Pebble beaches of the Murmansk coast – unique formations of the Kola Peninsula

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Abstract. The structure and formation of white-pebble beaches located on the Murmansk coast of the Barents Sea and observed in the area of the Teriberka settlement are considered in this paper. The uniqueness of such beaches is a presence of pebbles, which have a high degree rounding and can take the shape close to the egg geometry. A light boulder-pebble material of the beaches is located in canyons. Within a canyon, a beach (tidal and surf zones) and two terraces can be distinguished conditionally. Walls and bed of the canyons are composed of red rocks, supposedly, granites and enderbites, while the white boulder-pebble material of the beaches may be composed of gneiss-granites, plagiogranites and other ancient rocks. Due to wave activity in the Barents Sea, there is a continuous interaction of pebbles and boulders of the beaches with canyon-forming rocks. As the result of this process, peculiar shapes of the relief can be observed within tidal and surf zones of the beaches in the canyon bed – boilers, wells, trenches, grottos. Pebble beaches could have formed on the Murmansk coast as a consequence of the geological situation of the area, which included the uplift of the Baltic Shield, the destruction of ancient rocks and their abrasion against younger rocks. Pebble beaches are unique Arctic objects not only for tourism purposes, but also in terms of geology.

1. Introduction
The Kola Peninsula is located in the south-west of the Arctic zone. Despite its harsh climate and remoteness from the center of Russia, it has engaged the attention of the admirers of extreme tourism for a long time now. Not only residents of our country, but also foreigners come here to ski on the Khibiny slopes, visit Seidozero or enjoy the beauty of the Tersky coast. Recently, a small rural settlement on the northernmost side of the Kola Peninsula is drawing more and more attention of tourists.

The settlement of Teriberka is located on the Murmansk coast of the Barents Sea at the mouth of a river of the same name, near its confluence to the Teribersky Bay. This place owes its popularity to the “Leviofan” movie; it was mainly shot in the settlement in 2014. Thanks to the motor vehicle availability and the “Teriberka. New life” festival organized in 2015, the popularity of the settlement has increased significantly over time. Currently, many people come here to enjoy a spectacle of the endless tundra, see the Arctic Ocean and enjoy kitesurfing.

From a geological point of view, pebble beaches, common in the area, occupy a special place among famous landmarks of Teriberka. A unique feature of such beaches is a presence of pebbles with a high degree rounding. Pebbles are called “dragon eggs” or “dinosaur eggs” for their shape. Pebble beaches are popular among tourists, but only few of them know what geological formations they represent.
This article presents the data on a structure of white-pebble beaches near the settlement of Teriberka and their boulder-pebble material. The research is based on the study of topographic maps, satellite images of 70 boulder-pebble beaches and a visual inspection of 11 beaches. The studies have been conducted without the use of instrumental survey, and are preliminary in nature.

2. Geology of the area
In terms of geology, the area of the Teriberka settlement is confined to the Teribersko-Voroninsky segment of the Murmansk block stretched as a wide line along the northern coast of the Kola Peninsula. The Murmansk block consists of the ancient rocks of the Baltic crystalline shield, which cropped out as a result of a long vertical lifting. 80% of the Murmansk block is composed of tonalites, plagiogranites and diorite-plagiogranites with the age of 3100 million years [5]. Younger hypogene rocks enderbit with the age of 2830-2790 million years and red potassium granites with the age of 2750-2600 million years have intruded those rocks [5, 6, 10]. All rocks are crossed by dikes of the Proterozoic and younger age [1].

Since the late Proterozoic (about 1600 million years ago), the Baltic shield has been constantly rising. This process was accompanied by a continuous destruction of rocks under the influence of exogenous processes (weathering), which led to a decrease in relief. This, in turn, was compensated by a new rise [7]. As a result, deep rocks with complex transformations of Precambrian (Archean and Proterozoic) age gradually appeared on the surface [2]. The most extensive areas of the outputs of potassium granites and enderbites occur in the Teribersko-Voroninsky segment.

3. Pebble beaches with “dinosaur eggs”
The shore of the Barents Sea near the settlement of Teriberka is embayed. There are quite common shallow canyons and rare bays along the rivers. Pebble beaches are usually located in the canyons, and the sandy beaches occur in the bays. White-pebble beaches are particularly numerous in the area between Maly Oleny island and Maly Zelenetsky island. There are more than 70 beaches within about 40 km, 15 of them are located in the settlement of Teriberka and are available for study.

Pebble beaches are composed of fragments of rocks, mostly light colors, probably, plagiogranites, gneiss-granites, tonalites and diorite-plagiogranites. The size of the boulders varies from 20 to 200 cm, while the size of the rounded pebbles is 10-20 cm. Boulder-pebble material of the beaches has a different degree of roundness. Remarkably, more elaborated and perfectly rounded boulders and pebbles on all beaches are egg-shaped (Figure 1). On some beaches, about 30% of the boulder-pebble material is composed of similar formations. The size of the egg-shaped pebble varies from 10 cm to 1 m, while the shape remains close to the ideal geometry of an egg (the ratio of the long and short axis 5:4 and 9:5). Such shapes of pebbles do not depend on what type of rocks it is composed of.

Figure 1. Egg-shaped pebbles
Boulder-pebble material forms pebble beaches and accumulates in the bed of canyons, which are trough-shaped depressions in the coastal part of the sea. The walls and bed of canyons, unlike whiter
formations of the beaches, are composed of red rocks, probably potassium granites and enderbites (Figure 2). Walls of the canyons are sharpened and smoothed. Within the canyons, there are two terraces in addition to boulder-pebble beaches [8]. The surf and tidal zones can be distinguished within the pebble beaches.

![Figure 2. White-pebble beach framed by canyon-forming red rocks.](image)

The beginning of the first terrace is marked by a storm shaft of pebbles and fins at an altitude of 7-10 m above sea level. The terrace flat rises up at a distance of about 200 m, where it ends with a shaft of the second older terrace at an altitude of 40-45 m. The first terrace is composed of well-rounded pebbles, but the pebbles are covered with lichen and, as a result, get a gray color. The second terrace is composed of poorly rounded pebbles and boulders. Rocks composing pebbles and boulders of terraces are similar to rocks composing the beach. Above the second terrace, there are numerous fragments of light gray rocks (presumably plagiogranites) lying on red rocks at an altitude of 70-110 m above sea level.

![Figure 3. Tidal beach area (dark area in the photo).](image)
level. It is assumed that they are remains of destructed ancient granite, which beach pebbles are composed of.

The surf zone starts from a shaft on the border with the first terrace and falls hollow down to the upper edge of the tidal zone. The width of the surf zone from the high tide line to the boundary shaft of the first terrace is different: the lip width of the zone sometimes is only 30 m, and it usually is 50-70 m on shores open to the sea. The length of the surf zone along the coast is controlled by the width of the canyons. This upper part of the beach is formed under the influence of large storm waves. It is the main area of white-stone beaches, where described above perfectly rounded egg-shaped pebbles are formed.

The tidal zone composes the lower part of the beach (Figure 3). It is periodically exposed at low tide and covered with water at high tide. The average height of the tides in the area of the Teriberka settlement is 4 m, the maximum height is 6 m. Depending on the slope, the width of the tidal zone varies slightly from 50 to 70 m. The length along the coastline varies widely from 50 m to 1 km depending on the width of the canyon. Pebbles and boulders in this area are covered with seaweed. Pebbles, generally, end in the tidal zone. On some beaches in this area, there are ruins and outcrops of bedrocks; it indicates the end of the pebble beach.

4. Joint work of boulder-pebble material and waves
The Barents Sea is non-freezing, so waves are active all year round. In the calm state of the sea, waves affect only the lower part of the surf zone. There is an active abrasive activity, movement and rounding of boulders under the constant influence of waves. In this part of the beach, the boulders are bigger. There are very large specimens up to 2 m. Conventional tidal waves are not strong enough to move such giants, so a powerful energy of storm waves is used. The height of storm waves on the Barents Sea coast can reach 10 m. The activity of sea waves provides an active interaction of boulder-pebble material with the bedrock forming the bed of canyons. As a result, there are numerous boilers, wells and trenches in the tidal zone, trenches may be also present in the surf zone.

Boilers are recesses of different sizes and rounded pits covering large areas of the granite bed surface (Figure 4A). Boilers are formed as a result of impact-rotational eroding activity of pebbles on red rocks and removal of the destroyed material. Given the large number of boilers, it can be assumed that many pebbles have passed this stage of grinding on granite.

Wells are deep round pits (Figure 4B). The wells reach 1-2 m in diameter and up to 1.5 m depth. The throat of wells is mainly oval or round. The walls of the well are always prepared with pebble material, and there are individual well-rounded pebbles at the bottom of the well. The origin of wells is connected with the long-term influence of pebbles on red rocks. Presumably, a group of pebbles accumulated in the recess for some reason and knocked the well out under the influence of waves. Meanwhile, most of the pebbles have not preserved, and there are only individual exemplars at the bottom. Wells can merge into trenches.

Trenches are elongated recesses in the bedrocks. The lengthening of trenches is always directed towards the sea (Figure 4C). Trenches are ditches with a “head” and a “tail”. The head of the trench faces the shore and the tail faces the sea. There is always a scattering of pebbles in the trench. They are usually accumulated in the head, less scattered over the trench. The walls and bottom of the trench are prepared with pebbles and smooth, they differ from simple cracks. Trenches are mainly located in the lower part of the beach surf zone and merge into the high tide zone, they are rarely fully located in the surf zone. The dimensions of the trenches are the first meters in width and depth and tens of meters in
length. The formation of trenches is associated with the impact effect of pebbles on the bottom and walls of the crack during the periods when storm waves were active, and pebbles were over the trench.

The grotto is a type of large trenches. The grotto structure is similar to the trenches, but a deep rounded niche with a cope is formed in their front section. One of the grottoes on the beach No. 5 is a trench of about 25 m length, 4.5 m depth and 5.7 m width. In the front section of the trench, there is a semi-circular cave with concave walls. A vaulted passage upward and an expanding passage to the sea are formed above the cave. In the front and middle sections of the cave, there is a pile of well-rounded boulders and large pebbles (Figure 4D). The bottom of the grotto is covered with boilers, in which there are rounded boulders.

5. Conclusion
Pebble beaches located on the Murmansk coast of the Barents Sea near the Teriberka settlement are occur in the bed of canyons. Within the canyons, you can see two terraces and a white-pebble beach. The bed and walls of the canyons are composed of red rocks, supposedly, granites and enderbites, while the white boulder-pebble material of the beaches may be composed of gneiss-granites, plagiogranites and other ancient rocks. In the tidal and surf zones of the pebble beaches, there are numerous traces of pebbles on the bed of canyons (boilers, wells, trenches and grottoes). The unique phenomena, in our opinion, include the ability of boulders and pebbles from the Murmansk block rocks to acquire an egg-shape when rolling under the action of sea waves.

The presence of two terraces traces two periods of the elevation velocity. The first period is marked by the shaft of the second terrace at an altitude of about 45 m, the second period is marked by the shaft of the first terrace at an altitude of 10 m above sea level. This is consistent with the generally accepted
theory that the Baltic shield experienced a constant vaulting uplift in the post-glacial period (since 11,000 years ago), which occurred at different rates and was accompanied by a sea-level regression [4]. Initially, the sea-line regression rate was 30-50 mm/year and then slowed down to 2-5 mm/year [3, 9]. The formation of pebble beaches on the coast of Teriberka may have occurred as a result of the destruction of the Murmansk block rocks due to the raising of the Baltic shield and the subsequent abrasion of more fragile, ancient rocks on stronger, younger rocks.

Unusual formations and extensive geological history turn pebble beaches into unique objects of geotourism in the Arctic zone of Russia.

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