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Oceanographic, marine geological and sedimentary research in the coastal area of West Antarctica

Abstract. We present the results of studying, mapping, and bathymetric profiling of the sea bottom relief from the research vessel *Noosfera* and the map of the Argentine Islands' underwater relief based on current data. The paper contains a brief description of the material, granulometric (grain size analyses), and mineral composition of bottom sediments collected during the expedition in deep and shallow sites, as well as an analysis of sedimentation conditions in the region. We also provide the results of a study of the taxonomical and ecological diversity of siliceous microfossils of bottom sediments in Penola Strait; the material is illustrated with a table of images of diatoms studied using the scanning electron microscope. The fieldwork methods on the research vessel and in the laboratory and analytic works are described.

Keywords: Argentine Islands, bathymetry, diatom, geology, paleoecology, sediments

1 Introduction

The results of studying, mapping, and bathymetric profiling of the sea bottom relief have been provided from the research vessel RV *Noosfera* in the area of the Ukrainian Antarctic Akademik Vernadsky station (hereinafter Vernadsky). Vernadsky is the former British Antarctic station Faraday on Galindez Island of the Argentine Islands, which was transferred to Ukraine in 1996. The map of the Argentine Islands' underwater relief was constructed based on year-round geological monitoring and annual research. These results have been based on studies of the geological structure and sedimentation processes on West Antarctica's shelf, continental slope, and coastal shelf close to Vernadsky from the very start of marine geological studies.

A comprehensive approach to long-term marine-geological research with the analysis of findings from different periods will significantly supplement the existing database. The accumulated data include information on oceanographical parameters of the studied area and lithology, mineralogy, and micropaleontology of sediment cores. That allows determining the main patterns of sedimentation processes in the area of the Argentine Islands, reconstructing the geological and climatic history of the region, and clarifying its role in global climate processes.

A complete database of paleoclimate records is being formed to reconstruct the spatio-temporal evolution of the Holocene temperature at the global level. This database includes published, temperature-sensitive, quality-controlled proxy records dating back 12000 years to the Holocene and is publicly available in Linked Paleo Data (LiPD) format (Kaufman et al., 2020). The multi-proxy database contains paleotemperature series based on environmental, biophysical, and geochemical indicators. We hope that our research on the waters of the Argentine Islands will be able to add to the global database.

Many countries conduct a wide range of research on marine and terrestrial (lake) sediments in the Antarctic. Radiocarbon dating is used to compare marine and terrestrial sediments. Much attention is paid to sea ice to determine its role in the Holocene changes, as sea ice is a key driver of modern climate. On the west coast of the Antarctic Peninsula, there is a clear correlation between changes in sea ice extent and coastal temperatures (Gersonde et al., 2005; Bentley et al., 2009).

Multifaceted research of siliceous and calcareous microfossils is also very important. Paleoclimatic analysis in the region is based, in particular, on the study of siliceous microplankton in the water column, ice formations, and bottom sediments of Antarctic waters (Xiao et al., 2016), etc. Special attention is paid to the diatoms' role as the markers of the current changes in the ocean habitats; this property allows us to use them for paleoceanographic reconstructions (Zielinski & Gersonde, 1997; Armand et al., 2005). In Antarctica, marine diatoms from locations around West Antarctica, particularly the Antarctic Peninsula, Ross Sea, and Weddell Sea, are mainly available for detailed study. On the contrary, marine diatom floras from the East Antarctic location are rarely published, and such data are incomplete (Cremer et al., 2003). Therefore, it is in the studied region that this method is used to determine the conditions of sedimentation, ecology, and paleoclimatic phenomena.

The data of diatoms in the sediments provide high-resolution information about changes in oceanographic processes and paleoclimate during the Late Quarternary period reconstructions (Zielinski & Gersonde, 1997; Armand et al., 2005). Therefore, an important part of oceanographic research is dedicated to the current geographical distribution of the main species of algae and communities in the water column and their skeletons in the sediments in different sectors of the Southern Ocean. The distribution of diatoms, especially paleoecologically significant species in the surface sediments of the Southern Ocean, has clear patterns that may be related to the properties of the surface waters and the duration of sea ice coverage (Buffen et al., 2007).

Such studies tackle the diatoms' connections with the ice cover, conditions of spreading and concentration of the marine ice in the polar regions, and recovery of the seas' surface paleotemperature to reconstruct the ancient climates and to update the oceanological databases (Crosta et al., 2005; Romero & Armand; 2010; Cefarelli et al., 2010). Tracking past climatic changes and forecasting future ones by analyzing the diatoms' taxonomy and distribution requires profound autecological knowledge for every registered taxon (Al-Handal & Wulff, 2008). Questions about siliceous microalgae's composition, habitat, and participation in biogeochemical processes are being investigated (Armand et al., 2005). The activity of skeleton-forming organisms is strongly influenced by the silica cycle in modern oceans, which is closely related to other biogeochemical cycles, like those of carbon and nitrogen, of carbon export to the deep sea. The precipitation of silica by diatoms decreases dissolved silica concentrations in shallow marine waters (Romero & Hensen, 2002).

Diatoms of the Southern Ocean are also studied as a source and exporters of organic carbon and related nutrients and as a deciding factor regulating carbon's global oceanic fixation. The organic carbon flow in the pelagic waters is influenced by the diatoms' numbers, composition, and cell sizes. Their shells' morphology, size, and diversity strongly affect the uptake and export of nutrients. The cells of diatoms living in the cold, silica-rich Antarctic waters have up to sixfold higher Si content per (volume fraction) than the diatoms of the warm equatorial waters (McNair et al., 2018).

Many researchers of the Polar Ocean address the composition, habitats, and participation of the siliceous microalgae in the biogeochemical processes (Armand et al., 2005). In the area of Vernadsky, diatoms from bottom sediments were studied, the taxonomic composition and ecology of the complexes were determined, and conclusions were drawn about their stratigraphic position, the sedimentation conditions, and paleoclimatic events during the formation of sediments. The processes of transportation and re-deposition of Neogene diatomites have been discovered. In the southern part of the Scotia Sea, diatoms from the bottom sediments of the southern part of the Drake Passage, Penola Strait, Lemaire Channel, Grandidier Channel, Gerlache Strait, Wiggins Bay, Girard Bay and the French Channel (65°10′45.0″ S 64°20′25.2″ W) were studied (Ogienko, 2014; Olshtynska & Ogienko, 2017; Olshtynska et al., 2019).

The impact of various factors on changes in the conditions of sedimentation and paleoclimatic events was evaluated. Diatoms showed that sedimentation in the Late Quarternary in these waters occurred in marine cold water (−1 °C to +1.5 °C), similar to modern conditions, at a depth of not more than 10 m and indicated the presence of a dense sea ice cover in the winter period and drifting ice in the summer season (Ogienko, 2014; Olshtynska & Ogienko, 2017). There were also studied the material composition of sediments, diatoms, and silicoflagellates, and authigenic mineralization of the bottom sediments of the shallow areas of Stella Creek, Galindez Bay (65°14′49.9″ S 64°15′00.7″ W), and Winter Strait (65°14′50.5″ S 64°15′37.3″ W) near Vernadsky (Olshtynska et al., 2019).

Our present work highlights the recent findings on the marine bottom relief and distribution of bottom sediments in the Argentine Islands group, carried out by bathymetric profiling and local polynomial interpolation. Special attention was paid to the mineral and micropaleontological composition of the bottom sediments of the Penola Strait core No. 362, which were formed at a depth of 271 m and correspond to the Late Quaternary, to use the data for paleogeographic and climate analysis.

2 Materials and methods

Marine geological and oceanological research was performed in the South Ocean in the area of the Argentine Islands and the waters close to Vernadsky. The fieldwork included two main approaches, i.e., the contact (sampling) and distant (echo-sounding) methods. The underwater relief using bathymetric profiling was studied to establish the forms and positions of the main morphological elements and identify sites of current bottom sediments' accumulation. This allowed further sampling of bottom sediments for their material, mineral, and micropaleontological composition.

Our study used the cartographic results of bathymetric profiling of the sea bottom relief, the echo-sounding profiles (68332.5 m length), and the 90912 sites with known depths and coordinates. These data were collected during a seasonal Antarctic expedition in March 2022. To correct the echo-sounding data with previous cartographic results, we used the depths from the bathymetric map BA 3575 (1 : 15000). The material for a lithological characteristic consisted of 77 bottom sediment samples collected on the three West Antarctica polygons: South Shetland (21 stations on 7 sections), South Orkney (36 stations on 7 sections), and the polygon in the Argentine Islands waters close to Vernadsky (14 stations). For micropaleontological characterization, ten rock samples (50 cm of sediment layer) from column No. 362 of the Penola Strait were used.

In addition, the underwater relief of deep parts of Penola Strait was studied by bathymetric profiling. Within the shallow waters close to the Argentine Islands, depths were measured using the echo sounder chartplotter Lowrance Elite-7 Ti2, and sampling was done by hand winch and the Van-Veen type bottom grab with a bottom coverage surface of 0.1 m^2.

Besides studying the marine bottom relief and distribution of bottom sediments in the Argentine Islands group, an important part of the work was focused on research in the Penola Strait. The study was conducted from the RV *Noosfera*. During the first fieldwork stage, we analyzed the depth profile using the echo sounder-chartplotter Lowrance Elite-7 Ti2 from a Zodiac boat to identify the most favorable conditions for selecting sample sites.

We applied the local polynomial interpolation method to construct a digital elevation model (DEM) of the underwater relief (Schaum, 2008). This method selects measurements in a given radius around an interpolated site and then calculates the depth using a polynomial function. Based on the network of depth measurements in the region, the radius was set at 500 m, which permitted us to use only the measurements closest to the sites, excluding errors from including remote measurements. The fifth degree's polynomial function chosen for calculation is capable of describing a complex shape and reflecting the real relief with minimal aberrations.

Siliceous organisms were extracted from the rocks by boiling the samples in sodium pyrophosphate solution for 10 min, washing them with distilled water, placing them in a PS-10d ultrasonic cleaner, and finally washing them with distilled water through a sieve with a mesh size of 5 μm to remove sediment.

The mounting medium Naphrax with a high refraction coefficient was used to prepare permanent microscopic slides that were examined for diatoms under light microscopy.

Diatoms were identified and enumerated using a light microscope (Olympus CX41). Micrographs were taken using JEOL-6490 LV (JEOL Ltd., Japan) scanning electron microscopes and Canon PowerShot G7 digital camera (Canon Inc., Tokyo, Japan) at a magnification of ×600–800.

The numerical and percentage ratio between taxa was determined after counting 300–400 diatom valves per sample. The semi-quantitative abundance of diatoms per sample was binned into the following categories: fragments, very rare (1–2 specimens per slide), rare (several specimens in 5–20 fields of view), frequent (1 specimen in 2–5 fields of view), common (1 specimen per field of view), abundant (2 specimens per field of view), very abundant (several specimens per field of view).

The ecological structure of diatom complexes was analyzed in relation to salinity: marine and euryhaline; by species habitat: plankton, benthic and epiphytes, epiphytic association with the macroalgal, warm-water, cold-water, cryophiles, living on the ice edge, on the lower surface of the ice.

Diatoms were determined according to the classification of L. Medlin and I. Kaczmarska (Medlin & Kaczmarska, 2004), Dictyochophyceae – according to the classification given in AlgaeBase (M. Guiry & G. Guiry, 2023). Diatoms were identified by the following main sources: Glezer et al., 1974; Hasle & Syvertsen, 1997; Cremer et al., 2003; Al-Handal & Wulf, 2008; Gogorev, 2013; Li et al., 2014; Al-Handal et al., 2022.

When identifying diatoms and silicoflagellates, nomenclatural transformations are taken into account according to the AlgaeBase – the Global Algological Database for Taxonomy, Nomenclature, and Distribution (http://www.algae base.org) (M. Guiry & G. Guiry, 2023).

3 Results

3.1 Geological and oceanological research

We studied and mapped the underwater relief. To cover the studied territory and to correct the echo-sounding data with previous cartographic results, we used depth readings from the BA 3575 bathymetric map (1 : 15000). As a result, we drew a detailed map of underwater relief in the Argentine Islands area (Fig. 1).

As a result of bathymetric observations, we found marine bottom sites with a layer of modern

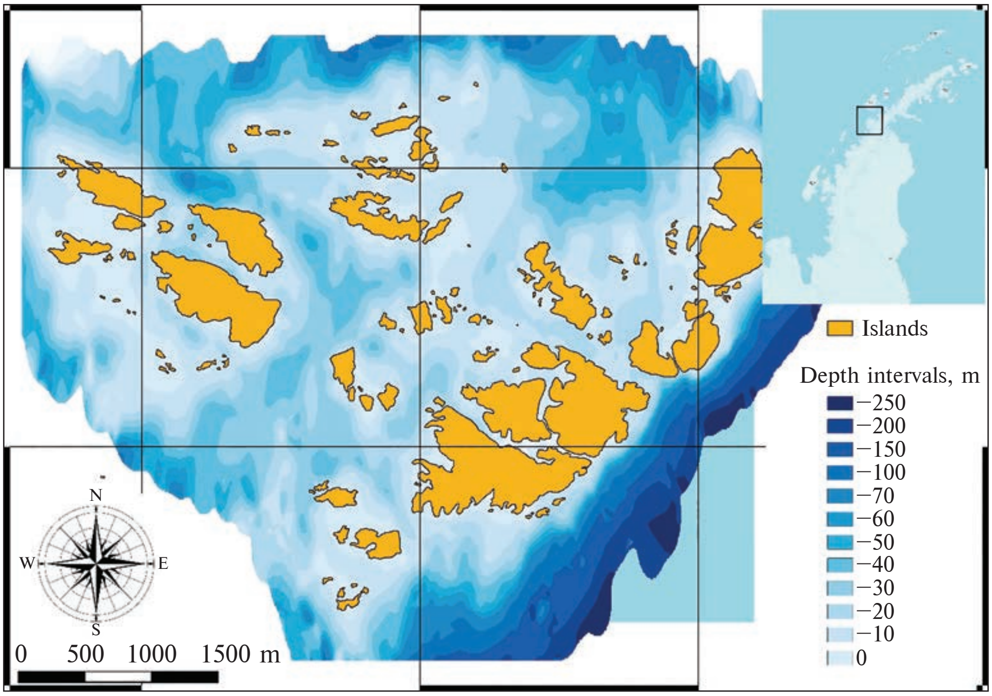

Figure 1. Map of the underwater relief of the Argentine Islands region
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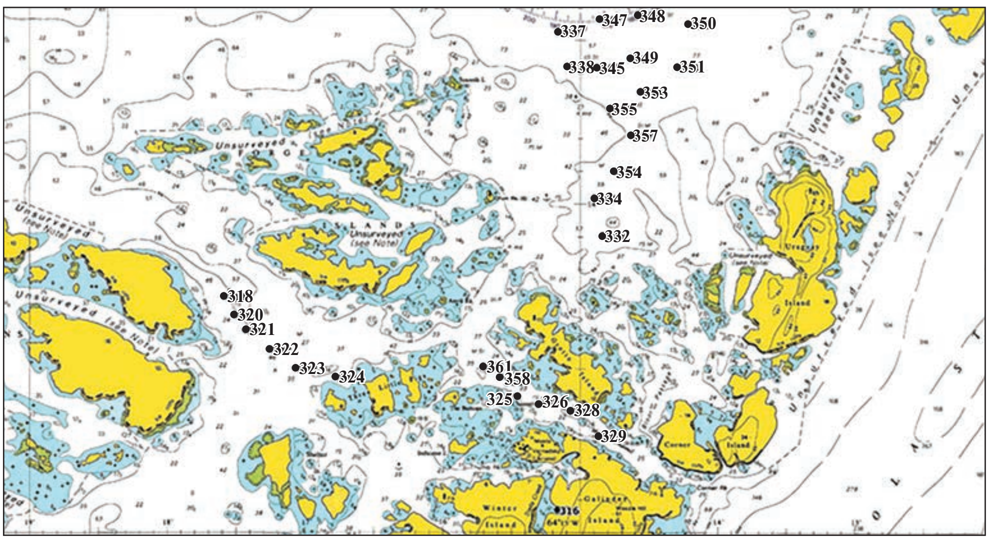

Figure 2. Locations of marine bottom sampling sites. The background is BA 3575 bathymetric map (https://www.amnautical.com/products/british-admiralty-nautical-chart-3575-argentine-islands-and-approaches)

bottom sediments thick enough to sample. On these sites, samples were taken from a Zodiac boat with a hand winch and the Van-Veen bottom grab with 0.1 m^2 covering. In total, 27 samples of surface bottom sediments were taken; the sites' locations are shown in Figure 2.

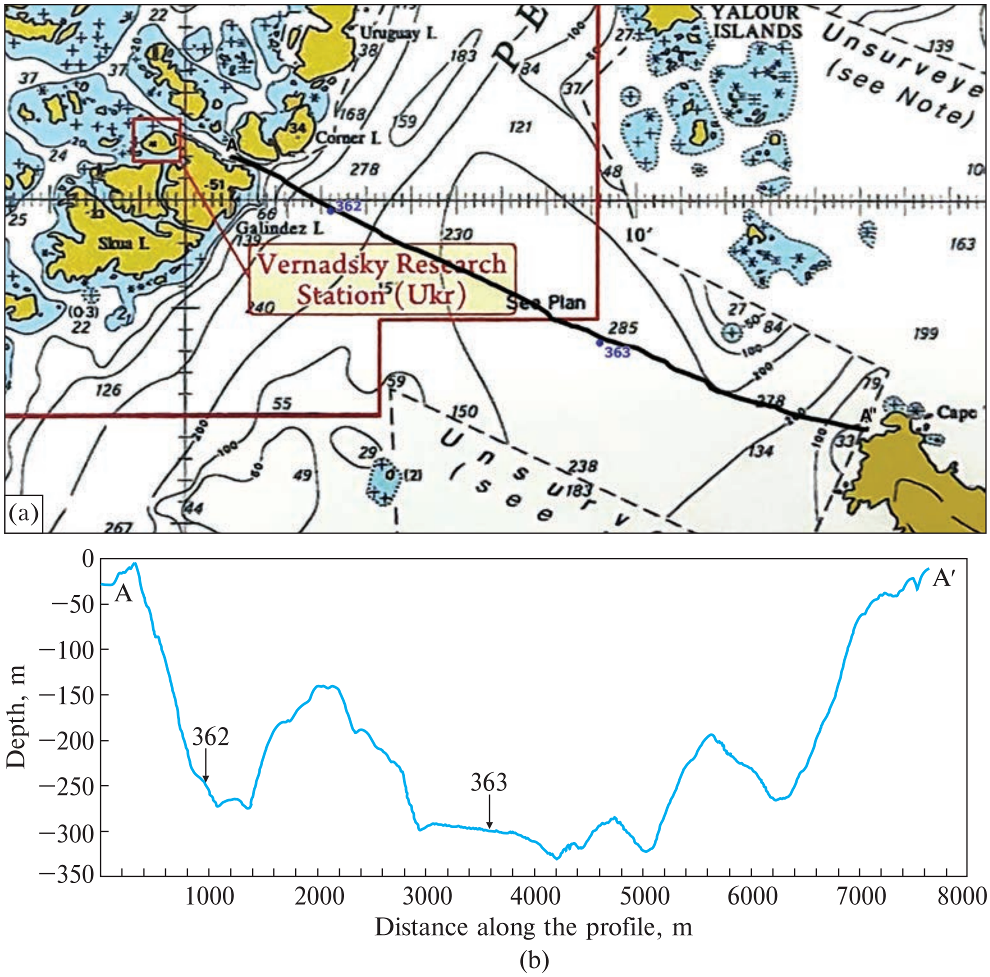

Figure 3. Bathymetric observations and sampling sites in the Penola Strait; (a) — map of profile in Penola Strait and sediment columns location (the background is BA 3575 bathymetric map), (b) — bottom relief profile with sediment columns position

Another important area for understanding sedimentary processes in the Argentina Islands region is the Penola Strait. That strait separates the islands from the Antarctic Peninsula. It is interesting from the structural-geological view because the strait, about 8 km wide, has a tectonic origin and is in the fault zone and the border between the Eastern and Western domains of the Antarctic Plate (Savchyn et al., 2021).

The bottom relief in the Penola Strait had a fairly complex morphology; we identified two depressions with quite steep slopes and a significant degree of fragmentation, but mostly flat deep-sea parts separated by an underwater rock ledge (Fig. 3).

In each depression, bottom sediment columns were sampled from the ship using straight flow gravity corer.

The bottom samples were classified as silty mud with ductile consistency with sand admixtures and occasionally crystalline rock fragments of 0.5–5 cm. A brief field description is presented in Table 1.

During the fieldwork, 77 samples of bottom rocks were collected from different depths (80–328 m) for a further comprehensive study of their characteristics, particularly grain size analysis, mineral, chemical, and microfaunistic composition. The results will update the existing database, which will allow to identify the main principles of sediment accumulation in this region of the world ocean and clarify the geological and climatic history of the Antarctic continent.

3.2 Mineralogical and micropaleontological research of the 2021–2022 geological materials

The latest geological materials for the western sector of the Antarctic and the waters adjacent to Vernadsky were analyzed, and the following works were performed:

- During the fieldwork, a preliminary characterization of sedimentary matter, granulometric, and mineral composition of rocks was carried out.
- In the laboratories of the National Academy of Sciences of Ukraine, lithological studies were started.
- In all 77 samples of bottom sediments (6 stations and 27 sampling points), skeletal remains of the following groups of siliceous microfossils were found: diatom algae (Bacillariophyceae) – in significant quantities, silicoflagellates (Dictyochophyceae) – in a small amount, spicules of sponges (Porifera) – in a significant amount and few skeletons of radiolaria (Radiolaria).

According to the preliminary study of samples from station No. 362, Penola Strait (Table 1), quartz, plagioclase, amphiboles, and siderite were found in the bottom sediments. There are bacteriomorphic framboidal clusters of iron sulfide microcrystals among the authigenic minerals. It is observed that some diatom frustules, mainly convex and voluminous *Thalassiosira*, are filled with framboidal pyrite, also known from other waters of the region (Olshtynska et al., 2019; Korsunsky et al., 2020).

The microalgae with opaline silica skeletons are a very important element of the Antarctic ecosystem. The diatoms comprise up to 40% of the Southern Ocean's primary production and are the staple non-calcifying group of the local phytoplankton. By being the leading source of the world's biological silica, they dominate the biogeochemical silica cycle and influence the changes in other macroelements' biogeochemistry (such as nitrogen, carbon, and phosphorus).

Microalgae and other groups of organic remains were studied under light and scanning electron microscopes. The taxonomic composition of major diatom taxa and silicoflagellates was determined in 10 samples from station No. 362, Penola Strait. Their ecological and biogeographic characteristics and distribution in a layer of 50 cm sediments were analyzed (Table 2).

Associations of bottom sediment diatoms from the Penola Strait at different section levels have a similar taxonomic structure. The genus *Thalassiosira* significantly dominates in all samples (very abundant, several specimens per field of view). Among other taxa, the genera *Cocconeis*, *Fragilariopsis*, *Eucampia*, *Actinocyclus*, and *Ellerbeckia* are frequent or common. *Odontella* and *Stellarima* are

Table 1. Field description of bottom sediments from the Penola Strait

Interval (m)	Description
St. № 362. Penola Strait, 65°15.0558 S, 064° 13.3634 W; sea depth 271 m. Total core sample output 0.5 m	
0.00–0.50	Silty mud with sand, grey, brown-grey, dense, with many weakly rolled rock fragments of 0.5—5 cm
St. № 363. Penola Strait, 65°15.6607 S, 064° 10.3860 W; sea depth 328 m. Total core sample output 1.0 m	
0.00–0.20	Silty mud, grey, soft, non-layered
0.20–0.75	Silty mud, dark grey, with dark brown to black spots, low-ductile
0.75–1.00	Silty mud, brown-grey, with spots of black silt, dense, non-layered, with sand and small gravel

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often found. Among Dictyochophyceae, representatives of the genus *Octactis* are frequent. Radiozoa fragments are present.

The diatoms in the sediments are well preserved, especially in the upper layers of the section, where very large, some over 200 μm, unbroken valves and frustules of microalgae are often present. Among them are the largest Antarctic endemic *Trigonium arcticum* Brightwell, *Actinocyclus actinochilus* (Ehrenberg) Simonsen, *Symbolophora microtrias* Ehrenberg, *Porosira glacialis* (Grunow) Jørgensen, *Cocconeis californica* Grunow, *Odontella weissflogii* (Grunow) Grunow (Table 3). Seventy-eight species of diatoms from 28 genera were identified from the bottom sediments of Penola Strait No. 362. The basis of the diatom complex is made up of genera *Thalassiosira*, *Cocconeis*, *Eucampia*, and *Fragilariopsis*. The genus *Thalassiosira* is represented by 6 species. The most numerous are *Thalassiosira antarctica* Comber (c. 40%) and *Thalassiosira lentiginosa* (Janisch) Fryxell (3% of the total diatom assemblage).

Penola Strait sediments contain a large group of species of the genus *Cocconeis*, the largest number *Cocconeis costata* W. Gregory — above 9% and *Cocconeis fasciolata* (Ehr.) N.E. Brown, above 2%. Such characteristic species as *Eucampia antarctica* (Castracane) Mangin, *Ellerbeckia sol* (Ehrenberg) Crawford, *Actinocyclus actinochilus*, *Odontella litigiosa* Van Heurck, and *Odontella weissflogii* are quite often found throughout the section of the bottom sediment core.

The genus *Fragilariopsis* includes four species; they make up 5% of the complex, characteristic *Fragilariopsis kerguelensis* (O'Meara) Hustedt (4%) as well as *Thalassiothrix antarctica* Schimper ex Karsten (2%) the maximum number is in the interval of 45—50 cm.

The distribution of diatoms in sediments is regulated by both water temperature and sea ice conditions. According to the biogeographical and ecological characteristics, a significant percentage of diatoms from Penola Strait sediments are pelagic open-ocean taxa typical for this region in general (Zielinski & Gersonde, 1997; Crosta et al., 2005; Romero et al., 2005). Cold-water species living in the open ocean near the ice's edge prevail among them.

Thalassiosira antarctica (warm-water and cold-water forms) is an Antarctic diatom associated with sea ice and low sea surface temperatures, living in waters with high concentrations of sea ice and close to the ice edge, but rarely found in sea ice (Gersonde & Wefer, 1987; Leventer, 1991; Zielinski & Gersonde, 1997; Gersonde & Zielinski, 2000; Taylor & McMinn, 2001; Olshtynskaya & Ogienko, 2017). The species was very abundant in all samples of bottom sediments (Fig. 4).

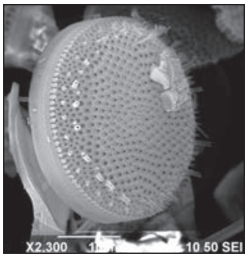
The ice-related diatom *Eucampia antarctica* common here is typical of the transition between glacial and glacial-marine deposits (Gersonde & Wefer, 1987; Leventer, 1991; Zielinski & Gersonde, 1997; Cremer et al., 2003; Crosta et al., 2005; Olshtynskaya & Ogienko, 2017). *Eucampia antarctica* var. *recta* is common in many Antarctic regions and the Southern Ocean, and it is a widely used paleoproxy associated with a neritic environment with floating ice.

Table 2. Characteristic taxa of diatoms and silicoflagellates from the station № 362, Penola Strait, the interval 0.00—0.50 cm

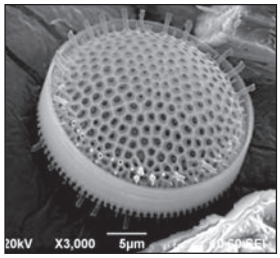
Taxon	Abundance of the total diatom population, %
Actinocyclus	2
Achnantes	2
Amphora	1
Chaetoceros spores	3
Cocconeis	11
Ellerbeckia	4
Eucampia	4.5
Fragilariopsis	5
Odontella	1.2
Porosira	2
Thalassiosira	70
Thallasiotrix	4
Trigonium	1.2
Dictyochophyceae	1

Table 3. Dominant diatoms from the Penola Strait sediments, station № 362

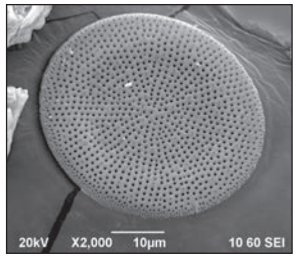
Taxon	Habitat of diatoms
Actinocyclus sp.	Plankton
Actinocyclus actinochilus (Ehrenberg) Simonsen, 1982	Seasonal sea ice
Amphora ovalis (Kützing) Kützing, 1844	Cold-water in open ocean
Asteromphalus sp. *Asteromphalus hookeri* Ehrenberg, 1844 *Asteromphalus hyalinus* Karsten, 1905	Open sea and ocean
Chaetoceros sp. hypnospores	Open sea and ocean
Cocconeis californica Grunow, 1880 *Cocconeis costata* Gregory, 1855 *Cocconeis fasciolata* (Ehrenberg) N.E. Brown, 1920 *Cocconeis infirmata* Manguin, 1957	Epiphyte
Diatoma rhombica O'Meara, 1877	Open sea and ocean
Diploneis sp.	Benthic
Ellerbeckia sol (Ehrenberg) Crawford & Sims, 2006	Summer sea benthic and epiphytic
Eucampia antarctica var. recta (Mangin) G. Fryxell & A.K.S.K. Prasad, 1990	Cold-water Antarctic marine plankton and cryophilic
Fragilaria sublinearis f. sublinearis Van Heurck, 1909	Seasonal sea ice
Fragilariopsis cylindrus (Grunow) Krieger, 1954	Seasonal sea ice
Fragilariopsis kerguelensis (O'Meara) Hustedt, 1952	Open sea and ocean
Frustulia copulata Kützing, 1833	Benthic and epiphytic
Grammatophora sp.	Benthic
Navicula sp.	Benthic
Odontella weissflogii (Grunow) Grunow, 1884	Open sea and ocean
Pleurosigma sp.	Benthic
Porosira glacialis (Grunow) Jörgensen, 1905	Cold-water Antarctic marine plankton and cryophilic
Pseudonitzschia turgiduloides (G.R. Hasle) G.R. Hasle, 1996	Open sea and ocean
Stellarima microtrias (Ehrenberg) G.R. Hasle & P.A. Sims, 1986	Seasonal sea ice
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902	Open sea and ocean, cosmopolite
Thalassiosira anguste-lineata (A. Schmidt) G. Fryxell & Hasle, 1977	Open sea and ocean
Thalassiosira antarctica (T1) Comber, 1896	Warm water form, seasonal sea ice
Thalassiosira antarctica (T2) Comber, 1896	Cold-water form, open ocean
Thalassiosira frenguellii O.G. Kozlova, 1964 *Thalassiosira lentiginosa* (Janisch) Fryxell, 1977 *Thalassiosira gracilis* (Karsten) Hustedt, 1958	Open sea and ocean
Thalassiothrix antarctica Schimper ex Karsten, 1905	Open sea and ocean
Trigonium arcticum (Brightwell) Cleve, 1868	Open sea and ocean, marine epiphytic



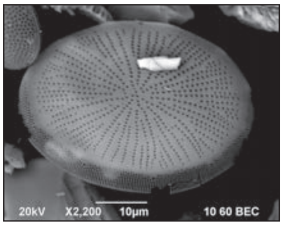
Thalassiosira antarctica (cold)



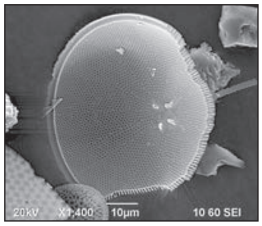
Thalassiosira antarctica (warm)



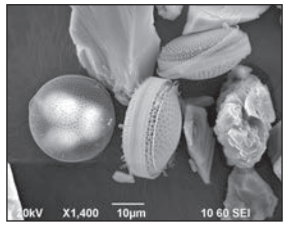
Thalassiosira lentiginosa



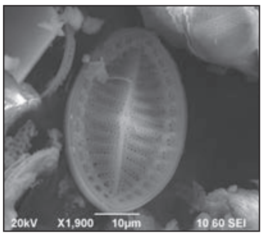
Actinocyclus actinochilus



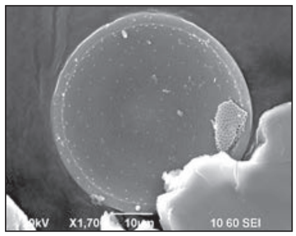
Stellarima microtrias



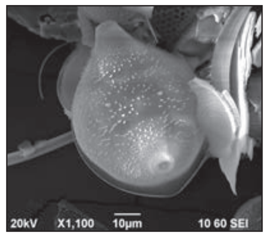
Thalassiosira antarctica (framboids' formation inside the diatoms' frustules)



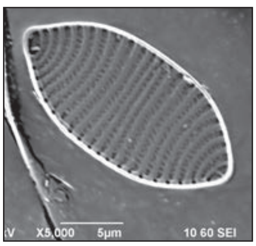
Cocconeis fasciolata var. fasciolata



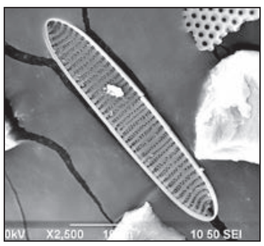
Porosira glacialis



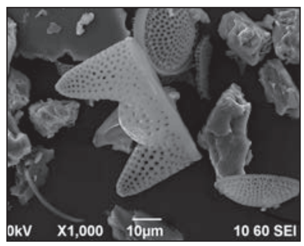
Odontella sp.



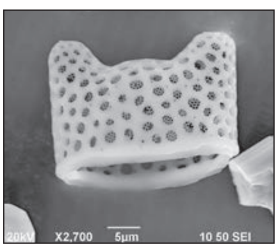
Diatoma rhombica



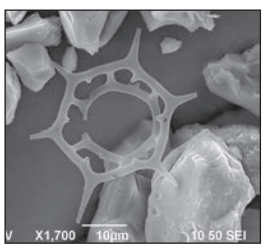
Fragilaria sublinearis f. sublinearis



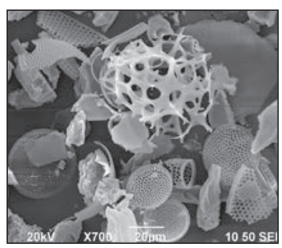
Eucampia antarctica (resistant spore, view from the girdle)



Eucampia antarctica var. recta



Octactis octonaria



Radiozoa skeleton among diatoms

Figure 4. Typical species of diatoms and silicoflagellates of bottom sediments from Penola Strait, station № 362, interval 0.00–0.50 m (scanning electron microscopy)

Fragilariopsis kerguelensis (a frequent species), endemic to the waters of the Southern Ocean, is a pelagic species of the open ocean. It dominates the the open-ocean assemblages south of the Polar Front. It is found in sedimentary deposits with sea ice cover for up to 8 months a year and in places with no ice during the summer (Crosta et al., 2005).

Such species as *Paralia sol*, *Porosira glacialis*, *Actinocyclus actinochilus*, *Odontella litigiosa*, *Odontella weissflogii*, and *Thalassiosira lentiginosa* are found in a noticeable amount throughout the section of the core of the bottom sediments. *Thalassiosira lentiginosa* is associated with open ocean conditions up to the sea ice edge. *Actinocyclus actinochilus* is considered a typical Antarctic neritic species in the ice edge zone (Olshtynska et al., 2019).

Porosira glacialis is a marine planktonic neritic species in cold coastal waters adjacent to sea ice. It predominantly grows in the open ocean behind the edge of sea ice and is commonly found in pack and fast ice samples.

At the same time, epiphytes, or marine semibenthos, species of the genera *Cocconeis*, *Diploneis*, and *Amphora* make up a significant part of diatoms, more than 12%. Species of the genus *Cocconeis* (*C. costata* – up to 7%, *C. fasciolata* – up to 3%) are polyhalobs associated with thickets of mussels and macroalgae. These species are likely transported by drifting ice along with macrophytes and deposited in the Penola Strain as the ice melts (Gerasimiuk, 2008; Riaux-Gobin et al., 2009).

Cocconeis costata is common throughout the section, with a maximum value of 9.1% in the 40–45 cm interval.

Based on the composition of the diatom assemblage, the mixed ecological model of open water taxa with ice-associated taxa and epiphytes, it can be assumed that the sea ice in the study area during the Neoglacial period was in the form of loose sea ice that expanded and contracted seasonally and migrated.

4 Discussion

The tectonic fault in the Penola Strait and the Lemaire Channel has been identified in several publications (Curtis, 1966; Savchyn et al., 2021). It is one of the main fault structures separating the various domains of the Antarctic Plate. The fault-block structure presence of the Argentine Islands group itself was assumed but not substantiated (Mytrokhyn & Bakhmutov, 2021). On the other hand, during the LGM age, large valleys were completely occupied by ice flows (Davies et al., 2012; Lavoie et al., 2015). Because of ice erosion, the valleys acquired a specific shape with steep sides and a relatively level bottom. The retreat of the glacier leads to the gradual straits release, and the beginning of sedimentation processes (Johnson et al., 2011). In the deepest parts of the straits, as in the Penola Strait, accumulation of sedimentary strata could have begun 8–10 thousand years ago. The much shallower straits between the individual islands of the Argentine Islands group were freed from permanent ice cover much later. Unfortunately, we could not take a complete section of sediments in the Penola Strait to time the very start of sediment accumulation.

However, it can already be argued that the Argentine Islands' underwater relief was formed under the influence of two main processes – tectonic and glacial erosion. The main directions of the straits between the islands are determined by the tectonic structure of the "feathering" part of a large fault in the Penola Strait area. Based on the underwater relief analysis, it can be assumed that there is an orthogonal network of local tectonic discontinuities. In this case, one direction is parallel to the Penola Strait, and the other is perpendicular. Subsequently, during the ice age, these directions were worked out by glacial flows and turned into wide valleys with steep sides and relatively flat bottoms.

A bathymetric study in the Penola Strait showed that it consists of two parallel depressions, separated by a rocky uplift, which extend almost along its entire length (Fig. 3, b). At the same time, the depression closer to the Argentine Islands has a V-shape with steep sides and most likely a predominantly tectonic genesis. The depression located closer to the Antarctic Peninsula has a wider bottom with a complex structure and significant flat areas. Most likely, ice erosion processes played a significant role in forming this part of the Penola Strait bottom.

Among the authigenic minerals in the bottom sediments of the Penola Strait, we found bacteriomorphic framboid clusters of iron sulfide microcrystals. They are contained in the valves of diatoms, mainly of the bulky *Thalassiosira* genus. Diatom frustules filled with framboidal pyrite are also known in other waters of the region (Olshtynska et al., 2019; Korsunsky et al., 2020).

Foraminiferal-nanofossil-diatom muds contain pyrite framboids only in microfossils, where they form separate microenvironments; in black shales, framboids are evenly distributed.

Although iron sulfide formation in deep-sea sediments is common, and pyrite is one of their most common minerals, there are many questions related to how framboids are formed (Schallreuter, 1984).

5 Conclusions

Marine geological research allows the implementation of a complex of works covering research in such areas as the study of the geological structure and processes of sedimentation on the shelf and continental slope of the western sector of the Antarctic, the lithological composition of sedimentary rocks of the Antarctic shelf, their paleontological characteristics, facies and paleoecological conditions of formation, as well as the detection of pollution of the aquatic environment and bottom sediments by pollutants.

A planar geophysical survey of the underwater relief was carried out, and the most promising areas of the bottom were selected for sampling bottom sediments.

According to the preliminary results of bathymetric profiling, the shapes and positions of different bottom morphological elements were determined. Analyses of underwater relief morphology allow determining modern bottom sediments accumulation areas, their planar distribution, and vertical capacities. Applying the local polynomial interpolation method in creating a digital surface of the bottom of the work area made it possible to reproduce its real relief as clearly and completely as possible with minimal deviations. At the same time, the total length of echo-sounding profiles was almost 70 kilometers, providing 90 912 points with depth and coordinate reference measurements.

Bathymetry data in the Penola Strait show two parallel depressions running almost along its length, divided by a rock uplift.

An important component of the fieldwork was the selection of vertical columns of bottom sediments (77 samples) at three sites in the western Antarctic sector: South Shetland (21 stations on 7 sections), South Orkney (36 stations on 7 sections) and a test site in the waters of the Argentine Islands, adjacent to Vernadsky (14 stations) from sea depths from 328 to 80 m for further research of their grain size analyses, mineral, chemical and microfaunistic composition.

We describe the distribution of biogenic opal thanatocoenotic assemblages in core top sediments from the Penola Strait. In the bottom sediment samples, valves and frustules of diatoms, silicoflagellates, spicules of sponges, and skeletons of radiolarians were detected and preliminarily identified in different quantities.

78 species of diatoms were identified from the upper 50 cm of the bottom sediments of Penola Strait No. 362. The distribution of diatoms in the sediments of the Antarctic region is controlled by both water temperature and sea ice conditions. Regarding biogeographic and ecological characteristics, a significant percentage of diatoms from the sediments of the Penola Strait belong to pelagic open-ocean taxa, typical for this region as a whole. The most numerous genera are *Thalassiosira*, *Eucampia*, *Paralia*, *Fragilariopsis*, and *Cocconeis*. *Thalassiosira antarctica* is an Antarctic diatom species rarely found living within sea ice. In the Bransfield Strait, western Antarctic Peninsula, the maximum abundance of *Thalassiosira antarctica* in the Holocene sediments is related to cold climate episodes and the persistent influ-

ence of the cold Weddell Sea water (Gersonde & Wefer, 1987; Leventer, 1991; Zielinski & Gersonde, 1997) and proximity to ice edge (Heroy et al., 2008). *Thalassiosira lentiginosa* is associated with open ocean conditions up to the sea ice edge. *Actinocyclus actinochilus* is believed a typical Antarctic neritic species in the ice edge zone. A relatively increased number and diversity of typical open water species and those associated with ice, such as *A. actinochilus, F. kerguelensis, Thallasiotrix antarctica, Rhizosolenia styliformis, Stellarima microtrias* is characteristic of the lower part of the studied section, in the interval of 35—50 cm. The increased prevalence of *Eu. antarctica* up to 4.5%, an indicator of meltwater with reduced mineralization, was observed in the upper 15 cm of sediments. *Eucampia antarctica* is a widely used paleoproxy that shows a marked increase in the frontal boundary, characterized by high productivity and a preference for nutrient-rich waters. This species, associated with neritic environments with floating ice, may indicate relatively warmer climatic conditions with predominantly stratified water during the formation of the upper sediment layer (Cremer et al., 2003; Crosta et al., 2005).

At the same time, epiphytes, or marine semibenthos, are present here. Based on the composition of the diatom association and the mixed ecological pattern of open water taxa with those associated with ice, it can be assumed that the sea ice in the study area during the Neoglacial was loose sea ice, which expanded and contracted seasonally. It is also possible to assume an increase in surface water temperatures during the formation of the upper layer of bottom sediments.

The mineral composition of bottom sediments included quartz, plagioclase, amphiboles, and siderite. Among the authigenic minerals, bacteriomorphic framboidal clusters of iron sulfide microcrystals were determined.

A comprehensive approach to long-term marine-geological research incorporating the findings from different periods will significantly replenish the existing database. The accumulated data include information about the research trips, oceanographical parameters of the study area, sampling sites, and lithological, mineralogical, and micropaleontological characteristics of the sediment cores. We shall come closer to determining the main patterns of sedimentation processes in the area of the Argentine Islands, reconstructing the geological and climatic history of the region, and clarifying its current role in global climate processes.

Author contributions. S.K. provided the materials, O.O. prepared the manuscript, and Ye.N. wrote and edited the manuscript.

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Conflict of Interest. The authors declare no conflict of interest.

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Океанографічні, морські геологічні та седиментологічні дослідження в прибережній зоні Західної Антарктиди

Реферат. Стаття описує комплекс геологічних та океанографічних робіт Української антарктичної експедиції 2021—2022 рр., отримані попередні результати та стислі висновки. Наведено результати вивчення, картування й батиметричного профілювання рельєфу морського дна та мапу підводного рельєфу навколо Аргентинських островів на основі сучасних даних. У роботі надано короткі характеристики речовинного, гранулометричного (аналіз розміру зерен) та мінерального складу донних відкладів, зібраних на глибоководді та мілководді, й аналіз седиментаційних умов регіону. Представлені результати вивчення таксономічного різноманіття й екологічного складу діатомових водоростей донних відкладів у затоці Пенола (станція № 362, глибина 271 м); матеріал ілюстрований таблицею біогеографії та екології домінуючих видів і зображеннями характерних діатомових, отриманих за допомогою електронної мікроскопії. Описані польові методи та методи камеральної обробки й аналізу. Для обробки картографічних та батиметричних результатів залучено метод локальної поліномінальної інтерполяції; геологічні матеріали оброблено методом дезінтеграції для відокремлення кременескелетних мікроводоростей. За діатомовими асоціаціями змішаного екологічного складу зроблені висновки, що льодовий покрив у досліджуваному районі під час формування 50 см шару осадів протягом неольодовикового періоду був переважно у формі пухкого морського льоду, який сезонно розширювався і скорочувався. Проведені роботи спрямовані на вивчення геологічних закономірностей утворення та будови шельфу Антарктиди, сучасних особливостей седиментації, і є важливим елементом пізнання як минулого цього континенту, так і його значення у формуванні фізико-географічних умов нашої планети, потенційних змін, що можуть відбутись в майбутньому.

Ключові слова: Аргентинські острови, батиметричне профілювання, геологічні дослідження, діатомові водорості, донні відклади, комплексні експедиції