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Comparison and analysis of subglacial bedrock core drilling technology in Polar Regions

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Abstract

The Gamburtsev Mountains, located in East Antarctica, is the direct geomorphological cause of the formation of Dome A. Drilling the core of the Gamburtsev subglacial mountains is one of the primary goals of modern polar research, which is important to understand its formation and evolution process, the ice sheet formation of Dome A, glacial motion, climate change, and so on. This paper describes the status and progress of subglacial bedrock drilling technology. Existing subglacial bedrock drilling technologies are also discussed, including common rig rotary drilling, wire-line core drilling, coiled tubing drilling, and electromechanical drilling. Results of this paper will provide valuable information for Chinese subglacial bedrock core drilling project in the Gamburtsev mountains.

Keywords: Ice core drilling technology; Subglacial bedrock drilling; Rig rotary drilling; Wire-line core drilling; Coiled tubing drilling; Electromechanical drilling

1. Introduction

The Gamburtsev Mountains is a subglacial mountain range located in East Antarctica near Dome A. This mountains range is approximately 1200 km long, and reaches an elevation of more than 3000 m, although the mountains are completely covered by over 600 m of ice and snow. The size of this mountain range is larger than that of the European Alps, but its geology is completely unknown because it is buried under a thick ice sheet. Considering the location of the mountains within what is considered to be a stable intraplate setting, their high elevation and huge dimension are puzzling. Thus, the origin and compositions of the Gamburtsev Mountains have given rise to a significant number of speculations. Some scientists believed that the Mountains originated from the mid-Carboniferous inversion of an intracratonic basin during the Paleozoic era, or were generated by continent–continent collision between East and West Gondwana during the last Precambrian–Cambrian Pan-African event (van de Flierdt et al., 2008; Liu et al., 2006; Hansen et al., 2010). However, other scientists argued that the Mountains were created by volcanic eruptions produced by a mantle plume, that is, a rising column of hot rocks within the Earth's interior

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which generates large volumes of magma as it approaches shallower depths (Sleep, 2006; Tulaczyk et al., 2002). The answer to this question is essential to understand the behavior and evolution of the Antarctic ice sheet, which can help us to know how our planet will react to global temperature. Verifications of the origin and age of the Gamburtsev Mountains are also extremely important to better comprehend subglacial environments and Antarctic ice sheet dynamics. Hence, understanding the crustal and upper mantle structure of the Gamburtsev Mountains is a major target of activities during the ongoing international Polar Year, which includes highly resolved geophysical measurements and drilling through the ice (van de Flierdt et al., 2008). Drilling through the ice sheet and penetrating into the subglacial bedrock are one of the primary goals of modern polar region research. The report “Future Science Opportunities in Antarctica and the Southern Ocean” published by America National Academy of Sciences clearly stated the importance of sampling the Gamburtsev Subglacial Mountains bedrock, and the plans to develop fast drilling equipment and techniques for ice and bedrocks (Zapol et al., 2011). Sampling the subglacial bedrock of Gamburtsev Mountains is an important research content in The Polar Research Special Project in China's 13th Five-Year Plan.

In this paper, the subglacial bedrock core drilling practices in Polar Regions were reviewed. Four drilling systems that could be used to drill subglacial bedrocks were discussed and evaluated, including commercial surface-driven rotary drilling, wire-line drilling, coiled tubing drilling, and cable suspended electromechanical drilling. The advantages and limitations of each method were also analyzed. The results of this study are expected to offer a reference for further improvements.

2. Commercial surface-driven rotary drilling technology

Commercial surface-driven rotary drilling technology is widely used in various drilling fields, such as petroleum extraction, mining, environmental, and geothermal industries. In this conventional core drilling method, the hole is advanced by rotating a drill string consisting of a series of hollow drill pipe to the bottom of which is attached a core barrel with a coring bit. This drill bit rotated either by a top-drive or a table-drive system is used to penetrate rocks. As drilling proceeds, cuttings are removed by a continuous circulation of fluid (either air or water based) that flows down inside the pipe string and up-hole along the annular space between the borehole walls and the pipe string, as shown in Fig. 1. After separating rock cuttings in solids control system, the drilling fluid is pumped back into borehole to circulate. When the core has been cut, the entire drill string and its integral core barrel is tripped out of the borehole. Then the core is removed from the core barrel, after which the empty core barrel and the entire drill string is tripped back into the hole.

The first time adopting this coring method in ice drilling is beginning from the early 1950s. During 1956–1957, a mechanical rotary 314 skid-mounted drilling rig was used in the Greenland ice sheet drilling project. The core barrel assembly and drill rods were all approximately 6 m in length. Therefore, the core with length of 6 m was obtained in each drilling run. Two Joy model WK80 compressors driven by UD-16diesel engines were used to provide compressed air to transport ice chips to the surface. And air to air heat exchanger was adopted to cool the compressed air. Four cored holes were completed, and cores were obtained at depths of 305 and 411 m (Lange, 1973; Patenaude et al., 1959).

The second similarly modified rig was used effectively by the U.S. Army Cold Regions Research and

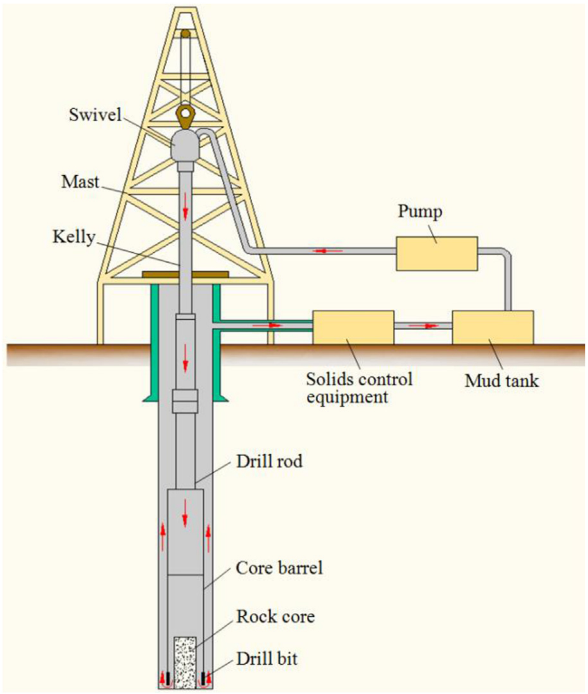

Fig. 1. Conventional rotary core drilling scheme.