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# Research and visualisation of the submarine relief of the Argentine Islands (Western Antarctica) using GIS methods

**Maryna Krochak[1], Valentin Holoborodko[2], Yevgen Voropai[2]**

[1] Institute of Geological Sciences, National Academy of Sciences of Ukraine (Kyiv, Ukraine)
[2] Institute of Geology, Taras Shevchenko National University of Kyiv (Kyiv, Ukraine)

## article info

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**correspondence to**
Maryna Krochak; Institute of Geological Sciences, NAS of Ukraine; 55B Olesia Honchara Street, Kyiv, 01054 Ukraine.
Email: mkrochak1960@gmail.com
orcid: 0000-0003-4144-7098

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## abstract

The aim of this study is to investigate the geomorphological structure and genesis of the submarine relief under the influence of morphogenetic factors within the sub-Antarctic shelf area near the Argentine Islands, where the 'Akademik Vernadskyi' Ukrainian Antarctic Station is located. The research is based on the construction and analysis of a digital seafloor model using GIS tools. The primary data for constructing the digital terrain model (DTM) of the studied water area were bathymetric maps from the British Admiralty (Admiralty Surveys of the UK), along with maps constructed based on echo-sounding (boat-based) depth surveys. The database covers an area of 5.6 km² and includes 760 data points. The 3D model was created using ArcGIS software and Surfer 10. The model provides a clear illustration of the surface relief formed under the influence of endogenous and exogenous geological processes. The Argentine Islands are considered a horst, bounded by a fault. The model reveals the fault-scarp nature of the main fault that separates the Argentine Islands horst from the Penola Strait, as well as horizontal ledges of large blocks and second-order step-faulted blocks that complicate the displacement surface, small transverse depressions with suspension flow deposition cones. In the underwater relief, the straits between the islands appear as shallow, linear depressions oriented parallel and perpendicular to the marginal fault. Their formation resulted from the combined influence of primary tectonic factors and secondary glacial erosion processes. It is likely that these depressions were initially formed under terrestrial conditions due to glacial erosion by descending glaciers moving toward the deep strait during the Quaternary glaciation, when sea levels were significantly lower. The applied method of three-dimensional modelling has proven to be an effective tool for visualising the features of the submarine relief. The generated digital terrain models clearly reveal fine-scale elements of the seafloor morphology that are not readily discernible from conventional bathymetric maps.

# Дослідження і візуалізація підводного рельєфу Аргентинських островів (Західна Антарктика) ГІС методами

**Марина Крочак, Валентин Голобородько, Євген Воропай**

**Резюме.** Метою роботи є дослідження геоморфологічної будови підводного рельєфу та його генезису під впливом рельєфоутворюючих факторів, в межах Приантарктичного шельфу в районі Аргентинських островів, де розташована Українська антарктична станція «Академік Вернадський». Дослідження базується на побудові та аналізі засобами ГІС цифрової моделі морського дна. Вихідними даними побудови ЦМР акваторії є батиметричні карти Британського адміралтейства (Admiralty Surveys of the UK), а також карти, побудовані на основі ехолотних (катерних) промірів глибин. База даних охоплює площу 5,6 км$^2$ і містить 760 точок. Для створення 3D моделі застосовано програмне забезпечення ArcGIS та Surfer. Аргентинські острови розглядаються як горст, обмежений розломами. На моделі проявляється скидовий характер головного розриву, що відокремлює Аргентинські острови від протоки Пенола, горизонтальні площадки крупних блоків та блоки другого порядку ступінчастого скиду, що ускладнюють поверхню зміщувача, дрібні поперечні улоговини з конусами виносу суспензійних потоків. У підводному рельєфі протоки між островами проявляються як неглибокі прямолінійні депресії, орієнтовані паралельно і перпендикулярно крайовому скиду. Їхнє формування відбулося під впливом первинного тектонічного фактора та вторинної екзараційної діяльності льодовиків. Можна припустити, ці депресії сформувалися ще в наземних умовах у результаті екзарації сповзаючих льодовиків у напрямку глибокої протоки під час максимального четвертинного заледеніння, коли рівень моря був значно нижчим. Застосований метод тривимірного моделювання зарекомендував себе як ефективний засіб візуалізації особливостей підводного рельєфу. Створені цифрові моделі рельєфу чітко виявляють дрібномасштабні елементи морфології морського дна, які нелегко помітити на звичайних батиметричних картах.

Ключові слова: Аргентинські острови, Приантарктичний шельф, математична модель, підводний рельєф, блоково-розломна тектоніка, екзараційна діяльність льоду.

Адреса для зв'язку: Марина Крочак; Інститут геологічних наук НАН України; вул. О. Гончара, 55Б, Київ, 10054 Україна; Email: mkrochak1960@gmail.com, orcid: 0000-0003-4144-7098.

## Introduction

On 3 November 2010, the Cabinet of Ministers of Ukraine adopted Resolution No. 1002 'On Approval of the State Target Scientific and Technical Programme of Research in the Antarctic for 2011–2020.' The purpose of the programme is to conduct fundamental and applied scientific research in the Antarctic, to ensure effective functioning of the 'Akademik Vernadsky' Antarctic station. Geological and geophysical studies of the Antarctic shelf are included in the programme of scientific activities in the Antarctic carried out by the National Antarctic Research Centre of the Ministry of Education and Science of Ukraine. Scientific institutions of the National Academy of Sciences of Ukraine are involved in the work.

The novelty of the study is the use of a digital elevation model to clarify the features of the seabed geomorphology formed by certain geological processes, such as ice erosion and suspended sediment flows. The study area, i.e. the area of the Argentine Islands, is located near the west coast of the Antarctic Peninsula as part of the Wilhelm Archipelago (Fig. 1). It is located 9 km south-west of Petermann Island and 7 km north-west of Cape Tuxen on the Kyiv Peninsula and is separated from the peninsula by the Penola Strait. The area is represented by a group of islands separated by shallow straits, one of which hosts the Ukrainian Antarctic station 'Akademik Vernadsky' (Cape Marina of Galindez Island). The Argentine Islands are considered as a horst, complicated by a stepwise discharge of the eastern wing and a simple single-block discharge of the western wing. The horst is bounded by a discontinuity, the strike of which coincides with the direction of the fairway part of the Penola Strait [Kylchitskiy *et al.* 2010]. The relief of the islands is hilly, with insignificant dissection. The highest points do not exceed 50 metres. The shores are rocky, except for those covered by glaciers. The rocks exposed on the islands are mainly of volcanogenic and metamorphic origin.

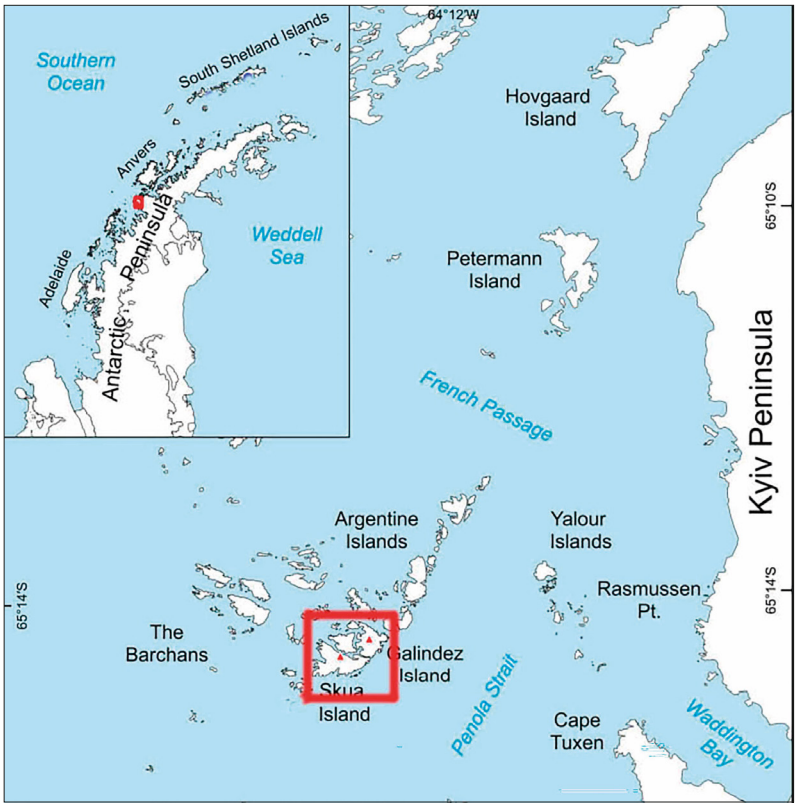


**Fig. 1**. The Argentine Islands on the map of the Antarctic Peninsula [Krzewicka *et al.* 2024]. The study area is marked with a red square.

**Рис. 1**. Досліджувана ділянка Аргентинських островів на (показана червоним квадратом) на мапі Антарктичного півострова [Krzewicka *et al.* 2024].

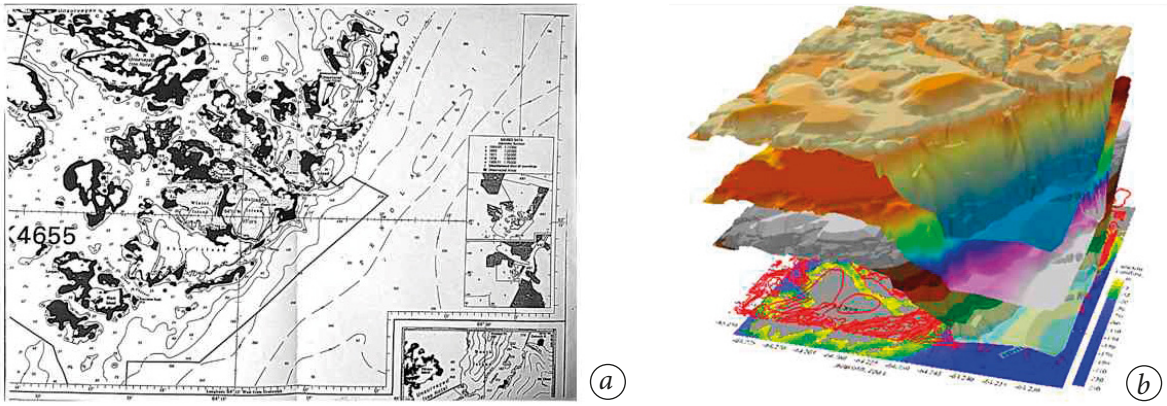


**Fig. 2.** Source cartographic material and DEM: (*a*) a fragment of the British Admiralty chart of the Argentine Islands area; (*b*) visualisation of the sequential stages of mathematical model creation.

**Рис. 2**. Вихідний картографічний матеріал та ЦМР: (*a*) фрагмент карти Британського Адміралтейства акваторії ділянки Аргентинських островів; (*b*) візуалізація послідовних стадій побудови математичної моделі.

The relief-forming role of geological processes of the western shelf of the Argentine Peninsula has been investigated by foreign and Ukrainian scientists [Gozhik *et al.* 2002; Greku 2006; Dowdeswell *et al.* 2008; Kylchitskiy *et al.* 2010; Gales *et al.* 2013]. The methodology used to analyse the mathematical model of the underwater relief of the Argentine Islands block allowed us to confirm the previously formulated conclusions about the joint action of tectonics and glacial exaration in the formation of the bottom geomorphology in this area. Our studies reveal new details of the underwater relief and add information about the presence of canyon-like transverse depressions on the eastern slope of the horst, probably caused by the erosive action of suspension flows.

The purpose of this work is to study the underwater relief in the area of the Antarctic Islands where the 'Akademik Vernadsky' station is located and to identify the natural factors that led to its formation. Using numerical data from bathymetric maps, we sequentially conducted stages of mathematical modelling to construct three-dimensional digital elevation models (DEM) between the islands Skua, Galindez, Winter, Corner, Grotto, and the Forge Islands (Fig. 2). Such visualisation allows us to comprehensively study the topography of the site, describe it in detail, and trace the effect of natural geological factors that influenced their formation.

## Materials and Methods

The territory of the Argentine Islands (geographic coordinates 65°13'45"–65°16'00" S, 64°18'00"–64°12'00" W) and an area of 5.6 km$^2$ was selected for building 3D models. This area represents a group of islands separated by narrow straits formed as a result of the rise in the level of the world ocean after the melting of the ice cover of the Quaternary glaciation. The basis for mathematical modelling of the relief were bathymetric charts of the British Admiralty Surveys of the UK (Admiralty Surveys of the UK) at a scale of 1 : 60 000 (1996) tablet No. 4655. The cartographic data were supplemented with echosounder (boat) measurement data 2002 visualised on the bathymetric map of the Argentine Islands archipelago [Gozhik *et al.* 2002].

The depth database included an array of XYZ coordinates of 730 measurement points and digitised bathymetric map marks. Statistical and cartographic analyses of bathymetric data were performed using Surfer package functions. Kriging interpolation type was used to predict values at points with no measurements based on data from surrounding points. Further construction and processing of the obtained model with visualisation of relief features of the study area was performed using ArcMap software modules.

## Results and Discussion

The basic DEM of the seabed and islands based on depths taken from existing maps was initially created using the Surfer package functions (Fig. 3a). The resolution and quality of this DEM depends on both the input data and the chosen interpolation method. The modelling resulted in a surface that is generalised, smoothed, and does not show small elements of the underwater relief.

Further processing of the DEM, aimed at reproducing the relief details, was performed in the ArcGIS software and its modules. The ArcMap module was used to georeference the paper map and create a vector input model (Fig. 3b). A simple but robust method of manual data entry at sector junctions was used to combine the individual sectors into a single model. The data were converted to a TIN model (Fig. 4a). The next step was to build a raster digital model consisting of cells, each of which has its own height value (in our case, a colour shade corresponding to depth).

For better visual perception of the relief features of the research object, a suitable vertical scale was chosen. The standard colour scheme was changed: brown-blue shades were used for visual perception of the mathematical model reflecting the seabed with islands (Fig. 4b). Based on this model, the final three-dimensional volumetric surface model was created.

The number of classes (height intervals) was increased to improve detail and smoothness of colour rendering. Level flat areas around the islands and between the islands of Winter, Skua, and Galindez probably correspond to areas of ice cover. Therefore, the model surface at -5...0 metres was highlighted in white, giving it a greater resemblance to the natural environment of the circumpolar basin (Fig. 4c).

The final model (Fig. 4c) is as close as possible to the natural object and clearly reflects small details of the underwater relief that were not visible on the original maps and images. It allows the relief of the seabed surface formed under the influence of endogenous and exogenous geological processes to be studied, and to clarify the preliminary results of research and reveal the features of the geomorphologic structure of the seabed of the investigated water area.

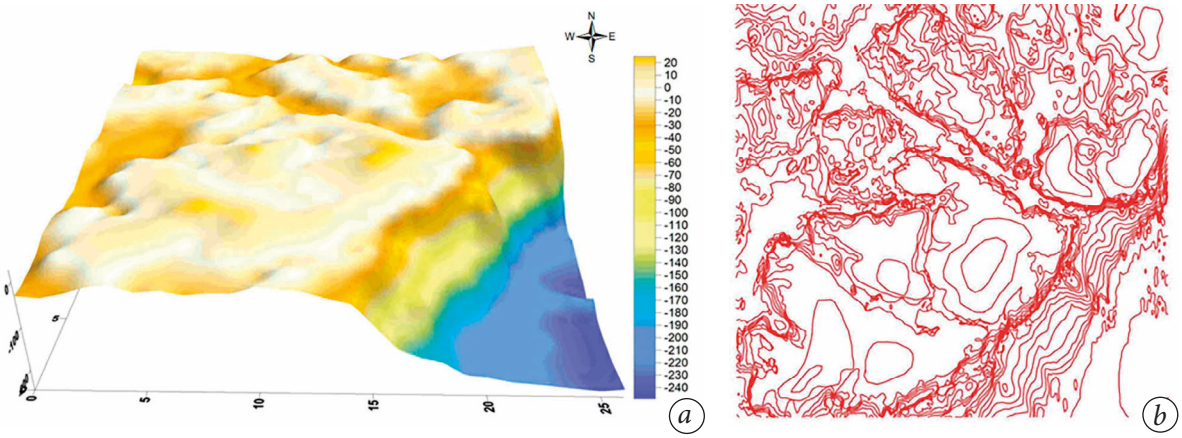


**Fig. 3.** Digital relief model of the section of the Argentine Islands: (*a*) the initial 3D base model (Surfer); (*b*) the initial vector model (ArcMap).

**Рис. 3**. Цифрові моделі рельєфу ділянки Аргентинських островів: (*a*) перша базова 3D модель (Surfer); (*b*) вихідна векторна модель, (ArcMap).

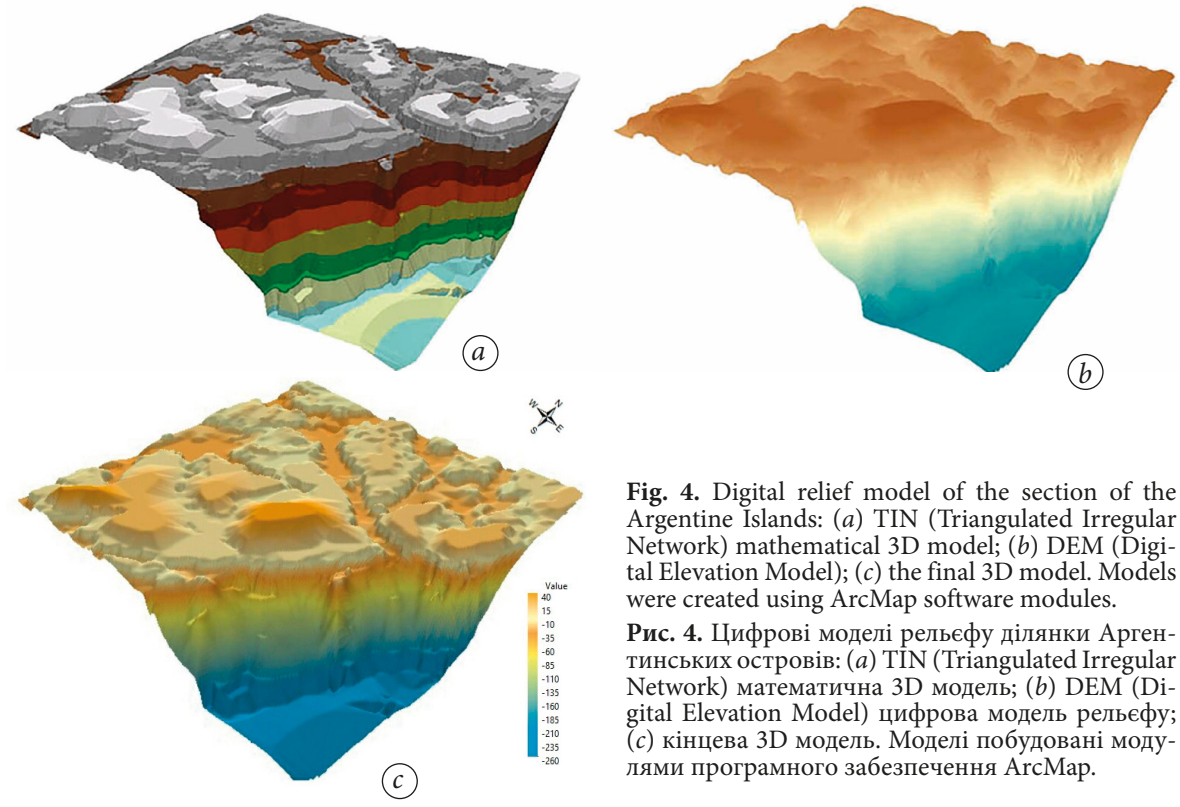


**Fig. 4.** Digital relief model of the section of the Argentine Islands: (*a*) TIN (Triangulated Irregular Network) mathematical 3D model; (*b*) DEM (Digital Elevation Model); (*c*) the final 3D model. Models were created using ArcMap software modules.

**Рис. 4.** Цифрові моделі рельєфу ділянки Аргентинських островів: (*a*) TIN (Triangulated Irregular Network) математична 3D модель; (*b*) DEM (Digital Elevation Model) цифрова модель рельєфу; (*c*) кінцева 3D модель. Моделі побудовані модулями програмного забезпечення ArcMap.

The horst nature of the studied area is clearly illustrated by the constructed model, as detailed by Kylchitskiy *et al.* [2010]. It reproduces well the normal fault character of the main north-east trending fault separating the Argentine Islands from the Antarctic Peninsula. Additionally, clear horizontal terraces of large blocks and secondary step fault blocks are discernible, complicating the fault plane. The 360° rotation of the model (Fig. 5) allows us to better examine small geomorphological elements on the eastern wing of the structure. These are shallow transverse hollows that cut through the eastern steep slope of the horst. Some of these resemble canyons typical of the continental slope of the Antarctic mainland margin, studied by researchers on the western slope of the Antarctic Peninsula [Dowdeswel *et al.* 2004; Greku 2006; Dowdeswell *et al.* 2008; Gales *et al.* 2013; Campo *et al.* 2017].

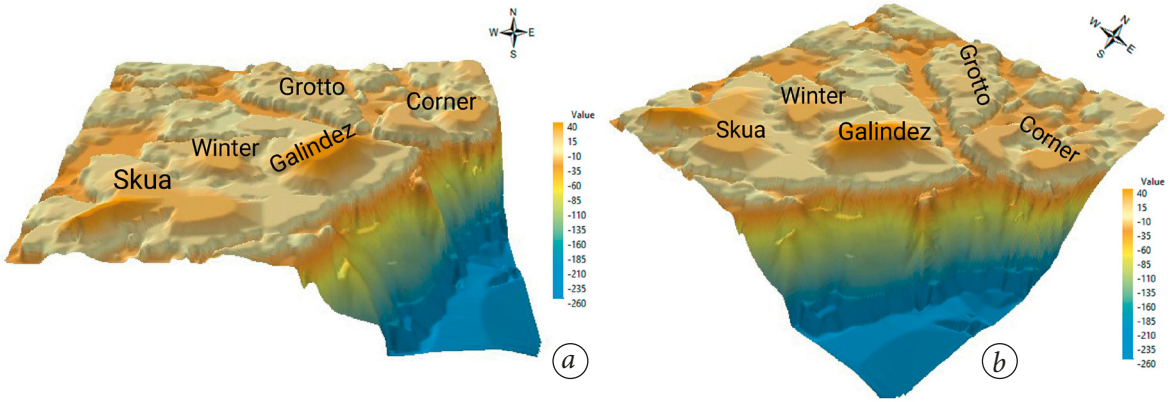


**Fig. 5.** Raster model built using ArcGIS methods from two spatially different orientations: (a) from north to south, (b) from northwest to southeast.

**Рис. 5.** Растрова модель, побудована методами ArcGIS з двох просторово орієнтованих позицій: (a) з півночі на південь, (b) з північного заходу на південний схід.

As indicated in these studies, canyon formation is linked to the erosive action of submarine turbidity currents containing sedimentary material released from beneath ice sheets. Currents move from the edge of the shelf down the continental slope and unload debris material at the base of the slope, forming sediment cones. In the DEM, these transverse troughs can be interpreted as shallow gullies resembling canyons, serving as prominent drainage channels for debris material from the uplifted Argentine Islands block towards the Penola Strait.

In our digital elevation model, the straits between the islands appear in the underwater topography as shallow (within the first few tens of metres), straight depressions oriented both parallel and perpendicular to the marginal fault. Researchers primarily associate this regular orientation of geomorphological features with tectonic factors—specifically, the formation of longitudinal and transverse structures along second- and third-order faults [Greku 2006; Kylchitskiy *et al.* 2010]. In addition to tectonics, the formation of these trough-like valleys was significantly influenced by the erosional activity of flowing glaciers and meltwater streams originating from the ice sheet. According to researchers [Heroy & Anderson 2005; Greku 2006], during the maximum Quaternary glaciation, when sea levels were lower, this part of the shelf was exposed as land and covered by ice sheets. As the glaciers moved down the slope following the general relief gradient, they scoured the subglacial bedrock, carving out U-shaped valleys with flat bottoms and steep sides. The underwater topography of depressions between islands of our DEM closely resembles glacial trough valleys found on land. Also, this is clearly illustrated by digital elevation models of the seafloor in the Skua Creek Bay area (based on echo sounding data) created by Sinna *et al.* [2015] (Fig. 6).

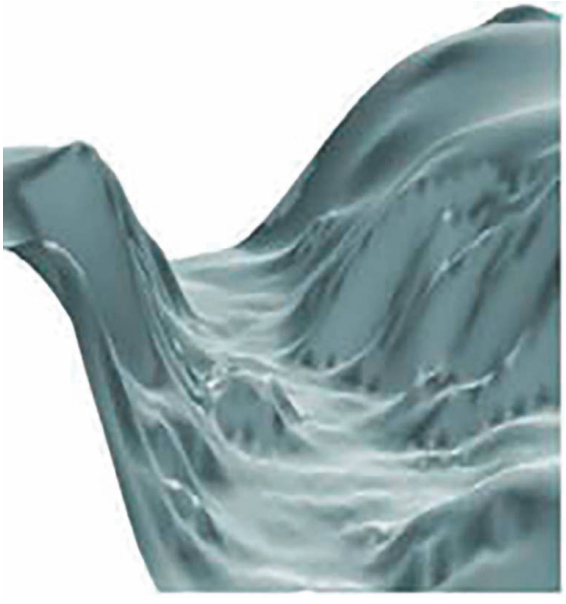

**Fig. 6.** Seafloor section of Skua Creek Bay based on echo sounding survey data [Sinna *et al.* 2015].

**Рис. 6.** Ділянка дна затоки Skua Creek за даними ехолотної зйомки [Sinna *et al.* 2015].

## Conclusions

The applied method of three-dimensional modeling has proven to be an effective tool for visualising the features of the submarine relief. The generated digital terrain models clearly reveal fine-scale elements of the seafloor morphology that are not readily discernible from conventional bathymetric maps. These detailed data on the underwater topography of the Argentine Islands sector serve as valuable supplementary information for reconstructing the geological processes that have shaped the present-day morphology of the region.

The relief of the Argentine Islands has developed as a result of the combined influence of endogenous and exogenous factors. Tectonic activity has determined the geological framework of this horst zone, whereas surface processes—such as meltwater erosion and glacial scouring—have contributed substantially to the formation of secondary landform features. Glacial exaration played a crucial role in the development of trough-shaped depressions between the islands. These features most likely formed during the peak of the Quaternary glaciation, when glacial trough valleys developed under terrestrial conditions.

Moreover, the morphology of the steep horst slopes has been further modified by both erosional and depositional processes associated with turbidity flows. Suspension currents transport terrigenous particles, and their combined erosive action—stemming from the movement of water and entrained solid material—induces linear incision into the rocks of steep slopes. This process results in the formation of canyon-like depressions that serve as primary pathways for the downslope transport of clastic material from the uplifted block of the Argentine Islands towards the Penola Strait. The transported debris is subsequently deposited on the horizontal benches of the stepped fault structure, forming small alluvial fans.

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**Declarations**

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Conflict of interests. The authors have no conflicts of interest to declare that are relevant to the content of this article.

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