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Grain Size of the Seabed Sediments Underlying Polymetallic Nodules in the Exploration Area of Interoceanmetal

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ABSTRACT

Deep seabed sediments have been classified in various ways: either by the size of particles, the description of components, the process of formation, or some combination of these three. The simplest means for describing sediment is by the size distribution of its particles. This is termed *grain size* or *gradation*. Classifications based on grain size have been widely used in marine geological research. They represent the systematic division of continuous ranges of sizes into classes or grades.

KEY WORDS: Deep seabed sediments; grain and aggregate size distribution; ultrasonic treatment.

INTRODUCTION

Particle size distribution of soils is one of the basic parameters used in soil science and engineering geology. Interoceanmetal (IOM) in cooperation with West Pomeranian University of Technology, Szczecin, Poland, carried out in geotechnical lab series of laser-aided measurements in the device *Mastersizer 2000* to gain grain (particle) size and aggregate distribution on 137 samples of fine-grained cohesive sediment collected from the seabed of the IOM exploration area in the Clarion-Clipperton, Pacific Ocean. The method is based on the measuring of laser light intensity scattered on the sediment particles. Being compared with the sedimentation method the method of laser diffraction is suspected of underestimation of clay fraction due to non spherical shape of clay particles.

DEEP SEABED SEDIMENTS

In the IOM exploration area (eastern part of Clarion Clipperton Zone) the deep sea sediments belong to *Marquesas* and *Clipperton* formations. Based on the origin and composition they can be divided into four litho-stratigraphic units. The lowest lithofacies I consists of biogenic calcareous ooze (foraminifera silty clay and coccolith -foraminifera silty clay) which is the product of primarily biogenic accumulation with more than 50 % siliceous or calcareous microfossils. The overlying lithofacies II is made up of radiolarian ooze (fig. 1), X-ray amorphous. These sediments are biogenic, pelagic and detrital, and produced in part by halmyrolysis and erosion of basalt. Sediments of these two lithofacies are thought to represent *Marquesas* formation (Oligocene and Miocene age). Lithofacies III is represented by zeolithic clay (phillipsite) or reddish brown clay and denser zeolithic

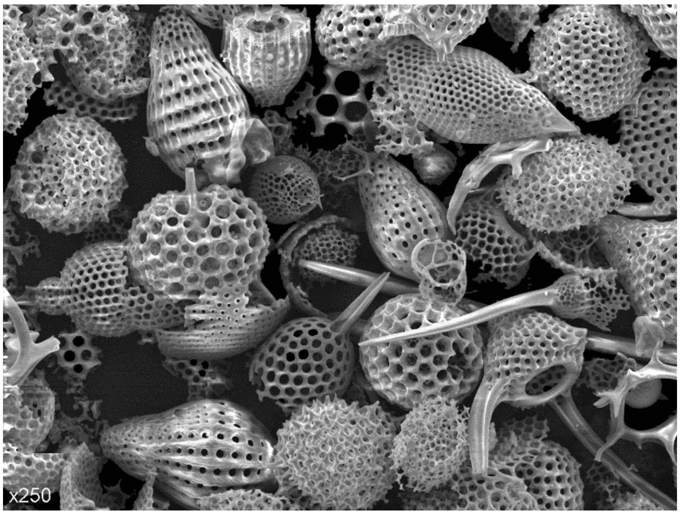

Fig.1: Radiolaria Source: nestlaboratory.com

crusts of Miocene and Pliocene age. Higher up in the section are sediments assigned to lithofacies IV with siliceous silty clay, ethmodiscus clay, and calcareous silty clay. This section features a distinct top layer consisting of siliceous silty clay which grades into lighter-coloured sediment with a mottled appearance. Sediments of lithofacies III and IV have been attributed to the *Clipperton* formation. In addition, reworked diatom ooze (fig.2) occurs that is typically lacking in polymetallic nodules.

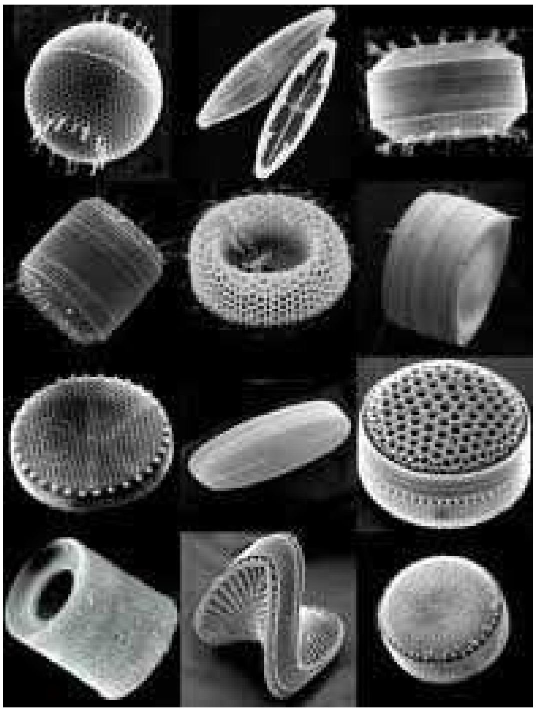

Fig.2: Diatoms (Diatomophyceae)   Source: paleontologia.pl

From the geotechnical point of view deep seabed sediments are cohesive soils with large proportion of fine-grained particles which attract each other. This is true when the fine-grained particles include a significant amount of clay. They contain hydromuscovite (2M illite), kaolinite plus chlorite (13-18 %), and montmorillonite (20-30 %). Typical of montmorillonite is its mixed-layered structure with illite packets and a low Fe^{+2} content. Clay minerals are platy (non spherical), with negative surface charge. Water in contact with particles becomes organized in a manner dictated by the charges around the plate. Sufficient ions are present in natural water to permit altering of the surface charge on some clay particles. Different clay minerals exhibit stronger or weaker negative charges.

CLASSIFICATIONS

Classification Casagrande (1948) relied on No.200 sieve separation on coarse and fine grained with 50 % criterion. Dimension D=0.074 mm corresponds to the size of the particles, which may be visible to the naked eye. Such classification is mainly used by engineers (table 2).

The most commonly used scale is that of Krumbein [1963], who based his classification on the systems of Wentworth [1922] and Udden [1914]. Krumbein's scale commences at 1mm and increases and decreases by powers of 2; each grade limit is twice as large as the next smaller grade limit. Particle sizes are normally expressed as *phi (φ) units*. The value of φ is equal to the negative logarithm to the base 2 of the particle diameter in millimeters and is a more convenient expression of size:

$$\varphi = -\log_2 D/D_0 \qquad (1)$$

where
φ is the Krumbein phi scale,
D is the diameter of the particle, and
D_0 is a reference diameter, equal to 1 mm (to make the equation dimensionally consistent).

This equation can be rearranged to find diameter using φ:

$$D = D_0 \times 2^{-\varphi} \qquad (2)$$

Then, the subdivisions for the finer deep seabed sediments are as shown in table 1 and table 2 (geology column).

Table 1. A part of Wentworth scale for fine-grain soils

Millimeters	**Wentworth Grade**	**Phi φ Scale**
>2	Granule	-1
>1	Very coarse sand	0
>1/2	Coarse sand	1
>1/4	Medium sand	2
>1/8	Fine sand	3
>1/16 (0,0625)	Very fine sand	4
>1/32	Coarse silt	5
>1/64	Medium silt	6
>1/128	Fine silt	7
>1/256 (0,0039)	Very fine silt	8
<1/256	Clay	>8

Table 2 shows the size ranges that define different particle sizes as used by engineers, geologists, and soils scientists. Each profession has a slightly different assignment of size range for defining the same particle. This evolved from the different purposes of each profession in describing the particle size distribution of a soil.

Table 2. A Comparison of Particle-Size Classes used by Geologists, Engineers, and Soil Scientists (in millimeters)

Class	**Geology**	**Engineering**	**Soil science**
Pebbles	> 2 (Gravel)	> 4.75	> 2
Sand	2 – 0.063	4.75 – 0.074	2 – 0.050
Silt	0.063 – 0.004	0.074 – 0.005	0.050 – 0.002
Clay	< 0.004	< 0.005	< 0.002

Source: Johnson, De Graff, 1988

METHODOLOGY AND PHILOSOPHY

The dispersion of soil samples for particle size distribution measurement can be carried out with two equivalent methods:

- chemically (using hexametaphosphate solution), or
- physically (by ultrasound).

Our studies were carried out in a specialized laboratory for geotechnics in West Pomeranian University of Technology, Szczecin, Poland, on a modern laser instrument «Mastersizer 2000» of Malvern Instruments. The intensity of laser light registered on the particular detectors of the measurement system can be converted to the particle size distribution. Laser diffraction measures an angular variation of intensity of light scattered as a laser beam passes through a dispersed particulate sample. Large particles scatter light at narrow angles with high intensity, whereas small particles scatter light at wider angles but with low intensity (fig.3). The size range accessible during the measurement is directly related to the angular range of the scattering measurement. Modern instruments make measurements from around 0.02 degrees through to 135 degrees. A logarithmic detector sequence, where the detectors are grouped closely together at small angles and more widely spaced at wide angles, yields the optimum sensitivity. Finally, the detector sequence is generally set up such that equal volumes of particles of different sizes produce a similar measured signal. The measurement range of the apparatus used is 0.02–2000 µm.

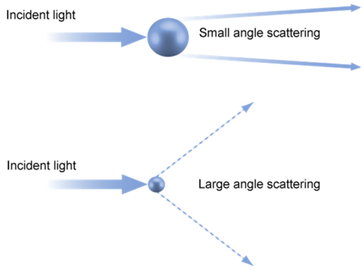

Fig.3: Scattering of light from small and large particles

Totally 137 samples of seabed sediments were taken at 49 box corer stations of 0-43 cm depth interval within the first exploration block H11 (5372 km^2). Firstly the samples in the natural state (as aggregates) were analyzed, after which came a 20 kHz ultrasonic treatment for 5-7 minutes smashing the sample to primary particles. Thus, the two sets of data were obtained, after which the composition of the seabed sediments can be seen:

- **aggregate** (size),
- **grain** size.

With a view to maximizing the use of relatively large sample set (137 samples), it was possible to carry out both aggregate and granulometric analysis with 2 different angles, namely, on the known types of sediments (depending on hydrated amorphous silica or opal content), and on the depth interval of sampling in the box corer:

1. The types of sediments angle:

- 35 samples of siliceous silty clays, where SiO_2 > 10 %,
- 13 samples of transforming type from siliceous to slightly siliceous silty clays,
- 65 samples of slightly siliceous silty clays, where SiO_2 = 5 – 10 %,
- 4 samples of transforming type from slightly siliceous clays to zeolithic clays,
- 18 samples of zeolithic clays, where SiO_2 < 5 %,
- 1 sample of radiolarian ooze, and
- 1 sample of zeolite crust.

2. The depth interval of sampling angle:

- 49 samples 0-10 cm,
- 45 samples 10-15 cm,
- 36 samples 25-30 cm,
- 7 samples 30-40 cm.

With accordance to table 2 the size ranges for geologists were chosen.

RESULTS

The results obtained are presented in tables, charts and Sheppard triangles. Medians of aggregate and grain composition of any type of sediment document silt class as prevailing class in deep sea sediments (table 3). For grains the silts form 54 to 60 % of the sample and, for aggregates slightly less: 53-55 %. Logically, after ultrasonic treatment the clayey proportion rose and the sandy proportion dropped. The ultrasonic treatment caused the growth of clayey constituent of siliceous silty clays for 121 % (11.8 → 26.1 %) while of slightly siliceous and zeolithic clays only 84 and 87 % respectively (table 3). Possibly opal content can play some small role in the ability of the sediment to be easily dispersed.

Table 3. Aggregate and grain size composition of deep sea sediment according to type of sediment (median data)

	Aggregates, %			Grains, %		
Type of sediment	Sand	Silt	Clay	Sand	Silt	Clay
Siliceous silty clays	35.7	53.5	11.8	14.0	59.8	26.1
Slightly siliceous silty clays	28.5	54.6	16.5	13.9	56.5	30.5
Zeolithic clays	29.0	53.2	17.0	13.1	54.5	31.9

Table 3 as a whole arranges deep sea sediment to clayey silts regardless the type of sediment.

As for the depth of sediment sampling 4 intervals (levels) were fixed. The composition can be better seen in two charts (fig.4 and fig.5) which indicate that the contents of particular classes practically remain the same at all levels. Silt component oscillates between 50 and 60 % for both aggregates and grains while sands and clays switch their positions after ultrasonic treatment (smashing).

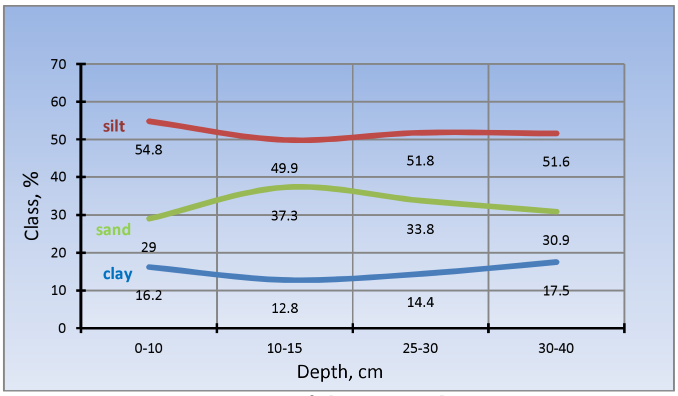

Fig.4: Aggregate composition of deep sea sediments in H11 in given depth intervals

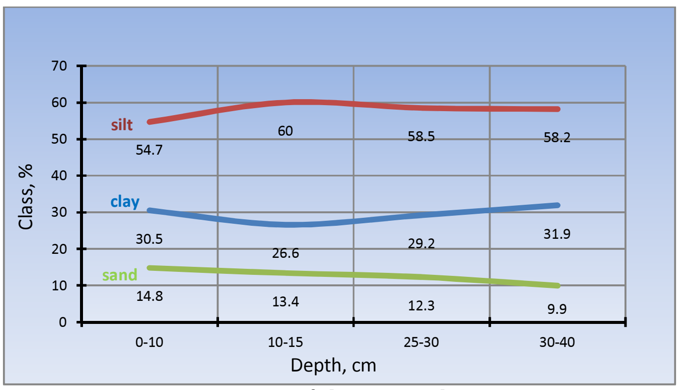

Fig.5: Grain size composition of deep sea sediments in H11 in given depth intervals

Shepard's triangles show the shift of sandy silts "plume" as aggregates, fig.6 (a), to the clayey silts window as grains, fig.6 (b).

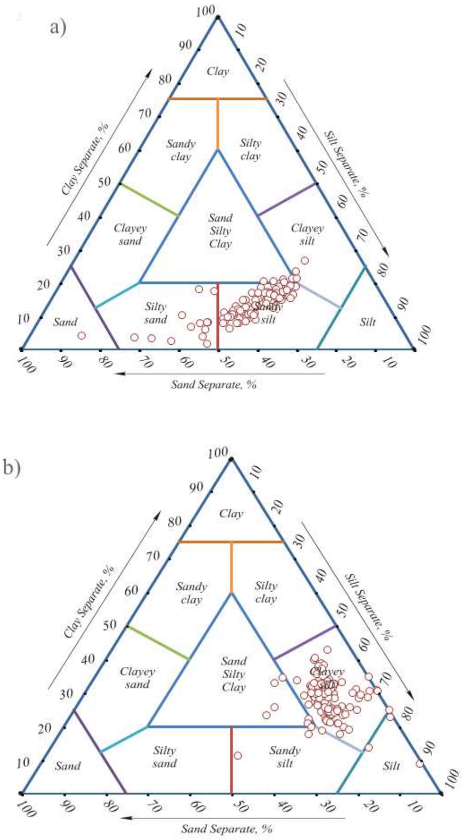

Fig.6. The Shepard's triangles with aggregate (a) and grain size (b) distributions of deep seabed sediments in the IOM exploration area

Table 3 below summarizes all the results of the experiment. The prevailing grain size class of deep sea sediments within exploration block H11 noted as average and/or median is silt. As the second most frequent fraction is clay we are entitled the deep sea sediment to call **clayey silt**. This statement is strongly supported with small values of standard deviation for any class.

Table 3. Final statistics of aggregate and grain size composition of deep sea sediments within exploration block H11

	Aggregates, %			Grains, %		
Class	Sand	Silt	Clay	Sand	Silt	Clay
$\bar{x}$	33.2	52.1	14.7	13.8	57.5	28.7
med	29.7	54.06	15.9	13.7	56.9	29.7
Stdev δ	10.2	6.7	4.4	6.6	6.5	5.6

OTHER RESULTS

The same as above set of samples was analyzed at University of Szczecin, Institute of Marine and Coastal Changes, in the Laboratory of Geology and Paleogeography Unit and in the Sedimentological Laboratory of the Marine Geology Unit. The samples were subjected to a 4-minute ultrasonic treatment at the maximum sound intensity 20 kHz and pump rate 2000 rpm. In the result of measurements Maciag (2011) discovered that mean particle size vary from 5.86 to 8.08φ ($\bar{x} =$ 6.83φ) with median from 5.75 to 8.08φ, ($med =$ 6.97φ). From 137, 115 samples (83.9 %) show unimodal distribution and 22 bimodal distribution (16.1 %). Histogram comparison between mean and median is presented on fig. 5.

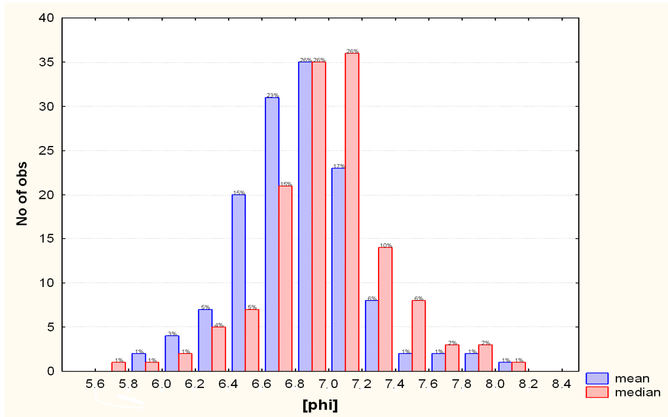

Fig.5: Histogram comparison between mean and median of grain size distribution (Maciag, 2011).

According to the Wentworth scale (table 1) the sediment examined belongs to **fine silt**. Statistics of the measurements is demonstrated in table 4.

Table 4. Grain size distribution of deep seabed sediments, in % (Maciag, 2011) in accordance with classes used by geologists (table 2)

Class	Sand 2-0.063 mm	Silt 0.063-0.004 mm	Clay <0.004 mm
$\bar{x}$	5.7	70.2	24.1
med	5.6	71.0	22.9
Stdev δ	2.8	4.6	6.3

If to compare results from table 3 and table 4 the only one conformity has been seen: silt is a prevailing class. But proportions of one class to another are different. Using the same method (ultrasound) and the same set of samples shows how individual the particle size distribution research is.

According to the Russian methodology (pipette method) which was used on samples retrieving in 2004 the deep seabed sediments from the IOM exploration area (part B2 – 63 000 km^2) are **silty clays** due to high content of fraction under 0,005 mm which was considered the border between silts and clays. No laser treatment of samples was then used. Statistics of 134 samples measurement shows table 5. The border clay-silt is 0.005 mm and silt-sand 0.063 mm. According to table 2 there is neither geology nor engineering classification. Note the high level of standard deviation values on the silt and clay fractions which may question the methodology used.

Table 5. Grain size distribution of deep seabed sediments, in % (Anakon, Sankt Petersburg, 2005)

Class	Sand 2-0.063 mm	Silt 0.063-0.005 mm	Clay <0.005 mm
$\bar{x}$	5.8	22.0	71.9
med	4.3	20.5	74.4
Stdev δ	4.6	10.7	11.4

In 1995-97 IOM participated in Benthic Impact Experiment (Modlitba, 1998). As a part of various kinds of measurements was also grain size distribution. The 56 sediment samples (à 30 grams each) were subjected to a 2-minute ultrasonic treatment on laser-aided device FRITSCH in geotechnical laboratory of Slovak Academy of Sciences, Bratislava. Modlitba divided all box/multi corer cross-section (max 50 cm) into 10 depth intervals. Unfortunately, Modlitba as a soil scientist chose clay-silt border at 2 µm (with silt-sand border at usual 63 µm) so the proportion of clay fraction must be obtained too small. The results are demonstrated in table 6.

Table 6. Grain size distribution of deep sea sediments from Benthic Impact Area

Depth interval, cm	Sand 2-0.063 mm	Silt 0.063-0.002 mm	Clay <0.002 mm	n samples
0-5	11.4	75.8	12.8	8
5-10	8.3	76.9	14.8	14
10-15	16.6	70.2	13.5	3
15-20	23.9	66.6	9.8	8
20-25	15.4	72.3	12.3	9
25-30	12.3	74.8	12.9	3
30-35	12.9	71.5	15.7	7
35-40	10.4	75.1	14.6	2
40-45	20.7	65.9	13.4	1
45-50	11.9	74.5	13.6	1
$\overline{x}$	14.4	72.4	13.3	
med	12.6	73.4	13.5	
Stdev δ	4.8	3.8	1.6	

Another disadvantage of this series of measurements is different number of samples from particular depth intervals and, relatively small area of sampling (270 km^2) as well. Therefore the small values of standard deviation are surprising. But irrespective of these failings if to take the clay-silt border at 0.004 mm the final proportions of particular classes would be similar to the 2011 and 2012 series of measurement.

CONCLUSIONS

The authors

- suggest to use grain size classification for geologists as the most suitable for exploration of nodule fields,
- note that it is quite difficult to compare results obtained with different methods, from different size of areas, although some certainty can indicate computed standard deviation,
- also note that opal content in deep sea sediment can make ultrasonic smashing easier,
- share the opinion that results achieved allow to state that deep sea surface sediments in the IOM exploration area (located in the eastern part of Clarion-Clipperton fracture zone) belong to clayey (fine) silts,
- believe that the knowledge of grain size distribution of deep seabed sediments is rather of scientific nature while aggregate size distribution has practical significance as regards the various geotechnical solutions concerning future mining operations for polymetallic nodules on the seabed and protection of marine environment.

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REFERENCES

Bednarek, R, Dreiseitl, I, and Seul, C (2012). *Raport z badan skladu granulometrycznego probek osadow oceanicznych*, West Pomeranian Technological University, Szczecin, archive IOM, pp 3-9.

Bieganowski, A, and Ryzak, M (2011). *Methodological aspects of determining soil particle-size distribution using the laser diffraction method, J. Plant Nutr. Soil Sci. 2011, 174, pp624–633.*

Casagrande, A (1948). *Classification and identification of soils*, Trans A.S.C.E., New York, p 113.

Dreiseitl, I (2009). *Badania geologiczno-inzynierskie osadow oceanicznych zawierajacych konkrecje polimetaliczne w aspekcie rejonizacji obszarow wydobywczych*, West Pomeranian Technological University, Szczecin, Ph.D. thesis, pp 48-50.

Duxbury, AC, Duxbury, AB, and Sverdrup, KA (2002). *Oceany swiata*, Wydawnictwo naukowe PWN, Warszawa, pp 139-149.

ISBA (2012). *Prospector's Guide for polymetallic Nodule Deposit in the Clarion-Clippertov Fracture Zone*, Technical Study No. 6, Kingston, pp 43-45.

Johnson, RB, and DeGraff, JV (1988). *Principles of Engineering Geology*, John Wiley & Sons, pp 81-91.

Kennett JP (1982). *Marine Geology*, Prentice Hall, New Jersey, pp 396-491.

Krumbein, WC, and Sloss, LL (1963). *Stratigraphy and Sedimentation*, 2nd edition, Freeman, San Francisco.

Maciag, L, et al (2011). *Sedimentological and thermogravimetrical characteristics of selected pelagic sediments from Clarion-Clipperton Zone*, Mar Ecol Consulting Szczecin, archive IOM.

Modlitba, I (1998). *Inzenerno-geologiceskije svojstva donnych osadkov i konkrecij poligona na ucastke B2-IOM*, archive IOM, pp 27-33.

Nichols, G (2009). *Sedimentology and Stratigraphy*, Second Edition, Wiley-Blackwell, pp 258-262.

Zaruba, Q, and Mencl, V (1976). *Engineering Geology*, Academia Prague, pp 95-99.