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RESEARCH METHODS AND INSTRUMENTS

Modified Gravity Corer: Advantages and Offshore Testing

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Abstract—A modified gravity corer (MGC) for more efficient and high-quality sediment core sampling is considered. Such design elements as the core catcher, section muff joints, the weight, and loop have been modified; the crown and locking plate have been removed. As a result of comparative testing in the South Chukchi Basin of the Chukchi Sea, it is shown that the MGC sampled 30% longer cores than the standard gravity corer (SGC). Judging from the distribution of such a redox-sensitive element as iron in the cores, when the MGC is used, a surface oxidized film remains in sediments. Thus, the disturbance of properties and textures/structures of sediments under sampling is the lowest.

Keywords: sediment core, gravity corer, modification, Chukchi Sea

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INTRODUCTION

The study of waterbodies, including the largest and deepest—seas and oceans—is inextricably intertwined with bottom sediment sampling. Bottom sediments of modern and ancient seas and oceans, which are studied by marine geology, sharply predominate over continental sediments [18]. Currently, marine geology is developing in such main directions as [21]: (1) underwater geological survey; (2) search for and exploration of underwater mineral deposits; (3) research on general and theoretical marine geology—stratigraphic, lithological, geochemical, metallogenic, etc.; (4) paleoceanological and paleoclimatic studies; (5) engineering research; (6) environmental studies. Achievements in all of these areas are impossible without the creation and development of technical tools and methodological advancements for sampling marine sediments. In this case, it is necessary to take into account a number of important requirements, the main ones of which are: (1) representativeness of the samples taken; (2) undisturbed structure and stratification of samples; (3) reliability, ease of use, and simplicity of design; (4) economic efficiency of the sampling process [21].

To obtain long samples of bottom sediments (cores), different types of corers are used [8, 16, 21, 22, 24–27, 30, 33]. The most common are gravity corers, which are embedded in bottom sediments under their own weight (kinetic free fall energy).

A serious drawback to all corers is degradation of the sediment surface layer when the tube penetrates the seabed, the washing out of sediment when raised aboard the vessel, and movement of the corer from a vertical to horizontal position. Usually, one tries to compensate for this disadvantage with the joint use of the instrument with boxcorer and/or multicorers. With the help of a boxcorer and multicorer, an undisturbed sediment surface layer is obtained, with penetration into seabed by less than 1 m. Consecutive lowering of several samplers from the ship increases the time to complete a station. In addition, it is impossible to collect samples at one point; the distance between points can be up to one nautical mile (vessel drift). The problem of obtaining sediment cores with undisturbed texture/structure and stratification has been solved for shallow waterbodies using drill corers and vibration corers [7, 9, 21, 29]. Sampling in such waterbodies (lakes, estuaries, bays, lagoons, marine coastal zones) is usually done from small vessels under conditions of relative hydrodynamic stability with the possibility of simultaneously dropping stern and side anchors, as well as drilling from ice. For seas and oceans with more complex sampling conditions, no optimal technical solution has yet been found.

The aim of our study is (1) to analyze the shortcomings of the standard gravity corer (SGC) for collecting sediment cores in sea and ocean conditions; (2) make changes to the design to eliminate/minimize shortcomings, produce a modified gravity corer (MGC); (3) conduct a comparative test of the performance characteristics of the MGC and SGC in underway conditions, furnishing evidence of more efficient and high-quality sampling using the MGC.

GRAVITY CORER: STANDARD AND MODIFICATION

The SGC is a steel tube (shaft) with a removable cylinder at the top (Fig. 1). The cylinder is called the head wall, and the winch cable is attached to it through a rig-

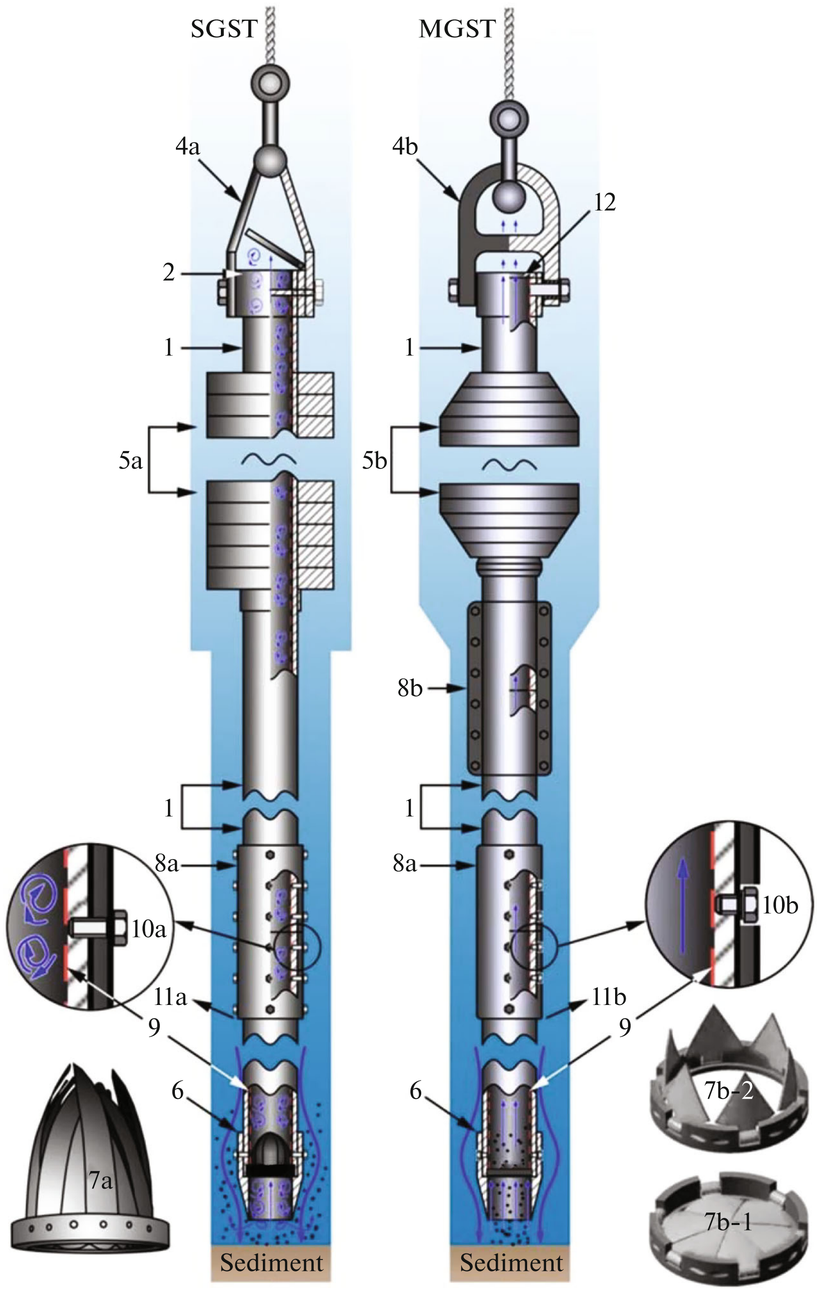

Fig. 1. Schematics of standard and modified gravity corers (SGC, MGC): general and sectional views. (1) Shaft; (2) head wall; (3) locking cover; (4a) fixed rigging shackle; (4b) rotating rigging bracket; (5a) cylindrical weight, (5b) spindle-shaped weight; (6) impact head; (7a) brass blade core lifter with lanceolate blades; (7b) steel blade core lifter with triangular blades in closed (7b-1) and open (7b-2) positions; (8a) single-piece coupling; (8b) detachable coupling; (9) core-containing liner; (10a) bolt with nonrecessed head; (10b) a bolt with recessed head; (11a) sharp end of coupling; (11b) end of coupling, smoothed with chamfer; (12) cotter pin. Blue arrows show direction of water flows during sampling of sediment cores [15]; black dots are sediment particles.

ging shackle. The upper part of the shaft is equipped with a weight (weight module) so that the SGC can efficiently cut into bottom sediments. The lower end of the shaft is equipped with an impact head with a special valve, a core lifter, which prevents the core from falling out of the SGC under its own weight after sampling. At the top of the head wall is a locking cap, which protects the core from being squeezed out of the SGC by the oncoming water flow during lifting. The shaft can be solid, but more often it consists of sections connected by couplings. Inside the shaft there is a plastic core-containing liner. The length of the solid shaft does not exceed 3 m; a sectional one, 25 m; however, usually in marine geology, an SGC with a length of 6–8 m and diameter of 50–127 mm is used [8]. Sectional SCGs are very large and heavy and are used only on ships equipped with a hydraulic U-frame and winch (a deck crane, slipway, and a grate above it are also preferable).

Fig. 2. View of modified gravity corer (a) and its individual elements (b–d) in marine expeditionary conditions. For numerical legend, see caption to Fig. 1.

During lowering and raising operations, the SGC is suspended on a cable to the U-frame by the lifting shackle. Using the U-frame, the corer is brought over the side of the vessel. The SGC on a cable, the length of which is controlled by a winch, drops to the seabed and is embedded in bottom sediments, then the winch pulls out the SGC together with the sampled core and lifts it onto the ship. When aboard, the SGC is laid horizontally, the impact head is removed, and followed by the liner with the core.

There are flaws in the SGC design; when these are fixed, sampling can be done more efficiently, with better quality (Figs. 1, 2) [10].

Core lifter. The SGC is equipped with a bladed core grabber, usually made of brass or another relatively soft alloy (Fig. 1, pos. 7a), which guarantees the elasticity and low strength of this structural element. The blades are lanceolate in shape and are always closed in the shape of a cone, significantly reducing the internal cross-sectional area of the shaft. Accordingly, when moving through the water towards the seabed, additional resistance is created in the area of the impact head, and immediately before the corer enters the sediment, strong turbidity occurs. Because the core lifter blades are elastic, at the moment of penetration into the sediment, the core is deformed and cut into a "rose." In addition, the blades in the SGC often break off, which leads to partial or complete loss of the core during recovery.

We propose a steel blade core lifter with increased rigidity and strength with triangular-shaped blades (Fig. 1, pos. 7b). The blades do not close when moving in water towards the seabed (Fig. 1, pos. 7b-2; Fig. 2e), and the area of the internal cross-section of the MGC shaft does not decrease. With this position of the blades, the surface layer of sediment is virtually undisturbed; only the edge parts of the core in the area of contact of the sediment with the liner are deformed.

Sections and couplings. The SGC sections are connected by single-piece couplings (Fig. 1, pos. 8a) by bolts; the bolt heads are not recessed into the body of the couplings (Fig. 1, pos. 10a). Parts protruding above the surface create additional resistance when the SGC moves in water and in bottom sediment, increasing the likelihood of fasteners breaking. Since the couplings are single-piece, their quick disassembly and "reloading" of the shaft during a station is very difficult. As a result, if it is necessary to retrieve two cores at one station, two SGCs are required.

We propose using two types of couplings: detachable and single-piece. The MGC has only one detachable coupling (Fig. 1, pos. 8b). It consists of two half-cylinders and connects the weight module to the shaft. Owing to this, one MGC can select several cores at one station: the detachable coupling is disassembled, the shaft with the first extracted core is disconnected and replaced with another, pre-prepared shaft for sampling the next core. Single-piece couplings in MGC are similar to those used in SGC (Fig. 1, pos. 8a; Fig. 2b). The number of single-piece couplings depends on the number of sections being connected. In all MGC couplings, the bolt heads are recessed (Fig. 1, pos. 10b; Fig. 2b), and the ends are smoothed with chamfers to create a more streamlined contour (Fig. 1, pos. 11b).

Weight. The SGC uses cylindrical steel disks as weights, the number and mass of which depends on the task at hand and the sediment density (Fig. 1, pos. 5a).

We propose using steel disks, which together form not a cylindrical, but a more streamlined spindle-shaped body (Fig. 1, pos. 5b; Figs. 2c, 2d). In addition to the advantages from viewpoint of hydrodynamics, a spindle-shaped weight contributes to the safe performance of lowering and lifting operations by minimizing the risk of the MGC catching on the lattice above the slip.

Locking cover. Although the locking cover has a significant negative effect—additional drag during descent—it is an obligatory element of the SGC (Fig. 1, pos. 3), because during lifting, the brass core lifter of the SGC (Fig. 1, pos. 7a) does not guarantee retention of the core inside the corer: the core can fall out owing to its own weight and the oncoming water flow.

We propose removing the head wall with a locking cover from the MGC design. In MGC, unlike SGC, a steel core grabber is used (Fig. 1, pos. 7b; Fig. 2e), which can withstand all loads arising during the sampling process. Because the blades of the steel core lifter do not close when lowering the MGC (Fig. 1, pos. 7b-2), and there is no locking cover, the shaft cross-section remains completely open. This significantly reduces drag. As a result, all else being equal, the MGC penetrates deeper into bottom sediments and generates less turbidity than the SGC. Lifting the MGC on board the vessel occurs such that the upper open part of the shaft, devoid of a locking cover, is above the deck level, and through this upper open part, a weighted spherical chamber made of semisolid rubber can be immersed inside until it touches the sediment surface. Before immersing the chamber, a cotter pin is removed from the shaft (Fig. 1, pos. 12; Fig. 2d), which secures the plastic liner with the core. The chamber is equipped with a tube and connected to a compressor pump that puts air into the chamber and thus separate the surface of the sediment from the bottom layer of water.

Rigging bracket. In the SGC, the rigging bracket (Fig. 1, pos. 4a) is fixed to the head wall band by welding. During hoisting and hoisting operations with the transfer of the SGC from a horizontal to a vertical position and vice versa, a destructive fracture load occurs in the headband area; the rigging bracket often bends or breaks.

We offer a rigging bracket (Fig. 1, pos. 4b; Fig. 2d), which can rotate around the MGC shaft and is attached directly to the shaft with bolts (there is no headband in the MGC). The shaft in the area of the rotating rigging bracket is reinforced with a steel ring.

Taking into account all the changes we proposed in the design of the SGC, the MGC was manufactured.

TESTING GROUND: MATERIAL AND METHODS

The South Chukchi Basin (Central Chukchi Depression) of the Chukchi Sea was chosen as the testing area (Fig. 3). This is a large, slightly negative landform, almost a plain, within which the terrigenous and biogenic (amorphous silica) material accumulates and the stratigraphically most complete Holocene strata is formed with a thickness of at least 5 m [20]. The sea depth here varies from 45 to 55 m. Holocene

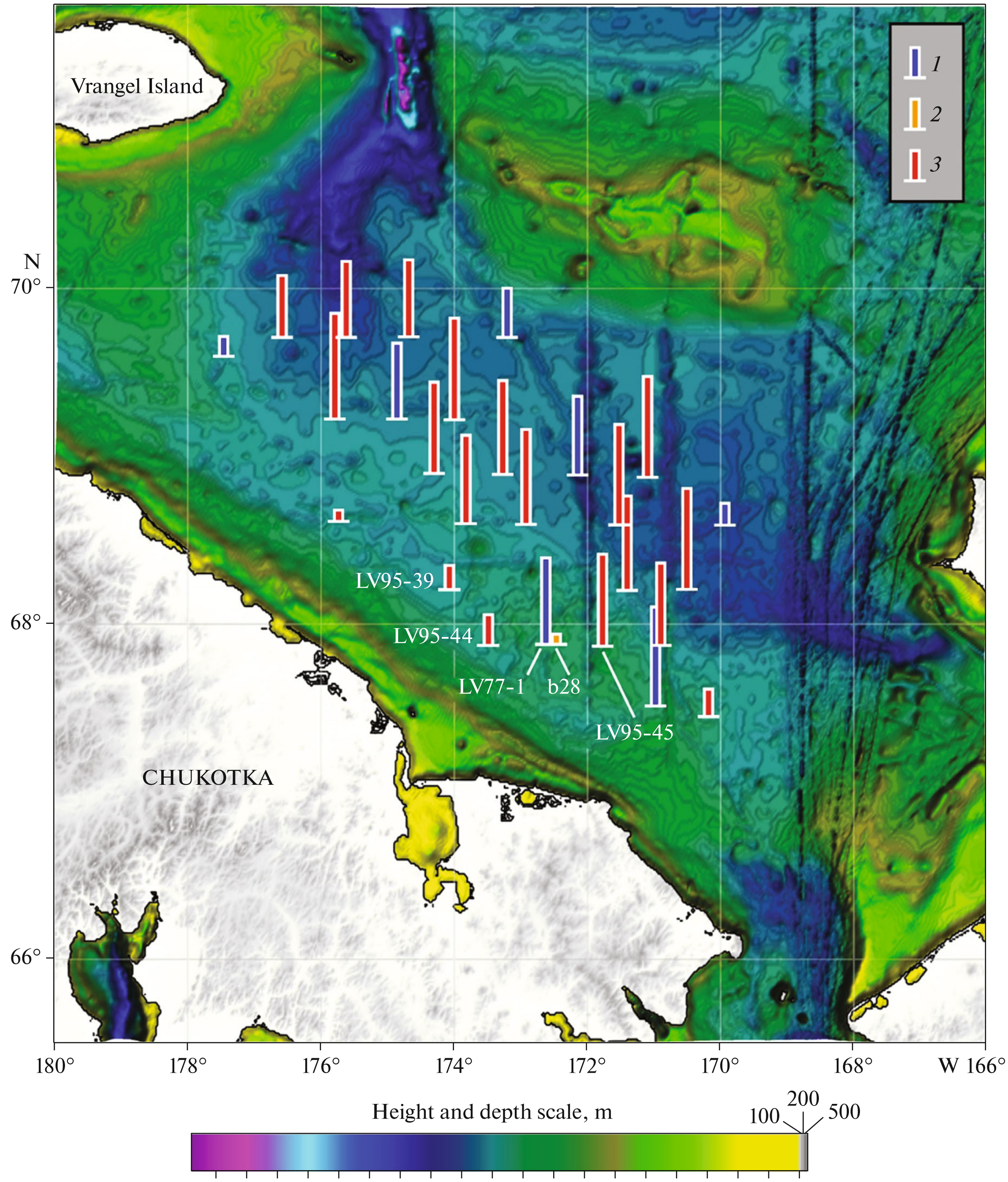

Fig. 3. Map of Chukchi Sea with sampling stations and relative sample lengths, including demonstration samples numbered as follows: (*1*) sediment cores taken with standard gravity corer (R/V *Akademik M.A. Lavrentyev*, 2016, 2018); (*2*) sediment sample taken with boxcorer (R/V *Professor Khromov*, 2012); (*3*) sediment cores taken with modified gravity corer (R/V *Akademik M.A. Lavrentyev*, 2021). The cartographic basis was compiled from GEBCO 2022 data.

sediments are monotonic, gray (reduced), significantly silty, soft, with a density of up to 1.6 g/cm^3, without any traces of an accumulation hiatus [13, 20]. Ice gouging is not widespread [19]. Cryogenic processes are also rare; the shelf of the Chukchi Sea is the nonglacial type [4]. Thus, the testing ground is characterized by uniform natural conditions and properties of bottom sediments, as well as good geological sampling and detailed study of some sedimentary sections [3, 6, 28, 31].

The MGC was tested the South Chukchi Basin in September 2021 on the R/V *Akademik M.A. Lavrentyev* (cruise 95). Sampling with the SGC was carried out earlier in the same area on the same ship, at the same time of year (cruise 77, 2016; cruise 83, 2018). Both corers had a length of 6 m, a shaft diameter of 160 mm, and a shaft wall thickness of 6 mm. The curb weight of the samplers was 650–700 kg, and the rate of their descent to the bottom was 2 m/s. The R/V *Akademik M.A. Lavrentyev*, along with the R/V *Professor Multanovsky* or, e.g., the R/V P*rofessor Khromov*, is one of the most common medium-sized vessels in the Russian research fleet [17]. The displacement of such vessels is 2000–3000 t, and the deck length is 65–82 m. They are equipped with everything necessary for sampling corers in sea and ocean conditions: a hydraulic U-frame (usually in the stern of the vessel), a winch, a slip, and a lattice above the slip, and quite frequently a deck crane. Thus, for the MGC and SGC, very similar sampling conditions are ensured, for which only the design differences of the samplers seem really significant.

All sediment cores obtained with SGC and MGC underwent mandatory colorimetric (color, texture) and X-ray fluorescence (chemical composition) express scanning by proven methods. Colorimetric scanning was performed using an original colorimetric photo installation based on a Canon EOS 6d Mark digital camera with a Canon EF 50mm f/1.2L USM lens (Japan) [1, 11, 12]. Before each shooting, the photo setup was calibrated using an X-Rite calibration kit (USA) [32]. The photo equipment operated at ultrahigh speed (2 min/m of core) with ultrahigh resolution (0.067 mm). This is especially important in conditions of rapid and irreversible changes in the color and texture of sediments that occur during raising and subsequent storage. Color information was recorded in the coordinates of the CIE L*a*b* color model. X-ray fluorescence scanning was performed using an original device based on a portable X-ray fluorescence spectrometer Olympus Vanta (USA) with a factory calibration [1, 5, 23]. The work was done with a step of 3 mm using the GeoChem geochemical analysis method.

TEST RESULTS

The length of sediment cores collected in the South Chukchi Basin using the MGC averaged 326 cm, and the using the SGC, 250 cm (Fig. 3). Accordingly, the penetration depth of the MGC into the sediments (sampling efficiency) was 30% higher. The length of sampling using a corer depends on many factors [21] and, above all, on the speed of descent of the tube to the bottom, its mass, and hydroaerodynamic shape. During testing, the SGC and MGC had very similar masses and the same speed of descent to the bottom. The sampling efficiency was almost completely controlled by the hydro-aerodynamic shape of the tubes. The MGC had a more streamlined shape. The main modifications in this case concerned the core grabber (replacement of a brass blade core grabber of increased elasticity and reduced strength with long lancet-shaped blades with a steel blade core grabber of increased rigidity and strength with short triangular blades) and the locking cover (removing the locking cover from the tube structure). In addition, the cylindrical weight was replaced with a spindle-shaped one, the protruding elements of the tube were recessed, and the corners were smoothed. The purpose of all these modifications was to ensure a constantly open internal section of the tube shaft and to create the most streamlined shape of the corer to minimize drag when the corer drops to the seabed and when it is embedded into sediments.

The quality of bottom sediment sampling is assessed by the degree of preservation of the natural structure and stratification of samples [21]. In most cases, reliable evidence that the sediment sample was taken with high quality is preservation of the upper oxidized layer. Even through in the main area of the Chukchi Sea the thickness of the upper oxidized layer does not exceed several millimeters (oxidized film) [14] and the oxidized layer is not visually distinguishable, it can be detected if it is not disturbed during sampling, by a combination of some colorimetric values (CIE a*, CIE b*) and geochemical (Fe, Mn) characteristics. In our case, the iron distribution was the most expressive. Unlike manganese oxides, iron oxides are less soluble in water and less mobile, so they turn into sediment earlier, already within the shelf, while manganese is usually carried beyond the shelf into the ocean [2]. A comparison of iron distribution curves in the upper parts of sedimentary sections obtained with different samplers—MGC, SGC, and boxcorer—showed that a similar distribution with an increased iron content in the surface layer of sediment (oxidized layer) is demonstrated by sections obtained using the MGC and boxcorer (Fig. 4). At the same time, the boxcorer pertains to samplers that do not disturb the surface layer of sediments and can therefore be considered to some extent the quality standard for sampling. Obviously, sampling using the MGC while preserving the natural structure and stratification of sediments became possible primarily due to changes in the design of the core lifter and removal of the locking cover. These modifications, aimed at reducing drag from water and bottom sediments, made it possible to significantly reduce disturbance of sediments when the MGC penetrates them.

CONCLUSIONS

Sampling of the longest cores of bottom sediments with minimal disruption of their properties and texture/structure is one of the pressing problems in the field of equipment for marine geological research. The most common device for collecting sediment cores in sea and ocean conditions is the standard gravity corer (SGC).

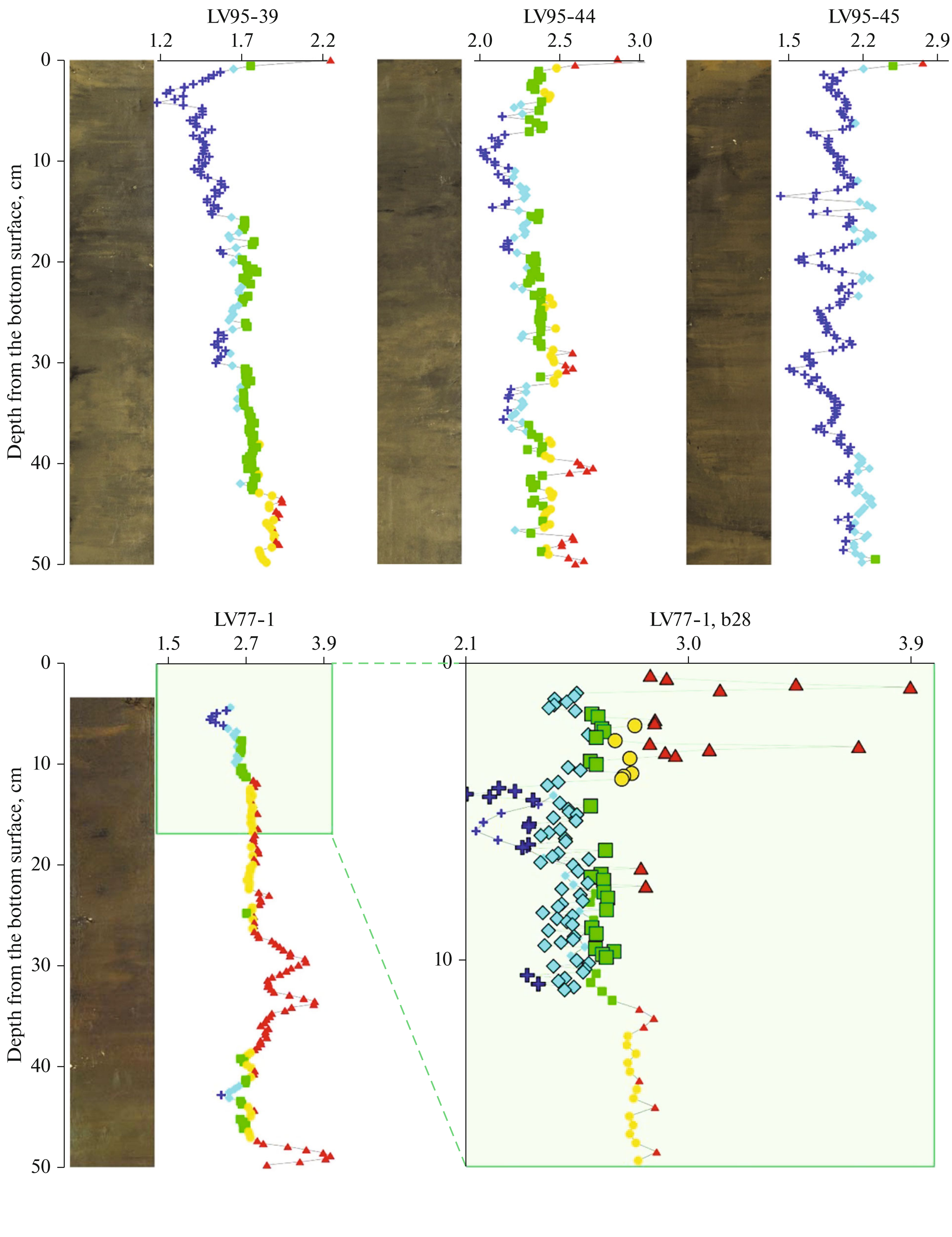

Fig. 4. Photographic images and iron distribution curves (%) for upper part of nearby sedimentary sections recovered in South Chukchi Basin of Chukchi Sea with modified gravity corer (cores LV95-39, LV95-44, LV95-45), standard gravity corer (core LV77 -1), and boxcorer (sample b28). Colored symbols show increased (red), slightly elevated (yellow), neutral (green), slightly decreased (light blue), and decreased (blue) iron contents with respect to average value for section (small symbols, tube; large symbols, boxcorer).

As a result of analyzing the shortcomings of the SGC and making a number of changes to the design, a modified gravity corer (MGC) was created. The changes concerned the core lifter, the couplings connecting sections of the tube, and the weight and rigging bracket. Elements of the SGC such as the head wall and locking cover were removed.

The main performance characteristics of the MGC were tested in the South Chukchi Basin of the Chukchi Sea. The results were compared with those obtained earlier in the same area under similar conditions using other samplers—the SGC and boxcorer. As a result, it was found that the MGC can sample cores 30% longer than with the SGC. The good preservation of the surface layer of sediments during MGC sampling, including a thin oxidized film, is indicated, first of all, by the similar distribution of the redox-sensitive element iron in sedimentary sections opened by MGC and the boxcorer (the boxcorer pertains to samplers that do not disturb the surface layer of sediments).

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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