PHYSICAL AND MECHANICAL PROPERTIES OF SEDIMENTS OF THE IOM EXPLORATION AREA (FEATURES OF FORMATION, PATTERNS OF SPATIAL VARIABILITY)

Kondratenko A.[1], Dreiseitl I.[2]

[1] FSBI "VNIIOkeangeologia", St. Petersburg, Russia, kondr@vniio.nw.ru

[2] Interoceanmetal Joint Organization, Szczecin, Poland, i.dreiseitl@iom.gov.pl

Introduction

The Interoceanmetal Joint Organization (IOM) exploration area is located in the eastern part of the Clarion-Clipperton ore province (the northern equatorial zone of the Pacific Ocean). It includes two sectors (B_1 and B_2) with a total area of 75 000 km^2 (Fig. 1). The principal geological, geotechnical and ecological research is concentrated in the B_2 sector. The bottom relief in the region is characterized by the predominance of hilly-ridge plains with a meridional type of dismemberment, complicated by individual volcanic structures or their clusters 200 to 475 m high. The ocean depth varies from 4500 to 4700 m in the troughs, from 4300 to 4500 m in the undulating plains and from 4200 to 4300 m on the horsts [Neizvestnov et al, 2004].

Modern sedimentary lithogenesisin the World Ocean is represented by the pelagic and terrigenous (continental) types. Both are expressively different and basically determine the formation of the material composition of the seabed sediments as well as their physical and mechanical properties. In the IOM exploration arealithogenesis

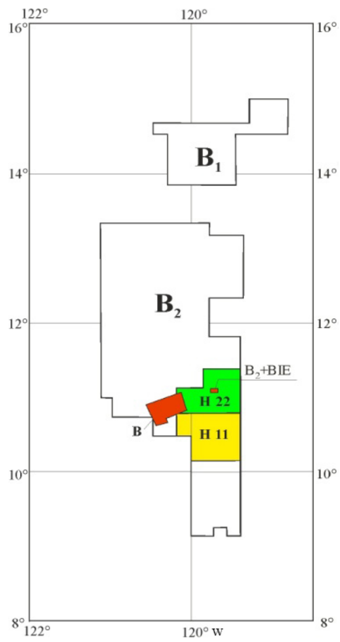

Fig. 1. IOM exploration area. B_1, B_2 — two sectors of the IOM exploration area, H11, H22 — exploration blocks (2009, 2014), B — the area of special geotechnical works (1989), B_2 + BIE — benthic impact experiment (1995,1997).

is of pelagic type. The pelagic type, in comparison with the terrigenous type, is characterized by the dominance of biogenic sedimentation against the background of a deficiency of solid terrigenous material, low rates of sedimentation, insignificant content of organic matter, suppression of the reduction processes, oxidative conditions of early diagenesis and predominantly red-colored sediments [Svalnov, 1991, Murdmaa, 1991].

Geotechnical stratification of sediments

The magmatic rocks (basalts) of the basement and Cenozoic deposits of the sedimentary cover (Marquesas and Clipperton formations) take part in the geological structure of the IOM exploration area [Dreiseitl, Kondratenko, 2013, 2014]. Three geotechnical strata (from top to bottom) are distinguished in the sedimentary cover. The first geotechnical stratum (IGK-I) includes soft argillaceous and siliceous-argillaceous sediments of the Holocene-Late Miocene age, up to 20 m thick. The stratumis further divided into the geotechnical layer (IGC-I_1) of the siliceous-argillaceous sediments containing polymetallic nodules up to 0.15 m thick and the geotechnical horizon (IGG-I_2) of soft argillaceous and siliceous-argillaceous sediments, underlying the deposits of nodules. The sediments of this stratum occupy about 80 % of the seabed surface. The second geotechnical stratum(IGK-II) is represented by soft argillaceous sediments of the Middle-Early Miocene age. The stratum thickness does not exceed 10 m. The third geotechnical stratum (IGK-III) of the soft carbonate and argillaceous-carbonate sediments of the Middle Miocene-Late Oligocene age was foundlying on a basalt basement. The thickness of the stratum is 90 m. The outcrops of pre-Quaternary sediments are confined to the slopes of horsts and erosions. The outcrops of the basalt basementare mainly found on the steep slopes of horsts and volcanic structures.

Features of formation of the material composition and physical and mechanical properties of the sediments

Soft argillaceous and siliceous-argillaceous sediments (Table 1), including the deposits of polymetallic nodules, were formed in the specific thermobaric conditions below the carbonate compensation depth.

The IOM exploration area is located in the equatorial zone of increased bio productivity of the surface waters, which, at the stage of sedimentation, determines the volume and content of biogenic components of the bottom sediments, represented by siliceous (diatom and radiolarian) skeletal remains of plankton microorganisms. The rate of accumulation of the siliceous-argillaceous sediments in this zone is 1-5 mm in 1000 years [Svalnov, 1991].

At the water-sediment interface, the hydrodynamic activity of the bottom waters, and in particular the benthic storm, are important for the redistribution of sediments along the lateral [Demidova, Kontar, 1989]. Here we observe the erosions of pre-Quarterly sediments, inconsistency of the thickness of siliceous-argillaceous strata (IGC-I_1), uneven "blanketing" of nodules and accumulation of diatom sediments in the local depressions, which refer to the bottom stirring, transfer and redisposition of the bottom sediments [Dreiseitl, Kondratenko, 2014].

Table 1

Physical and mechanical properties of the first geotechnical stratum (block H11)

Strata (horizon) index	Type of sediment	Depth interval, cm	Bulk density, g/cm^3	Moisture, %	Vane shear strength, kPa	No of tests
IGC-I_1	Slightly siliceous-argillaceous and siliceous-argillaceous sediments (geochemically active layer)	2-8	$\frac{1.16\text{-}1.20}{1.18}$	$\frac{327\text{-}467}{380}$	No data	20
IGG-I_2	Siliceous-argillaceous sediments ($SiO_{2\ am}$> 10 %)	10-30	$\frac{1.17\text{-}1.22}{1.19}$	$\frac{319\text{-}397}{356}$	$\frac{2.0\text{-}4.3}{2.9}$	29
	Slightly siliceous-argillaceous sediments ($SiO_{2\ am}$5 - 10 %)	10-35	$\frac{1.18\text{-}1.23}{1.21}$	$\frac{266\text{-}404}{323}$	$\frac{1.8\text{-}9.4}{4.1}$	53
	Argillaceoussediments ($SiO_{2\ am}$< 5 %)	10-30	$\frac{1.22\text{-}1.24}{1.23}$	$\frac{270\text{-}298}{280}$	$\frac{4.8\text{-}9.5}{7.0}$	13

Remark. Numerator — min and max values, denominator — arithmetic mean.

The basis of the material composition of the first stratum sediments is argillaceous material (up to 85%) [NeizvestnovYa.V. et al, 2004]. The siliceous detritus in the form of skeletal remains of radiolarians and fragments of tropical diatoms Ethmodiscus rex, as well as zeolites and manganese micronodules, is of subordinate importance. The argillaceous material is notable for its polymineral composition. It is represented mainly by hydromica in the form of a fine crystalline variety - illite (40%) and authigenic smectite - montmorillonite (35 %). Also small amounts of chlorite (17%) and kaolinite (8%) are present [Depowski et al,1998]. The material composition of the first stratum sediments indicates that its formation is influenced by the processes of biogenic and authigenic sedimentation.

The content of organic carbon C_{org} in the sediments varies from 0.14 to 1.34% (block H22), atthe average content of 0.49%. The maximum contents of C_{org} (1.34%) are noted in the near-seabed surface (0-5 cm) and are associated with the vital functions of benthos. As the biological activities ceasedown the sediment, the content of C_{org} decreases in the depth interval of 25-30 cm to 0.14%.

According to the data of in situ measurements, in the siliceous-argillaceous sediments we observe a stable oxidative physico-chemical situation, the Redox potential ranging from + 402 to +565 mV and the acid-base potential - from 7.10 to 7.80.

The microstructural study of sediments showed that argillaceous and siliceous-argillaceous varieties (Fig. 2) are characterized by the typical cellular microstructure with the open oval and isometric cells formed by clay and biogenic clay aggregates. The dimensions of the aggregates and cells increase in the direction from the argillaceous to siliceous-argillaceous sediments.

Thus, the processes of early diagenesis occurring under the oxidative conditions in the absence of energy of decomposition of organic matter are weakly expressed in the formation of authigenic minerals, micronodules, aging of colloids with the formation of large argillaceous and biogenic argillaceous aggregates [Kozlov, 2003].

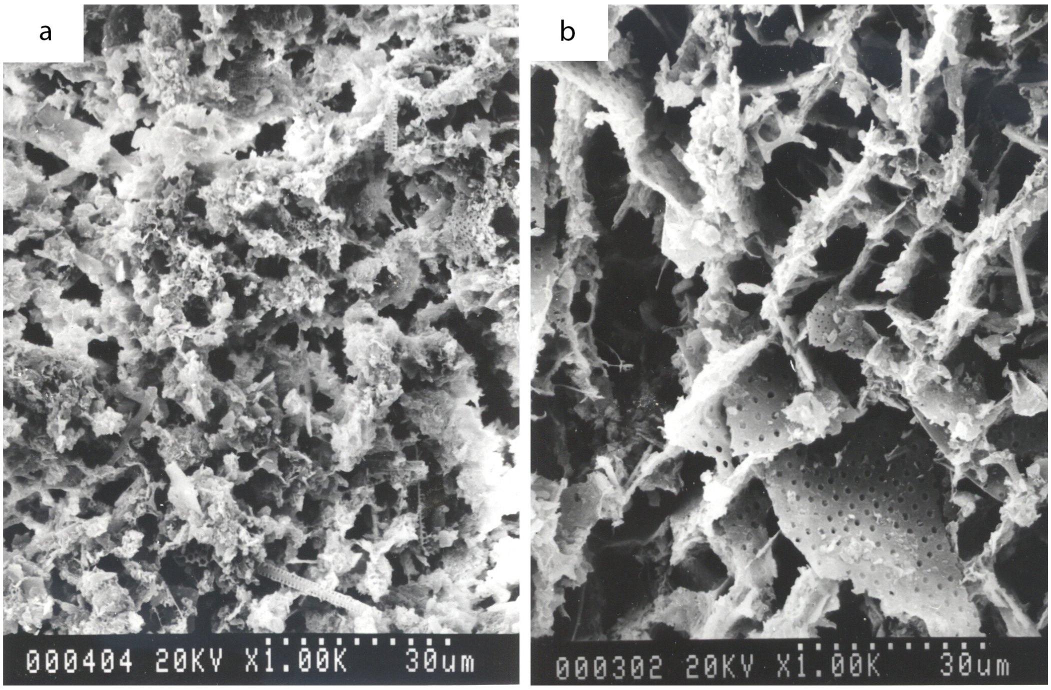

Fig. 2. Microstructure of argillaceous (a) and siliceous-argillaceous (b) sediments of the first geotechnical stratum in the depth interval 5—15 cm (el. microscope, 1000×)

Regularities of spatial variability of physical and mechanical properties of seabed sediments

The spatial variability of the physical and mechanical properties of the seabed sediments of the first geotechnical stratum is inextricably linked with their material composition. In sector B_2, the distribution of argillaceous and siliceous-argillaceous sedimentsis largely determined by pelagic sediment genesis. It was observed that as the depth of the ocean increases, the content of amorphous silica is significantly increasedin the seabed sediments, in the depressions reaching 20-25%. The main regularities of the local lateral variability of physical and mechanical properties of the seabed sediments in the near-bottom surface are clearly related both to the content of amorphous silica and to the depth of the ocean.

Within blocks H11 and H22 correlations between bulk density, vane shear strength and the content of amorphous silica in the sediments were revealed. With an increase of amorphous silica in the sediments, bulk density and vane shear strength tend to decrease. Similar dependencies, a decrease of bulk density and vane shear strength, are also observedat increasing the depth of the ocean [Dreiseitl, Kondratenko, 2012].

Physical and mechanical properties of the sediments along the cross-section were studied in special area B (Fig.1) based on the results of sediment sampling (up to a depth of 1.8 m). The properties along the cross-section (vertical variability) are affected mainly by the processes of diagenesis and material composition of sediments.

For the sediment cores recovered in special area B, a decrease in the content of amorphous silica downalong the cross-section is typical ranging from 1.18-1.20 g/cm^3

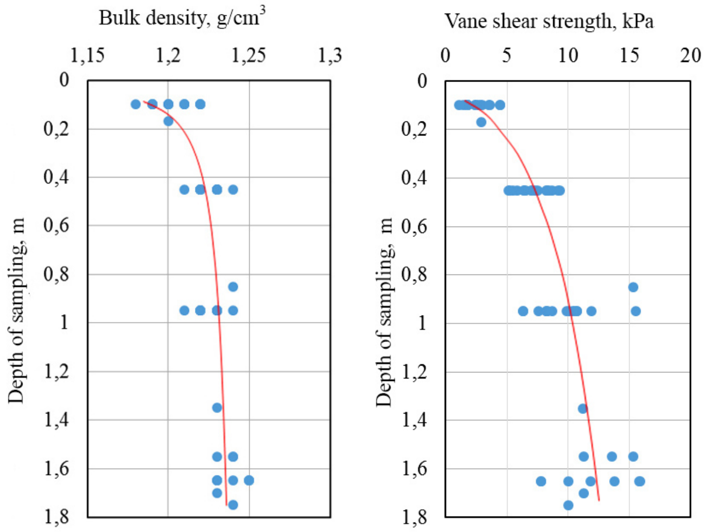

Fig. 3. Vertical variability of bulk density (left) and vane shear strength (right) in siliceous-argillaceous sediments (sector B_2, special area B)

in the upper part of the cross-section (0.1 m), to 1.24-1.25 g/cm^3 in the lower part of the cross-section (1.7 m). The same dependence shows the vane shear strength, ranging from 1.1-4.4 kPa at a depth of 0.1 m, to 10-15 kPa at a depth of 1.7 m (Fig. 3).

An important factor that influences the variability of physical and mechanical properties of sediments is bioturbation (a mechanical agitation of the sediments by benthic organisms). Bioturbation is observed both in the cross-sections in the form of traces of benthic fauna and on the surface of the seabed in the form of small "knolls" composed of the sediments, clearly seen in the seabed photos. The bioturbation, disturbs the continuity of the sediments, thereby reducing their density and strength. At present, one may speak of the influence of bioturbation on the variability of the physical and mechanical properties only at a qualitative level. It should also be emphasized that the role of bioturbation is higher in the near-bottom surface of the cross-section.

Conclusions

– High-moisture (266-467%), low bulk density (1.16-1.24 g/cm^3) and low vane shear strength (1.1-16 kPa) argillaceous and siliceous-argillaceous sediments formed in the process of pelagic lithogenesis in the near-bottom part of the cross-section occur in the IOM exploration area.

– The spatial variability (lateral and vertical) of the physical and mechanical properties of argillaceous and siliceous-argillaceous sediments in sector B_2 determine the content of amorphous silica in the sediments and the processes of early diagenesis. The maximum contents of amorphous silica are typical for the local depressions where very soft diatom siliceous-argillaceous sediments are accumulated. The density and strength properties of the siliceous-argillaceous sediments have a stable correlation with the amorphous silica content.With the increase of the amorphous silica content in siliceous-argillaceous sediments, the bulk density and strength decrease.

– The diagenesis processes occurring under the conditions of hindered consolidation of the sediments mainly determine an increase of the strength of the sediments along the cross-section, as the structural skeleton of the sediments ages and hardens.
– The intensity of bioturbation processes has a definite effect on the variability of the physical and mechanical properties of the sediments, their scales being very important in the near-bottom surface of the cross-section.

REFERENCES

1. *Demidova, T.A, Kontar, E.A.* 1989. About near-bottom currents in the region of occurrence of polymetallic nodules. Reports of the Academy of Sciences of the USSR. V. 308. № 2. P. 468-472 (in Russian).

2. *Depowski, S., Kotlinski, R., Ruehle, E., Szamalek, K.* 1998. Surowce mineralne mórz i oceanów. Warszawa, Scholar. P. 106-121.

3. *Dreiseitl, I., Kondratenko, A.V.* 2012. Geotechnical research in the exploration area of Interoceanmetal joint organization. Minerals of the ocean-6 & Deep-sea minerals and mining-3 international conference. St. Petersburg, VNIIOkeangeologia. P. 67-71 (in Russian).

4. *Dreiseitl, I., Kondratenko, A.V.* 2013. Geoacoustic and photo-profiling as remote techniques of choice in nodule field exploration. 42nd Underwater Mining Institute conf. Rio de Janeiro, Brasil. P. 69-78.

5. *Dreiseitl, I., Kondratenko, A.* 2014. New geological and geotechnical considerations within the Interoceanmetal exploration area. 43rd Underwater Mining Institute conf. Lisbon, Portugal. P. 125-128.

6. *Kozlov, S.A.* 2003. Formation of the structure and engineering-geological properties of the deep-sea sediments of the Pacific Ocean. Marine engineering and geological research. St. Petersburg, VNIIOkeangeologia. P. 99-113 (in Russian).

7. *Murdmaa, I.O.* 1991. Oceanic pelagic lithogenesis. Lithology and minerals. № 5. P. 3-18 (in Russian).

8. *Neizvestnov, Ya.V., Kondratenko, A.V., Kozlov, S.A.* et al. 2004. Engineering geology of the Clarion-Clipperton Ore Province in the Pacific Ocean. St.Petersburg, Nauka. 281 p. (in Russian).

9. *Svalnov, V.N.* 1991. Dynamics of pelagic lithogenesis. Moscow, Nauka. 256 p. (in Russian).