakeholders through publications (peer-reviewed articles, abstracts, books), conferences, workshops and seminars. In particular, we value the regular meetings with our industrial partners, who are as keen as we are to see our newly developed knowledge be put in practise. More about the academic platform MUDNET can be found on the website https://www.tudelft.nl/mudnet.

1.1. The MUDNET foundation

In October 2020, the MUDNET foundation was created. The aims of the foundation are to:

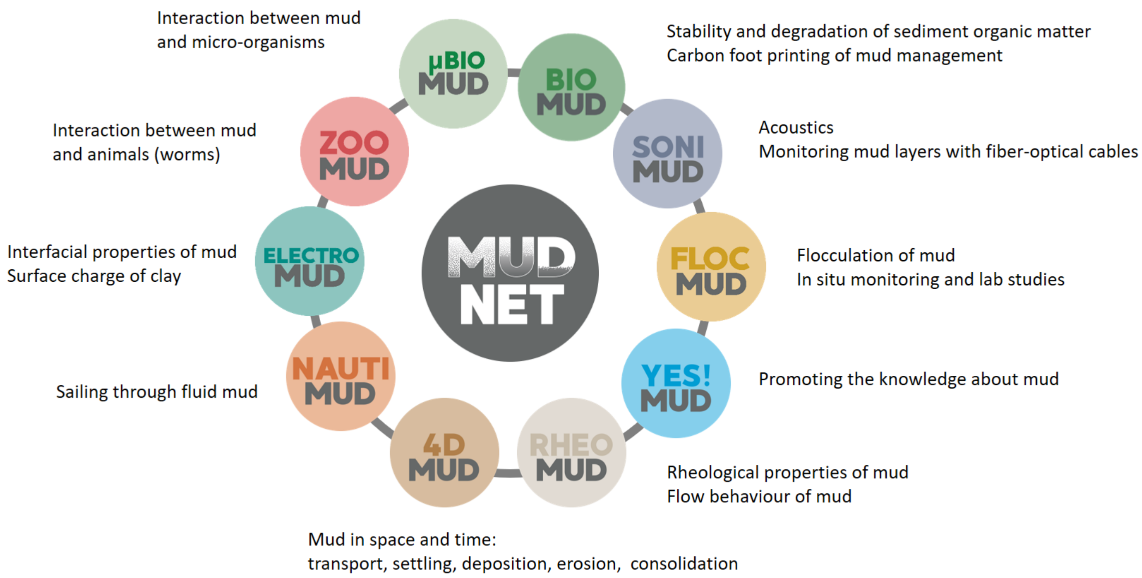
- Provide an academic exchange platform for fine-grained sediment expertise, regarding processes, behaviour and management consequences

- Promote interdisciplinary and multi-methodological collaborative research on fine-grained sediments: unite experimentalists and modellers in the fields of geosciences, physics, chemistry and biology
- Share findings between science, private and public stakeholders such as port operators, dredgers, authorities
- Facilitate contacts between industry and academia Identify research gaps and needs
- Promote and facilitate education

From left: Julia Gebert, Deyan Draganov, Claire Chassagne, Alex Kirichek , October 2020 (creation of the MUDNET foundation) – Photo: Alex Kirichek

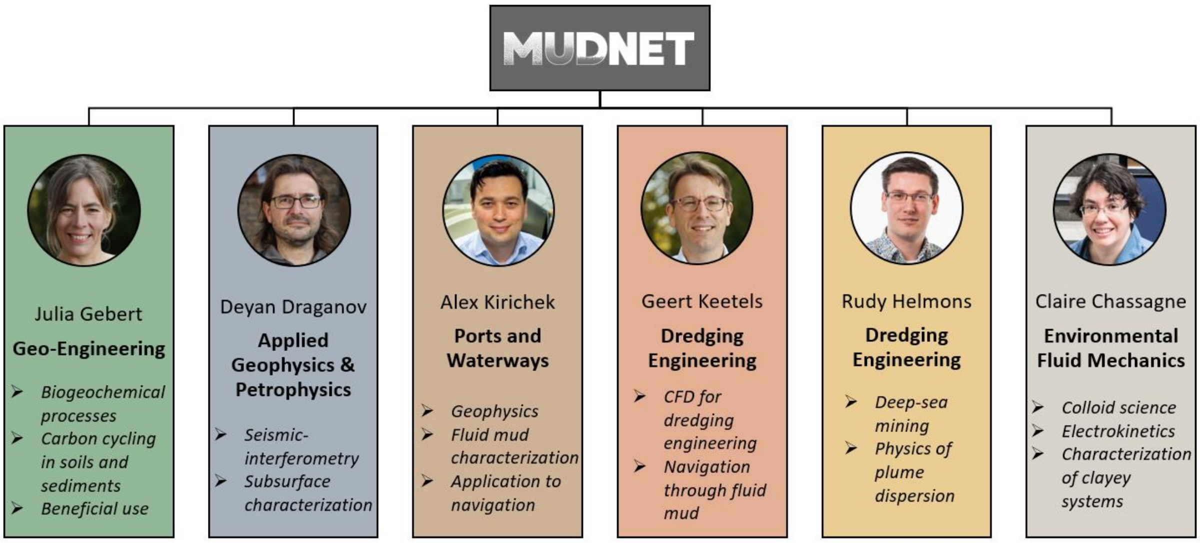
1.2. The MUDNET topics in a nutshell

The main themes of research under investigation in the frame of MUDNET are given in the figure below. All these themes have of course a certain degree of overlap. For example, the interfacial properties of mud (ELECTROMUD) will help to determine the flocculation ability of a mud suspension (FLOCMUD). The rheological properties fluid mud (RHEOMUD) can be studied in relation with the mud composition (BIOMUD). This interdisciplinary enables to get a better understanding of the causal relationships between changes in environment and mud behaviour.



2. Staff and students at MUDNET

The MUDNET projects are led by 6 staff members of the TU Delft, working in 4 different sections, within the Faculty of Civil Engineering and Geosciences and the Faculty of Mechanical, Maritime and Materials Engineering. The MUDNET team furthermore includes PhD students and postdocs, along with MSc's and BSc's, supervised by one or more members of the MUDNET staff.



Overview of PhD, MSc and BSc students and their research topics within MUDNET (completed theses can be downloaded from the repository of TU Delft, https://www.tudelft.nl/en/library)

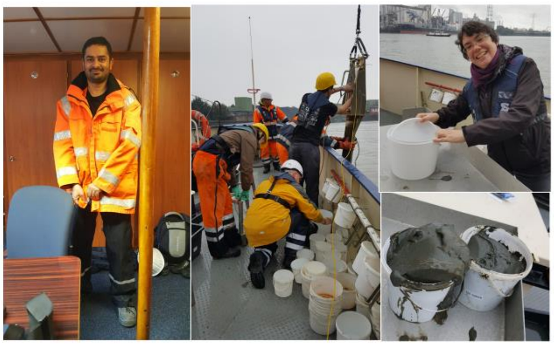
	Name	Title thesis	MUDNET supervisor
FLOCMUD			
PhD	Maria Ibanez	*Flocculation and consolidation of cohesive sediments under the influence of coagulant and flocculant*	Claire Chassagne
PhD	Zeinab Safar	*Flocs and fluff in the Rhine-ROFI*	Claire Chassagne
PhD	Zhirui Deng	*Algae-induced flocculation in the Yangtse estuary*	Claire Chassagne
PhD	Waqas Ali	*Flocculation in dredging plumes with application to deep-sea mining*	Claire Chassagne Alex Kirichek
PDEng	Gosia Wyszynska	*Design for a bioremediation method for oil-sand tailings*	Claire Chassagne Alex Kirichek
Postdoc	Ryan McIver	*Design of a FLOC CAMera (FLOCCAM) to study the settling velocity of flocs*	Claire Chassagne Rudy Helmons
Postdoc	Caroline Grilo	*Role of charge reversal of iron ore tailing sludge on the flocculation tendency of sediment*	Claire Chassagne
MSc	Dolf Enthoven	*Flocculation in lock-exchange experiments*	Claire Chassagne Rudy Helmons
MSc	Ziyan Zhang	*Flocculation in drift-flux modelling*	Rudy Helmons Geert Keetels

RHEOMUD			
PhD	Ahmad Shakeel	*Rheological properties of mud in the port of Hamburg*	Claire Chassagne Alex Kirichek
MSc	Jan-Willem de Klerk	*Effect of organic matter degradation on the rheological behaviour of mud*	Claire Chassagne Julia Gebert
BIOMUD			
PhD	Florian Zander	*Aerobic and anaerobic degradation of organic matter in mud*	Julia Gebert
MSc	Xin Li	*Investigation of Gas Generation by Riverine Sediments: Production Dynamics and Effects of Sediment Properties*	Julia Gebert Claire Chassagne
BSc	Lodewijk Pleij	*Effect of movement on the settlement of fluid mud*	Julia Gebert Claire Chassagne
BSc	Paul Pana	*Climate impact of sediment management*	Julia Gebert Claire Chassagne
BSc	Matthijs Boelger	*Climate impact of sediment management options in Port of Hamburg*	Julia Gebert
BSc	Lauran de Jong	*Time Series Analysis of Organic Matter Degradation in Riverine Sediments from the Port of Hamburg, Germany*	Julia Gebert Claire Chassagne
BSc	Adam Lisowski	*Quantification of organic matter pools in river sediments*	Julia Gebert
BSc	Daniel Ernste	*From sediment to soil: Physical, chemical and biological ripening processes*	Julia Gebert Claire Chassagne
BSc	Lucia Alconchel	*Effect of redox conditions of sediment organic matter degradation in time and space*	Julia Gebert Claire Chassagne
µBIOMUD			
Postdoc	Zeinab Safar	*Microbiological analysis of fluid mud from the Port of Emden*	Alex Kirichek Julia Gebert Claire Chassagne
SONIMUD			
iPhD	Menno Buisman	*Fiber-optics to assess the composition of sediment layers*	Claire Chassagne Alex Kirichek Deyan Draganov
Postdoc	Xu Ma	*Characterization of sediment layers using acoustic methods*	Alex Kirichek Deyan Draganov
MSc	George Woofenden	*Using reflected seismic waves to estimate rheological properties of the fluid-mud layer for port applications*	Alex Kirichek Deyan Draganov
MSc	Menno Buisman	*Seismic analysis of fluid mud*	Alex Kirichek Deyan Draganov Claire Chassagne

MSc	Diego Denzler	*Monitoring fluid-mud layers at ports and waterways: ultrasonic measurements for shear parameters using Fiber Optics*	Deyan Draganov Alex Kirichek
NAUTIMUD			
PhD	Stefano Lovato	*Sailing through fluid mud*	Geert Keetels
MSc	Pavan Goda	*Experimental research on sailing through the fluid mud*	Geert Keetels Alex Kirichek
MSc	Karin Leijs	*CFD simulations of the flow around a cargo ship in shallow water navigation with muddy seabed*	Geert Keetels
4DMUD			
PhD	Mohamed Elerian	*Near-field conditions of a sediment plume discharged from a deep sea mining vehicle*	Rudy Helmons
MSc	Yannick Wijmans	*Near-field low concentration sediment discharge experiments*	Rudy Helmons
MSc	Daan Deckers	*Suspended sediment behaviour of a reallocation pilot study, using model hindcasts and measurements*	Alex Kirichek Claire Chassagne
MSc	Marlein Geraeds	*The hydrodynamics of an eco-innovative sediment reuse project in the Rotterdam Waterway*	Alex Kirichek Claire Chassagne
MSc	Auke Tempel	*Sediment traps for reducing maintenance dredging costs in the Port of Rotterdam*	Alex Kirichek Claire Chassagne
MSc	Sjoerd de Groot	*Suspended Sediment Modelling in the Port of Rotterdam*	Alex Kirichek Claire Chassagne
MSc	Sebastiaan Ma	*Laboratory study on the efficiency of water injection dredging on mud from the Port of Rotterdam*	Alex Kirichek

3. Brief description of MUDNET projects

3.1. Rheology of mud



A monitoring campaign in the harbour of Hamburg: collecting samples of which the rheological properties were analysed in the laboratory

Mud, a cohesive material, consists of water, clay minerals, sand, silt and small quantities of organic matter (i.e., biopolymers). Amongst the different mud layers formed by human or natural activities, the fluid mud layer found on top of all the others is quite important from navigational point of view in ports and waterways. An innovative way to define navigable fluid mud layers is to make use of their rheological properties, in particular their yield stress. In order to help the development of in situ measurement techniques, it is essential that the key rheological parameters are estimated beforehand.

The following research questions are addressed in the PhD work of A. Shakeel:

- Which rheometer geometry and rheological protocol are more suitable for the mud samples [1]?
- Is there only one yield point? If not, which yield stress is important for defining nautical bottom [1]?
- How is yield stress dependent on depths and locations in the harbor [2]?
- Is the density or volume fraction of solids enough to predict/link the rheology of the natural sediments?
- How much different are the rheological properties of naturally collected mud layers and artificially made layers by diluting a consolidated mud sample?
- What is the extent and rate of structural recovery in mud after pre-shearing as a function of several parameters including TOC, density, pre-shear rate, etc. [3]?
- How we can model the two-step yielding behavior of mud to get the desired rheological parameters?
- How we can mimic the rheological properties of natural mud by using pure clay and biopolymers?

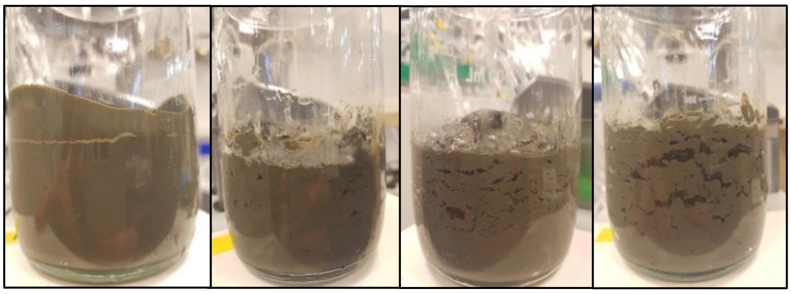
[1] Shakeel, A., Kirichek, A., & Chassagne, C. (2020). Yield stress measurements of mud sediments using different rheological methods and geometries: An evidence of two-step yielding. Marine Geology, 427, 106247.

[2] Shakeel, A., Kirichek, A., & Chassagne, C. (2020). Rheological analysis of mud from Port of Hamburg, Germany. Journal of Soils and Sediments, 20, 2553–2562.

[3] Shakeel, A., Kirichek, A., & Chassagne, C. (2020). Effect of pre-shearing on the steady and dynamic rheological properties of mud sediments. Marine and Petroleum Geology, 116, 104338.

3.2. Turnover of sediment organic matter

The biological decay of sediment organic matter under reducing conditions leads to the formation of methane, carbon dioxide and others gases, mostly released as bubbles into the sediment, the water column and eventually the atmosphere. Magnitude and rate of gas generation are a function of the content and the degradability of sediment organic matter and are therefore subject to spatial and temporal variation on different scales. Depending on the source type, chemical composition and degradability of sediment organic matter as well as composition and activity of the responsible microbial community will vary.



Formation of gas induced cavities in sediment over time in the lab

Gas induced cavities in freshly sampled mud

Gas generation causes a series of potential problems:
Sonic depth finding can be obstructed through reflection of sonic waves by gas bubbles in the sediment. Gas generation delays consolidation of sediment-to-be-dredged or of subaquatic base fills made from sediments. On the other hand, the degradation of organic matter also causes undesired subsidence in constructions made from sediments. Gas generation reduces sediment density, viscosity and shear strength and thereby enhances the susceptibility of subaquatic embankments and constructions towards erosion. Under the influence of gas generation, the sediment rheological parameters change, impacting the navigable depth. Methane as a potent greenhouse gas affects the carbon footprint of sediment management options.

In detail, the research objectives of BIOMUD are:

- Analysis of sediment organic matter properties and identification of those relevant for degradability
- Quantification of the degradable organic matter pool
- Quantification of gas generation potential and emission
- Analysis of composition and abundance of the relevant microbial communities
- Assessment of the role of gas generation for sediment rheological properties
- Development and validation of a sediment gas generation model.

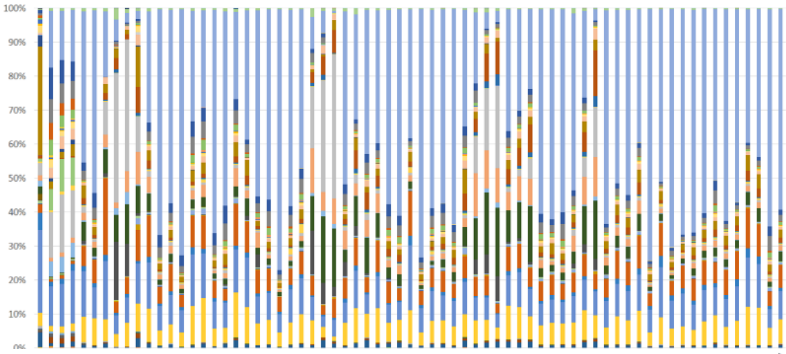
The benefits for stakeholders from BIOMUD research include the improved assessment of the environmental impact of dredging and relocation with respect to carbon cycling and carbon footprinting, an improved knowledge base to enhance beneficial use of sediments as construction material in embankments or area profiling, both subaquatic and on land , enhanced planning reliability for operators of dredged material landfills with respect to gas treatment and landfill subsidence and the improved assessment of the necessity of safety measures on all sites handling gas-generating sediment.

[1] Gebert, J., Knoblauch, C., Gröngröft, A. (2019): Gas production from dredged sediment. Waste Management 85, 82-89.

[2] Zander, F., Heimovaara, T., Gebert, J. (2020): Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. DOI: https://doi.org/10.1007/s11368-020-02569-4

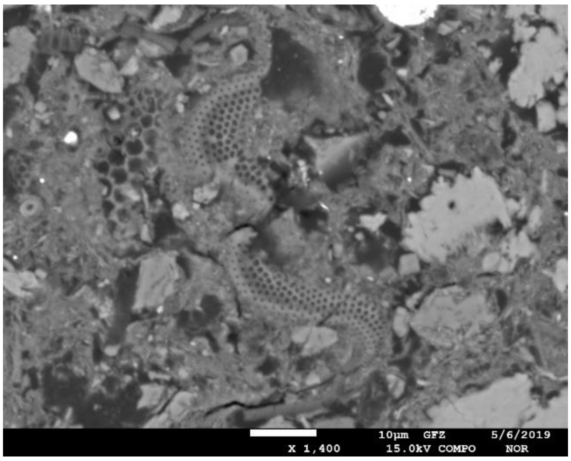
3.3. Composition and activity of the mud microbial community

Microorganisms such as bacteria, archaea and algae facilitate cycling of carbon and other elements in sediments. By primary production, algae add easily degradable organic matter to the sediment-aquatic system. By breaking down organic matter, be it under aerobic or anaerobic conditions, microorganisms can inhibit or destroy organic bonds between mineral sediment particles and therefore prevent formation of larger agglomerates, which reduces settlement of suspended particles and yield points of already settled sediments. Some microorganisms form extrapolymeric substances (EPS), consisting of exopolysaccharides, proteins, lipids and nucleic acids, which are essential to biofilm formation and due to their low density can promote that fine grained particles remain in suspension. These few examples highlight just some processes governed by microorganisms in the sediment-aquatic environment, such as carbon release into the atmosphere, but also indicate the relevance of their activity for sediment properties and therefore sediment management.



Diversity of Archaea in sediments from the Port of Hamburg

µBIOMUD investigates spatial and temporal patterns of the composition and activity of the sediment microbial community and their response to changing environmental conditions. These analyses are carried out in close cooperation with Prof. Dr. Mirjam Perner (GEOMAR, Kiel, Germany), Dr. Ines Kohn (University of Hamburg, Germany) and Dr. Fiorenza Deon (U Twente and TU Delft, The Netherlands).

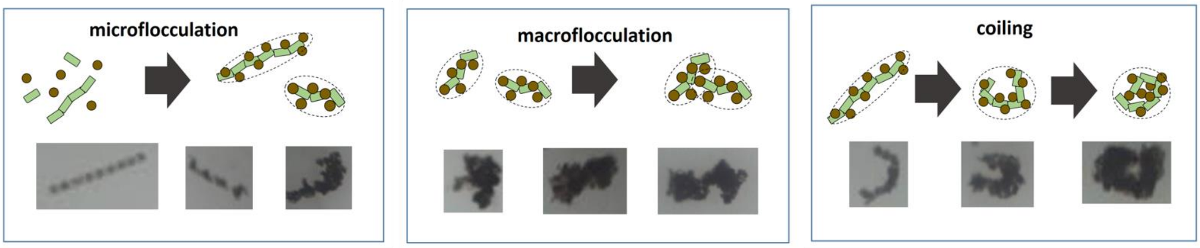


Diatoms in sediments from the Port of Hamburg

[1] Zander, F., Heimovaara, T., Gebert, J. (2020): Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. DOI: https://doi.org/10.1007/s11368-020-02569-4

[2] Gebert, J., Perner, M. (2015): Differentiation of microbial community composition in soil by preferential gas flow. European Journal of Soil Biology 69, 8-16.

3.4. Flocculation of mud in coastal and marine systems



Flocculation is defined traditionally as the process of aggregation and break-up of a collection of particles. The particles called “flocs” consist of aggregates of mineral clay particles and organic matter principally in the case of flocs found in coastal regions and marine environment. The size of flocs is changing in response to changes in environmental conditions (hydrodynamics, water chemistry, availability of flocculating agents such as exopolymers produced by microorganisms) [1,2]. We found that due to the presence of organic matter, flocs become elastic and seldom break. On the other hand, due to shear, flocs coil and become denser (their volume is reduced while their mass is conserved).

The following research questions are addressed in the PhD works of M. Ibanez, Z. Deng, Z. Safar and W. Ali:

- What is the role of organic matter (and in particular algae) in the transport of sediment in coastal areas?
- How can flocs’ properties (settling velocity and sediment content) be characterized in-situ?
- What is the role of flocculation in dredging plumes dispersion?
- How can flocculation be implemented in large-scale sediment transport models?
- How can the model be properly parametrized and calibrated?

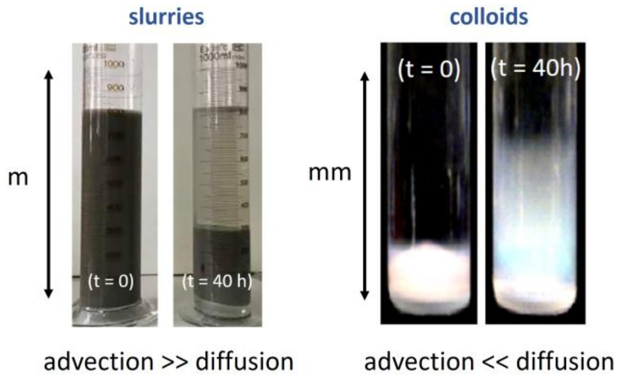
Adapted Population Balance Equations (PBE) are often used to model in-situ flocculation. We chose a novel approach based on the use of an adapted logistic growth model. This model has the advantage to be easy to implement in existing large-scale transport models (such as Delft-3D) and has a limited amount of input variables, all of which can easily be found from laboratory measurements. In contrast to most models, the particle classes we propose are not defined by particle size, but in terms of mineral sediment composition.

The model is at present parametrized using laboratory experiments, following the protocol that we recently developed.

[1] Chassagne, C., & Safar, Z. (2020). Modelling flocculation: Towards an integration in large-scale sediment transport models. Marine Geology, 106361.

[2] Deng, Z., He, Q., Safar, Z., & Chassagne, C. (2019). The role of algae in fine sediment flocculation: In-situ and laboratory measurements. Marine Geology, 413, 71-84.

3.5. Settling and consolidation of soft slurries



change in volume fraction (density) as function of time for a given position is given by:

advection — diffusion

$$\frac{\partial \phi_S}{\partial t} = v_0 \frac{\partial}{\partial z}[\phi_S f(\phi_S)] + D_0 \frac{\partial}{\partial z}\left[f(\phi_S)\frac{\partial[\phi_S Z(\phi_S)]}{\partial z}\right]$$

advection: due to gravity

diffusion: **colloids** : due to electrostatic repulsion (osmotic pressure); **slurries**: due to effective stress

The topic of dewatering and consolidation of soft slurries has regained interest over the past years as natural slurries (such as dredged material from silted channels) are thought to be economically good alternatives to the use of sand for building or filling materials. Large-scale projects have been initiated in the Netherlands (Marker Wadden, Kleirijperij) to study the feasability of large-scale dewatering and strenghening of soft slurries.

Modelling settling and consolidation can be done using advection-diffusion equations, as the one given above.

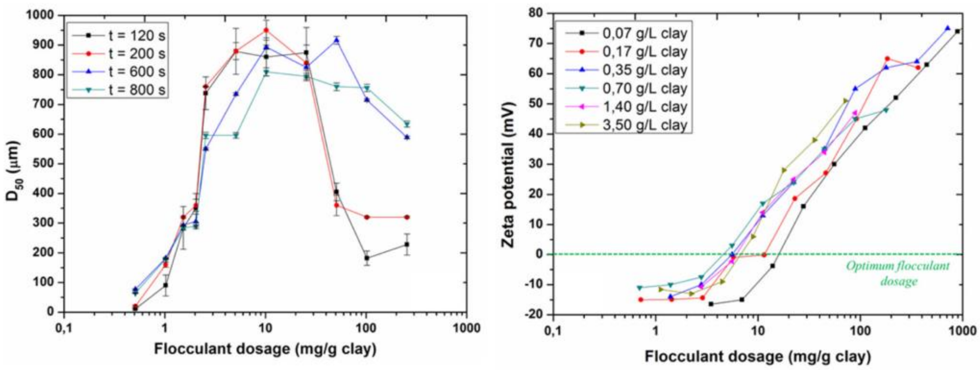
Recently [1], we have proposed a modelling protocol to assess the parameters required to predict the consolidation behaviour of soft slurries over time. We showed that with three parameters, found by fitting the settling height as function of time for a slurry of a given volume fraction (density), it was possible to predict the settling behaviour of slurries of same composition but different volume fractions.

Currently, we work at improving the model, so as to include flocculation and ripening processes.

[1] Chassagne, C. Understanding the natural consolidation of slurries using colloid science. In Proceedings of the European Conference on Soil Mechanics and Geotechnical Engineering, Reykjavik, Iceland, 1–6 September 2019.

3.6. Predicting the flocculation of clay

From traditional DLVO theory [1], it is expected that the point where the zeta potential becomes zero, flocculation is optimum. This has been verified over the years for a number of systems, and recently we have conducted a systematic investigation, by varying both clay and flocculant concentration to confirm this for clay suspensions in presence of a cationic flocculant [2]. We have also studied in detail the relation between flocculation and zeta potential for samples originating from the Rio Doce river [3], that was contaminated in November 2015 after the failure of a tailings pond dam at an iron mine in southeastern Brazil.



Mean floc size and zeta potential as function of flocculant to clay ratio: the point of zero zeta potential corresponds to the largest floc sizes.

[1] *Introduction to Colloid Science* by Claire Chassagne, DAP press, ISBN 9789065624376 (2019)

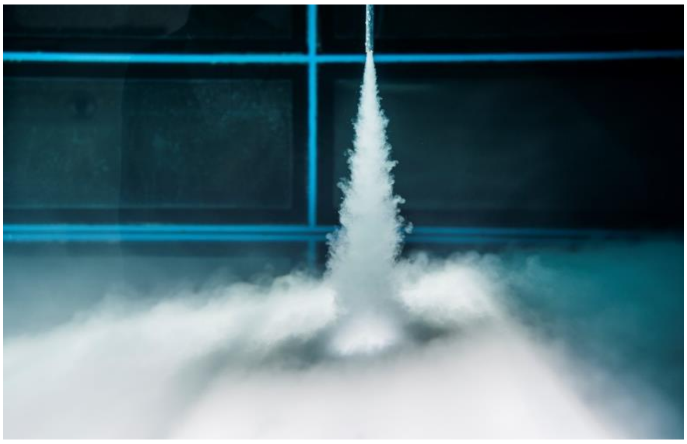
[2] Grilo, C. F., Chassagne, C., Quaresma, V. D. S., van Kan, P. J. M., & Bastos, A. C. (2020). The role of charge reversal of iron ore tailing sludge on the flocculation tendency of sediments in marine environment. Applied Geochemistry, 117, [104606]

[3] Shakeel, A., Safar, Z., Ibanez, M., van Paassen, L., & Chassagne, C. (2020). Flocculation of clay suspensions by anionic and cationic polyelectrolytes: A systematic analysis. Minerals, 10(11), 999.

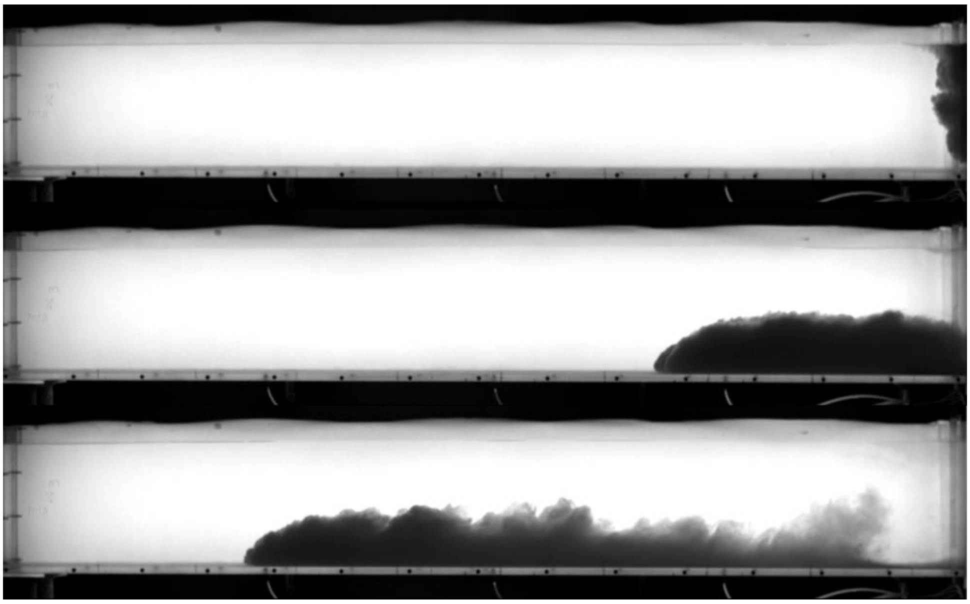
ELECTRO MUD FLOC MUD

3.7. Sediment dispersion and pickup in seabed mining activities

Technology development for sustainable, reliable and efficient mining of polymetallic nodules in the deep seas requires careful design, thorough understanding of the physical processes and integrated testing of all equipment and systems. As the collector collects nodules, it also collects sediments, which need to be separated and discharged at the seafloor, generating a sediment plume that can spread



over a vast area. Such plumes can be of impact on the local environment and unfortunately. In our research, we aim at better prediction of these plumes to support assessment of the potential environmental impact caused by the mining activity. Simultaneously, optimization of the sediment discharge conditions is expected to significantly reduce the spreading of sediment. It is in the so-called near-field region (< few hundreds of meters) relative to the mining vehicle or activity, where engineering solutions can influence the development and spreading of the sediment plume. All sediment deposition that can be achieved in the near-field region, will help to limit the area affected by the sediment plume.



This research is done in collaboration with partners from MUDNET to answer in particular the question

- How can flocculation be implemented in large-scale sediment transport models? (See 3.2)

3.8. Seismic characterization and monitoring of fluid mud

Fluid mud is one of the factors impacting the navigability in the ports and waterways. The bathymetry in areas with fluid-mud layers need to be routinely measured to provide navigation charts used by the vessels. Characterizing and monitoring the properties of the fluid mud can help understand the

geotechnical behavior of fluid mud. A good characterization requires capturing the dynamic changes of the bathymetry caused by storm events or dredging activities. This calls for non-invasive continuous measurements that provide high resolution in imaging of the water/fluid-mud interface and the characterization of the fluid-mud layer. Seismic methods using different types of waves would allow such imaging and characterization [1,2]. Techniques borrowed from marine seismic exploration can provide accurate imaging the water/fluid-mud layer and thus the bathymetry in the ports and waterways [2,3]. Estimation of the wave velocities inside the fluid-mud layer with high accuracy and repeatability would allow monitoring the geotechnical behavior, such as yield stress, of fluid mud in a nonintrusive and reliable way [1-3].

In the MSc work of M. Buisman and D. Danzler, the PhD work of M. Buisman, and Postdoc work of X. Ma, we investigate the following research questions:

- What seismic exploration techniques are best suited for high-resolution imaging of the water/fluid-mud interface?
- What type of waves can be used for continuous monitoring of the level of the water/fluid-mud interface?
- What seismic exploration techniques are best suited for high-resolution characterization and monitoring of the fluid-mud layer?
- What is the relation between the velocities of longitudinal and transverse waves and the yield stress and density of the fluid mud?
- What seismic receivers and sources can be used for monitoring and characterization of the fluid mud and how best to utilize them?

[1] Buisman, M. (2019). Seismic analysis of fluid mud. MSc thesis, Delft University of Technology.

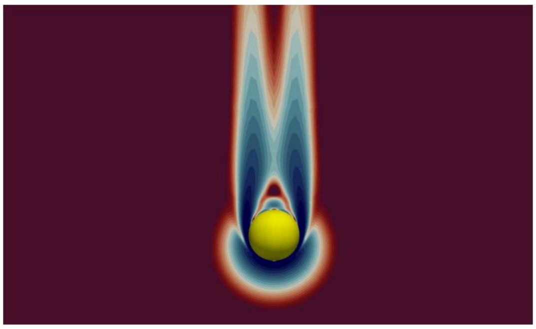
[2] Draganov, D., Ma, X., Buisman, M., Kiers, T., Heller, K., & Kirichek, A. (2021). Non-intrusive characterization and monitoring of fluid mud: laboratory experiments with seismic techniques, DAS, and DTS. in A. Maning, Ed., Sediment Transport - Recent Advances: IntechOpen, ISBN 978-1-83881-119-8, revision submitted.

[3] Ma, X., Kirichek, A., Shakeel, A., Heller, K., & Draganov, D. (2021). Laboratory seismic measurements for layer-specific description of fluid mud and for linking seismic velocities to rheological properties. Journal of the Acoustical Society of America, revision submitted.

3.9. Numerical modelling of ships navigating through mud

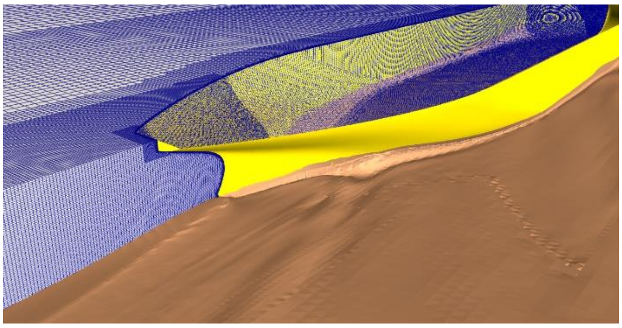
In this research we use Computational Fluid Dynamics (CFD) to investigate the effect of mud on the forces acting on ship. Rheological measurements showed that the Herschel-Bulkley model is suitable to describe the flow of mud. The Herschel-Bulkley model has been thus implemented in a viscous-flow multiphase CFD code called ReFRESCO, developed by the Maritime Research Institute Netherlands (MARIN).

Before applying the code to simulate the flow around a ship, the code has been tested both to ensure that there are no coding mistakes and that the code can handle a flow dependent viscosity with strong gradients across the fluid domain. Firstly, the code has been rigorously verified both for laminar single- and two-phase flows using the Method of Manufactured Solutions [1]. Secondly, the code was tested on simple benchmark problems such as Poiseuille flow and the flow around a sphere (Figure 1). Comparison with results from literature revealed that the code is able to reproduce the drag force on objects in Herschel-Bulkley fluids.



Contour diagram of viscosity for a sphere moving through a homogeneous Herschel-Bulkley fluid in laminar regime. Dark red and blue are high and low viscosity, respectively.

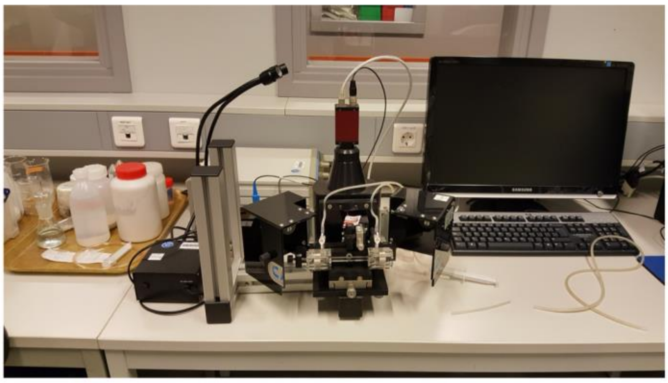
Current research is focussing on assessing how well standard RANS models such as k-omega and Spalar-Allmaras perform when applied to turbulent Herschel-Bulkley flows. Simulations of the flow of Herschel-Bulkley fluids over a flat plate at high Reynolds number showed that different RANS models can produce completely different results. Current efforts are thus being made to study how standard RANS can be modified to account for non-Newtonian rheology.



Furthermore, the CFD code has been applied to simulate the flow around a ship model both in homogeneous mud and in two-layer system with water on top and mud on the bottom. The goals of these simulation were both to test capability of the CFD code and to study the effects of mud rheology and UKC on the ship's resistance.

[1] Lovato, S., Toxopeus, S. L., Settels, J. W., Keetels, G. H., & Vaz, G. (2021). Code Verification of Non-Newtonian Fluid Solvers for Single-and Two-Phase Laminar Flows. *Journal of Verification, Validation and Uncertainty Quantification*, *6*(2), 021002.

4. Laboratory equipment



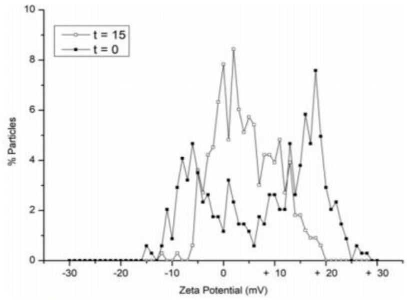
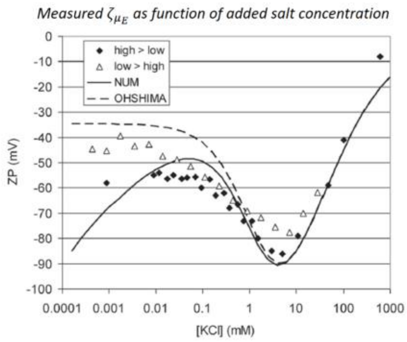


Fig. 7. Kaolinite particles (50%) in the presence of goethite (50%) at pH = 3 in demi water; At t = 0 (filled square) two zeta potential peaks are observed, one corresponding to kaolinite particles (around −10 mV) and one corresponding to goethite particles (around + 20 mV). After 15 min (open square), the particles have aggregated and formed aggregates of zeta potential of approximately 0 mV.

ZetaCompact (CAD instr.) – FL TUD/Deltares

This instrument is used to measure the electrophoretic mobility of suspended particles, from which particle size, particle surface properties and fluid properties can be derived. The ZetaCompact is more appropriate to study dense particles in the range > 1 µm (the software compensates for possible gravity effects), whereas the ZetaNano (Malvern Instr. – also in the lab) is suited for nanometric to micrometric particles

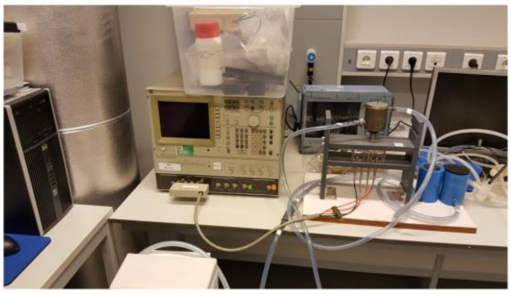
Grilo, C. F., Chassagne, C., Quaresma, V. D. S., van Kan, P. J. M., & Bastos, A. C. (2020). The role of charge reversal of iron ore tailing sludge on the flocculation tendency of sediments in marine environment. Applied Geochemistry, 104606.



ZetaNano (Malvern) – FL TUD/Deltares

This instrument is used to measure the electrophoretic mobility of suspended particles, from which particle size, particle surface properties and fluid properties can be derived. The instrument principle is based on laser Doppler velocimetry and can be used for particles < 10 µm. The ZetaNano can also be used to assess particle size, based on Dynamic Light Scattering, i.e. for particles < 1 µm.

Chassagne, C., & Ibanez, M. (2012). Electrophoretic mobility of latex nanospheres in electrolytes: Experimental challenges. Pure and Applied Chemistry, 85(1), 41-51.



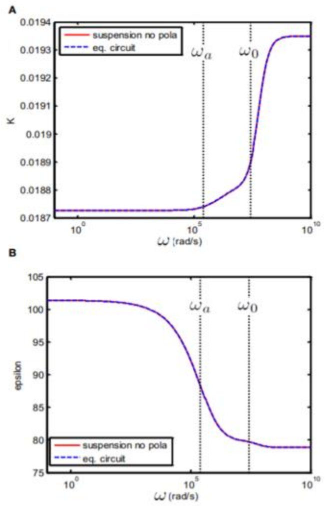
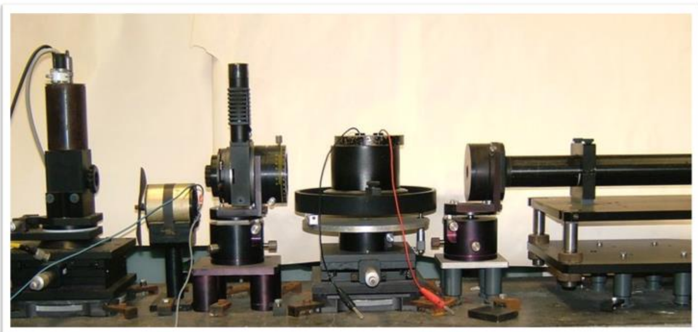


FIGURE 4 | (A) Conductivity K(S/m) and **(B)** relative permittivity (epsilon) as function of frequency of a suspension of 100 nm colloidal spheres ($\phi = 1\%$, $e\zeta/kT = 4$) in a 1 mM electrolyte solution of monovalent salt solution for which $D_1 = 2 \times 10^{-9}$ m^2/s and $D_2 = 3 \times 10^{-9}$ m^2/s. Red curve: the suspension in the absence of electrode polarization, corresponding to ε_s and K_s from Equation (8). Dashed blue curve: the equivalent circuit model corresponds to the theoretical prediction provided that one takes $R_b = 1/K_s$, $C_b = \varepsilon_0\varepsilon_s$ and $C_{EP} = 0$.

Dielectric Spectroscopy – FL TUD/Deltares

This home-made instrument combines a HP impedance meter and a home-made cylindrical cell. It can be used for a range of sediment suspensions, from very dilute to very concentrated. From the measurements, characteristic properties (particle size, particle surface properties, fluid properties) can be assessed. The measurements can also be used to confirm density measurements, as the suspension density is an input parameter of the associated model.

Chassagne, Claire, et al. "Compensating for electrode polarization in dielectric spectroscopy studies of colloidal suspensions: theoretical assessment of existing methods." Frontiers in chemistry 4 (2016): 30.



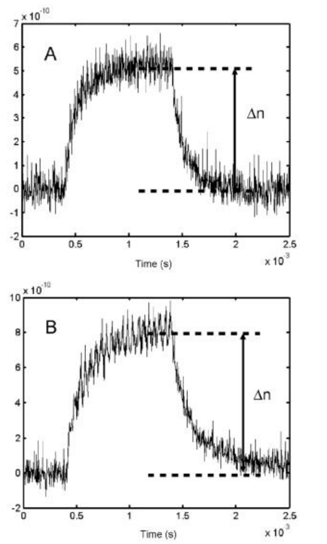


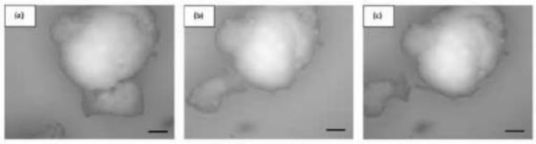
Fig. 1. Observed electrically induced birefringence Δn as a function of the time for (A) 35-nm diameter particles at a volume fraction of 0.46%, 2 mM of added KCl, and (B) 47-nm diameter particles at a volume fraction of 0.53%, 0.5 mM of added KCl.

Kerr effect – FL TUD/Deltares

This instrument is used to measure the change in the birefringence of a colloidal suspension as a function of applied electric field. Both field amplitude, duration and frequency can be changed.

Kerr effect studies enable to assess information about particle's relaxation mechanisms, surface charge and collective interactions.

Chassagne, C., Bedeaux, D., vd Ploeg, J. P. M., & Koper, G. J. M. (2006). Electrically induced anisotropy in a colloidal dispersion of nanospheres as measured by electric birefringence. Journal of colloid and interface science, 295(2), 528-534.



Images of cationic polyelectrolyte-based kaolin suspensions subjected to oscillation at (a) t = 0 s, (b) t = 3 s, (c) t = 5 s; Gap width = 100 lm; f = 1 Hz; A = 0.4 mm. Sequence of images shows the break-up of flocs. Scale bar represents 70 mm.

Rheometer (Haake, MARS, ThermoFisher) – FL TUD/Deltares

This instrument gives the relation between shear stress and shear rate, from which yield stress and viscosity of mud samples can be obtained (see RheOptiCAD)

RheOptiCAD – FL TUD/Deltares

This instrument is designed to visualize the changes in sample structure as function of shear rates – to be used in combination with a rheometer, which can measure stresses.

Shakeel, Ahmad, Paul JM van Kan, and Claire Chassagne. "Design of a parallel plate shearing device for visualization of concentrated suspensions." Measurement 145 (2019): 391-399.

Shakeel, A., Kirichek, A., & Chassagne, C. (2019). Rheological analysis of mud from Port of Hamburg, Germany. Journal of Soils and Sediments, 1-10.

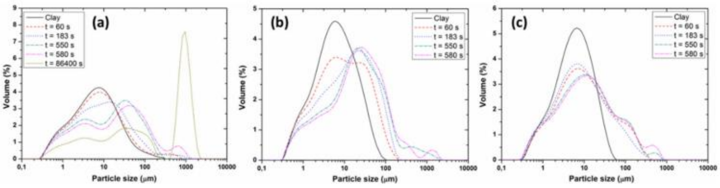
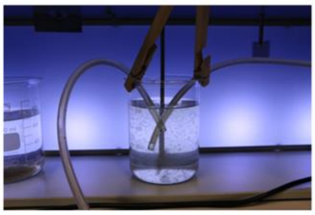


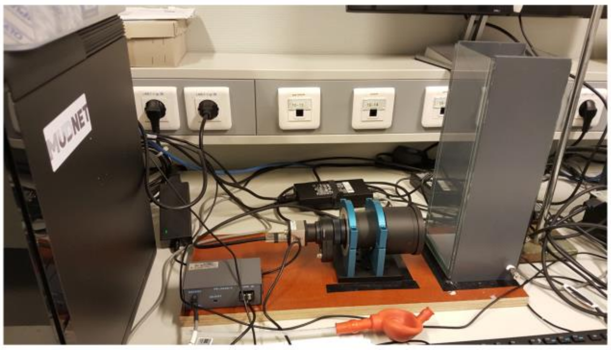
Figure 3. Particle size distribution for 0.7 g/L clay concentration with (**a**) 0.05 mg/g, (**b**) 0.25 mg/g and (**c**) 2.5 mg/g anionic flocculant. "Clay" represents the particle size distribution (PSD) of pure clay before addition of flocculant and t = 0 s corresponds to the time when the flocculant was added.



ParticleSizer (Malvern, MasterSizer 2000) – FL TUD/Deltares

This instrument is used to follow the evolution of particle size distribution in time, hereby enabling to study flocculation as function of applied shear rate (controlled independently via a peristatic pump)

Shakeel, A., Safar, Z., Ibanez, M., van Paassen, L., & Chassagne, C. (2020). Flocculation of Clay Suspensions by Anionic and Cationic Polyelectrolytes: A Systematic Analysis. Minerals, 10(11), 999.



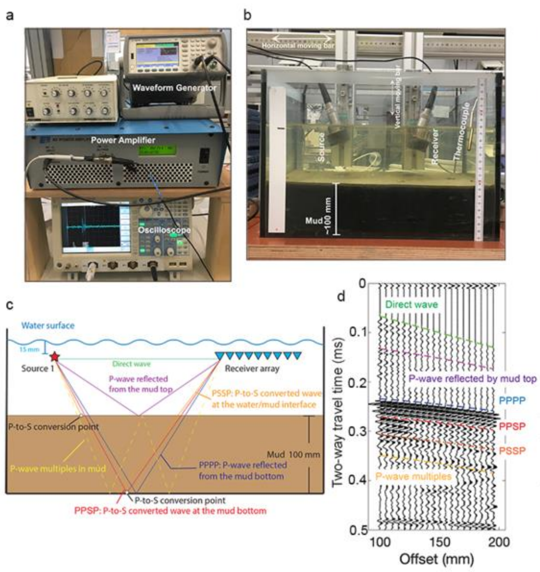
FLOCCAM – FL TUD/Deltares

This home-made instrument combines a settling column and a high-speed, full-frame camera coupled with a telecentric lens. It enables to measure floc sizes and settling velocities from which their density can be estimated.

Sediment Balance – FL TUD/Deltares

This instrument records the mass as function of time of sediment that settles at the bottom of a settling column, from which particle size or density can be deduced.

Reflection seismic measurement system



(a) Signal-control part including the waveform generator, the power amplifier, and the digitial oscilloscope.

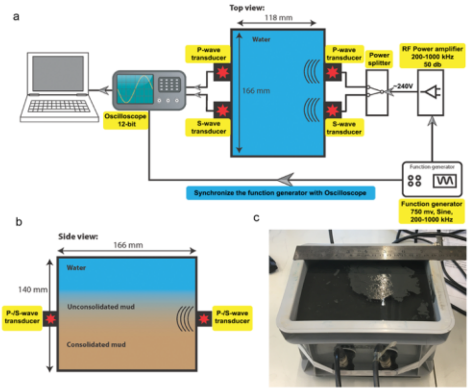
(b) ultrasonic-transducer position manipulator and the fluid-mud tank.

(c) Sketch of the reflection-measurement geometry and travelpaths of the different expected wave-type arrivals. The travelpaths are only illustrative and do not represent the actual propagation travelpaths.

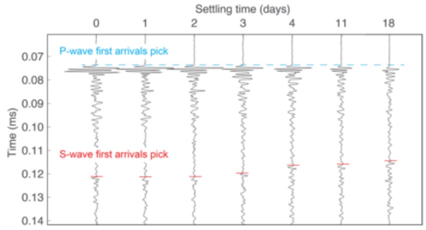
(d) Recorded common-source gather duet of Source 1.

Ma, X., Kirichek, A., Heller, K., & Draganov, D. Seismic Reflection Investigations of Fluid Mud: Laboratory Tests for Layer-Specific Characterization. In 82nd EAGE Annual Conference & Exhibition (Vol. 2020, No. 1, pp. 1-5). European Association of Geoscientists & Engineers*

Transmission seismic measurement system



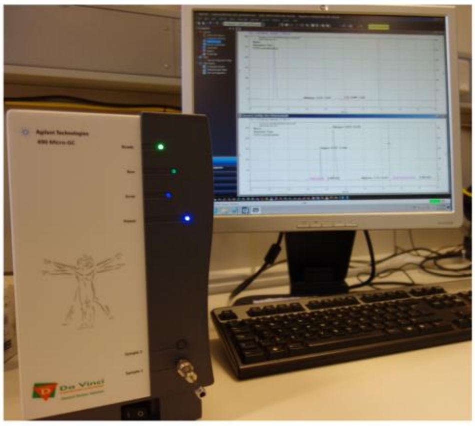
(a) Sketch of the seismic-transmission measurement system showing top view of a box containing water and fluid mud, to which are attached ultrasonic transducers.
(b) Sketch of the side view of the box with the ultrasonic transducers.
(c) The photo of the actual box and transducers installed on it.



Arrival time and amplitudes of the direct lognitudinal and shear waves using seismic transmission measurements during the settling process.

This instrument is used to measure the transmitting velocities and amplitudes of longitudinal and shear waves. The ultrasonic transducers installed on the measurement chamber to record the waveform. The velocities of longitudinal and shear waves can be derived by picking their first arrivals. The centre frequency of the transducers is 1 MHz. A waveform generator, an amplifier, and a digital oscilloscope are associated with the transducers for the excitation, amplification, and visualization of the signals, respectively.

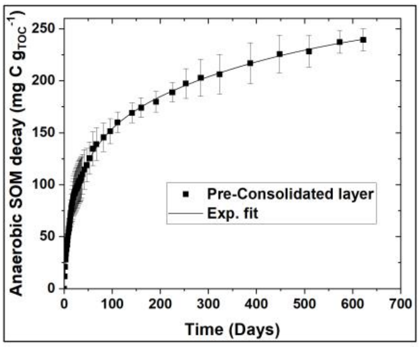
Ma, X., Kirichek, A., Shakeel, A., Heller, K, & Draganov, D. Investigation of fluid mud using seismic and rheological measurements, Journal of the Acoustical Society of America, revision submitted.*



Gas chromatograph (GC) - Agilent Technologies, 490 Micro-GC / TUD, CiTG, Geoscience, 00.710

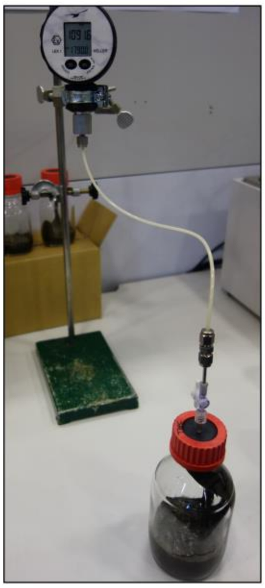
This instrument is used to measure the gas concentrations i.e. carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2) and oxygen (O_2) of e.g. incubated soils or sediments (compare Zander et al. 2020), landfill gases, etc. The gas concentration ranges between 0.01-15% (low range) and 15-60% (high range) with accuracy of 0.01 % for low range and 0.1% for high range.

***Zander** F, Heimovaara T, Gebert J. 2020. Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. Special issue. https://doi.org/10.1007/s11368-020-02569-4.*



Gas Endeavour – Bioprocess Control / TUD, CiTG, Geoscience, 00.710
This instrument is used to measure the gas flow of (anaerobically) incubated samples. The minimum gas flow is 2 ml per day (LDL). For smaller volumes, under anaerobic incubations, the evolution of pressure can be used. The system can be prepared to detect oxygen consumption.

Website Bioprocess Control: *https://bioprocesscontrol.com/bpc_products/gas-endeavour/*



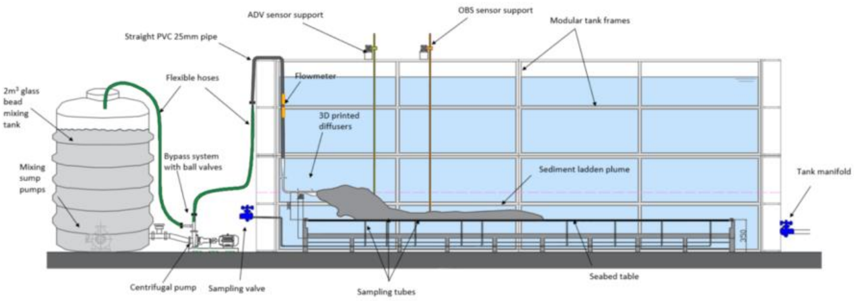
Incubation facilities / TUD, CiTG, Geoscience, 00.710 / K0.410 / K0.820
The instrument on the left is a differential pressure sensor (LEX1 by Keller, left), used to measure the pressure during anaerobic incubation. On the bottom right, a warming cabinet is shown, used for faster degradation at increased temperature. The six warming cabinet at CiTG have a capacity of about 300 Schott-bottles with a volume of 500ml. More details about microbial incubation can be found in Zander et al. (2020).

Zander *F, Heimovaara T, Gebert J. 2020. Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. Special issue. https://doi.org/10.1007/s11368-020-02569-4.*

Standard chemical analyses (Eh, pH, EC, NH_4^+, DOM) and instruments (phomometer, centrifuge) / TUD, CiTG, Geoscience, 00.710

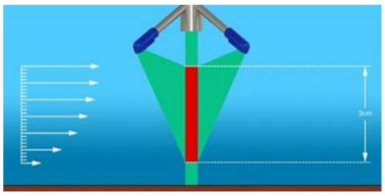
The centrifuges can be used for volumes up to 25 ml (Labofuge 300 by Heraeus, up left) and up to 250 ml (Megafuge 1.OS by Heraeus, up right) per container. The multi-parameter analyser (C1010 by Consort, down left) is used to measure redox potential (Eh), pH value (pH) and electrical conductivity (EC). The photometer (DR 6000 by Hach-Lange, down right) is used among others for measurement of dissolved organic carbon in pore water (DOC) and ammonium in pore water (NH_4^+) as also described in Zander et al. (2020).

Zander *F, Heimovaara T, Gebert J. 2020. Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. Special issue. https://doi.org/10.1007/s11368-020-02569-4.*

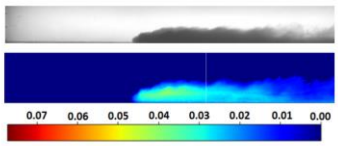


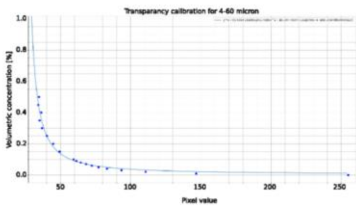
Modular flume setup

The modular flume consists of a set of steel or plexiglass panels, of 2.5 m in length and 1 m in height. The panels can be adjusted in any combination to accommodate large scale experiments. There are also two LED panel tables available, one with a level table, and one at an elevation. The flume has already been used for breaching experiments, vertical plume discharge and horizontal plume discharge conditions.



Accoustic Doppler Velocimetry Profiler (Nortek Vectrino Profiler)
This instrument can be used to measure velocity profile in a setup. The measurement principle is based on the Doppler shift. The sensor is able to measure velocity profiles in 3 dimensions, over a range of 30 mm, in increments of 1 mm. Backscatter of the SNR can be used to relate volumetric concentration for low concentrations of suspended matter. The sensor is mounted on a flexible stem (fig above) and it is possible to use the sensor in water depths up to 10 m.





Lock exchange setup for sediment laden turbidity currents
The tank, measuring 3x0.2x0.4 m (lxwxh), is made of plexiglass. Behind the tank, a LED panel is mounted. Diffuse photo paper is used to generate a uniform light source from the back of the tank, enabling the contours of the current, or in case of low concentrations, the transparency of the turbid mixture to be filmed. By making use of a HS camera in a dark-room, in situ concentration maps of the current can be generated.

5. Curriculum Vitae of MUDNET team

Claire Chassagne
FLOCMUD, RHEOMUD, ELECTROMUD, 4DMUD
Associate Professor – section of Environmental Fluid Mechanics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

I did my academic studies in Paris, where I was born, at the Université Pierre et Marie Curie (Sorbonne Université). I specialized in colloid science and electrokinetics and got my PhD (cum laude) at Leiden University in the Netherlands. In my PhD thesis, entitled *Double Layer Polarization in Electric Fields*, I propose a new analytical electrokinetic theory that describes what happens when an electric field is applied on a charged spherical colloidal particle in water. After my PhD, I did a postdoc at the University of Geneva (Switzerland) and another at the Norges teknisk-naturvitenskapelige universitet (NTNU) in Norway. In 2006, I came to the TU Delft where I work ever since.
Over the years, I diversified my research while I still continued to work in the field of electrokinetics. A very concrete example of the application of electrokinetics is its use in determining the flocculation ability of a suspension: under which conditions will (or will not) particles in the water aggregate together? Electrokinetic experiments can give an answer.

How did you come being interested in colloid science ?

After an introduction to the subject, during a master class, I came to realize how colloids are important in our daily life. Colloidal particles are microscopic particles: most drinks, food and drugs contain colloidal particles, microorganisms (bacteria, algae) are colloids, and one of the most abundant colloid on Earth is mineral clay.

What is your current research about?

With my students, we are developing several lines of research, all aiming to get a better understanding in the processes that lead to the observations made in the lab or in the field in terms of sediment behaviour. For instance, how and why do algae and sediment interact? What is the relation between the composition of mud and its flocculation, settling and consolidation behaviour? What are the rheological properties of fluid mud in harbours? For all of these research lines, colloid science comes one way or another into play.

What is MUDNET bringing to you?

My research is focussed on the colloidal, i.e. microscopic scale. The largest representative volume used in our experiments is a litre (a volume 10^{15} larger than the volume of a colloidal particle!) so clearly, in view of the application of my research, I needed to connect with researchers whose expertise is on larger scales. Also, I am a physicist, and studying the interactions between colloidal particles requires a multidisciplinary approach: (bio)chemistry play a key role for explaining the changes in physical properties of a clayey system over time. With the MUDNET team, we are able to link our expertise's and hereby offer a full multiscale and multidisciplinary approach to a specific research topic.

Alex Kirichek
RHEOMUD, SONIMUD, 4DMUD, NAUTIMUD
Assistant Professor – section of Ports and Waterways
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

My research interests lie on the boundary between water and soil. In particular, I have a passion for bringing new knowledge on fluid mud behaviour in ports and waterways including rheology of Non-Newtonian fluids, fluid mud dynamics, consolidation and in-situ monitoring of fluid mud for navigational purposes.
I joined Deltares as a researcher for mud-related research topics in the end of 2018. Before joining Deltares, I had been conducting my researcher at the Faculty of Civil Engineering & Geosciences at Delft University of Technology for about 7 years. First, I did my PhD study in Applied Geophysics and Petrophysics conducting a multi-disciplinary research by combining electrokinetics and sesimics knowledge for characterizing porous media. After completion of my PhD, I carried out a postdoctoral research at the section of Ports & Waterways, where I investigated new nautical bottom criteria for the Port of Rotterdam and tested innovative port maintenance methods. I will come back to the section of Ports & Waterways as an Assistant Professor in April 2021.

How did you come being interested in research topics that are related to fluid mud?

One of the goals of my postdoctoral research at TU Delft was to conduct a rheological investigation of fluid mud for navigational purposes. Very quickly I realized that studying a Non-Newtonian behaviour of mud is not a trivial task. First of all, there was no reliable protocols for conducting rheological analysis of mud in the laboratory (our research team filled this gap, see RHEOMUD). Second, rheological properties are stress and time dependent because of thixotropy. Therefore, complex thixotropic behaviour of mud had to be studies in-depth (b.t.w., solved by RHEOMUD as well). Third, all in-situ measurements of rheological properties had intrusive one-dimensional measuring principles. Thus, my geophysical background didn't allow me to have a nice sleep during the nights until our team launched the SONIMUD project aiming to develop a non-intrusive seismic monitoring technique for nautical applications. There is a long list of the research lines that our multidisciplinary team has opened on fluid mud. I have a feeling that there is more to come.

What is your current research about?

At this moment, I am synergising the knowledge that I our team has developed on fluid mud in order to apply our findings for developing a new sustainable port maintenance strategy including sailing through mud, conditioning of mud and creating natural barriers for preventing further spreading of fresh sediment into port basins.

What is MUDNET bringing to you?

MUDNET is an interdisciplinary research platform consisting of experts with different expertise. Sharing our recent findings within MUDNET always helps to reassess our research conclusions and look at the research questions from a different angle.

Julia Gebert
BIOMUD, µBIOMUD, 4DMUD
Associate Professor – section of Geo-Engineering
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

I studied biology, microbiology and soil science at the University of Hamburg in Northern Germany. Combining these fields to work on a very applied question, I completed my PhD on the microbial oxidation of methane in landfill cover soils. During my postdoc time, I built the second focus of my work, the feasibility of using dredged sediments as construction material for dikes and embankments. Hamburg operates one of the largest ports in Europe, so just as in the port of Rotterdam, dredging and handling of dredged sediments are a hot topic! I then joined Hamburg Port Authority, later becoming head of the Environmental Services Unit. My task was to oversee the environmental monitoring activities associated with dredging, relocation of sediment in the river, treatment and disposal on land. In this position, I got a good glance on what it all takes to operate a major port! In 2017, I was appointed Associate Professor in the section of Geo-Engineering at TU Delft and moved to The Netherlands.

What fascinates you about mud research?

Mud is so much more than just a mucky mess! It interfaces aquatic and terrestrial systems, with soils becoming sediments , when eroded, and sediments becoming soils when deposits have reached sufficient elevation and become unsaturated. Mud is full of life, harbouring many biological, chemical and physical processes. It allows us beautiful fundamental insights into the coupling of these processes while also being at the very heart of operation of ports and waterways as key infrastructure for our society. In this way, mud research and applied question practice benefit from each other.

What is your current research about?

Together with my students, my mud-related research focuses mainly on the degradability and stability of sediment organic matter (BIOMUD), both under aerobic and under anaerobic conditions. Organic matter plays a key role in sediment rheological behaviour and, obviously, for the cycling of organic carbon in the sediment-aquatic system and therefore also for the carbon footprinting of sediment management. In µBIOMUD, we focus on identifying patterns of the microbial community facilitating these processes and how the community is affected by changing environmental conditions. In a different research line, I study how sediment can be ripened into soil for use as earthen construction material. This is particularly relevant as climate change necessitates heightening and strengthening of our dikes.

What is MUDNET bringing to you?

MUDNET brings me in close contact with colleagues that study mud from the perspective of a different discipline and that master complimentary methods. These contacts have broadened my scientific horizon considerably, it is exciting to continue learning new things! Beyond the personal pint of view, our collaboration allows us to far better understand the behaviour of fine-grained sediments and to offer much more comprehensive solutions to the mud-related challenges as faced, for example, by ports and water boards.

Deyan Draganov
SONIMUD, 4DMUD
Associate Professor – section of Applied Geophysics & Petrophysics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

I am born in Sofia, Bulgaria. I obtained my PhD (cum laude) in 2007 from TU Delft. Currently, I am an Associate Professor at the section of Applied Geophysics and Petrophysics at the Department of Geoscience and Engineering at TU Delft (The Netherlands). My expertise and interests lie in the theory and application of seismic exploration methods, and especially seismic interferometry, from ultrasonics, through near-surface and exploration, to global scales. Since 2004, my research has resulted in 61 published papers, one book publication, and four book chapters. In 2010, I received the J. Clarence Karcher Award from the Society of Exploration Geophysicists. I was awarded VENI in 2007 (08115) and VIDI in 2012 (864.11.009) personal grants by the Dutch science foundation NWO. From 2006 till 2017, I served as Associate Editor for Geophysics and from 2017 to 2019 as an Assistant Editor for Geophysics.

How did you become interested in research topics that are related to fluid mud?

Since 2010, I am researching a specific application of seismic interferometry for layer-specific characterization of objects and the Earth's subsurface. Dr. Alex Kirichek, with whom we worked on CO2 sequestration, approached me in 2016 and asked if we could collaborate on seismic investigation of fluid mud. I found the idea very interesting and proposed to investigate it using layer-specific characterization by applying seismic interferometry.

What is your current research about?

With my students and postdocs, we are working on developing and applying seismic-interferometric techniques for investigation of archaeological and heritage sites, for mining exploration, for sequestration of CO2 and geothermal-energy extraction, for induced seismicity, and, of course, for characterization and monitoring of fluid mud in ports and waterways.

What is MUDNET bringing to you?

MUDNET gives the opportunity to look at the problem we are researching from different angles and to discuss it different experts, both from industry and academia. This helps keep the research focused on practical applications and address it using the right theoretical approaches.

Geert Keetels
NAUTIMUD, 4DMUD
Assistant Professor – section of Dredging Engineering
Faculty of Mechanical, Maritime and Materials Engg., TU Delft

Tell us about yourself

My research interest is Computational Fluid Dynamics (CFD) of sediment transport with a focus on dredging engineering applications. I obtained my PhD in applied physics at Eindhoven University of Technology in 2008 and continued as researcher and consultant at Deltares in Delft. Presently I'm working as an assistant prof in the dredging engineering section of the faculty of mechanical, material and maritime engineering (3me). I'm the project leader of the NWO project Sailing Through Fluid mud.

How did you become interested in research topics that are related to fluid mud?

After discussion with the Port of Rotterdam, Dr. Alex Kirichek and Dr. Claire Chassagne it became clear to me that this is an important topic and also very interesting from a scientific point of view.

What is your current research about?

In close collaboration with Marine Research Institute the Netherlands (MARIN) we have implemented several non-Newtonian models in their dedicated CFD code for ship hydromechanics ReFRESCO. After careful code verification we study the hydrodynamic forces for many mud conditions and sailing scenario's. In coming months experiments will start to further study the performance of the code.

What is MUDNET bringing to you?

It is interesting to address the complexity of fluid mud from several directions. MUDNET is also a recognizable contact point for stakeholders and academic partners.

Rudy Helmons
FLOCMUD, 4DMUD
Assistant Professor – section of Dredging Engineering
Faculty of Mechanical, Maritime and Materials Engg., TU Delft

Tell us about yourself

My name is Rudy Helmons. I did both my bachelor and master in mechanical engineering at Eindhoven University of Technology. My specialization is in fluid mechanics specializing in fluid mechanics. During my thesis project, I got introduced to the field of Deep Sea Mining, in which I am still involved. After my master, I started at IHC MTI, the research department of Royal IHC. During that time, I also obtained my PhD at Delft University. Within my PhD-research, I modeled the forces required to excavate deep sea deposits. Afterwards I remained at DUT to do a post-doc and finally become assistant professor in the group of Dredging and Offshore Engineering. In that position, I am responsible for education and research related to subsea operations, with an emphasis on deep-sea mining.

What is your current research about?

Together with my colleagues, we do research related to soil-tool-water interactions, typically for dredging and (deep sea) mining. Our contribution in MUDNET is two-fold. On one hand, we aim to improve the existing models to more accurately predict the interactions the spread of human induced turbidity plumes. One of the major challenges is that, so far, flocculation and its effects on the spread of these plumes is not yet considered in the dispersion models. The second line of our research focusses on how the processes and equipment can be improved to limit the disturbance caused to the environment.

What is MUDNET bringing you?

My research focusses mainly on the interaction of mining equipment, seabed and water column. In those applications, we look at length scales typically in the range of the equipment and larger, up to a few hundred meters. Obviously, on these length scales we can only consider the mixture of water and mud. Knowing how differently mud will and can behave, and what micro-mechanisms are causing the change in behavior will be beneficial to my research. Through the MUDNET community, we are in close connection with experts who really understand mud at the smaller scales.

Xu Ma
SONIMUD
Postdoc – section of Applied Geophysics & Petrophysics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself/ who are you?

I am working as a postdoc at the Section of Applied Geophysics and Petrophysics, TU Delft. I obtained the PhD in 2015 from Virginia Tech. My current research is mainly about using geophysical acoustic techniques to characterize fluid mud. I use laboratory experiments to measure the ultrasonic transmission and reflection velocities of fluid mud. Before joining MUDNET, I worked on mining-induced seismicity and seismic imaging, as well as hydrate-bearing sediments. In 2013, I received the Syd S. Peng Ground Control in Mining Scholarship, Society of Mining Engineering. In 2015, I received the ORISE postdoc fellowship from Department of Energy, the US.

How did you come being interested in fluid mud?

Before starting the research of fluid mud, I worked on porous media such as rocks and hydrate-bearing sediments. The experiences and skills of applying in porous media can be certainly used for investigating fluid mud. Fluid mud, however, has its unique characteristics. Unlocking the mystery of fluid mud can ensure the safe navigation of vessels in ports and waterways. Better adapting geophysical techniques in fluid mud to advance the knowledge of fluid mud really intrigues me.

Do you think your work can be of interest to industry?

Advised by Deyan Draganov and Alex Kirichek, I used the seismic transmission and reflection measurements to study the correlations between the propagation velocity of shear waves and the yield stress. The confirmation of the relationship between them can help establish a new geophysical technique to estimate the yield stress. This new technique is of low cost and is more efficient than the traditional methods that usually require the penetration into fluid mud.

How is the working environment at MUDNET?

Working at MUDNET is very fascinating. This is a truly interdisciplinary project to understand how fluid mud behaves in ports and waterways. The interdisciplinary team of geophysicists, geo-engineers, geo-microbiologists, physicists, and CFD experts from TU Delft and Deltares gives me multiple perspectives to think out of the box. Some knowledge from other disciplines can interpret some findings from my research in an astonishingly new way. On the other hand, I can see that how the input from my research benefits others' studies.

Florian Zander
BIOMUD
PhD candidate – section of Geo-Engineering
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

My name is Florian Zander and I was born in Hamburg (Germany). In April 2018, I started my PhD at TU Delft. Before, I did my B.Sc. in Geoscience and my M.Sc. in soil science both at the University of Hamburg. For my B.Sc., I analysed dredged sediments form the Port of Hamburg for the use in dike constructions, my M.Sc. was about the influence of urban soils on roadside trees. I am interested in soils and sediments, because of their high importance for our daily life i.e. for buildings, food production, flora and fauna, etc.

What is your PhD about?

My PhD is about the behaviour of sedimentary organic matter during degradation processes. I want to understand the function of (degraded) organic matter in suspended and settled sediments, i.e. its influence on the fluidic, slow settling sediment layers in harbour basins. The biogeochemical knowledge about fluid mud, supplemented by physical knowledge about fluid mud, will help harbour managements worldwide to save money by reducing their dredging costs.

What is your current research about?

My current research is about controls of organic matter degradation in suspended matter and sediments to find driving parameters that lead to organic matter degradation in tidal harbour sediments. Furthermore, with another (MUDNET) PhD candidate, I am currently working on the influence of organic matter degradation on fluidic and static yield stresses, focussing on long- and short-term stabilization processes in the mud.

What is MUDNET bringing to you?

MUDNET gives me the opportunity to share knowledge with other scientists interested in mud. The outcome of the MUDNET community can be applied to worldwide harbours dealing with fluid mud.

Stefano Lovato
NAUTIMUD
PhD candidate – section of Dredging Engineering
Faculty of Mechanical, Maritime and Materials Engg., TU Delft

Tell us about yourself

My name is Stefano Lovato and I was born in Turin, Italy. Since I was kid I always been fascinated by boats and ships, which inspired me to follow my academic studies in Marine Engineering and Naval Architecture at the University of Genoa. I did my master project at Maritime Research Institute Netherlands (MARIN), where my job was to verify and test a boundary-element method code for predictions of underwater noise propagation. During this experience, I developed a growing passion for scientific research and numerical simulations, which motivated me to apply for a PhD position. Thus, after my graduation at the University of Genoa in 2017, I moved to Delft, Netherlands, to start working on a PhD project at the Delft University of Technology about numerical prediction of muddy bottom effects on ships resistance and manoeuvrability.

What is your PhD about more precisely?

My current research is about the development and verification of a Computational Fluid Dynamics (CFD) code named ReFRESCO, originally developed by the Maritime Research Institute Netherlands, in order to study the effects of mud layers on ships hydrodynamics. Numerical methods are becoming more and more a popular tool to study complex flow phenomena, also thanks to the rapid growth of computer power over the past decades. In fact, solving numerically the governing equations of fluid mechanics is finally possible for a large variety of engineering problems. Nevertheless, one the most difficult part of CFD is to choose the right mathematical model. In particular, when it comes to study the effects of muddy bottoms on ships navigation, the choices of the rheological and turbulence models are certainly among the most challenging ones.

Do you think your work can be of interest to industry?

My work can be certainly of interest for the maritime industry. The presence of mud in many harbours channels around the world can have severe impacts on ships' manoeuvrability. This is cause of concerns among port authorities, who must decide, in order to guarantee safe navigation, whether it is more convenient to either impose a restriction on the size of ships that are allowed to access the channel or to remove the mud by intensive dredging operations. Both options come with great costs for harbours and consequently for society. Therefore, a better understanding of the impact of mud on navigation will help to create better regulations, allowing for an optimal compromise between costs and safe navigation.

What is MUDNET bringing to you?

MUDNET is giving me great opportunities to discuss and work with experts from different mud-related disciplines, which allows me both to extend my academic network and to bring new important insights to my research.

Ahmad Shakeel
RHEOMUD
PhD candidate – section of Environmental Fluid Mechanics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself!

Currently, I am a PhD student at TU Delft and working under the supervision of Dr. Alex and Dr. Claire. I completed my Masters in Engineering Rheology under Erasmus Mundus program from three European universities including KU Leuven Belgium, University of Minho Portugal and University of Calabria Italy. I did my master thesis related to the rheological characterization of polymeric gels for food and pharmaceutical applications. Before that, I completed my Bachelor studies in Chemical (Polymer) Engineering from Pakistan.

What is your PhD research about?

The main objective of my PhD research is to analyse the rheological properties of mud samples collected from Port of Hamburg, Germany. In short, I am investigating the influence of density and organic matter content on the behaviour of mud rheology, in addition to the seasonal and spatial variation within the port. Based on this detailed analysis, a simple empirical model is also developed to predict the rheological properties particularly yield stress of mud samples, from the flow curve, as a function of above mentioned parameters.

How did you come being interested in rheology of fluid mud?

As I already did extensive rheological experiments during my master thesis on soft matter (gels), this topic attracts my attention because of its focus on rheology of an interesting colloidal system having yield stresses. Fluid mud belongs to an exciting class of non-Newtonian materials and the knowledge of their rheological characteristics is quite important for ports and waterways applications.

Do you think your work can be of interest to industry?

The rheological properties particularly yield stress of mud sediments can be quite important for defining nautical bottom (i.e., navigable mud layers), which is typically defined on the basis of density. However, in the presence of organic matter, only density is not enough to predict the rheological properties of mud sediments and yield stress can be effectively used as a criterion for nautical bottom.

How is the working environment at MUDNET?

MudNet is a great platform to exchange ideas on a same topic (i.e., fluid mud) in different domains along with a nice research collaboration, in order to answer various research questions. For instance, I am working with Florian (working on BioMud project) in order to investigate the effect of organic matter degradation on the rheological properties of mud samples.

Zhirui Deng
FLOCMUD
PhD candidate – section of Environmental Fluid Mechanics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

My name is Zhirui Deng and I was born in Guangxi, China, and I finished my Bachelor degree in the Marine School of Sun Yat-sen University in Guangzhou, China. After that, I was recommended to directly continue my PhD study in Estuarine and Coastal Science at State Key Laboratory of Estuarine and Coastal Research (SKLEC) at East China Normal University, during that time, I received the funding from Chinese Scholarship Council (CSC) and became a PhD candidate of Department of Hydraulic Engineering at TU Delft and under the supervision of dr. ir. Claire Chassagne and prof. dr. ir. Zheng Bing Wang. My research topic is related to sediment transport, especially the biological effects on sediment flocculation.

What is your PhD research about?

Flocculation is a critical process of sediment transport in the estuarine area. My research aims to characterise the sediment flocculation processes under algae's effect by combining two main methods: in-situ observations and laboratory experiments. On the one hand, the temporal and spatial variation of sediment flocculation processes were analysed in detail. On the other hand, the mechanisms of algae effect on sediment flocculation were obtained in a series of experiments. Besides, I also studying the related behavior and properties of cohesive sediments. The knowledge developed from the bio-sediment flocculation can be applied to future sediment numerical modelling researches.

How did you come being interested in sediment flocculation?

Because my bachelor majors are marine biology and coastal engineering, I was naturally curious about the combination of the two disciplines, which encouraged me to choose the research topic about algae and sediment. Research of sediment flocculation has a characteristic of the intersection of multi subject, and it is a potential research field, has a comprehensive application view.

Do you think your work can be of interest to industry?

The sediment flocculation processes strongly influence the estuarine human activities like dredged channel, port expansion and maintenance, sea reclamation, etc. However, the sediment transport process is so complex that many factors affect the biological effects. Thus, a better understanding of sediment flocculation processes is beneficial to estuarine management and related industries.

Waqas Ali
FLOCMUD
PhD candidate – section of Environmental Fluid Mechanics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

My name is Waqas Ali, and I was born in Rawalpindi, Pakistan. I did my bachelors and masters in mathematics in Pakistan. During my masters in mathematics, I worked on multiphase flows that intrigued me to learn more about fluid flows and continue applying my mathematical skills in the domain of fluid mechanics. Therefore I moved to Grenoble France, where I did my Master 2 in environmental fluid mechanics at Université Grenoble Alpes. During my master degree in environmental fluid mechanics, I studied subjects ranging from geophysical flow to turbulence, numerical or experimental fluid mechanics. I enjoyed these courses by learning how one can implement theoretical knowledge into practical applications. From 2016-20 I worked on flow modelling of anisotropic fibre reinforced fluid at the University of Twente & ThermoPlastic Research Centre. In October 2020, I started my doctoral studies at the Technical University of Delft.

How did you come being interested in Fluid Mechanics?

Fluids in different forms, feature in human life and are a vital component of our existence. My research interest mainly lies in combining mathematical models to fluid flow problems applied to different industries. My first assignment was on a non-linear boundary value problem using the homotopy analysis method for bubbly two-phase flow. In my master 2 project, I formulated an asymptotic solution for the flow generated by reflection of the internal shear layer. Before starting at TU Delft, I worked on a project to understand fibre-reinforced polymer behaviour in compression modelling for the aerospace & automotive industry applications.

What is your current research about?

In my current research work, I focus on studying the effect of flocculation on dredging plumes. My project is part of a bigger project known as PlumeFloc, where various educational institutions and industries work together on different scales in order to understand sediment plumes generated during the deep-sea mining process. I plan to conduct multiple lab experiments for flocculation using different experimental settings, e.g. different types of flocculants & their concentration, different clay concentrations, different shear rates, etc.

What is MUDNET bringing to you?

I am happy to be a part of Mudnet where experts from various disciplines work on fluid mud, collaborate and share their research. Since my background is in Mathematics and its applications to fluids, through Mudnet, I get a different perspective on my research from my colleagues with expertise in rheology, biological fluids, acoustic to mention few.

Zeinab Safar
FLOCMUD
Postdoc/PhD candidate – section of Environmental Fluid Mechanics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

I am starting a Postdoc project on the fluid mud of port of Emden. In between I am finalizing my PhD which is about Suspended Particulate Matter (SPM) formation and settling in the Dutch coastal area. During my PhD, I focused on the flocculation process in natural waters, studying organic matter and sediment interactions. Before the PhD, I accomplished my Master in geochemistry at Utrecht University (UU) department of Earth Sciences. This master program included courses such as soil chemistry, aquatic chemistry and organic geochemistry. My Bachelor was a HBO, at Hoge school Utrecht (HU) as well in analytical chemistry.

What is your current research about?

During my PhD, I have combined in-situ data and laboratory experiments to analyse the SPM formation and settling through the water column. The role of natural organic matter and algae species was crucial, and the water column salinity stratification was of great importance. A conceptual model was developed to include the organic matter as a parameter in the large scale sediment transport models. In the new project I am working with fluid mud, investigating the influence of freshwater addition to it and changing settling behaviour and microbial community and other parameters.

What is MUDNET bringing you?

As my new project is fully with fluid mud, the MUDNET offers a nice opportunity to meet the experts in this topic and to exchange ideas with them. Being involved with this community could have fruitful future research ideas.

Mohamed Elerian
4DMUD
PhD candidate – section of Dredging Engineering
Faculty of Mechanical, Maritime and Materials Engg., TU Delft

Tell us about yourself

My name is Mohamed Elerian. I did my bachelor in Egypt in the field of Mechanical engineering and my master in Germany in water resources engineering from Stuttgart university. In both studies, I focused on fluid mechanics and then later I specialized on fluid dynamics. I worked on the industry after my bachelor studies for 4 years as a project engineer for buildings technologies and one year after my master studies in Germany as project engineer for the fluid extinguishing systems in factories. At the moment, I am in the middle of my PhD journey where I am studying how to reduce plume impact resulting from deep sea mining operations.

What is your current research about?

I am working in the field of deep sea mining (DSM). My main focus is on the polymetallic nodules collection. One of the major challenges regarding DSM is its environmental impact. Together with my teammates, we are trying to optimize the water-sand plume discharge from a hydraulic collector. We are using our knowledge on multiphase flows to investigate the sediment behaviour. Our main objective is to decrease plume intensity through increasing sediments settling potential and optimizing the discharge conditions. We are expecting that the flocculation will play a considerable role on increasing the settling velocities of the sediment particles. Implementing and testing the flocculation process on the current dispersion models is needed at the current phase of DSM research.

What is MUDNET bringing you?

My research focusses mainly on the sediment-fluid interaction in the deep sea environment. Cohesive sediments are dominant in such environments and my current focus is studying and increasing flocculation potentials in deep sea mining plumes. Investigating the micro-mechanisms of the flocculation process in deep sea environment is beneficial to my research. Through MUDNET groups, I am in close connections with cohesive sediment experts.

Menno Buisman
SONIMUD
iPhD candidate – section of Applied Geophysics & Petrophysics
Faculty of Civil Engineering and Geosciences, TU Delft

Tell us about yourself

Currently, I am an Industrial PhD candidate at TU Delft and the Port of Rotterdam. I received my MSc in applied geophysics from TU Delft, ETH Zurich and RWTH Aachen. During my master thesis, I developed passion for science and tackling complex problems.

What is your PhD about?

My research, which is funded by the Port of Rotterdam, Rijkswaterstaat, Smart Port and the Port of Hamburg, is about the application of fibre optics in ports and waterways. I focus on measuring the location of mud, implying the depth of ports and waterways, and the strength of mud, to determine if we can still sail through the mud. I believe that fibre optics could change the way we monitor (fluid) mud, because of how versatile and how cheap these fibres are. These fibres can be used to measure both temperature as seismic vibrations over a long range. I focus on the latter case.

How did you become interested in fibre optics?

During one of my elective courses for my master, I studied the advantages of using fibre optics over conventional measuring devices, such as geophones and hydrophones. I followed the developments with great interest and I noticed this field is gaining popularity rather fast. This is related to the rapid increase in performance and because of the relatively low costs.

Do you think your work can be of interest to industry?

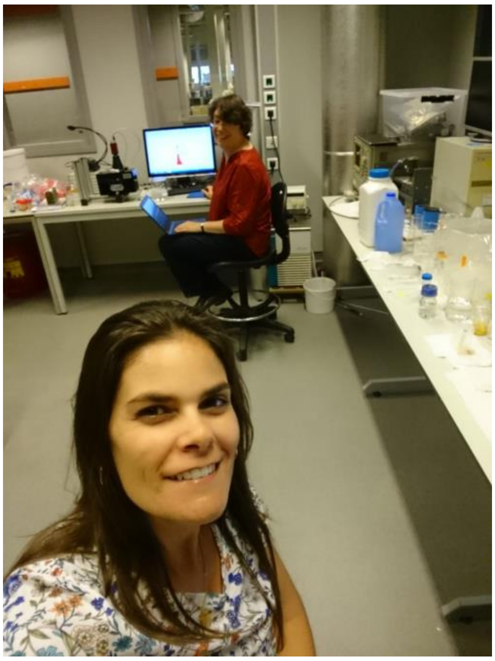
With my research I hope to have a major contribution to the current measuring techniques. The reason why I think this is possible, is because of the low costs of fibres and their long lifespan (likely over 20 years). This, among many other things, makes measuring mud with optical fibres, an attractive economical alternative compared to the current standard measuring techniques.

Laboratory activities 2018 - 2020

Snapshots from the video Port Authority's research program PRISMA - innovative dredging methods

Ahmad Shakeel preparing a sample for rheological measurements

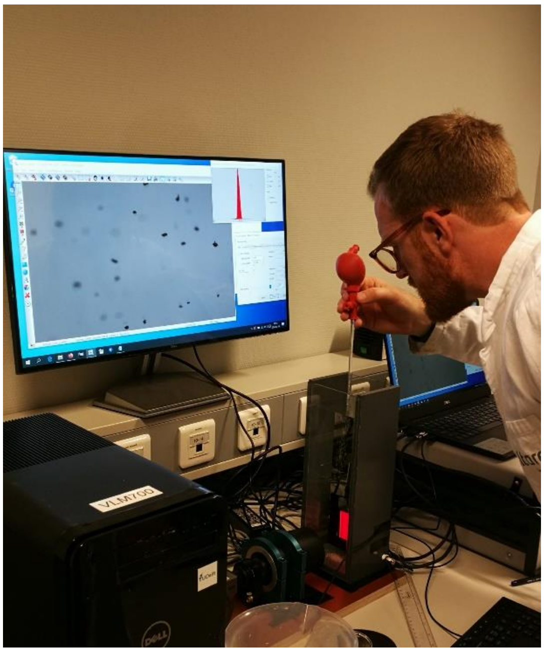
Alex Kirichek and Claire Chassagne preparing samples for video and particle size analysis



Visit of Prof. Andy Manning, with Zhirui Deng, Zeinab Safar and Claire Chassagne – Coffee break after LabsFLOC experiments

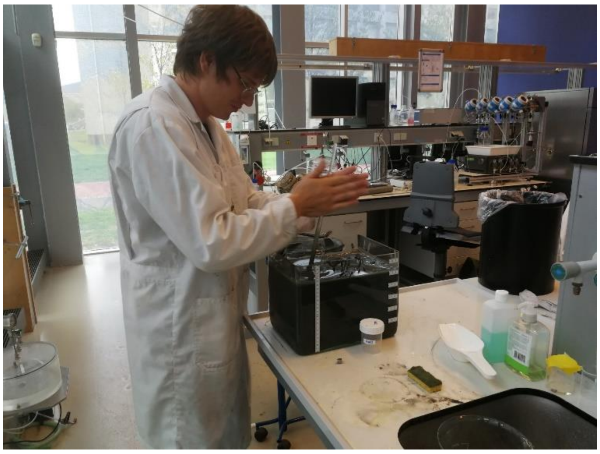
Visit of Dr. Caroline Grilo zeta potential measurements

Laboratory activities 2018 - 2020



Ryan McIver is testing the FLOCCAM

Menno Buisman in the laboratory



Waqas Ali is measuring particle size as function of time to study flocculation

The RheOptiCAD is operational before Christmas!

Laboratory activities 2018 - 2020

Discussing the best strategy to analyze mud: Alex Kirichek, Julia Gebert and Zeinab Safar µBIOMUD is launched!

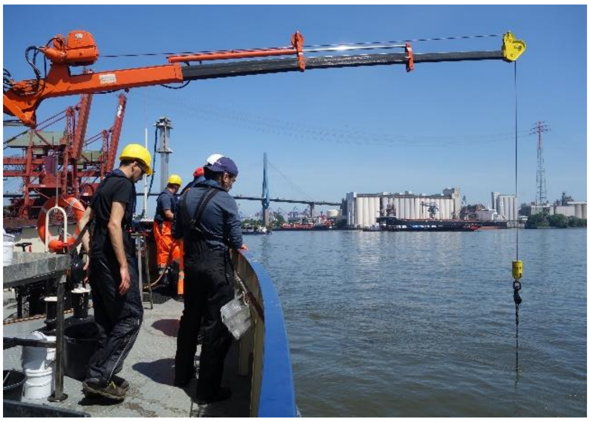
Large-scale seismic measurements (with a DAS cable)
Menno Buisman and MSc student Tjeerd Kiers

Preparing the conference: the coordinator Stefano Lovato at work during a MUDNET meeting!

In-situ activities 2018 - 2020

Sampling campaign in the Hamburg harbour

Julia Gebert and her favourite dike!

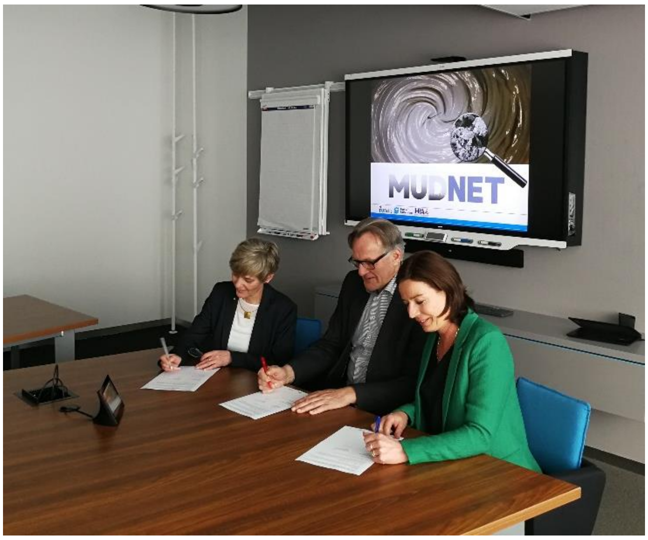


Zhiriu Deng during a monitoring campaign in China

Andy Manning and Alex Kirichek during a monitoring campaign in the Rotterdam harbour

Celebration of the graduation of Gosia Wyszynska

Celebration of the graduation of Maria Ibanez



Signature of the Memorandum of Understanding between TU Delft, Hamburg Port Authorities (HPA) and the Port of Rotterdam (PoR) – creation of MUDNET

CELEBRATIONS 2018 - 2020

6. Output

1. Kirichek, A., Chassagne, C., Winterwerp, H., & Vellinga, T. (2018). How navigable are fluid mud layers. Terra et Aqua, 151, 6-18.
2. Deng, Z., He, Q., Safar, Z., & Chassagne, C. (2019). The role of algae in fine sediment flocculation: In-situ and laboratory measurements. Marine Geology, 413, 71-84.
3. Shakeel, A., van Kan, P. J., & Chassagne, C. (2019). Design of a parallel plate shearing device for visualization of concentrated suspensions. Measurement, 145, 391-399.
4. Shakeel, A., Kirichek, A., & Chassagne, C. (2019). Is density enough to predict the rheology of natural sediments?. Geo-Marine Letters, 39(5), 427-434.
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15. De Lucas Pardo, M. A., & Kirichek, A. (2020). Wormen versnellen ontwatering slib. Ground Water, 18-19.
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