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The destruction of rocky shores at high latitudes according to precision measurements data

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Abstract. New high-precision data on the surface destruction rates of a co-seismically raised bench as a result of the Nevelsk earthquake in August 2, 2007, $M_w = 6.2$ in Nevelsk allowed to determine that the destruction of subvertical coastal cliffs occurs with the speeds nearly an order of magnitude larger, than the speed destruction of subhorizontal bench surfaces. The role of wave influence in the benches formation is mainly reduced to the mobilization and removal of debris obtained as a result of frost weathering at negative air temperatures. High-precision orthophotos and 3D models of high coastal ledge composed of volcanogenic-sedimentary rocks made it possible to identify the cliffs destruction mechanisms with non-uniform strength and to determine their quantitative parameters. It was found that the destruction occurs along structurally weakened zones, as well as during the collapse of large rocks blocks due to the formation of wave-breaking holes in rapidly destructing tuffs. Suffosion in tuffs and their contacts significantly weakens the solid characteristics of volcanogenic-sedimentary mountain massives. The retreat of the coastal scarp brow formed by volcanogenic-sedimentary rocks can reach several meters per year under these conditions.

Keywords: LNG plant, photogrammetry, sea cliff; shore platform, rock coastal erosion, depth suffusion.

1. Introduction

Abrasion is the main modern morpholithodynamics process on the rocky shores that form about 75% of the coastline [1]. Accurate and continuous destruction monitoring of the indigenous shores is almost impossible, so the average values for the periods of field observations of cartographic and remote surveys were used to determine the abrasion rate [2]. However, the long-term average abrasion rates of the indigenous coasts should be used very carefully at determining of the hazard and zoning of the coasts. It's widely known event when during the January storms of 1983 in California about 14 m of the cliff, composed of Miocene siltstone, was washed away; in the period from 1931 till 1982 it was retreating at an average speed of 0.2 m/year [3]. A similar phenomenon was observed by us quite recently in the area of the LNG plant "Prigorodnoye", located on the indigenous terrace, composed of weakly cemented Bykovo Suite (K2bk) mudstones and siltstones of the third stability class [4]. During the one storm in the autumn of 2017, 4-7 meters of the coastal ledge were destroyed, while for more than a decade period the shore was destroying at a speed of 0.1-0.15 m/year.



2. Overview of the problem

Urgent observations of the coasts destruction formed by rocky rocks were also carrying out during the period from 1999 till 2007 by the Center of State geological environment monitoring at the FSUGP "SakhGRE" on the Terpeniya Bay and the Tatar Strait coast.

In the Terpeniya Bay was documented the low indigenous terrace edge retreat, composed of Neogenic siltstones kurasiyskaya suite N1 (Cr). The average rate of coastal ledge retreat during the observation period was 0.26 m/year per running meter of the coastline (Figure 1). In the meantime, it should be noted that, as in the LNG "Prigorodnoye" coastal ledge case, the main erosion occurred simultaneously - in October 2006. The contribution of this storm event to the total amount of abrasion for the entire observation period was 77%.

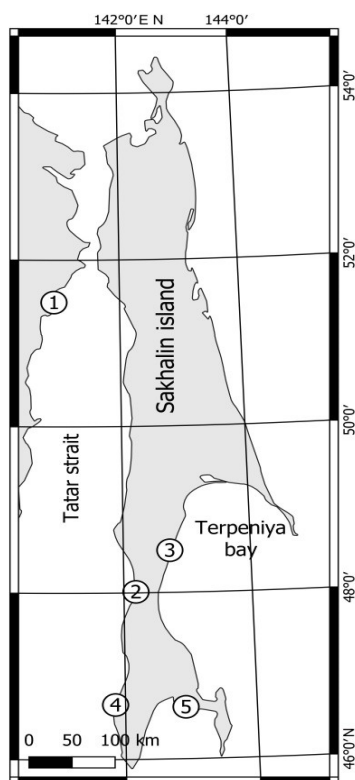


Figure 1. The factual material map: 1 – high cliff of De-Kastri Bay, 2 – cliff of the Tatar Strait, 3 – indigenous terrace ledge of Terpeniya Bay, 4 – bench near Nevelsk, 5 – shore ledge in the area of LNG “Prigorodnoye”.

On the Sakhalin shore of the Tatar Strait in the settlement Ilyinsky area a cliff edge retreat measurements were carrying out on three measuring sites. Despite the fact that the coastal ledge here is composed of lithified sandstone-siliceous kholmsk lithotype rocks of the fourth class of stability, the average annual cliff edge retreat rate approximately corresponds to the cliff destruction rate, occurred in rocks II and III lithotype [4]. The average annual cliff edge retreat rate is 0.25 m/year for site № 1, 0.32 m/year - for site № 2. The exception is the site № 3, where the average annual cliff retreat rate was 0.05 m/year per 1 running meter of the coastal ledge.

In the framework of this work we don't observe the hydrodynamics and morpholithodynamics coastal zone features in the areas of observations, don't consider cliff rocks structural-geological, lithological and stratigraphic features, and also the rocks weathering mechanisms. We'll note only that the area with the lowest coastal cliff destruction rates in the Tatar Strait is located in the small port structure wave shadow for the most energetically provided north direction waving.

Concerning the banks stability question which composed of indigenous rocks, it is necessary to note the following fact. For the road section in the settlement Vzmor'ye area in 2012, the coastal slope type protection was built. The natural middle Miocene age stone of the dacite composition was used as the main wave-decreasing element. The using of natural stone in marine hydrotechnical construction implies its ability to withstand multiple alternating freezing and thawing in a water-saturated state without visible destruction signs. According to DBC 5-84 "Departmental building codes" stone frost resistance must be at least $Mp3100$ [5]. But volcanic rocks (dacites) weren't very resistant to weathering processes: in the 2013 the monoliths cracked, and shore protection have already been destroyed.

3. Results

The study coastal platforms destruction – benches, formed on rocky shores with weak rock stability, allows to differentiate in a certain extent the wave effects and factors of subaerial weathering. The bench destruction study, which is coseismic raised to 0.8-1.0 m as a result of the Nevelsk earthquake in August 2, 2007, $M_w=6.2$ in the city Nevelsk gave the exceptional opportunity in this regard. The Neogene age rocks forming the bench are represented by greenish-gray fine-grained, clay, weakly cemented sandstones, and siltstones with calcareous nodules.

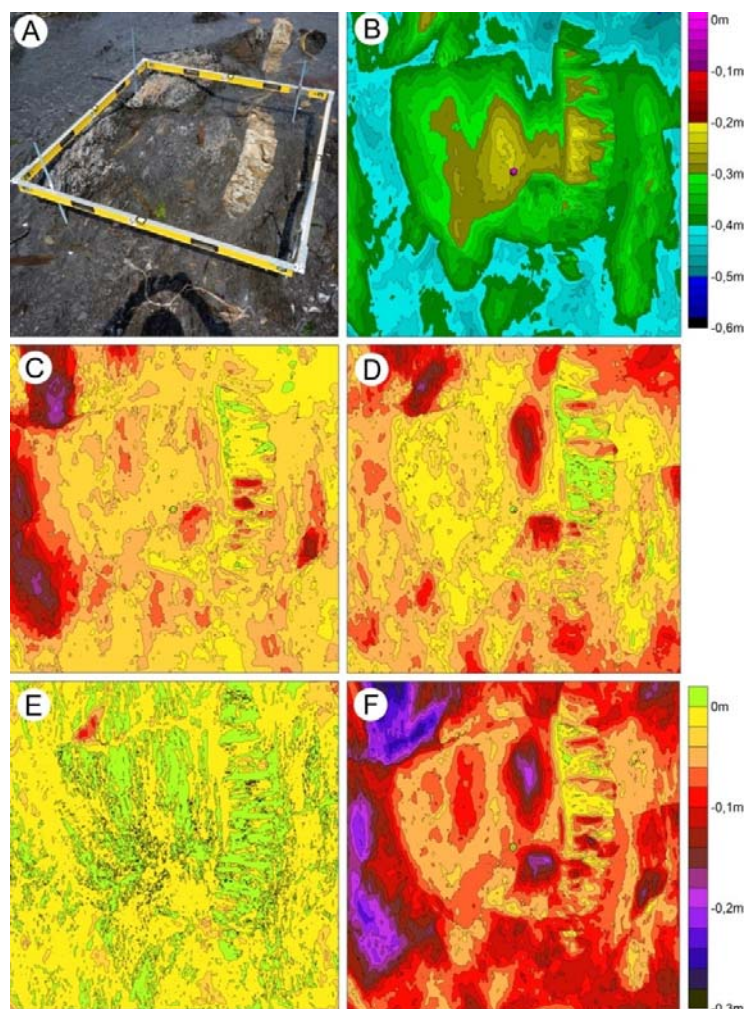


Figure 2. Maps of heights field and heights fields differences in years on the plot № 1. A – Photo of the plot in July, 2016. B – map of plot heights the in November 2018, C – the height difference in 2017.06-2016.07, D – the heights difference 2018.04 – 2017.06, E – the height difference 2018.11 – 2018.04, F – the height difference 2018.11 – 2016.07.

For 6 years we have been conducting instrumental observations along a 100 datum points network concreted into the bench surface in the Nevelsk, Sakhalin region area. Since June 2016 the measures were conducted by subtracting the field heights maps of the plots with 2.25 m² sizes with datum in the center. Height field maps were constructed by digital photogrammetric method in Agisoft Photoscan software. To bind the model, an aluminum frame with 1.5×1.5 meters sizes was used, which was installed horizontally by an optical autolevel. At the four frame corners there were markers with pre-measured coordinates encoded as a circular binary code. For the correct axes location in the space, frame was oriented by boussole. The Sony A6000 camera (24 megapixels) was used for the survey. Then the primary photo linking with the common points cloud construction was produced, points with low coordinates determining accuracy were removed from the cloud in the Agisoft Photoscan software. Then on the remaining reliable points base, the camera calibration was clarified and a dense cloud and polygon model were built.

The next step was a height field model building with a planned 0.001 m resolution. The height differences matrix for the period allows to calculate the specific destruction volume per 1 m² of the area and accordingly the average speed around the section (Figure 2).

The bench surface destruction average rate varies from 0.25 cm/year in the areas covered by debris material, washed from the sea bench part at superposition of maximum sea levels and waves, to 4.37 cm/year in the areas almost filled with water daily. At the same time, the siltstones destruction rate is about 2.5 times higher than the calcareous concretions destruction rate even within the one observational platform limits (Figure 2A).

Thus, the measured rates of coastal ledge retreat without direct wave impact (settlement Il'insky, plot № 3) approximately correspond to the destruction rates of the similar according rocks stability class on the bench. While the weathering products remove from the bench by sea water, in the case of cliff this is caused due to the slope, or gravitational processes mainly. In both cases, there aren't shock wave stress with the beach sediments abrading effect.

Available and low-cost photogrammetric methods also allow to obtain high-precision data of dangerous high steep coastal ledges composed of indigenous rocks [6,7].

According to the above-mentioned considerations, was investigated a coastal ledge which is limits the planned LNG plant building area from the south and east, located next to the oil loading terminal in the Klykov Peninsula (De-Kastri) section.

The modern geological and geomorphological section outlook was determined by the effusive formations in the Miocene series formation and their subsequent exogenous processing. As a result of coastal ledge destruction, which is up to 160 m high, was formed bench width 100 m over the past 6,000 years.

Identifying water inflows in the tuffs, contacts and disjunctive, which are indicators of possible suffusion in these areas, included the hydrogeological enclosed rocks characteristics studies, 3D models designing and coastal cliff orthophotos with fixing and defining of the underground waters exits parameters (Figure 3).

Groundwater classified by a filtration medium rank is layer-fractured in the upper zone, which is the most crevassed, and crevasse-vein in the tectonic disturbances zones. Both above-described watered layers in this area have a close hydraulic relationship and are characterized by a common level surface. In general, the level location depth decreases in accordance with the decrease in relief, and the maximum gradient is observed with the approaching to the coastal ledge.

The coastal ledge orthophotos was built in Agisoft Photoscan software by the ground photographs set projecting to a vertical planes located parallel to the ledge, which were performed by the SONY NEX camera. To obtain a correct orthophoto projection, a photogrammetric 3D model reconstruction of the ledge was carried out. For the most accurate correspondences searching, all images were performed in the RAW-format and then converted to the TIFF with extended dynamic range. The average photos resolution is 2.64 cm/Pix. Initial camera calibration was carried out with using of built in Agisoft Lens software. Then the photo linking and the photography centers coordinates calculation by constructing a sparse cloud was carried out. There were calculated 5 million connected points were at total. The model of lens distortions was elaborated by the recognized connecting points, which were registered on at least 3 images, then a dense cloud of points was built, 62 million points at total. A polygonal model was formed from a dense point cloud, which was used for obtaining orthophotos. The model was attached to the plot with the aid of coordinated markers located on the ledge. The total length of the studied coastal ledge exceeds 5000 m.

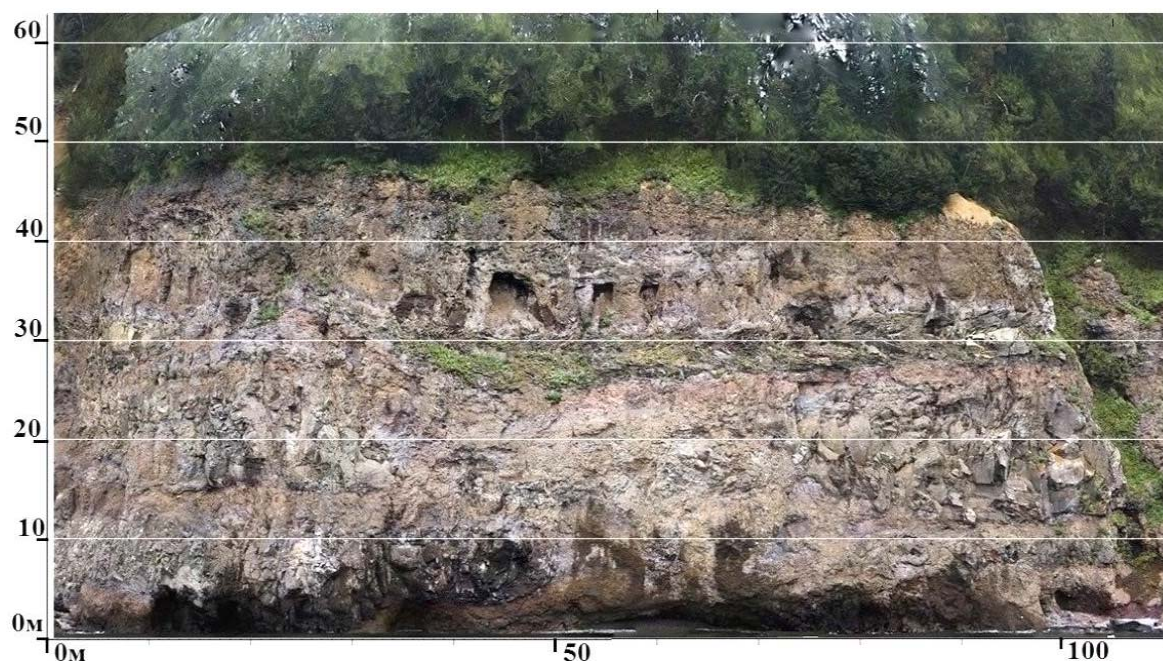


Figure 3. Water inflows in tuffs and weak areas (part of the coastal cliff orthophoto).

Directly within the section planned activity limits, at models and orthophotos analysis, 7 water flows in the moist spots form of several meters in size were found. Outside the proposed activity section during the observation period, groundwater discharge was carried out both in the contact-fracture zones and in tuffs. More than 30 areas with water inflows throughout the height of the coastal cliff were found.

4. Discussion and Conclusions

The appliance of monitoring techniques using remote sensing and observation data on high steep cliffs isn't possible due to the inclined viewing angles, structure heterogeneity and the complex ledge surface. Repeated photogrammetric surveys in a fixed coordinate system allow to solve monitoring problems with an accuracy which isn't inferior to laser scanning technologies [9].

Nevertheless, at the first stage of the high coastal ledges study, we also evaluated the shore destruction rates, especially at the surf zone entering of the coastal ledge sections with easily destructible geological complexes or disintegrated complexes of disjunctive zones. The morphometric parameters of the coastal ledge were determined in the areas of active slope processes caused by abrasive cutting of the ledge or rocks stability decreasing as a result of weathering and suffusion; the volumes of colluvial-proluvial forms at the foot were sated up.

The time of colluvial-proluvial buildups formation and their elements was based on the remote sensing materials analysis and the vegetation feature on the surface. The average speeds of the coastal ledge destruction along the rapid destruction zones are in the first zone more than 0.29 m/year, in the second zone is more of 0.44 m/year, in the third zone more 0.87 m/year. One-time coastal ledge retreats in the areas up to 100 meters can reach 7 meters per year, which is kind of unusual for bedrock.

The destruction of sub-vertical coastal ledges in the rocks of weak and medium stability under the conditions of wave action occurs at speeds about an order of magnitude greater than the rate of destruction of subhorizontal surfaces of the bench, composed of similar rocks. The role of wave impact in the development of bench mainly appears as the mobilization and removal of the fragments obtained as a result of frost weathering at negative air temperatures in the period of the open sea. The number of cycles of freezing and thawing in this period reaches several tens.

The measured rates of retreat of the coastal ledge without direct wave action approximately correspond to the rates of destruction similar to the class of stability of rocks on the bench. And in that and in other case, no shock wave loads with abrasions impact of beach sediments.

The applied photogrammetric methods also allowed to obtain high-precision data on high steep coastal ledges composed of bedrock.

The experience of evaluation of the engineering-geological safety of the infrastructure facilities of the planned LNG plant under the difficult conditions of the coast with volcanogenic-sedimentary rock complexes showed that the retreat of coastal ledges along weakened zones in areas up to 100 meters long can reach several meters per year.

The subsurface suffusion in tuffs and their contacts significantly weakens the strength characteristics of the volcanic-sedimentary rock massive and accelerates the weathering processes on the slopes of the coastal ledge. Rapid indicator of these dangerous geological phenomena can be the presence of groundwater outlets with a high degree of mineralization. In De-Kastri conditions, the mineralization of water manifestations is in 2-4 times higher than mineralization of water at the mouth of the rivers. It should also be noted that engineering-geological drilling up to bedrock, in the case of interlaying of monolithic andesite-basalts and "weak" tuffs, does not make sense, because the thickness of the "indigenous base", reached after the drilling of the slope deposits and eluvium, can reach only 1-2 meters.

References

- [1] Emery K O and Kuhn G G 1982 Sea cliffs: their processes, profiles, and classification *Geological Society of America Bulletin* 7. **93** 644–54
- [2] Sunamura T 1992 *Geomorphology of Rocky Coasts* (New York: J. Wiley) p 302
- [3] Griggs G and Savoy L 1985 *Living with the California Coast* (Durham: Duke University Press) p 394

- [4] Polunin G V and Buzlaev V A 1984 *The map of lithographic complexes and manifestations of exogenic processes of Sakhalin: scale 1:500000* (Moscow: SIGM)
- [5] 1984 VSN 5-84 MMF *Use of Natural Stone in Marine Hydraulic Construction* (Moscow: USSR Minmorflot 44)
- [6] Westoby M J Brasington J, Glasser N F and Hambrey M J 2012 Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications *J. Geomorphology* **179** 300–14
- [7] Afanas'ev V V 2018 Geomorphological aspects of the problem of selecting of the sites for the construction of liquefied natural gas plants on the coast of the Far East seas *Proc. XXXVI Plenum of the Geomorphological Commission of the Russian Academy of Sciences all-Russian scientific-practical conference with international participation Geomorphology – science of the XXI century* (Barnaul: Altai State University press) pp 26–31
- [8] Afanas'ev V V 2015 Problems of coastal using of subarctic seas (on the example of Sakhalin Island *Modern problems of using of the potential of marine areas and coastal zones. Proc. XI international science conference: in 2 parts* (Moscow: Moscow University S.Yu. Vitte.) p 118–30
- [9] Bemis S P, Micklethwaite S, Turner D, James M R, Akciz S, Thiele S T and Bangash H A 2014 Ground-based and UAV-based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology *J. of Structural Geology* **69** 163–78