Exploration of Gamburtsev Subglacial Mountains, Eastern Antarctica: Background and plans for the future

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Gamburtsev Subglacial Mountains, mountain range located in the central part of Eastern Antarctica, near Dome A, were discovered by the 3rd Soviet Antarctic Expedition in 1958 and named after Soviet geophysicist G.A. Gamburtsev (Sorokhtin et al., 1960). Exploring the history of the lithospheric structure of Gamburtsev Subglacial Mountains was one of the primary goals of the Fourth International Polar Year (2007-2008). The multi-national and multi-disciplinary Antarctica's Gamburtsev Province Project (AGAP) included aerogeophysics, traverse programs, passive seismic experiments and shallow ice core drilling (Bell, 2008). It was found that Gamburtsev Mountains with length of approximately 1200 km are larger than the Alps and are generally oriented southwest to northeast. They are about 2700 m high with sharpen peaks, although they are completely covered by ice and snow. The minimal thickness of ice above the peaks is estimated to be 600 to 1000 m.

The range has become the subject of great scientific interest because the mechanism driving uplift of the young-shaped Gamburtsev Mountains in the middle of the old Antarctic Plate is unknown. Ferraccioli et al. (2011) suggested that the combination of rift-flank uplift, root buoyancy and the isostatic response to fluvial and glacial erosion explains the high elevation and relief of the Gamburtsev Mountains. Modelling was based on the data obtained by geophysical remote sensing, and there is no single framework for interpreting these data. The next step of Gamburtsev Mountains exploration is connected with direct observation of ice sheet bed by drilling. It should be pointed out that drilling operations in Antarctica are complicated by extremely low temperature at the surface and within ice sheet, by ice flow, the absence of roads and infrastructures, storms, winds, snowfalls, etc. All that are the reasons that up to the present moment bedrock cores were never obtained at inland of Antarctica.

To recover subglacial bedrock samples, two types of subglacial drilling technologies might be considered: (1) commercial drill rigs with conventional core barrel, or wire-line core barrel, or coiled tubing, and (2) electromechanical cable-suspended drilling with near-bottom fluid circulation. These drilling technologies have different concepts, limits, performance, and applicable scopes.

To use commercial drill rigs in these heavy conditions, many components such as hydraulic system, fluid processing system and some others should be principally re-designed as they are not able to work at low-temperatures. Commercial drill rigs operate as outdoor machines, use tents, or primitive shelters that are not enough at extremely low temperatures and storm winds in Antarctica. In addition, commercial drill rigs are still very heavy and power consuming. They require a large logistical load to move and support, so that using in Antarctica not only disadvantageously but also in some cases impossible.

It is our opinion that the most effective method to penetrate subglacial bedrocks is non-pipe electromechanical drilling technology. This was confirmed by five successful projects carried out by U.S. and Russian specialists in the past on the Arctic ice sheets (Talalay, 2013). The main feature of the electromechanical cable-suspended drills is that an armored cable with a winch is used instead of a pipe-string to provide power to the down-hole motor system and to retrieve the down-hole unit. The use of armored cable allows a significant reduction in power and material consumption, a decrease in the time of round-trip operations, and a simplification in the cleaning of the hole from the cuttings.

In order to penetrate through the ice sheet up to the depth of at least 1000 m and to pierce into the bedrock in the region of Gamburtsev Mountains the development activity already has been started in China. The expected average daily production of ice drilling would be not less than 25 m/day. All drilling equipment (two 50-kW diesel generators, winch, control desk, etc.) will be installed inside a movable sledge-mounted warm-keeping and wind-protecting drilling shelter that has dimensions of 8.8×2.8×3.0 m. Mast has two positions: horizontal for transportation and vertical working position (mast height is 12 m). Drilling shelter is transported to the chosen site with crawler-tractor, and all equipment is ready to start drilling immediately upon arrival to the site. Total weight of drilling equipment (without drilling fluid) is near 15 tons.

To drill through ice and bedrock a new, modified version of the cable-suspended Ice and Bedrock Electromechanical Drill 'IBED' is designed and tested in order to solve three different tasks: 1) dry core drilling of upper snow-firn layer with bottom-air reverse circulation; 2) fluid core drilling of glacial ice with bottom-fluid reverse circulation; 3) bedrock core drilling. IBED drill has modulus construction, and different sections of the drill for different tasks are replaced as all of them have the same bayonet joint. The upper part is the same for all variants; it includes four sections: cable termination, slip rings section, antitorque system, electronic pressure chamber. The motor-gear sections are differed by rotation speed of the output shaft of the gear-reducer. All modulus contain 3 kW AC3 × 380 V submersible motor of Grundfos MS4000 type. The motor is pre-lubricated and can keep outer pressure up to 15 MPa. Gear-reducer for drilling in ice lowers the drill bit rotation speed to 100 rpm; gear reducer for subglacial drilling lowers the drill bit rotation speed to 500 rpm. In addition, module for dry core drilling contains vacuum pump for near bottom air reverse circulation instead of liquid-driven pump that is installed into other two variants. The rotation speed of air-driven pump is the same as rotation speed of the motor and the shaft from the motor connects through the inner space of the gear directly to fans. In modules for drilling with liquid the shaft from the motor connects with two gear-reduces: one for rotation of the core barrel and drill bit, and another one for driving of the pump. The pump is the Rotan CD33EM-3U332 pump with an internal idler gear. The capacity of the pump is 38-41 L/min with maximal pumping pressure of 0.2 MPa. IBED lower part for drilling in ice consists from two parts: chip chamber for filtration of drilling fluid and collecting chips, and core barrel with the drill bit. The outer/inner diameter of the ice core drill bit is 134/110 mm. Length of the core barrel is 2.5 m. Lower part of the bedrock variant is adapted for coring bedrock using special teeth diamond bit and contains standard 2-m length core barrel borrowed from conventional diamond drill string, chip chamber for gravity separation of rock cuttings and dead weights (appr. 200 kg) for increasing of the load on the diamond drill bit. The outer/inner diameters of the diamond bit are 57/41 mm. The preliminary tests showed that teeth diamond drill bit could penetrate into the granite with average rate of 3.18 m/h at low load (3 kN) and torque (28.8 N m).

The new approaches of subglacial bedrock drilling technology are connected with utilization of environmental friendly, low-toxic drilling fluids, e.g. low-molecular dimethyl siloxane oils or ester type. They have suitable density-viscosity properties, and can be consider as a viable alternative for drilling in glacial ice and subglacial bedrock.

The project is already funded by National Science Foundation of China (project No. 41327804) and Geological Survey of China (project No. 3R212W324424). According to approved schedule, the first field tests are planned to carry out just outside Zhongshan Station near Antarctic coast in season 2015-2016. Next season 2016-2017 the movable drilling shelter is planned to be transported to the chosen drilling site in the region of Gamburtsev Mountains, and drilling to the bedrock would be finished during two seasons.

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