

## Results of AMT survey of Patom crater area.

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### SUMMARY

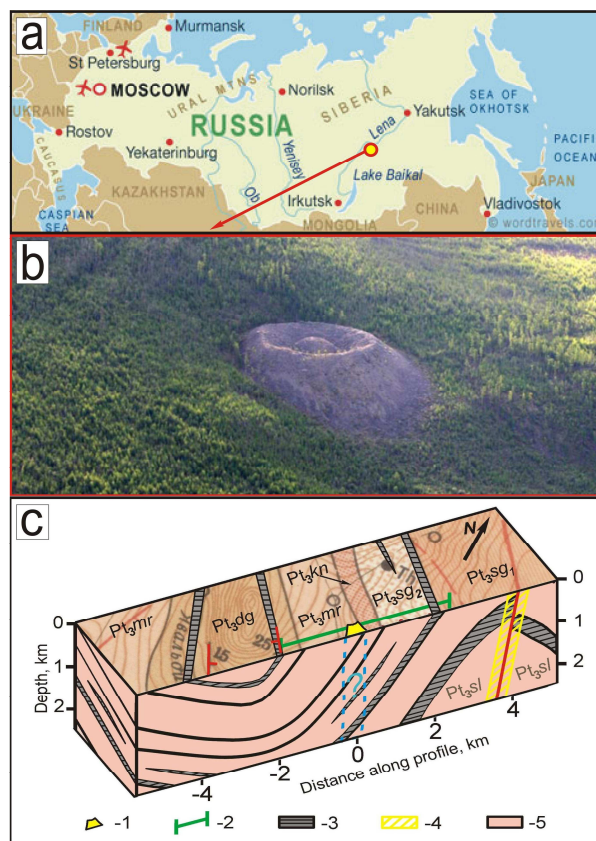
The geological interpretation of magnetotelluric soundings along 5 km profile across of the Patom crater has been performed. The Patom tectonic zone with the mark of Devonian fluid-metasomatic process has been discovered. The zone breaks the layers of carbonaceous shale of sedimentary host rocks. The new origin model of the Patom crater has been proposed. The principal of it is accumulation of methane under the bottom boundary the long-term permafrost in karst bag. The source of methane probably is subjacent layers of carbonaceous rocks. The methane had been converting in gas-hydrate form with heat release. The local thaw through the long-term permafrost had frozen during the "Little Ice Age". The result of this process was hydrolaccolite. The alternative concept is an underground blast of methane.

**Keywords:** Patom crater, magnetotelluric, cryogenic processes, methane hydrate, hydrolaccolite.

### INTRODUCTION

The Patom crater is located in the south of the Siberian platform (figure 1, a). The crater was discovered in 1949 by geologist V. Kolpakov [1]. The genesis of this structure is discussion. There are several variants of the crater origin: impact, volcanic or cryogenic process. The crater looks like a central type ring structure. It consists of lamps of limestone of Neoproterozoic age (figure 1, b). The diameter of the top ring-wall is about 70-80 meters. The amplitude is about 40 meters [2]. According to the dendrochronological method, the age of the crater is about 500 years.

The geology-geophysical expedition in August 2010 has been organized. The target of this expedition was getting new data to decide the Patom crater genesis. The main role of this expedition had played electroprospecting works by audiomagnetotelluric (AMT) and magitovariation (MVS) soundings. These works along profile across host medium rocks in transversely direction and Patom crater (figure 1, c) have been made by the geophysicists of Saint Petersburg Mining University. The highly productive equipment of “Phoenix-geophysics” and “AGCOS” Canadian companies has been used. The result of 2D inversion of AMT-MVS data is shown in figure 2. The feature of field works, analyze and interpretation are recounted in the article [3]. In this article the authors made the geological interpretation of geoelectrical cross-section. The two most likely models of the Patom crater genesis have been suggested.



**Figure 1.** Location of investigation area (a); photo of the Patom crater from the helicopter (b); geoelectrical model of the Patom crater area by 1:200000 scale geological map (c): 1 – Patom crater location, 2 – AMT profile, 3 – layers of black shale, 4 – faults, 5 – hosting terrigenous and carbonate rocks.

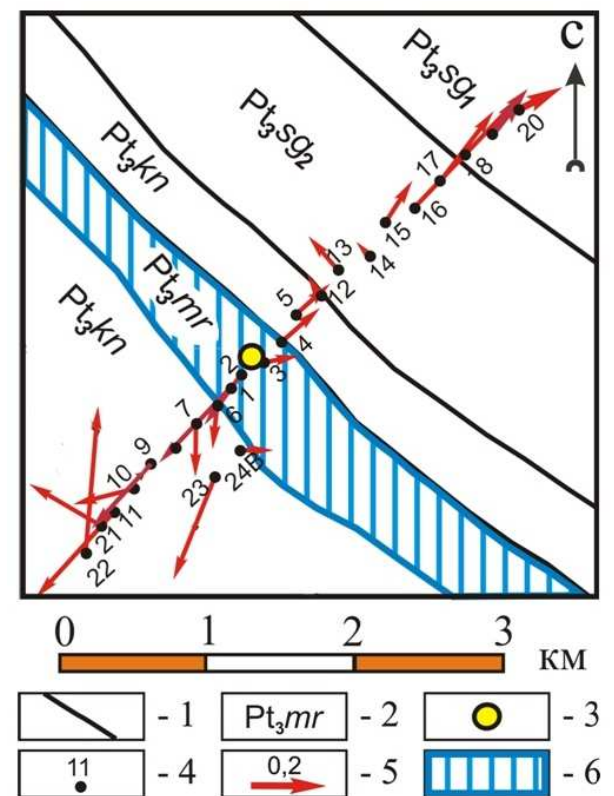
### METHODOLOGY

The geological interpretation of geoelectrical cross-section consisted of 2 steps. On the first step to earmark for a given area database has been created. The database consisted of the geological map, the topographic map, the cosmic photo, the map of detailed of gravimetric survey of the Patom crater area and the maps of induction arrows. The area interpretation has been completed by "lineament analyze" method. The one is a traditional method of data qualitative analyze. As the result of this analyzes the zone of lineaments concentration has been discovered (figure 3). This zone was called "Patom tectonic zone" (PTZ) by the authors. During the geological survey A. Savichev was determined tectonic type of contacts of Mariinskaya formation ( $Pt_3mr$ ) limestone with metasandstone of Konkuderskaya formation ( $Pt_3kn$ ) and one is located along PTZ boundaries. The second step of the interpretation was the geological interpretation of geoelectrical cross-section. For this operation the authors used petrophysical properties of primary type of the Patom area rocks.

### RESULTS

After geological interpretation the original geology-geophysical model of the top part of Earth crust along the profile has been constructed (figure 4). 3 blocks with different geological builds have been defined. Within the Nord-East block the geological contacts marked by 3 conductive carbonaceous shale dip in South-West direction angularly 15-20 degrees. It looks like a wing of syncline with the size about 3 km. This block is breaks by fault. The South-West block describes of the existence of an anticline. The one wings size is about 1.5 km. and rock dips in the South-West direction

The feature of the central block (or the PTZ) is the absence of conductive carbonaceous layers. The boundaries of this zone are electro conductive tectonic zones. They dip in the Nord-East direction angularly 35-45 degrees. The PTZ is about 600-650 m width. Limestone of Mariinskaya formation is present in the PTZ only. The bottom boundary of limestone is about 300-400 m and it is boundary the long-term permafrost about. The factor of the lack of conductive coaly layers of rocks in PTZ is not obvious. Probably it is connected with Devonian tectonic activation of the region and as a result of coaly substance redistribution. Host rocks of the Patom crater were exposed to different types of alteration (carbonatization of phyllites, pyritization of sandstones, and formation of galena-quartz and fluorite-calcite veins with selvage graphitization). These processes indicate a long time ancient hydrothermal activity in the Patom tectonic zone. The receipt of fluids could lead to the formation of ancient caverns in the limestone, the host medium rock of the Patom crater, which is confirmed by the discovery of large (up to 25 cm) calcite crystals within the crater [7].



**Figure 3.** Geology-structure plan of Patom crater area. 1 – geological boundary: 2 – geological assises: Patom crater: AMT-MVS stations: induction arrow (3000 Hz): The Patom tectonic zone (PTZ).

The Patom crater locates in the middle of PTZ. By According to the authors' opinion, this zone is the key to solve this unique geological object genesis. The absence of vertical fluids channel says that the traditional volcanoes [2, 5] and mud-volcanoes models [6] disagree with the Patom crater origin. The presence of permafrost and other factors allow confirming the genesis of the Patom crater with cryogenic process. By the author's opinion, the bottom boundary of the long-term permafrost was covered by methane. The gas generated in the bottom of the Proterozoic sedimentary cover. Methane accumulated under the cover of the long-term permafrost in the karst traps of limestone. It should be noted that near the crater V. Isaev in the gases extracted from the water, set the concentration of methane, reaching 4% [6].

The retrospective analysis of the changes in average temperatures over the last millennium shows that the beginning of the formation of the crater, some dendrochronological method [2], coincides exactly with the most significant cooling at the turn of the XV-XVI centuries, known as the "Little Ice Age". The transition of methane in hydrate form might cause the fall of temperature. It is possible to be methane hydrates stable in continental conditions, with the average surface temperature of  $-6^{\circ}\text{C}$  at the depths of 230-550 m (according to V.S. Yakushev [8]). The authors divide the two most probable model of the Patom crater genesis.

**Model 1.** The Crater is unusual hydrolaccolite. 500 years ago, the phase transition methane  $\rightarrow$  methane hydrate took place with the release of significant amounts of energy that probably resulted in going local melting of permafrost. The released pressure of water entered the vacant pore space and the frozen propping up the weak zone, (the phase transition of the methane  $\rightarrow$  hydrate methane occurs with a significant decrease in occupied space). This led to an increase in limestone blocks and turning on the surface to form a bulk of the cone. The modern shape of the crater began to take shape, starting from the XVIII century, when the phase of the warming occurred, and the "ice cap" under the Patom crater began to slowly thaw, causing a slow lowering of the top of the cone to form a large central peak. In the photograph (Fig. 1, b) it can be observed that the crater is depressed, the diameter of which is 3 times larger than the diameter of the crater. This fact was first mentioned by the authors, suggests that at present there is an active melting of the ice core of hydrolaccolite.

**Model 2.** The Crater is the result of underground methane explosion. As a result of the detonation or ignition of gases occurred excavation of fractured rock mass to the surface. Subsequently, the cone of the crater subsidence occurred along with the surrounding area.

### CONCLUSIONS

The geological section along the profile crossing the Patom crater has been construction as a result of the geological interpretation of the geoelectric cross-section according to the AMT-MVS data. As a result of our investigations a Patom tectonic zone is revealed. Its formation, according to the authors, is connected with the ancient (Devonian) fluid-tectonic events, which had followed at the world's largest Angara-Vitim granite batholite becoming. The latter, together with modern cryogenic processes specific to the region, played a decisive role in the formation of the crater.

The Complex geological interpretation of studies of the last years can take a crucial role in the formation of the crater to the migration, accumulation and transformation of the gas phase, primarily methane. The authors, as well as most other researchers of the Patom crater, believe that this phenomenon is the result of a unique coincidence of different geological factors: the development of the long-term permafrost, changing its depth by the influence of external and internal reasons, "plug" of limestone, the possibility of developing cavities in limestone, the possibility of accumulation of methane in the cavities, the of the PTZ, the presence of carbonaceous shale and carbonaceous sandstone into sedimentary cover as methane-generator. And another important factor is time. Obvious cryogenic structures have a short life near hundreds years. We are extremely fortunate to study the Patom crater phenomenon and build a genetic model until the time of its natural break-up.

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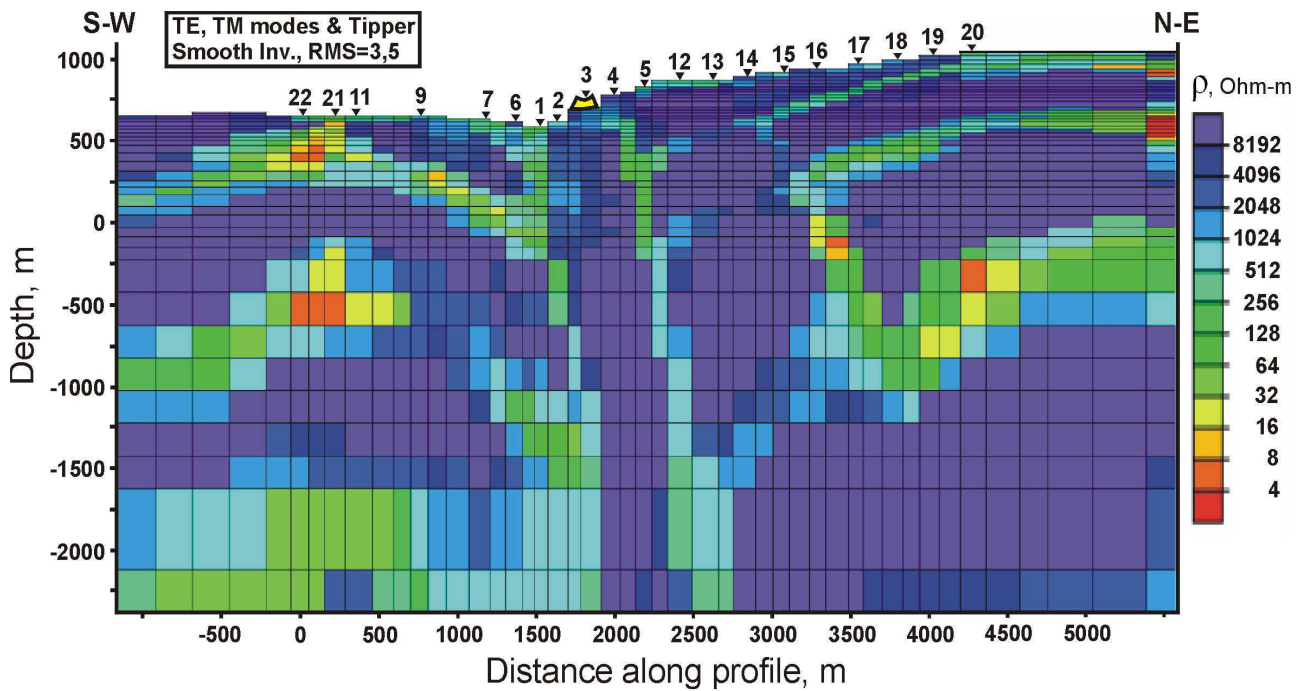


Figure 2. Geoelectrical model for the profile crossing the Patom crater (2-D inversion of AMT data result).

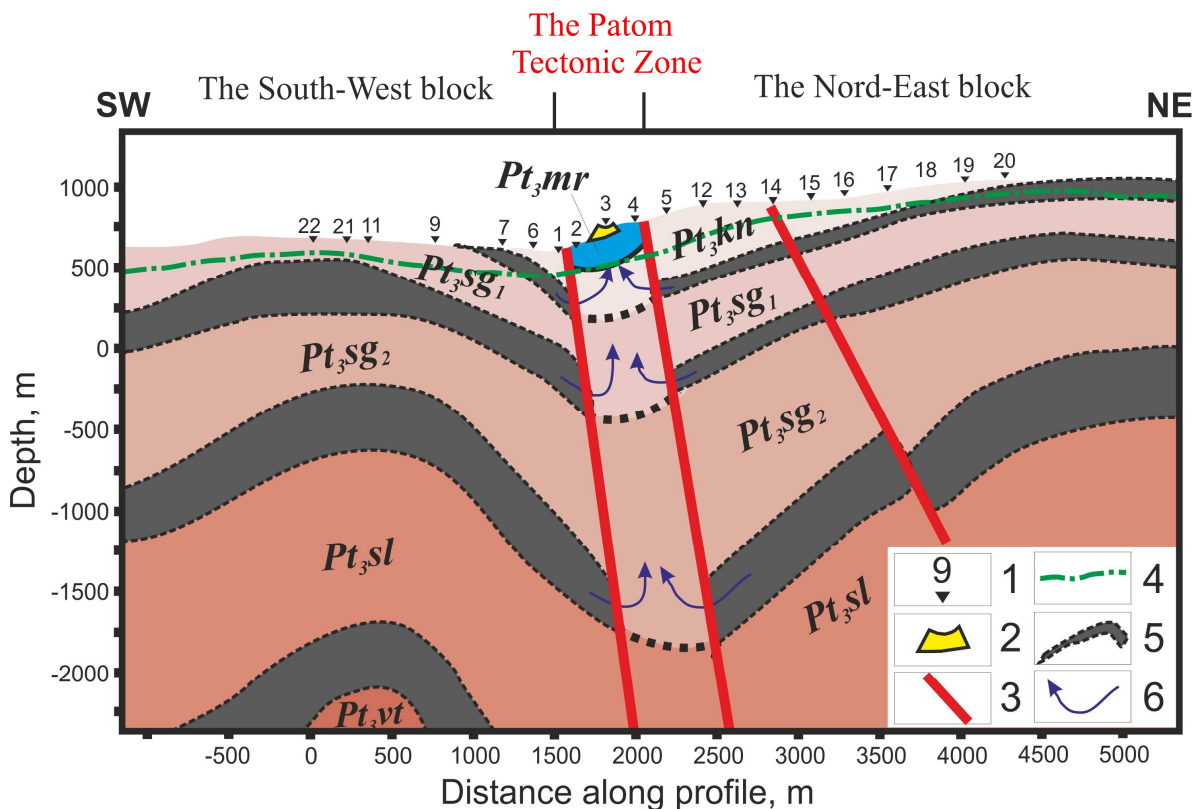


Figure 4. Geological model for the profile crossing the Patom crater. 1 – AMT-MVS stations; 2 - The Patom crater; 3 – faults; 4 – bottom boundary of permafrost; 5 – carbonaceous shale and sandstones, 6 – ways of methane migration. The limestone of Mariinskaya formation shown by blue color.