Nasiedkin, Ye., Olshtynska, O., Ivanova, G., & Mytrofanova, O. (2022). Studying the suspended matter in Antarctic Peninsula coastal waters to understand the local geological and ecological processes. *Ukrainian Antarctic Journal*, *20*(2), 135–150.
https://doi.org/10.33275/1727-7485.2.2022.696

Ye. Nasiedkin[1], O. Olshtynska[1,*], G. Ivanova[1], O. Mytrofanova[2]

[1] Institute of Geological Sciences of the National Academy of Sciences of Ukraine, Kyiv, 01054, Ukraine
[2] State Scientific Institution Center for Problems of Marine Geology, Geoecology and Sedimentary Ore Formation of the National Academy of Sciences of Ukraine, Kyiv, 01054, Ukraine

*** Corresponding author:** ol-lesia@ukr.net

Studying the suspended matter in Antarctic Peninsula coastal waters to understand the local geological and ecological processes

Abstract. We review comprehensive international studies of the mineral and organic suspended matter in the South Ocean. We suggest an experimental design to monitor these parameters at the Akademik Vernadsky station, where this research will be introduced. Applied aspects of marine suspension's qualitative and quantitative properties are a subject of active research, given its significance for several physical and biochemical processes such as sedimentation. Therefore, geological, biological, and climatological studies of the Antarctic shelf employ continuous observations of the suspension's distribution. Work in this area is aimed at investigating the qualitative and quantitative properties of the suspension and analysis of its organic and mineral components, determining the dynamics of the currents and transportation of suspended matter, the nature of sedimentation processes, their seasonality and connection with the direction of currents and movement of sea ice. To determine the possibility of researching the suspended matter in the waters around the Akademik Vernadsky station, we analyze our long-term experience of using sedimentation traps to study the suspended matter flows in the seas and rivers of Ukraine. The developed complex of field equipment can be used to sample the suspended matter in waters adjacent to the Akademik Vernadsky station. The light single-cylinder sedimentation traps were transferred to the team of the Ukrainian Antarctic Expedition 2022 for further use at the Vernadsky station.

Keywords: Argentine Islands, comprehensive research, marine suspended matter, monitoring, sedimentary traps, sedimentation

1 Introduction

The Antarctic ecosystem is sensitive to human impact, which disrupts its dynamic balance. However, on the other hand, this same vulnerability presents opportunities for studying the directionality of its changes and optimizing the ways humans interact with nature. The primary and most profitable subject of such analysis is the various biological or not processes (i.e., physical, chemical, and geological) that have not undergone anthropogenic alterations. Given the range of the current Antarctic research, both fundamental and applied, one can see that it prioritizes determining the causes and consequences of global warming, the role of the geological factors in the formation of our planet's shells, the interactions, and evolution of living organisms, etc. (Brewer et al., 1986; Arrigo et al., 2008; Belcher et al., 2017; Kim et al., 2019).

Special attention is paid to the plankton's role in shaping the input of organic carbon into the bottom sediments, seasonal features of its intensity and content, and the scope and bulk of various microalgae

contributing to these processes (Forest et al., 2011; Sampei et al., 2012; Riaux-Gobin et al., 2013), as subject to the effects of weather and ice situation (Smith & Nelson, 1986; Dunbar et al., 1998). One of the important branches of research is studying the seasonality and interannual variability of the sedimentation processes (Fischer et al., 2002; Chiarini et al., 2019) and the specifics of producers' distribution in the different vertical layers of the water column (Honjo et al., 2010; Ducklow et al., 2015). Other research topics are, for example, the component distribution and the qualitative composition of the lithogenic and the organogenic components of the vertical matter flows (Wefer et al., 1990; Collier et al., 2000) and the effect of temperature fluctuations on their intensity (Laws et al., 2000).

Suspended matter (SM) is one of the main components of the environment considered to clearly indicate the state and closely follow the changes in its formative processes. The matter includes particles of various composition and genesis (terrigenous, biogenic, volcanogenic, chemogenic, cosmogenic) suspended in the water column. It bears evidence of how active are the contributing biological and geological processes, becomes the initial sediment material and the food and waste of living organisms at different trophic levels, and transports various pollutants, etc. (Wefer et al., 1990; Collier et al., 2000; Sampei et al., 2012; Weston et al., 2013; Chiarini et al., 2019; Kim et al., 2019).

Lately, the SM distribution has been systematically monitored in the Antarctic region to study the oceanology processes, the biological part of the ecosystem, the geological and geochemical structure of the ocean floor, paleooceanological conditions (Brewer et al., 1986; Schloss et al., 1999). This is determined not just by the leading role of the water suspension in the formation of the sediment cover but also by the multifaceted process of the sediment genesis in the aquatic environment; once input, the matter can be moved, aggregated, dissolved, and transformed in many mechanical, chemical or biological ways. The properties of the sediment flow play an important part in the hydrobiological sphere, lowering the water's transparency and so affecting how deep the light penetrates it, its temperature, and sorption rates for the dissolved substances. Ecologically, it has become the main pollutant carrier in the seas and rivers.

The abundance of publications dedicated to the material composition of SM in the coastal waters of the South Ocean and aimed at finding its sources, means of transfer from the terrestrial habitats, shore abrasion, hydrobiological processes, and re-sedimentation mechanisms shows how important it is for us to know its organization in the East and West Antarctica (Frignani et al., 2000; Anadón & Estrada, 2002; Ducklow et al., 2008; Weston et al., 2013). Real-time observations of the qualitative and quantitative composition of the aquatic SM and its distribution in time and space allow us to study the vertical and horizontal motion of the water flows, variability of currents, the position of the thermo- and picnoclines, seasonality and synoptic transformation of the water body in different areas, and the specifics of the water layers' stratification under different conditions.

The paper reviews literature on regular observations of the qualitative and quantitative composition of the water suspension using sedimentation traps in the southern seas. Section 2 briefly describes the materials and methods, in particular, the selection and processing of the literary sources and presents the authors' field experience. Specific examples of multidirectional studies of water suspension are considered in Section 3, which includes data on its distribution in time and space, intensity of its vertical and horizontal movement, and the connection with currents, thermo- and pycnocline, seasonality, ice conditions, synoptic situation, and biological processes. Section 4 discusses the promising research directions to follow at the Ukrainian Antarctic Akademik Vernadsky station (hereinafter – Vernadsky station), and Section 5 provides the conclusions.

2 Materials and methods

The aim of the paper is the analysis of international, mostly recent comprehensive studies determining the qualitative and quantitative properties of the suspended matter in the Antarctic coastal waters. To this, we added our own experience of many years. During that time, we created and introduced into practice systems of

monitoring sedimentary matter in the rivers and seas of Ukraine, developed based on a complex of field equipment for collecting water samples.

The general approach was determined by our main goal, which was to evaluate, based on the international experience of studying the suspended matter in the Antarctic waters, the relevance, possible efficiency, and prospects of introducing this kind of field research at the Vernadsky station. This was achieved by critical analysis of scientific and methodical literature, summarized from the empirical and theoretical points of view.

The methodology of the proposed research and specifics of working in the waters near the Vernadsky station, and further determination of its qualitative and quantitative composition is drawn from the long-term practical experience of the Institute of Geological sciences which was gained in the previous years installing monitoring systems of various complexity in rivers and seas of Ukraine.

3 Results

The last decades have seen much interest in the qualitative and quantitative properties of the suspended matter in the coastal waters of Antarctica, and that interest is growing. The main applied aspects of such research are determining the amount and character of the organic and mineral components of the sea SM, including the effect of global climate changes. Through consuming enormous quantities of CO_2, the Southern Ocean plays a large part in regulating the planet's climate. The carbon is dissolved in the water column, and there it actively participates in photosynthesis and is transformed into organogenic suspended matter.

The specifics of its production, conditions of its development, and intensity of consumption by the sea organisms etc. determine, to a large extent, the formation of the sedimentary flows which deposit carbon on the sea floor and stabilize the Earth's carbon balance by taking it out of the global cycle. Field observations of these physical and biological processes support or correct the assumptions about the intensity of interaction between atmospheric and oceanic

Figure 1. Type of sedimentary trap used to study the Southern Ocean—Sedimentary trap Technicap PPS3/3 (the photo is taken from the manufacturer's website https://www.technicap.com/products/sediment-trap)

carbon. In particular, the phytoplankton's development depends on the illumination, temperature, and chemistry of seawater, directions and velocities of the currents, upwelling zones, etc. and, in turn, provides data on the intensity of the vertical flows of the sedimentary material and the effect of climate change.

In this field, significant attention is paid to the input and transport of the suspended solid particles, specifics of the sedimentary processes, their seasonality and their connection with the distribution of currents and the movements of sea ice in different shoreline regions (Wefer et al., 1990; Collier et al., 2000; Ducklow et al., 2008; Honjo et al., 2010; Sampei et al., 2012; Weston et al., 2013).

The main tool of marine studies is the sedimentary traps of various kinds (Fig. 1). The set-ups differ in design, exposition, and spatial configuration. All in all, field research on the distribution, directions, and intensity of the marine SM flows in the Antarctic waters using sedimentary traps in order to determine their chemical parameters is a common practice, and the results are used in the biological, geological, glaciological, oceanological, climatological, and other fields (Dunbar et al., 1998; Schloss et al., 1999; Riaux-Gobin et al., 2013; Belcher et al., 2017; Chiarini et al., 2019; Kim et al., 2019).

Sedimentary traps are an important tool to determine the geographic and biological factors of export-

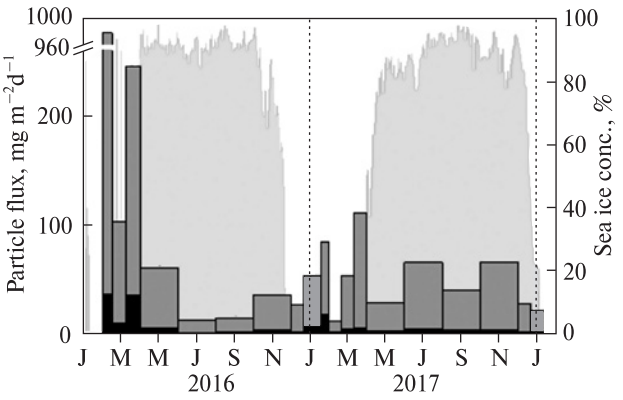


Figure 2. Intensity of sedimentary flows (grey columns) and accumulation of organic carbon particles (black columns) in the sedimentary traps in the Amundsen Sea, according to the field monitoring results (Kim et al., 2019). The x-axis shows the time in months, and the grey color denotes the surface sea ice content

ing the organic matter produced in the surface waters to the bottom sedimentary layers. In particular, this allows to study various aspects of the producers' distribution in the water in the framework of climate research. The Antarctic seas are known to have high primary productivity and carbon consumption rates through the action of the "biological pump", which makes Antarctica a key region where to study the changes in primary productivity and how it is connected with the cryosphere, physicochemical parameters of the water column and nutrient content. All these parameters affect the intensity of phytoplankton bloom, retention, and export of carbon in the water column and on the sea floor (Frignani et al., 2000), considered to be among the key factors of regulating the atmospheric CO_2 (Siegenthaler et al., 2005). The acute need to understand how the biogeochemical carbon cycles relate to the rise in atmospheric CO_2 in the recent decades (Brewer et al., 1986) moved the problem to the frontlines of research.

Studying the Amundsen Sea shelf in the marginal zone of the sea ice of the frontline areas of the western part of the Antarctic Peninsula and other waters proved that the character of sedimentary processes in the region supports the close temporal connection of the phytoplankton bloom in the spring and summer and the intensity of the vertical flow of the suspended particles (Collier et al., 2000; Anadón & Estrada, 2002; Fischer et al., 2002; Arrigo et al., 2008; Ducklow et al., 2008; Honjo et al., 2010; Forest et al., 2011).This has lately become a subject of research in the near-polar oceanic basins using sedimentary traps. The water columns of the polar latitudes are influenced by the ice cover, especially in the edge glacier zones (Smith & Nelson, 1986). The seasonal fluctuations of the generation and input of primary production are determined by the shortness of the phytoplankton bloom, starting with the thawing of ice cover and ending with the deposition of a lot of biogenic material into the bottom sediments (Kim et al., 2019). By the results of field monitoring in the Amundsen Sea, the change in the number of suspended particles in polar waters correlates with the seasonal variability of primary production except for the lithogenic component (Fig. 2). However, the clayey component and the organic particles also aggregate in the process of biological consumption.

The authors explain the year-to-year fluctuations in the recorded biomass by the difference in ice thickness and, therefore, in the light available for phytoplankton development. Other authors (Riaux-Gobin et al., 2013), based on field research, suggest that it is important to consider the succession models of phytoplankton to reveal long-term trends in the ecosystems of the Southern Ocean; in their opinion, this is a more sensitive marker than biomass or productivity index. The presence of currents in subglacial waters can also be confirmed by the change in biodiversity and quantitative parameters of sampled microalgae.

Another important question, investigated in many studies using SM traps, is the typification of the sedimentary processes on the Antarctic shelf, the main components of the current-day sedimentary matter, their re-distribution depending on the geographical factors, seasonality, distance to the continent, and changes in the ice cover configuration. Besides tracking the current-day patterns of the sedimentary conditions in the Antarctic seas, this method allows to discover the sedimentation processes in the past geological epochs and to predict the future changes related to the acidification of the ocean, changes in its temperature regime and reduction in the ice cover.

The published findings show that the sedimentary flows of different Antarctic regions are highly hetero-

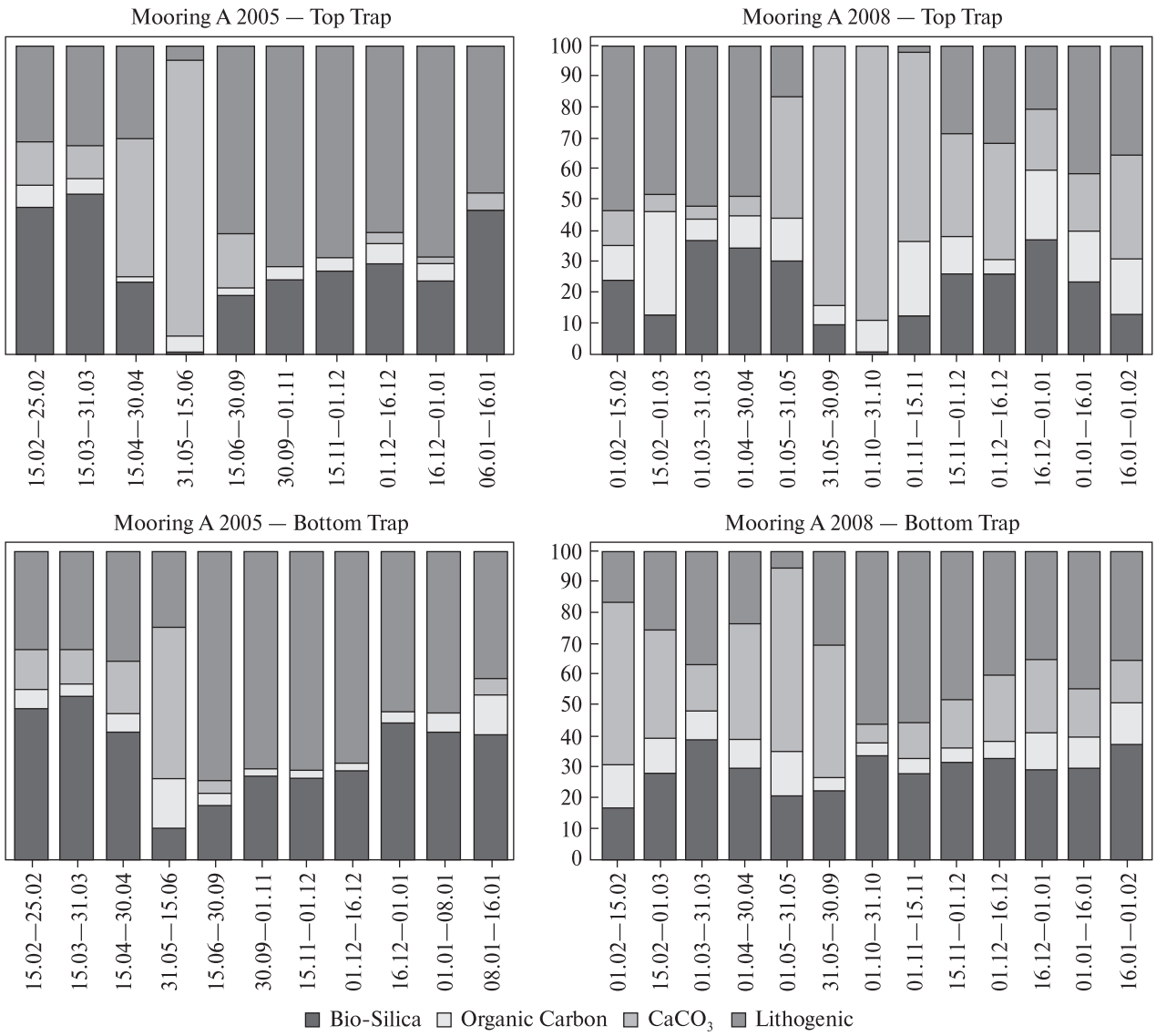


Figure 3. The vertical distribution of the main components of the sedimentary flows of the suspended matter (%) from the traps of two vertical layers (monthly and yearly dimensions), 2005–2008, in the Ross Sea (Chiarini et al., 2019)

geneous in the distributions of the biogenic and mineral components and depend mostly on the season, ice situation, and water temperature (Laws et al., 2000). They can change substantially within a single year and over several years (Ducklow et al., 2008; 2015).

Information yield of this kind of research is largely improved if traps at a single observation point are placed at different depths, allowing evaluation of the degree of the sedimentary material's transformation of the component composition during its sinking (Fig. 3) and the effect of the hydrochemical and hydrodynamical situations. Thus, when Chiarini et al. (2019) conducted their study in the Ross Sea from the oceanographic moorings, the upper-level traps allowed them to measure the emission of the particles falling from the productive upper layer. The lower-level traps provided the data on the currents at the border of the water and the upper layer of the bottom sediments.

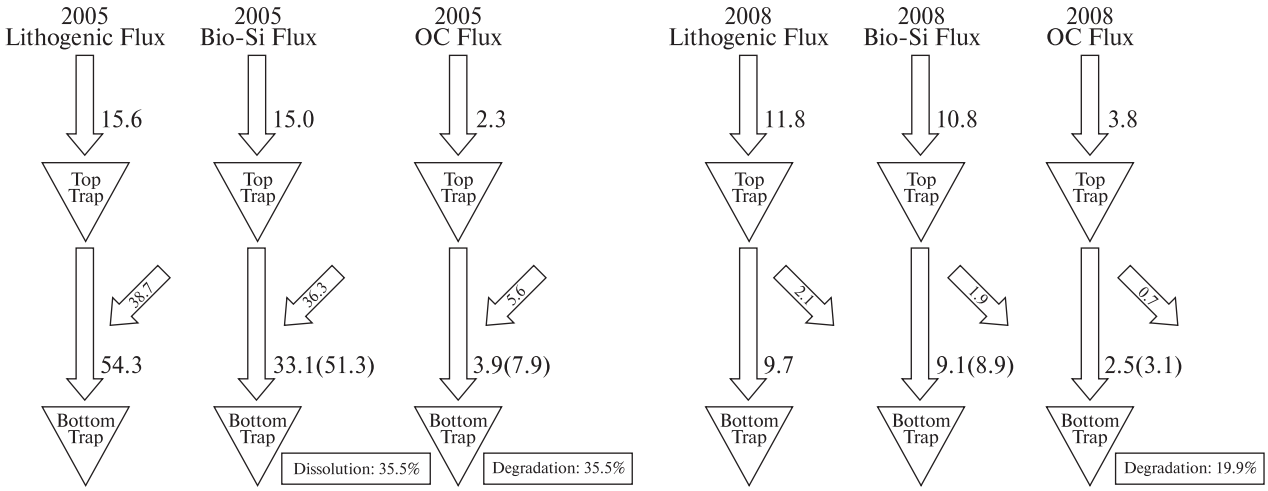


Figure 4. The balance of the accumulated matter mass and the processes of lateral advection (2005 and 2008) for the sedimentary traps placed at different depths. The numbers near the vertical arrows are the annual integral flows of the lithogenic and biogenic silica and the organic carbon (g/m^2) in the upper and lower sedimentary traps. The numbers near the side arrows are the sum of the outer input data, and the numbers in parentheses are the expected currents (Chiarini et al., 2019)

This allowed not just studying the intensity of the sedimentary matter currents but also distinguishing the non-correspondence of the intensity of the vertical SM flows during the summer and early autumn and the peaks of algal blooms in the photic water layer. Studies showed high interannual variability of both the matter's amount and composition, shaped by different factors of the phytoplankton's development, ice situation, re-sedimentation, as well as lateral advection of flows of lithogenic and biogenic silica and organic carbonat different depths (Fig. 4).

Analysis of different variables (particle flows, their origin, distribution of the sea ice, and chlorine concentration) collected in the Ross Sea yielded new findings on the seasonality of the biogeochemical processes. The results underlined their substantial interannual variability and confirmed the importance of serial observations. Databases based on the results of systematic observations allow to tentatively determine the character and roles of the forces behind the seasonal variability of some geological and biological processes.

The importance of this field of knowledge caused a number of innovative methods of simultaneous research of the main parameters of sedimentation flows. In particular, Mc Donnell & Buesseler (2010) used a new combination of sampling methods, which included visual quantitative fixation of suspended particles in the water column *in situ* and sampling of the substance of vertical sediment flows using sedimentation traps. At the same time, suspension fixation, in order to minimize deformation and damage to particles, took place in the medium of viscous polyacrylamide gels. These studies were conducted over a long time at different depths and locations on the continental shelf along the western part of the Antarctic Peninsula, in particular, in Marguerite Bay.

Studies have revealed regularities in the natural conditions of the formation and distribution of marine suspension but have difficulties modelling sedimentation (for example, the vertical velocities of particles by size classes). The researchers concluded that a certain additional influence on the processes of sedimentation is created by the material composition of the particles, particularly the krill fecal granules, and the suspension's concentration in the water column. The authors note that their studies will help elucidate the mechanisms shaping the characteristics of solid particles' vertical flows and are useful for verifying models of the movement of sedimentary flows from the photic zone of the Southern Ocean to bottom sediments.

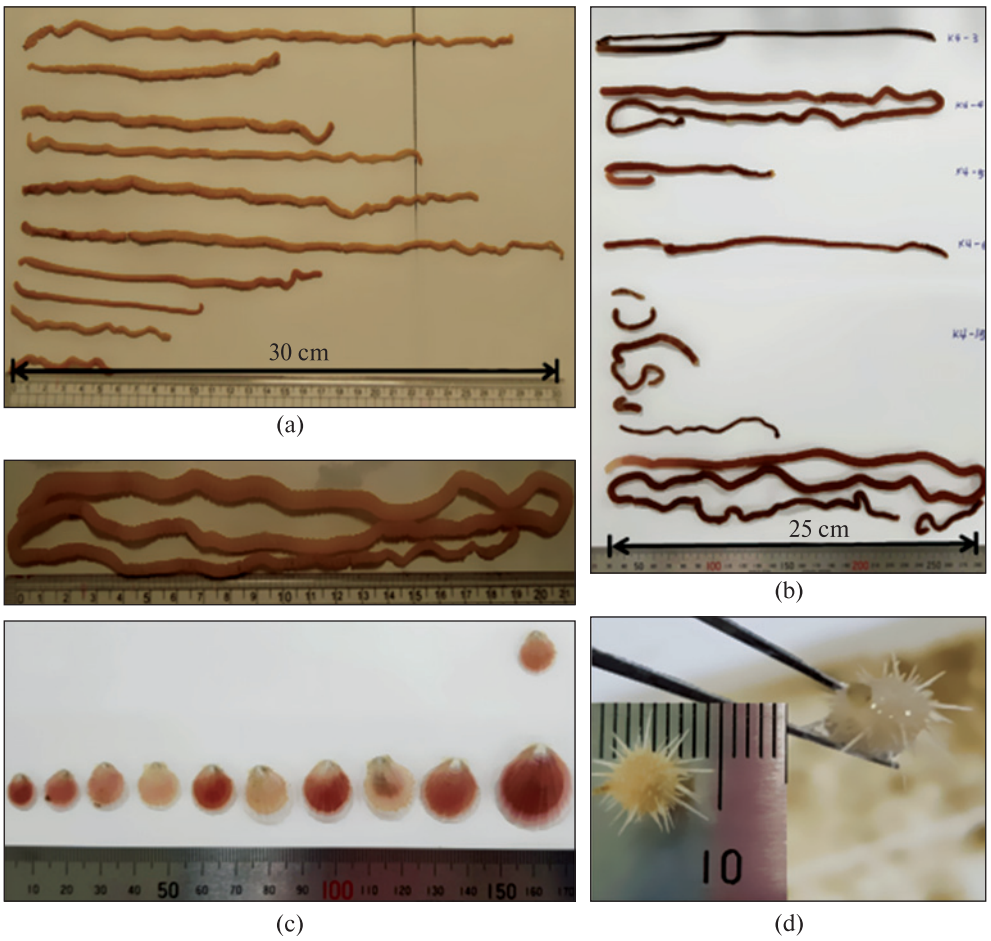


Figure 5. Invertebrates from sedimentary traps in the Amundsen Sea: (a), (b) worms, (c) – scallops, (d) – sea urchin (Kim et al., 2019)

The other important applied aspect is studying trophic links between certain kinds of biological communities on the Antarctic shelf and establishing the part played by the ice cover, in particular, by the temporary ice in the processes carrying the benthic organisms over long distances. Thus, Kim et al. (2019) used sedimentary traps in the Amundsen Sea and showed the possibility of tracking benthic invertebrates' dispersal from the coastal zone to great depths (over 600 m) by the anchor ice (Fig. 5).

The researchers installed the traps 130–567 m above the sea floor in three sites of the Amundsen Sea. The study lasted for several years. They trapped many benthic invertebrates (long and slender worms, a sea urchin, and young sea scallops). The number and diversity of these organisms, trapped mostly in winter, support them being brought in with anchor ice which had captured them on the shelf where it had formed and then carried them along, well-preserved. It is exactly the anchor ice accumulating in the places where the epibenthic animals can grow over the objects on the sea floor (such as mollusks and sea urchins) in the over-cooled water and then carry them with the mineral component.

Schloss et al. (1999) used sedimentary traps to characterize SM's quantitative and qualitative parameters in the coastal environment. They found that the processes of production and sedimentation of SM in the Antarctic seas, including the factors of re-sedimentation and periodic input of the mineral compo-

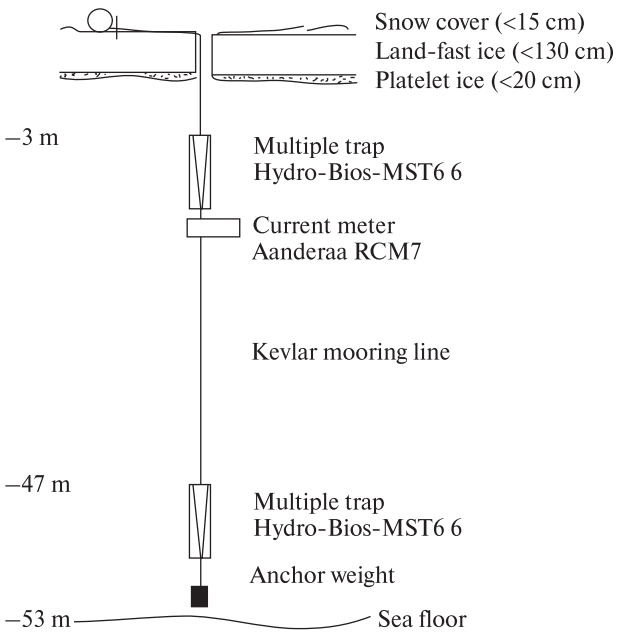


Figure 6. An example of placement and equipment of vertical sedimentary traps installed from the surface of the ice cover in East Antarctica (Riaux-Gobin et al., 2013)

nent by the meltwater from the shore, have a direct effect on the distribution of the benthic organisms' nutrition. Some benthic organisms, according to their developmental ecology stage, can have different nutrition sources in different seasons, as determined from the ratio of the mineral and organic components in their compositions. In particular, the studied bivalvians' physiology is influenced more by the summer nutrition, which induces growth and sexual maturing, while in winter, the mollusks feed on dissolved organic matter and bacteria. This is largely determined by the re-distribution of the organic and inorganic SM over the year.

The efficiency of sedimentary traps is also confirmed by the experience of studying the distribution of krill's fecal pellets (Belcher et al., 2017). This experiment was based on krill's ability to produce big fecal pellets, which constitute a sizable part of the mesopelagic particles and are considered a predominant component of the organic carbon flow in the upper 200 m of water. The data confirmed that the pellets can both support the high rate of the exported organic carbon and efficiently transport carbon through the mesopelagial.

To sample materials in the field, the methods require reliable and expensive equipment, navigation systems, and technical support provided by research vessels equipped to lower them and take them out of the water. If traps are combined with other tools, the research gains in efficiency, and the sample becomes much more informative.

An important requirement of SM-trapping stations used in the Southern Ocean (Dunbar et al., 1998; Riaux-Gobin et al., 2013) is outfitting the traps with sensors to measure the currents' speed and direction in the water column, temperature, salinity, and transparency. The intensity of vertical sedimentary flows and the SM content are recorded together with the factors which shape them. Vertical "garlands" of sensors on cables are successfully used regardless of the ice situation. The tools, their working depths and the order can be adjusted to fit specific tasks (Fig. 6).

In the studies set in East Antarctica (Dunbar et al., 1998; Riaux-Gobin et al., 2013), the traps were placed at different vertical levels, which allowed measuring the emission of the falling particles from the most productive water layer while the bottom traps yielded data on the flows at the border of the water and the upper layer of the sediments.

Among important research directions, other field of research successfully employs sedimentary traps to sample and study SM, and that is tracking anthropogenic pollution.

Until recently, Antarctica's remoteness from industrial centers was thought to make it "a natural laboratory" to study the background parameters of various natural compounds that had not undergone anthropogenic influence. Human activity in the coastal regions of the continent has already contaminated them enough to be classified as "conditionally ecologically pure" over the last century. The activity of the research bases, tourism development, ever heavier traffic, etc. lead to gradual pollution, mainly with oil products and heavy metals (Deprez et al., 1999; Balks et al., 2002). The distribution of several dangerous stable compounds in the World Ocean, in particular, through the trophic networks, had brought about such consequences as organochlorine pesticides accumulated in the muscles and fat of penguins and sea mammals of Antarctica.

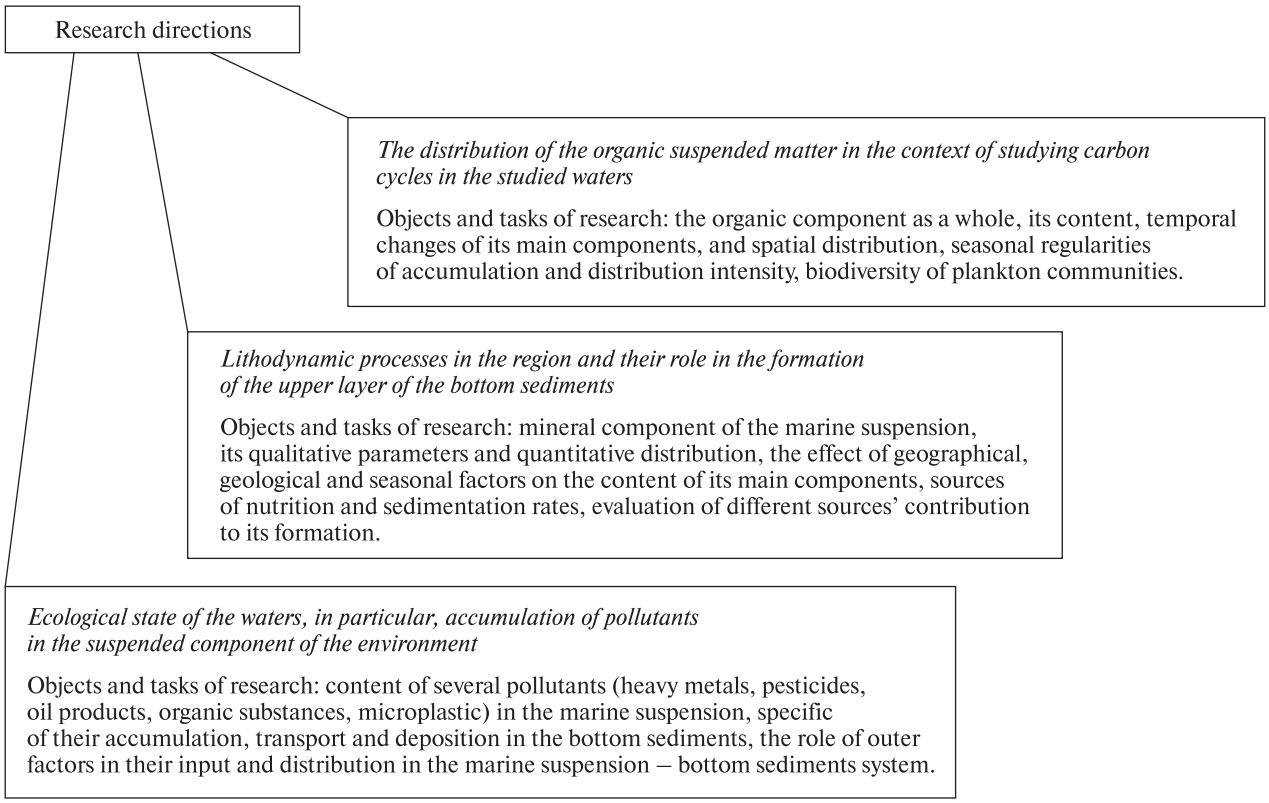


Figure 7. Generalized research directions of the marine suspension using sedimentation traps in the area of the Vernadsky station

Additionally, the density of polar stations and tourism intensity are particularly high on the Antarctic Peninsula, making the local aquatic ecosystems most vulnerable; ecological monitoring their components becomes an urgent task. This includes monitoring suspended matter also, as it is an important link in the migration pathways of most pollutants into the bottom sediments, where they accumulate due to aggregation, sorption, or biological processes causing their suspension.

4 Discussion

The reviewed experience is evidence of a higher information value of comprehensive interdisciplinary research using traps to sample the suspended matter and proves the expedience of field observations to study the connection of marine sedimentogenesis with climate change and many other highly relevant environmental processes. Based on the literature and our own research experience, we consider that monitoring the following parameters in the waters at the Vernadsky station will be valuable:

– SM content to find the role of different sources in the formation of the sedimentary flows and the upper layer of the modern bottom sediments;

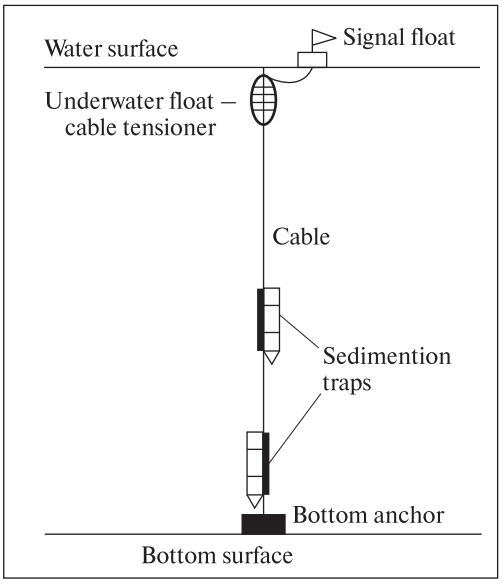
– temporal and spatial parameters of the marine suspension's distribution in the context of the geographical, oceanological, and biological factors mobilizing and transporting the sedimentary material;

– formation of the SM's organogenic component to evaluate the seasonality and distribution of the producers in the photic zone, their biodiversity, and quantitative parameters;

– intensity of the vertical currents of SM to evaluate the general sedimentary situation within certain areas of the shelf;

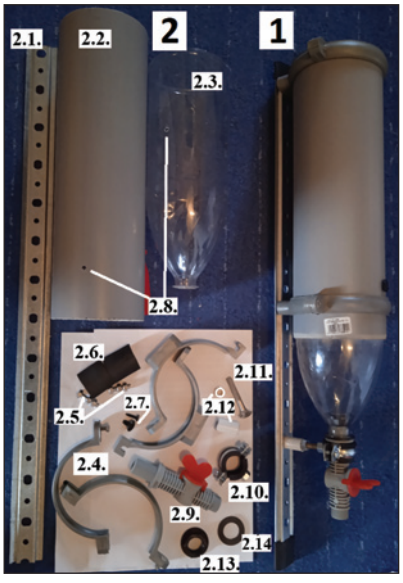
– presence of pollutants (heavy metals, pesticides, oil products, organic substances, and microplastic) in

1)



2)

3)



4)

Figure 8. Sedimentation traps: 1) the garland of three traps in the process of sampling (geoecological research of the IGS NAS of Ukraine, the Black Sea, 2013) (Nasiedkin et al., 2013); 2) examples of placement of vertical sedimentary traps; 3) traps made for experimental research and optimization of the observation methods in the waters near the Vernadsky station during the seasonal works (2022); 4) general view of the trap (1) and accessories (2): 2.1 Galvanized fixing bar; 2.2 Outer part of the sedimentation tank; 2.3 Inner part of the sedimentation tank; 2.4. Fixing clamps of the sedimentation tank; 2.5. Threaded stud with nuts and locknuts (fix the clamps on the bar); 2.6. Rubber tips on the end of the bar; 2.7. Plastic clip – retainer of the walls of the outer and inner sedimentation tank and a system for draining excess water; 2.8. Holes for clips; 2.9. Drain faucet for selected water suspension; 2.10. Clamp, which fixes the drain system to the bar; 2.11. Bolt, which fixes the drain system to the bar; 2.12. A clamping tube of a bolt of system of drain to a lath and a nut; 2.13. Plastic nut, which fixes the faucet to the neck of the trap; 2.14. Rubber gasket between the drain system and the neck of the trap

the marine suspension and the laws of their transport and deposition in the bottom sediments.

To solve these problems, the special attention needs to comprehensive systematic environmental monitoring in the area of the Vernadsky station as required by the Environmental Protection Protocol. Creating a system of long-term observations of the suspended matter's distribution in the waters near the Vernadsky station would allow obtaining representative data on the sedimentation currents' physical, geochemical, and biological properties and provide a framework to interpret data on various aspects of marine ecosystems.

Due to the weather and ice situation in the area of the Vernadsky station, the biological productivity there is relatively high, and the lithogenetic processes, are active. This makes field research on the composition and distribution of the marine suspension of the Ar-

gentine Islands an important approach to studying the sedimentary situation and its dynamics. These studies would be substantially novel due to the regional specifics of precipitation and re-distribution of the effect which the processes acting in the cryo-, athmo-, geo- bio-, and hydrosphere have on the sedimentation. Other promising scientific field is mapping the anthropogenic pollutants and emissions from natural disasters such as large-scale forest fires in the Southern Hemisphere (Liu et al., 2021).

We propose such research activities using sedimentary traps in the area of the Vernadsky station (Fig. 7).

The theory and creation of a system of comprehensive monitoring of physical, geological, chemical and biological processes shaping SM's parameters require further development of tools and techniques. A preliminary study requires cheap and efficient tools.

In the last decades, the Department of Modern Marine Sedimentogenesis of the Institute of Geological Sciences of the National Academy of Sciences (IGS NAS) of Ukraine has designed and implemented systems of monitoring the sedimentary flows in riverine and marine basins (Nasiedkin et al., 2013; Olshtynskaya et al., 2019). Years of practice of periodic observations proved the efficiency of using light, compact and cheap traps which do at the same time meet the requirements imposed by the riverine and the marine environments (Fig. 8).

Sedimentation traps, along with traps for the selection of atmospheric aerosol, were the main field equipment for several scientific projects of competitive target topics of the National Academy of Sciences of Ukraine such as "Creation of a system of observations of the state and variability of natural conditions in the "land – sea" interaction zone" (2010–2014) and "Monitoring the impact of economic activity on natural complexes and control of negative changes in their composition" (2015–2019) (Nasiedkin et al., 2013; Nasedkin & Ivanova, 2014; Mitropolsky et al., 2016).

The traps allowed us to collect long-term data series, at different depths and in different conditions. Analysis of monthly samples over many years made it possible to determine the intensity of input and the main factors affecting the distribution of suspension, including seasonality, hydrometeorological conditions, and hydrobiological factors (composition and distribution of aquatic microflora) (Tymchenko & Nasiedkin, 2012; Olshtynskaya et al., 2019).

Studying the qualitative parameters of the suspension (mineral, chemical, and granulometric composition), microelements content, and the organic component made it possible to separate the anthropogenic component and determine the criteria for classifying the substances as anthropogenic or natural according to their morphology and microelements (Nasiedkin et al., 2009; Nasiedkin, 2013; Nasedkin et al., 2019; 2022).

A wide range of analytical studies (X-ray diffraction method, electron microscopy, laser sedimentography, X-ray fluorescence analysis, the study of phyto- and zooplankton associations) and hydrometeorological investigations (directions, duration, and velocity of winds and hydrodynamic conditions) were combined into a single database. A correlation analysis of a number of indicators within time series revealed a relationship between several factors, elucidating their role in the formation of qualitative and quantitative indicators of sedimentation processes and confirming the possibility of predicting the course of sedimentation processes from the influence of a complex of hydrophysical, hydrobiological and hydrometeorological factors.

We manufactured and handed over to the State Institution National Antarctic Scientific Center light single-cylinder sediment traps, which were delivered to the Vernadsky station. These traps will be used for the following:

– approbation in Antarctic waters;

– development of the methodology of their installation and removal;

– determination of the optimal exposure time;

– locating the most suitable installation sites for various scientific purposes;

– selection of the optimal number of cylinders for simultaneous use, which in the future will allow obtaining samples of the natural substance of the required volume for complex laboratory studies.

The ease of assembling and disassembling, small weight, cheap manufacture, and minimal preparations for installation allow using the traps frequently

at small depths (up to 50 m). The minimal metal content protects them from corrosion. The absence of metal fastenings in the accumulating cylinders and above makes them suitable for ecological research such as determining the metal content in the water.

In this design, the storage cylinder of the trap sampler is made from 100 mm plastic pipes (the ratio of the cylinder length to the inlet diameter is 1/5). As a rule, a sediment trap consists of two or three sedimentation cylinders on one platform. The lower part of the trap, where the suspension directly accumulates, is a hermetically fixed transparent two-liter plastic tank. The simple design avoids suspension loss during the siphoning of the water layer above the accumulated substance and the entire sample from the hole in the bottom of the trap. Transparent plastic allows for visual fixation of the features of the distribution of the accumulated substance. The light weight of such a device makes it easy to install and remove it using small vessels. The observation station is one or several traps located at different vertical levels in the water column (depending on the tasks set), fixed to a vinyl-braided cable, the tension of which is determined by the bottom weight on the one hand and the float on the other. In order to avoid destruction or deviation from the straight line, the main float is kept deeper, and a signal buoy connected to the structure remains on the surface.

High manufacturability and low cost of production determine the possibility of quick assembly of sediment traps of this type and wide use in any field conditions. Sampling time is determined by the research tasks, the accumulation rate etc. The exposure time of the traps should be from 1 to 2 months, depending on weather, ice, hydrodynamic conditions, location depth, and configuration. When removing the trap and extracting the suspended matter, the excess water layer can be decanted through the hole closed by the clip, this can be done by unscrewing the plastic screw fixing the clip. The remaining water with a suspension (approximately 1 l) must be thoroughly shaken in the cylinder, washing off the substance deposited on the inner walls, then open the tap, pour into a container for transporting and storing the sample. During operation, it is advisable to collect near-bottom suspended substance and install the stations with traps at different sites, which will reduce the probability of tool loss. When setting traps, it is desirable to avoid water areas of straits with difficult ice conditions and significant currents, bottom topography with significant slopes and depths over 40–50 m. The preliminary design for the trap network to be adjusted to the current ice situation has been transferred to the station and is being tested in the field together with the traps themselves.

If the experiment is successful and the works are continued, further experiments will be done to adjust the method to specific tasks.

5 Conclusions and recommendations

The study found evidence that in the last years, as the Southern Ocean has become the object of various research approaches, marine geology remains very important; various aspects of the science touch upon the present-day sedimentation and the role of marine biota in these processes, determination of the link between the climate change several external factors and events of historical geological events.

In particular, one fieldwork method has been largely developed and improved: SM monitoring with sedimentation traps accompanied by direct sampling. As these data have high information load, they are used in various disciplines such as geology, oceanology, marine biology, glaciology, and climatology. Such works allow to understand the contribution of different natural sources to the formation of sedimentation flows and production of the modern sediments, determine the geographical, oceanological, and biological factors of mobilization and transport of the sedimentation material, and evaluate the scope of the development and horizontal distribution of the producers in the photic zone, their taxonomic content, and quantitative parameters.

The link between the processes of marine sedimentogenesis and the climate changes, seasonality, synoptic transformation of the water mass, and ice situation, as well as a number of current natural processes, which are a matter of valuable research, makes such studies a promising field for the Ukrainian polar scientists. Analyzing the foreign publications and our

own experience (Nasiedkin et al., 2013), we found that creating a system to monitor the distribution of the suspended matter in the waters near the Vernadsky station can become an important and informative branch of research. The main applied aspects of such works can be considered the following:

– the distribution of organic matter in the marine suspension in the context of global climate change,

– the dynamics of the input and patterns of transport of the solid particles suspended in water, determination of their qualitative and quantitative parameters, the dependence of their distribution on the seasonality, speed, and direction of the currents, and ice situation,

– the presence, content, and dynamics of the polluting substances in the water column and the uppermost layer of bottom sediments.

Given the specifics of the environmental conditions in the area of the Vernadsky station, the high biological productivity of the waters, and the activity of lithogenetic processes, the field studies of the content and distribution of the marine suspension in the Argentine Islands area are important for interdisciplinary research. Considering the substantial body of knowledge we have amassed over the years, on the granulometric, lithologo-mineralogical, and paleontological composition of the sedimentary matters of the bottom sediments of the Antarctic shelf in the region (Olshtynskaya et al., 2019), including the results of SM analysis will help to fully and comprehensively describe some current and past processes. This will let us identify the mechanisms and patterns of the present-day sedimentogenesis of polar waters, find out how the sedimentary material enters the system, discover the specifics of solid matter washed off the land and of shore abrasion, the cyclic development of the shoreline plankton communities and their dependence on the climate conditions.

As for the methods and equipment, studies on the Antarctic shelf indicate that sedimentary traps are quite efficient as a universal tool for sampling in the field. Their sensor arrays can be adjusted to fit different depths and expositions. To make an observation system for several physical, geological, chemical, and biological processes that shape the SM's quantitative and qualitative parameters, we need to develop and introduce the appropriate methods and technology.

We used our experience to create the devices and submit them to the Ukrainian Antarctic station for experimental use during the seasonal expedition of 2022. The light, compact, and inexpensive single-cylinder traps can fit hand-carry luggage and be used in coastal seawater without rigging a specialized boat as they require minimal handling to prepare and deploy.

Given the shortness of the time when they can be used in the environment (only two to three months) and the lack of experience in doing this kind of research in the polar environment, the goals of the season's work are to test the traps' performance, adjust the methodology, empirically determine the optimal exposition time, and find the most suitable areas and depths to use them.

If the field test is successful, its scientific and practical adjustment can become a timely and promising research direction to learn more about the Sixth continent.

Author contributions. Ye. N. and O. O. reviewed the literature and wrote a draft of the article, G. I. and O. M. edited the manuscript and selected the illustrative material.

Acknowledgments. The study was carried out at the expense of funding within the framework of the project "Evolution of marine and lake facies of bottom sediments of the Argentine Islands region under the influence of geological and climatic factors" of the State Special-Purpose Research Program in Antarctica for 2011–2023.

Conflict of Interest. The authors state that they do not have a conflict of interest.

References

Anadón, R., & Estrada, M. (2002). The FRUELA cruises. A carbon flux study in productive areas of the Antarctic Peninsula (December 1995 – February 1996). *Deep-sea Research. Part II, Topical Studies in Oceanography*, *49*(4–5), 567–583. https://doi.org/10.1016/S0967-0645(01)00112-6

Arrigo, K., van Dijken, G., & Bushinsky, S. (2008). Primary production in the Southern Ocean, 1997–2006. *Journal of Geophysical Research. Oceans*, *113*(C08). https://doi.org/10.1029/2007jc004551

Balks, M., Paetzold, R., Kimble, J., Aislabie, J., & Campbell, I. (2002). Effects of hydrocarbons spills on the temperature and moisture regimes of Cryosols in the Ross Sea region. *Antarctic Science, 14*(4), 319–326.

Belcher, A., Tarling, G., Manno, C., Atkinson, A., Ward, P., Skaret, G., Fielding, S., Henson, S., & Sanders, R. (2017). The potential role of Antarctic krill faecal pellets in efficient carbon export at the marginal ice zone of the South Orkney Islands in spring. *Polar Biology*, *40*(10), 2001–2013. https://doi.org/10.1007/s00300-017-2118-z

Brewer, P., Bruland, K., Eppley, R., & Mc Carthy, J. (1986). The Global ocean flux study: status of the U.S. GOFS program. *EOS. Science News of AGU*, *67*(44), 827–832.

Chiarini, F., Ravaioli, M., & Capotondi, L. (2019). Interannual variability of vertical particle fluxes in the Ross Sea (Antarctica). *Nature Conservation*, *34*, 417–440. https://natureconservation.pensoft.net/article/30732

Collier, R., Dymond, J., Honjo, S., Manganini, S., Francois, R., & Dunbar, R. (2000). The vertical flux of biogenic and lithogenic material in the Ross Sea: Moored sediment trap observations 1996–1998. *Deep-sea Research. Part II, Topical Studies in Oceanography*, *47*(15–16), 3491–3520. https://doi.org/10.1016/S0967-0645(00)00076-X

Deprez, P., Arens, M., & Locher, H. (1999). Identification and assessment of contaminated sites at Casey station, Wilkes Land, Antarctica. *Polar Record, 35*(195), 299–316.

Ducklow, H., Erickson, M., Kelly, J., Montes-Hugo, M., Ribic, C., Smith, R., Stammerjohn, S., & Karl, D. (2008). Particle export from the upper ocean over the continental shelf of the west Antarctic Peninsula: A long-term record, 1992–2007. *Deep-sea Research. Part II, Topical Studies in Oceanography, 55*(18–19), 2118–2131. https://doi.org/10.1016/j.dsr2.2008.04.028

Ducklow, H., Wilson, S., Post, A., Stammerjohn, S., Erickson, M., Lee, S., Lowry, K., Sherrell, R., & Yager, P. (2015). Particle flux on the continental shelf in the Amundsen Sea Polynya and Western Antarctic Peninsula. *Elementa: Science of the Anthropocene*, *3*, 000046. https://doi.org/10.12952/journal.elementa.000046

Dunbar, R., Leventer, A., & Mucciarone, D. (1998). Water column sediment fluxes in the Ross Sea, Antarctica: Atmospheric and sea ice forcing. *Journal of Geophysical Research. Oceans*, *103*(C13), 30741–30759. https://doi.org/10.1029/1998JC900001

Fischer, G., Gersonde, R., & Wefer, G. (2002). Organic carbon, biogenic silica and diatom fluxes in the marginal winter sea-ice zone and in the Polar Front Region: Interannual variations and differences in composition. *Deep-sea Research. Part II, Topical Studies in Oceanography*, *49*(9–10), 1721–1745. https://doi.org/10.1016/S0967-0645(02)00009-7

Forest, A., Tremblay, J., Gratton, Y., Martin, J., Gagnon, J., Darnis, G., Sampei, M., Fortier, L., Ardyna, M., Gosselin, M., Hattori, H., Nguyen, D., Maranger, R., Vaqué, D., Marrasé, C., Pedrós-Alió, C., Sallon, A., Michel, C., Kellogg, C., ... & Piepenburg, D. (2011). Biogenic carbon flows through the planktonic food web of the Amundsen Gulf (Arctic Ocean): A synthesis of field measurements and inverse modeling analyses. *Progress in Oceanography*, *91*(4), 410–436. https://doi.org/10.1016/j.pocean.2011.05.002

Frignani, M., Langone, L., Labbrozzi, L., & Ravaioli, M. (2000). Biogeochemical processes in the Ross Sea (Antarctica): present knowledge and perspectives. In F. M. Faranda, L. Guglielmo, & A. Ianora (Eds), *Ross Sea Ecology* (pp. 39–50). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-59607-0_4

Honjo, S., Krishfield, R., Eglinton, T., Manganini, S., Kemp, J., Doherty, K., Hwang, J., McKee, T., & Takizawa, T. (2010). Biological pump processes in the cryopelagic and hemipelagic Arctic Ocean: Canada Basin and Chukchi Rise. *Progress in Oceanography*, *85*(3–4), 137–170. https://doi.org/10.1016/j.pocean.2010.02.009

Kim, M., Yang, E. J., Kim, H. J., Kim, D., Kim, T.-W., La, H. S., Lee, S., & Hwang, J. (2019). Collection of large benthic invertebrates in sediment traps in the Amundsen Sea, Antarctica. *Biogeosciences*, *16*(13), 2683–2691. https://doi.org/10.5194/bg-16-2683-2019

Laws, E., Falkowski, P., Smith, W. O. Jr., Ducklow, H., & McCarthy, J. (2000). Temperature effects on export production in the open ocean. *Global Biogeochemical Cycles*, *14*(4), 1231–1246. https://doi.org/10.1029/1999GB001229

Liu, S., Xing, J., Westervelt, D. M., Liu, S., D. Ding, Fiore, A. M., Kinney, P. L., Zhang, Y., He, M. Z., Zhang, H., Sahu, S. K., Zhang, F., Zhao, B., & Wang, S. (2021). Role of emission controls in reducing the 2050 climate change penalty for PM2.5 in China. *Science of the Total Environment*, *765*, 144338. https://doi.org/10.1016/j.scitotenv.2020.144338

McDonnell, A. M. P., & Buesseler, K. O. (2010). Variability in the average sinking velocity of marine particles. *Limnology and Oceanography*, *55*(5), 2085–2096. https://doi.org/10.4319/lo.2010.55.5.2085

Mitropolsky, O., Nasedkin, E., Fedoseenkov, S., Ivanova, A., & Dovbysh, S. (2016). Recovery and adaption of the project of monitoring sedimentary processes on the Black sea shelf at the testing ground «Zaporizhzhia». *Geology and Mineral Resources of World Ocean*, *3*, 89–94. (In Ukrainian)

Nasedkin, E. (2013). Features in the distribution of copper in the composition of matter sedimentation on the Southern coast of Crimea. *Hydroacoustic journal*, *10*, 127–138. (In Ukrainian)

Nasedkin, Ye., & Ivanova, A. (2014). Monitoring sedimentacionnyh procesov v zone vzaimodejstvija sushi i morja [Monitoring of sedimentation processes in the zone of land-sea interaction]. In V. A. Ivanov, & V. A. Dulov (Eds.), *Monitoring of the coastal zone in the Black Sea experimental sub-satellite testing area* (pp. 490–503). (In Ukrainian)

Nasiedkin, Ye., Osokina, N., Ivanova, G., & Kuznietsov, O. (2009). Sezonnyi rozpodil pestytsydiv v zavyslii rechovyni Chornoho moria [Seasonal distribution of pesticides in the sus-

pended matter of the Black Sea]. *Geology and Mineral Resources of World Ocean, 1*, 80–86. (In Ukrainian)

Nasiedkin, Ye., Mytropolskyi, O., & Ivanova, G. (2013). *Monitorynh sedymentatsiinykh protsesiv u zoni vzaiemodii sukhodolu ta moria* [Monitoring of sedimentation processes in the area of interaction between the land and the sea]. EKOSI-Hidrofizyka. (In Ukrainian)

Nasedkin, Ye., Bondar, K., Tsyupa, I., Dovbysh, S., & Ivanova, G. (2019). Results of comprehensive ecological studies of sediment substance by geochemical and magnetic methods. *Geological Journal, 3*(367), 15–23. https://doi.org/10.30836/igs.1025-6814.2019.3.177967 (In Ukrainian)

Nasedkin, Ye., Olshtynska, O., Ivanova, G., & Mytrofanova, O. (2022). Some features of iron distribution in the suspended matter of the Dnieper river within Zaporizhzhia city. *Geochemistry of technogenesis*, *7*(35), 24–28. https://doi.org/10.32782/geotech2022.35.03

Olshtynskaya, A., Nasedkin, Ye., & Ivanova, A. (2019). Preliminary results of investigations of diatoms (Bacillariophyta) from the water suspension of the Dnipro river within Zaporizhzhia city (Ukraine). *International Journal on Algae*, *21*(2), 177–190. https://doi.org/10.1615/InterJAlgae.v21.i2.70

Tymchenko, Yu., & Nasiedkin, Ye. (2012). Perspektyvy zastosuvannia metodiv diatomovoho analizu dlia monitorynhu vplyvu hidrometeorolohichnykh faktoriv na protsesy osadko nakopychennia [Prospects of using methods of diatom analysis to monitor the hydrometeorological factors' effect on sedimentation processes]. *Visnyk of Taras Shevchenko National University of Kyiv: Geology, 58*, 4–10. (In Ukrainian) http://www.geolvisnyk.univ.kiev.ua/en/archive/2012/N58/tymchenko.pdf

Riaux-Gobin, C., Dieckmann, G., Poulin, M., Neveux, J., Labrune, C., & Vétion, G. (2013). Environmental conditions, particle flux and sympagic microalgal succession in spring before the sea-ice break-up in Adélie Land, East Antarctica. *Polar Research*, *32*, 19675. http://dx.doi.org/10.3402/polar.v32i0.19675

Sampei, M., Sasaki, H., Forest, A., & Fortier, L. (2012). A substantial export flux of particulate organic carbon linked to sinking dead copepods during winter 2007–2008 in the Amundsen Gulf (southeastern Beaufort Sea, Arctic Ocean). *Limnology and Oceanography*, *57*(1), 90–96. https://doi.org/10.4319/lo.2012.57.1.0090

Schloss, I., Ferreyra, G. A., & Kowalke, J. (1999). Particle flux in an Antarctic shallow coastal environment: a sediment trap study. *Scientia marina*, *63*(1), 99–111.

Siegenthaler, U., Stocker, T. F., Monnin, E., Lüthi, D., Schwander, J., Stauffer, B., Raynaud, D., Barnola, J.-M., Fischer, H., Masson-Delmotte, V., & Jouzel, J. (2005). Stable carbon cycle-climate relationship during the late Pleistocene. *Science*, *310*(5752), 1313–1317. https://doi.org/10.1126/science.1120130

Smith, W. O. Jr., & Nelson, D. M. (1986). The importance of ice edge phytoplankton blooms in the Southern ocean. *Bio Science*, *36*(4), 251–257. https://doi.org/10.2307/1310215

Wefer, G., Fisher, G., Fütterer, D. K., Gersonde, R., Honjo, S., & Ostermann, D. (1990). Particle sedimentation and productivity in Antarctic waters of the Atlantic sector. In: U. Beil, & J. Thiede (Eds.), *Geological History of the Polar Oceans: Arctic Versus Antarctic* (pp. 363–379). Kluwer Academic Publishers.

Weston, K., Jickells, T., Carson, D., Clarke, A., Meredith, M., Brandon, M., Wallace, M., Ussher, S., & Hendry, K. (2013). Primary production export flux in Marguerite Bay (Antarctic Peninsula): Linking upper water-column production to sediment trap flux. *Deep-sea Research. Part I, Oceanographic Research Papers*, *75*, 52–66. https://doi.org/10.1016/j.dsr.2013.02.001

Received: 18 January 2022
Accepted: 28 January 2023

Є. Насєдкін[1], О. Ольштинська[1,*], Г. Іванова[1], О. Митрофанова[2]

[1] Інститут геологічних наук НАН України,
м. Київ, 01054, Україна

[2] Державна наукова установа «Центр проблем морської геології, геоекології та осадового рудоутворення НАН України»,
м. Київ, 01054, Україна

* **Автор для кореспонденції**: ol-lesia@ukr.net

Завислa речовина прибережних акваторій Антарктичного півострова для дослідження геологічних процесів і стану антарктичних екосистем

Реферат. У роботі оглянуто й проаналізовано міжнародні комплексні дослідження мінеральної та органічної складової морської завісі у водах Південного океану, а також запропоновано систему моніторингу складових морської завісі для впровадження цього наукового напрямку на Українській антарктичній станції «Академік Вернадський». Якісні та кількісні властивості завислої речовини у водах регіону є предметом активних прикладних досліджень, зокрема при проведенні комплексних робіт геологічного, біологічного, кліматологічного спрямування; підвищена увага до розподілу завислої речовини у водному середовищі шельфової зони Антарктиди визначається важливістю морської

зависі для формування осадового покриву дна та перебігу низки фізичних та біохімічних процесів у водній товщі. Дослідження охоплюють якісні та кількісні властивості зависі, вміст органічної речовини й мінеральної компоненти, динаміку надходження та транспортування завислих твердих частинок та характер седиментаційних процесів, їх сезонності та зв'язку з напрямом течій і пересуванням морського льоду. Для визначення можливості проведення робіт з вивчення завислої речовини в акваторіях навколо станції «Академік Вернадський» аналізується власна багаторічна практика використання придонних пасток для дослідження процесів морської седиментації та перенесення речовини у шельфовій зоні, а також визначаються раціональні методи використання в специфічних полярних умовах створеної і впровадженої у попередні роки вітчизняної системи моніторингу потоків осадової речовини в морських і річкових басейнах України. Розроблений комплекс польового обладнання може бути застосованим для відбору зависі з водного середовища акваторій, прилеглих до станції «Академік Вернадський». Зразки устаткування, зокрема, легкі одноциліндрові седиментаційні пастки, використовуватимуться для проведення експерименту з відбору завислої речовини з вертикальних седиментаційних потоків під час майбутніх сезонних робіт українських антарктичних експедицій.

Ключові слова: Аргентинські острови, комплексні дослідження, моніторинг, морська завислa речовина, седиментаційні пастки, процеси сучасного осадконакопичення