

## COMPLEX GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS IN ANTARCTICA

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### ABSTRACT

The results of the complex geological and geophysical investigations on the Livingstone Island, Antarctica during the campaign 2000-2001 are presented. Seismic signals, tsunamis generated in the South Bay, destructive geodynamic phenomena – landslides, rockfalls, deep erosion, etc., are investigated. The UV radiation, wind and temperature changes, humidity and hydrology regime have been observed as well. Some preliminary results of the geological probing, gemstone deposits and fossils are presented as well. The results obtained support the proven facts that Bulgarian Antarctic Base and its surroundings are suitable place for complex natural investigations.

### INTRODUCTION

The complex geological and geophysical investigations have been done during the expedition 2000-2001 for about 40 days – 1<sup>st</sup> December till 10<sup>th</sup> January in the area of the Bulgarian Antarctic Base (BAB) on the Livingstone Island – Antarctic South Shetlands. Several projects have been under the execution: seismological – with MINEDU, Tsunamis – with Geophysical Institute and a project on geodynamics – with New Bulgarian University (NBU). Many samples of rocks and minerals have been collected for Mining and Geology University and NBU collections and sampling of soils, waters, organic materials has been performed.

### SEISMOLOGICAL OBSERVATIONS

The main purpose of the seismological observations was to establish the first Bulgarian seismological station on Antarctica. It was successfully executed and since 4<sup>th</sup> December the measurements started. The coordinates of the station measured by GPS were as follows [Rangelov, 2001]: 62 38'25.4"S and 60 21'55.1"W, height - 12.5 m.

The station was equipped by a GVB device produced by GeoSIG, with a three component geophone with own frequency – 4.5 Hz. The records have been interrupted by different reasons – electricity interruptions, memory limits, other duties etc. As a result more than 250 records from different sources have been recorded. Natural seismic emissions are generated by ice cracks, icefalls, surf, rockfalls, wind, rock cracks and possibly earthquakes. Artificial seismic signals have been generated by hammering, electric generator, human and animal's activity. For the signal identification different criteria have been used. Base method was the spectral analysis in both forms – Fast Fourier Transformation (FFT) and power spectrums (PS). Other method applied was the 3D representation of the vector sum of the signal on the three components – a vertical and two

horizontal. Additional criteria – the signal envelope, and velocity, acceleration and displacement have been applied as well as filtering windows (Hemming, Hening, Bartlett, etc.) for the same purposes. The software is included in the device options. The results of the signal classification are as follows: 7 signals from icefalls, 21 – ice cracks, 3 – rockfalls, 12 – surf (wind and tsunami influence), 121 – wind noises, 2 – probable local earthquakes, more than 80 – artificial. The normalized spectral characteristics are presented on fig. 1.

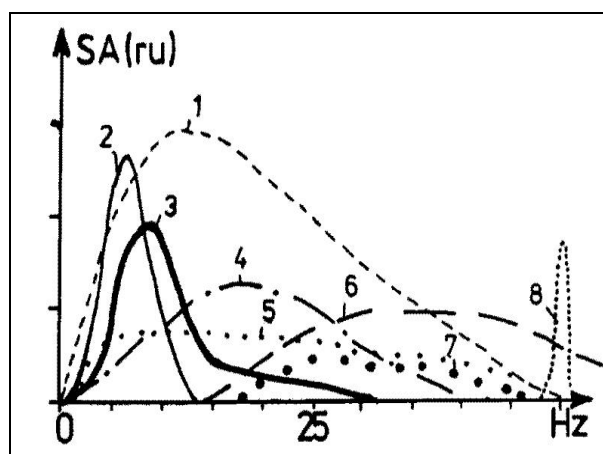


Figure 1. General spectral characteristics of the seismic signals registered on the Livingstone Island.

1 – earthquakes(?); 2 – icefalls; 3 – surf;  
4 – artificial signals; 5 – wind microseisms;  
6 – rockfalls; 7 – ice cracks; 8 – 50 Hz.

The active experiments show the attenuation of the wave amplitudes twice for about 50 meters on the soft soil and the same for about 300 meters for the hard rock. Very often the attenuation is extremely high – more than 10 times for the local moraines' deposits formed by the glaciers.

The icefalls generated huge local tsunamis in the South Bay. They have been described in Rangelov [2001]. For the whole time period more than 20 cases have been registered. A lot of data are missed due to the different reasons – bad weather, night time, other duties of the observer, etc. The run-ups and their maximum amplitudes have been registered by primitive equipment – marked rope and a chronometer. That's why the reliable results must be considered for the amplitudes greater than 50-60 cm. An exceptional case of an extremely high tsunami has been registered due to the big ice block (more than 300 meters) fall. It generated huge tsunami with amplitude of about two meters. The generating mechanism is different. Usually the icefalls are connected with a big acoustic noise. The travel time from the source to the BAB beach is different, but in the range of 10-15 seconds. This time is enough to avoid the dangerous influence of the wave on the researchers. The wind waves very often reach 3-4 meters high. The time pulses for them are in the range of 8-14 sec. The tides are estimated by the data for the Spanish base. The maximum values reached 2 meters.

Table 1. Parameters of the observed tsunami waves

No	Month day	time h.min.	H [m]	T [sec.]	Tr.time [min.]	No
1	12.03	10.21	0.8	23	6.2	2
2	12.04	20.40	1.2	30	6.5	2
3	12.05	14.20	1.0	25	7.2	1
4	12.09	16.30	2.0	16	5.5	4
5	12.09	12.36	0.8	21	7.5	2
6	12.13	11.13	1.1	20	8.2	3
7	12.17	10.05	0.7	18	5	3
8	12.17	14.15	0.8	19	6.5	4
9	12.17	15.36	0.7	20		3
10	12.17	16.15	0.9	21		3
11	12.17	17.47	1.0			3
12	12.25	18.36	0.9		7.5	2
13	12.29	11.15	0.7	22	5.5	2
14	12.29	12.18	1.0	24	6.5	3
15	12.31	19.31	0.6	30	4.5	3
16	01.02	12.16	0.6		4.2	2
17	01.05	19.16	0.8	22	5.5	2
18	01.06	13.36	0.6	21	2.5	2
19	01.06	13.40	0.6	26	2.5	2
20	01.08	11.46	0.8		2.3	2
21	01.08	11.56	0.8		2.3	2

H – run-up; T – wave pulse; Tr.time – travel time; No – number of the waves.

The specific hydrology regime nears and around the BAB, suggested an idea to measure the underground water level changes. The experiment shows a negative connection. Due to the water level height generated by the snow melting process, the transmission is not possible. The underground water table is stable on the beach and no influence from the sea is detected. The dominant is the hydrology regime from the land to the sea due to the snow and ice melting process.

Near the base other geodynamic effects could be observed – erosion, rockfalls, active volcanoes, glaciers with all accompanying events they are able to produce (ice falls, ice cracks, moraines transport, etc. [Рангелов, 2001]. The big gravel and stone blocks on the beach are very dangerous for the people due to the wetness and slippery surfaces producing frequent traumas on the people.

### Erosion

The erosion is deep and often reaches 3-4 meters due to the continuous cycle of the melting and freezing waters in the rocks' pores. The erosion together with the sharp relief are the main generators of the rockfalls and the rock's cracks. Similar effects on the relief have the surface faults. Most of them are of a listric type due to the extensional tectonic regime. In a crack of such fault an elementary experiment was establish, measuring the movement on the surface. About 1 mm was detected in a left (west) lateral displacement. This means very active fault movement. Usually the cracking and the erosion are orientated by the cleavage. This leads to a slices parallel to the cleavage. There are as well block perpendicular cracks, which formatted block image of the rock surface, especially on the basic rocks. Sometimes due to the reach quartz zones some rocks formatted clearly expressed cliffs. Special measures against the erosion are not necessary. The base is on the hard rock of the basaltic dyke.

### Abrasion

The abrasion is strongly developed in the surf zone. The main dynamic factors are several – erosion, big tide amplitudes, ice movements with the morenas transportation, temperature changes, etc. The most exposed to the abrasion forms are the cliffs and the vertical rock walls. The abrasion effects are clearly expressed as well on the formations with the tectonic origin. A natural cave due to the abrasion of the fault planes is located near (about two kilometers) southeast of the base.

### Glaciers

The glaciers are located everywhere and near surroundings the base. The biggest (Johnson, Perunica, etc.) have very large dimensions (tens of kilometers) and sometimes depths reach more than 300 meters, according the Spanish researchers. They have very active dynamic movements, in some places more than 25 meters per year.

The glaciers are main source of the moraines, other ice materials (such as glacier's "milk") and deposits. The most dangerous event for the researchers is to fall down in the ice cracks (frequently deeper than 30-40 meters). It can bring fractures, contusions even deaths. The icefalls are also dangerous because they can splash the researchers or to generate tsunamis in the South bay. The main way of protection is the alpine equipment and tracks in couples with continuous radio connection with the base during the tracking sessions. The small ice pieces generated by the glaciers are also main dangerous component during the debarking phase. The velocity of the wind movement of this active agent is extremely high during the windy time – the whole bay (more than 5km. length) can be covered for about 30-45 minutes.

### Rockfalls

The rockfalls are due to the deep erosion. The sharp relief formatted different volumes of rockfalls. They have different dimensions – from several up to thousands of tons [Панренов, 2000]. They are very sensitive and often started their movements due to different triggers – strong winds, steps, etc. The rock pieces of the rockfalls have different dimensions – from centimeters to meters. In the near BAB surroundings more than 25 different rockfalls have been investigated and mapped. The seismic signals generated by them have been registered and can have practical implementations for the seismic hazard purposes about the vulnerability and stability of the different structures affected by such events. The careful watch and approaching to the rockfall places can help to avoid negative effects and dangerous behavior of the falls to the researchers. The recommended measures are – good weather, careful measurements and safety equipment to prevent the negative effect of these phenomena.

### Active volcanoes

The active volcano Disseption is located to the 40 km northeast. This is a very active volcano. The last eruption was reported 1974. Traces of its activity are clearly visible on the Livingstone Island – volcanic bombs, ash and pyroclastites are usual view on the glaciers and the beaches. The volcanic rocks are basic – basalt and andesite basalts. [Панренов, 2001]. On Livingstone Island local recent volcano is reported [Kamenov 2000]. It is located SW of the base but is difficult for the investigations. Can be dangerous in case of under ice eruption, which can bring heavy floods. The volcano is relatively far from the base that's why the preliminary effects can be observed earlier. The local dykes have been investigated and prove the idea that the local volcanic activity can be expected [Kamenov 2000].

### OTHER NEGATIVE PHENOMENA

#### Ultraviolet rays

This is the most dangerous environmental phenomenon observed on the Island. It acts on the eyes and the skin and can produce heavy damages and burning. Due to the ozone hole the daytime quantity is too big [Панренов, 2001]. A simple indicator for the comparative measurements between (UVA-soft) and (UVB-hard) rays has been used for the observations. During the clear sunny days (not very frequent event) the UV index reaches about 12. The UVA and UVB rays attack the surface layers of the skin. The danger is a result of the possible lightening effects on the eyes and burning of the skin. 2-3 hours stay on the open air is equivalent of the III degree burning effects. Clothes, hats and protective glasses can do the protection. For the open skin – the protective foam can be used with a high UV factor.

#### Strong winds and temperature changes

These are the most dangerous meteorological elements. Very often strong, impulsive winds can be observed. The velocity reaches up to 150 km/h. Similar winds and storms can "blow" the person and the instrumentation in the bay. Directly connected with the windstorms are the temperatures. There is clearly expressed so-called "feeling temperature". Frequently the temperature of about  $-2-3^{\circ}\text{C}$  according to the wind and the humidity can be felt as  $-20^{\circ}\text{C}$ . Vice versa – the temperatures of

$+2^{\circ}\text{C}$  can be felt as  $+20^{\circ}\text{C}$ . Sounds of the cracking stones are frequently observed during such days [Панренов, 2001]. The temperature variations during the astral summer are not big – most frequently in the range  $\pm 3-4^{\circ}\text{C}$ . Measurements made by the extreme thermometer show that during the winter the temperature goes below up to  $-25-30^{\circ}\text{C}$ . Everyday variation can be observed cycling around the zero. This process brings the effects of the deep erosion due to the freezing and melting cycle. The most natural phenomena acting on the Livingstone Island are schematically presented on fig.2.

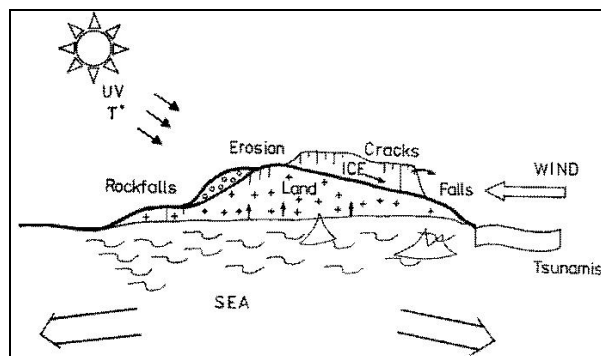


Figure 2. Main factors generating the geodynamics on the Livingstone Island

### GEOLOGICAL INVESTIGATIONS

The results obtained from these investigations are preliminary and not yet completed. The interpretations will follow by the investigations of the respective specialists.

#### Petrochemical contents of the rock samples

Table 2. Results of the chemical analysis for some selected rock samples

№	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O
A1	55.10	17.10	9.31	4.24	6.37	3.16
A2	75.10	10.91	3.97	1.47	0.56	3.05
A3	66.30	11.48	2.71	0.38	0.89	3.61
A4	54.10	15.04	10.89	4.20	7.10	6.65
A5	62.00	15.04	8.69	1.94	2.11	4.14
A6	77.10	11.01	2.18	0.80	0.38	2.84
A7	70.00	13.76	5.72	1.88	1.62	1.72
A8	77.40	11.47	2.29	0.18	0.93	3.24

The petrochemical analysis has been done according to the AES-ICP standard. In table 2 the values for some selected sample are presented: A1 – gabbro; A2 – pyroclastic tuff; A3 – andesite; A4 – dolerite; A5 – trahite (Ca); A6 – sandstone; A7 – argillite; A8 – granite-porphir. On the island due to the intrusions the thermal metamorphism is very frequent, especially near the gabbro-dioritic body of the Hesperides point, as well as near the dyke's intrusion. [Kamenov, 2000].

#### Precious and semiprecious stones

Near the base, up to now, only semiprecious stones have been discovered. A small deposit of onyx (brown-red sliced agate sometimes including pyrite) and a lot of veins of amethyst with different sizes (from several centimeters up to several meters) have been described. The onyx is rare

mineral, sometimes have nice properties and can be polished well. The amethyst has larger distribution. Usually appears as aggregates, very rare – like crystals or inclusions in the quartz veins. The color is light violet, sometime – dark violet. The samples have jewelry properties. Epidote is another frequently discovered mineral. The magmatic rocks very often look useful for decorative purposes. Very often the findings of manganite, pyrite, chalcopyrite, galenite, sphalerite, etc. can be recognized. Quartz crystals are also discovered. In the sediments microscopic crystals of garnet, olivine, epidote, hematite, sometimes circone can be found. The collectors can collect all described minerals.

### Fossils

For the first time near the BAB fossils from belemnites have been found. The specialists from New Zealand have made the analysis on the eight samples. The identification shows two types dated – Belemnopsis (Berias-Valangine) and Hibolites (Turonian). All specimens have been discovered on the beach, included in dark sandstone gravel similar to the Maier's Bluff formation. The dimensions of the detrituses are between 2 and 5 cm. The fossils themselves are light white, because of the Ca dominance. This is due to the postformation changes. Only one sample is bigger. The samples are firmly included in the mother's rock and to extract them mechanically is impossible. The sample can be found everywhere on the beach and formed large fans. This is may be indicator that they are coming with the glacier's materials. The frequency of the findings is about 10% from all dark colored rock gravel. Up to now there are no information about the discoveries of the fossils on the basement rocks.

### CONCLUSIONS

The results obtained give a light idea about the large possibilities for the geological and geophysical investigations on the Livingstone Island. The BAB appears as a test site for the geology, geophysics and the geodynamic investigations. The results are preliminary and even in this case show the large improvement for the observed facts and phenomena. All

described phenomena can be observed in natural environment due to the lack of different anthropogenic noises. The large possibilities provided by the Bulgarian Antarctic Base, can and must be in use for the increased geological and geophysical investigations in Antarctica.

### Acknowledgments

GeoSIG provided the seismograph for the seismic station. Dr. Challinor and Dr. Briggs from the Waikato University – New Zealand executed the fossils investigations. NBU provided support for the Antarctic project 24/08.01.2002. Dr. Tokmakchieva investigated the rock samples. MGU labs – made the petrochemical analysis.

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