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SEISMICITY IN THE BRANSFIELD STRAIT, ANTARCTICA, FOR THE PERIOD 2020–2023 AS RECORDED FROM LIVV SEISMIC STATION

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Abstract

The Bransfield Strait is situated between the Antarctic Peninsula and the South Shetland Archipelago. The seismic regime of the area is characterized by volcanic and tectonic activity, expressed in shallow, weak to moderate earthquakes. The global seismic networks locate the stronger earthquakes in this region. Weak events are recorded by standalone stations installed on the Antarctic continent and neighbouring islands, the number of which is not sufficient for good location. In the study, we present the processing of the seismic data for the period from January 2020 to January 2023 registered by Bulgarian Antarctic station LIVV and the produced results. The single-station localization method was applied and calculated, epicentres were compared with those listed in the European Mediterranean Seismological Centre catalogue. In the study period, the seismic pattern is dominated by swarm volcanic seismicity around Orca volcano, as well as three earthquake clusters of unknown origin in the vicinity of Livingston Island.

Key words: seismicity, Bransfield Strait, Antarctica, Orca volcano

Introduction. The South Shetland Islands are situated between South American continent and the Antarctic Peninsula and have volcanic origin. North

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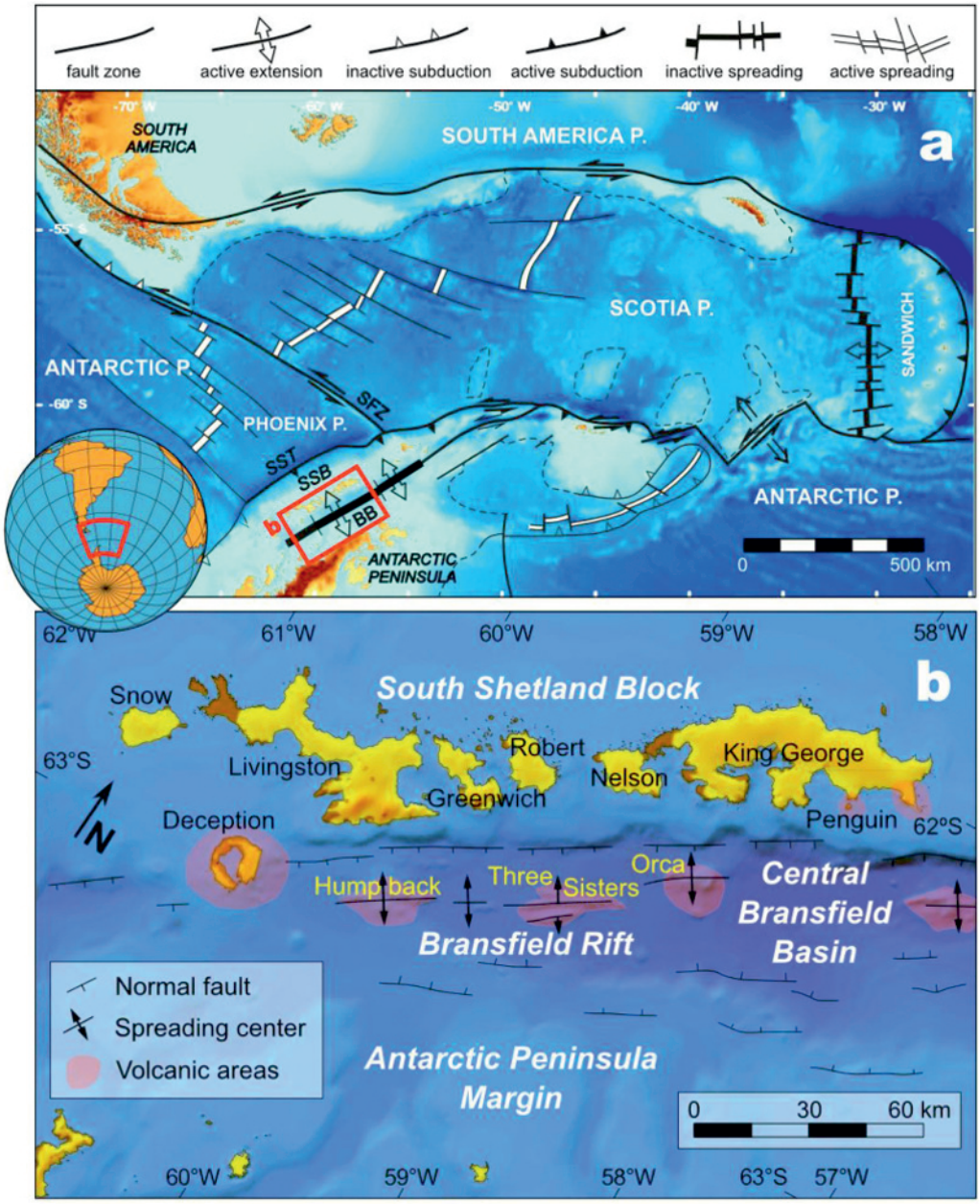


Fig. 1. Map of South Shetland Islands and volcanic structures in Bransfield Strait. (The figure is based on [12] without modifications)

of the islands is the Drake Passage, and south of them is the Bransfield Strait (Fig. 1) [1]. An important feature of Bransfield Strait is the presence of volcanic and tectonic seismic activity. Deception, Penguin, and Bridgeman Islands are

stratovolcanoes that are the only visible part of a large ridge system between Bridgeman and Deception Islands, about 300 km long with continuous volcanic activity in this region. For instance, the recent eruptions of Deception Volcano are in 1967, 1969, and 1970. Penguin Island is also estimated to have erupted less than 300 years ago [2].

The South Shetland Trough, located northwest of the islands, is a remnant segment of an ancient subduction zone [1], which is connected to the now non-existent Phoenix plate, which was located between the Pacific plate, the Antarctic plate and another one now non-existent plate – the Bellingshausen plate, located in the southeastern part of the Pacific Ocean. It merged with the Antarctic plate about 61 million years ago. The Phoenix plate had divergent boundaries with the Pacific and Bellingshausen plates and slowly subducted beneath the Antarctic in the aforementioned subduction zone. There was also ridge-forming activity in the area. Active subduction in the region is thought to have stopped around 3.3 million years ago, leaving a small remnant of the Phoenix Plate – later merged with the Antarctic Plate [3].

Typical seismicity for Bransfield Strait consists of shallow, weak to moderate earthquakes [1]. This type of seismicity is attributed to weak magmatic activity along the ridges and crustal movements during the extension of the strait and rift along its axis. Sporadic deep earthquakes (up to about 65 km), a result of residual subduction, are also detected north of the South Shetland Islands. One of the active areas in the Bransfield Strait is Deception Island with moderate to intense seismic activity [4].

Seismicity around Bransfield Strait and the South Shetland Islands is difficult to study because of the complex dynamics of the area generating earthquakes of varying magnitudes and the lack of a dense network of seismic stations. Analyses of the data subsequently revealed that seismic activity in Antarctica is not limited to the regions of the two major active volcanoes, nor is it as weak as previously thought [5].

Data. Around the end of August 2020, an earthquake swarm was detected in the strait by the global seismic networks. Many authors [6–8] reported that the series numbers over 85 000 volcanic-tectonic earthquakes since its beginning [6], and about 130 of them have magnitudes greater than Mw = 4.0. The peak of the series is expressed by two large earthquakes, one in early October and the second in early November with magnitudes of Mw = 5.9 and Mw = 6.0, respectively. After the two major earthquakes, the series began to slowly subside. The epicentres of the earthquakes are in a region south of King George Island near an underwater shield volcano named Orca which was considered inactive until recently. At the end of January/early February, seismic event activity decreases significantly, but does not stop completely. The cited authors declared that there are weak seismic events in the following months. However, due to the low coverage of seismic stations in the area, the weak seismicity has not been studied.

The earthquake swarm near Orca volcano was recorded also on seismic station LIVV, situated on Livingston Island. In order to analyze the weak seismic activity in the studied region before and after the swarm, the data within the time period from the beginning of 2020 to March of 2023 recorded by the LIVV station are used.

Seismic station (LIVV) on Livingston Island. The Bulgarian base "St. Kliment Ohridski" is situated on Livingston Island which is the second largest of the South Shetland Islands. During the Antarctic expedition in 2015, the first Bulgarian permanent broadband seismic station (LIVV) was installed on the island. The station is located near the Balkan glacier and about a kilometer away from the Bulgarian Antarctic base (Fig. 2). The coordinates of the station are 62°38′11″ S and 60°20′89″ W.

The station is equipped with two seismometers – one broadband Guralp cmg 40T and one short-period Geospace, which cover the frequency range for the study of local, regional and global seismicity [9,10]. The seismometers are placed on bedrock and oriented to the geographic north. There is thermal and hydro insulation around them in order to prevent external influences and noise. The sampling frequency is 100 Hz.

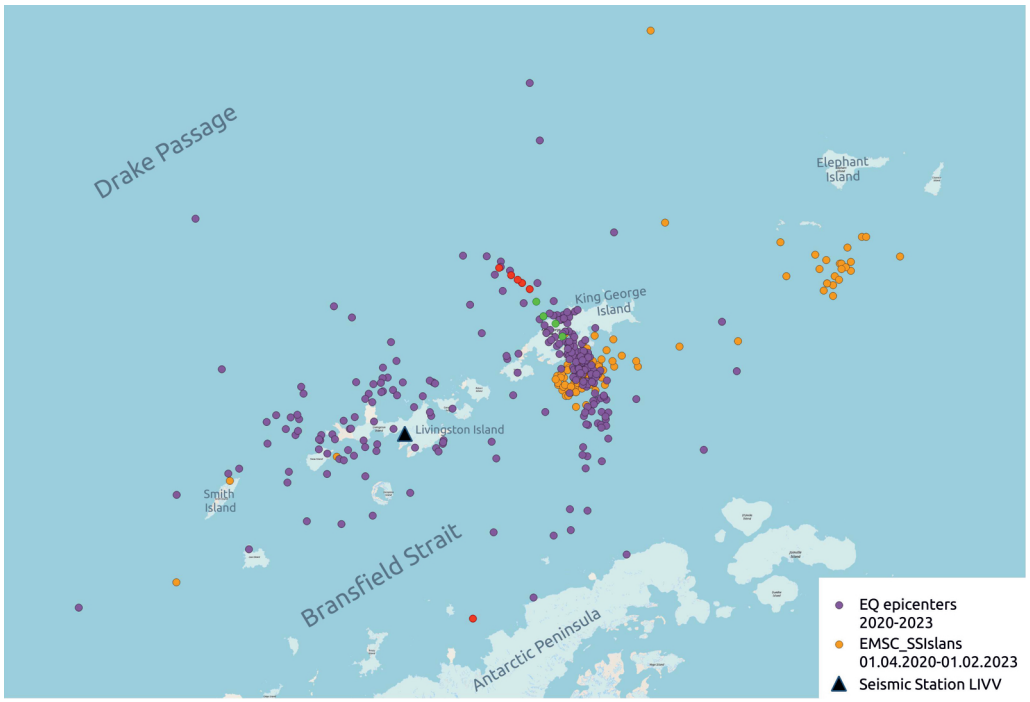


Fig. 2. Map of the earthquakes in Bransfield Strait and near Livingston Island in the studied period. Orange dots show earthquakes taken from EMSC catalogue, purple dots show epicentres for events recorded on LIVV station and located using single station method. Red and green dots show the possible epicentre of two earthquakes, respectively, or the error in epicentre estimation

Single-station location method. The standard method of earthquake localization involves triangulation from a minimum of three stations. In the case of Antarctica, however, this is difficult to realize while many local earthquakes are recorded only from one seismic station. On the other hand, the functioning of the seismic stations in the area is interrupted frequently or the stations are installed temporarily. Sometimes data is available from only one or two stations located too far apart. For these reasons, single-station localization method is used for earthquakes' epicentres estimation. This method is based on the analysis of a three-component seismogram to construct the back azimuth vector of the earthquake. The distance to the epicentre is obtained in the standard way – by a velocity model for the region and the differences in the arrival times of S-waves and P-waves. The geographic coordinates of the epicentre are estimated based on the back azimuth (BAZ) and distance to the station. For automated calculation of the epicentres a Python code was developed [9].

The velocity model of the region was calculated using a rock sample from the bedrock on which the seismic station is installed. The model was improved for larger distances (100 and 160 km) using a self-programmed simulation in the Python software Pyrocko Cake [11]. After defining the velocity model, a simulation of seismic wave propagation is run in order to generate a travel-time table for a certain layout of the seismic station and the source in the area with the selected velocity model. The velocity model is: for P-wave – 0–2 km – 2 km/s; 2–8 km – 6 km/s; 8–16 km – 6.5 km/s; 16–23 km – 7.2 km/s; below 23 km – 8.2 km/s. For S-wave, the model is: 0–2 km – 1 km/s; 2–8 km – 3.2 km/s; 8–16 km – 3.8 km/s; 16–23 km – 4 km/s; below 23 km – 4.8 km/s.

Results. Seismic data were visually scanned and more than 600 earthquakes were distinguished. For the events with clear onset, the time difference of P and S wave arrivals (S arrival time $-$ P arrival time) and the amplitudes of the onset are measured. As a result, the number of the events to be localized by single-station method is reduced to 120. The calculated epicentres are mapped in Fig. 2 with the purple circles. The seismic station LIVV in Fig. 2 is marked by a black triangle. Most of the recorded events have $S-P$ time difference in the range between 12.5 and 14 s. They occurred in the region of Orca volcano.

Orange dots represent the epicentres of the earthquakes listed in the EMSC catalogue for the same period. It is noted that the epicentres of the main groups of events located using single-station method coincide with the epicentres from the EMSC catalogue. Due to the uncertainty of localization method used in the study, the cluster of estimated epicentres is more dispersed than the cluster of EMSC epicentres.

It can be concluded that the time table used to calculate the distances and the back azimuth is appropriate and the epicentres obtained are close to the real ones. However, some discrepancy is observed as well. Namely, there are a lot of events whose epicentres are arranged in an elongated strip with a northwest-southeastern

orientation. Such a distribution is the result of a correctly calculated distance from the seismic station to the epicentres and an incorrectly calculated BAZ. This inaccuracy is explained by the weaknesses of the used method. The method is strongly affected by seismic noise, which can influence the onset amplitudes. In order to accurately measure the first wave arrival, a filter can be applied. On the other hand, in many cases, the filter applied affects the ratio A_e/A_n, which is used to obtain the back azimuth. Therefore, preferably the onset amplitude should be read from the raw recordings.

To demonstrate the sensitivity of the resulting locations (azimuthal estimates) to misreporting the onset amplitude, two earthquakes were selected. The distance of the seismic stations to their epicentres is in the range of 114 km to 117 km, the $T_S - T_P$ time difference is from 12.5 s to 14 s, which suggests that the earthquakes belong to the cluster near the Orca volcano. The onset amplitudes were read manually from the raw waveforms. The first deflection is not clear and a few possible onset amplitudes were measured. The resulting locations are presented as follows: for the April 26, 2021 earthquake in the first half of Table 1; for the June 02, 2021 earthquake in the second half of Table 1. The epicentres are plotted in Fig. 2 with red and green dots, for the April 26, 2021 event and the June 02, 2021 event, respectively.

The calculated azimuth estimates differ for the two events. The epicentres in Table 1 vary within 11 azimuthal degrees. Moreover, there is one location whose BAZ is equal to 160 degrees. The resulting BAZ estimates are in the range of 15 degrees.

The examples above allow us to understand and explain the possible reasons for the different earthquake locations calculated by the single-station method with respect to the EMSC epicentres. The method is useful and gives adequate results

Table 1

The different locations for the epicentre of the 26/04/2021 event and 06/02/2022 events

Date	Longitude	Latitude	Azimuth	Distance, km
First event				
26-04-21 23:17	−58.9755	−61.8079	38.53773	117
26-04-21 23:17	−59.0274	−61.7897	36.8699	117
26-04-21 23:17	−59.1047	−61.7645	34.44482	117
26-04-21 23:17	−58.8856	−61.842	41.51317	117
26-04-21 23:17	−59.2461	−61.7238	30.16309	117
26-04-21 23:17	−59.5549	−63.6207	160.0963	117
Second event				
06-02-22 23:01	−58.7238	−61.9927	50.49232	111
06-02-22 23:01	−58.5805	−62.0333	54.68879	114
06-02-22 23:01	−58.8079	−61.9116	45.60309	114
06-02-22 23:01	−58.4993	−62.1041	59.18429	113

for the events with a sharp first deflection. It gives the opportunity to study the seismic regime in the region with single seismic stations installed.

A second set of earthquake epicentres, downloaded from EMSC catalogue, is also seen east of King George Island (orange dots in Fig. 2). This series begins at the end of January 2021 with an earthquake of magnitude Mw = 6.9. The main earthquake was followed by a series of aftershocks. The epicentres of the earthquakes are located near the volcanic Bridgeman Island and are probably triggered by its activity in a similar way to the series around Orca. A part of them were detected by the LIVV station, with a $T_S - T_P$ difference of about 25 s. Due to very high ambient noise, most of the earthquake records were not suitable for applying the single station localization method. Seismic activity is also observed around the submarine volcanoes between the Bransfield Rift and the islands, as well as along the "remnant" of the ancient subduction zone – the South Seychelles Trough.

In the studied period, about 40 events were localized near Livingston Island. The epicentres of those events form three clusters which are marked by red circles in Fig. 3. One of the clusters is situated in the north-eastern direction from Cape Shirreff of the Livingston Island. The second cluster comprises the western part of the Livingston Island (Byers Peninsula) and the Snow. The third cluster is in the north-western direction of the Snow Island. One event from EMSC catalogue is presented in the second cluster. There, a small number of events are also reported in [12].

The red arrow in Fig. 3 shows a group of earthquakes located near the south-eastern coast of Livingston Island. In this area, high seismic activity was observed in 2014–2016 and reported in [4] and [13].

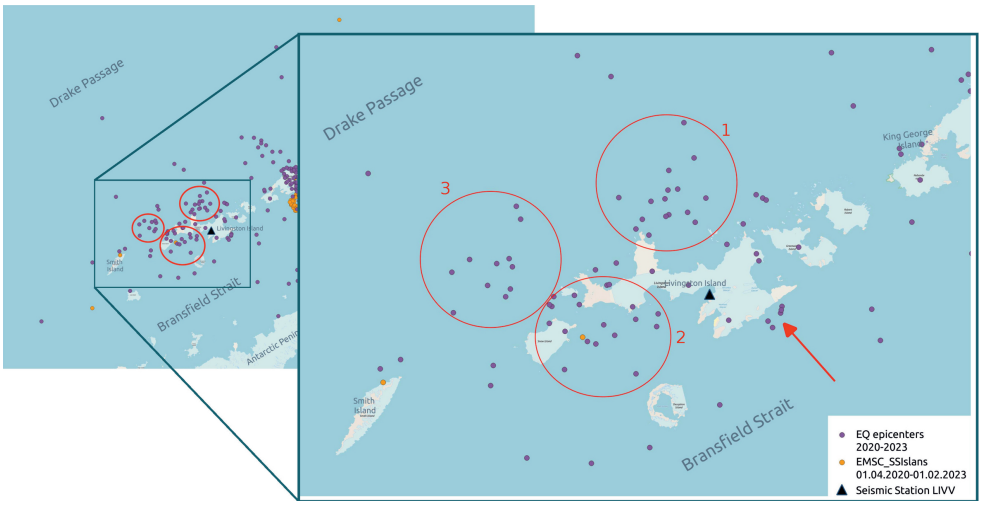


Fig. 3. Seismicity near Livingston Island. Earthquake epicentres form three clusters

Conclusion. Seismicity of South Shetland Islands is relatively well studied compared to the Antarctic continent. However, the available number of seismic stations is not sufficient for a more detailed study of the seismicity and to obtain a complete picture of the seismic regime of the area. In the study, more than 600 earthquakes in the period from January 2020 to the end of January 2023 are registered by the seismic station LIVV. One hundred and fifty of them are localized using single-station method. Most of the epicentres are located around the Orca volcano and were probably caused by the movement of magma. In most cases, these epicentres match the earthquake locations in the EMSC catalogue. There are three more groups of epicentres in the region of Livingston Island whose origin is not clear yet. On the base of the produced results, it can be concluded that the applied single-station localization method produces good epicentral estimates especially for the events with sharp onset of the waveform. LIVV station provides a valuable opportunity to monitor and study seismicity in the region of Livingston Island, as well as around the nearby islands. It is necessary to work on the minimization of the errors that are obtained, as well as on the methods for reducing the noise in the signals or more precisely determining the amplitudes of the first arrivals. Also, using the more precise model of the earth crust in the region is another option to improve the localizations. The installation of a larger number of seismic stations would reveal more aspects of the seismicity of this very interesting and unexplored region.

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