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Geological drilling in McMurdo Dry Valleys and McMurdo Sound, Antarctica: Historical development

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ABSTRACT

Geologically, Antarctica is the least explored place on earth. A thick ice sheet covers 98% of the continent, the environment is harsh, and the movement of people and equipment is difficult and costly. Yet in recent decades the McMurdo Sound region has attracted intensive geological drilling because it is crucial for better understanding of past ice sheet behavior, including the evolution of both the East and West Antarctic Ice Sheets. Drilling started with the Dry Valley Drilling Project (DVDP) in 1973, resulting in 15 boreholes ranging in depth from 4 to 381 m. The last hole, DVDP-15, was drilled in 1975 from the local fast sea-ice covering McMurdo Sound. Since then, eight offshore sites (MSSTS, CIROS-2, CIROS-1, CRP-1, CRP-2/2A, CRP-3, AND-1B, AND-2A) have been cored, with much experience gained in both operational support and drilling procedures. Penetration depth has increased from 64.6 m (DVDP-15, 1975) to 1284.9 m (AND-1B, 2006) below the seafloor. This paper reviews both onshore and offshore geological drilling in the McMurdo Dry Valleys and McMurdo Sound, focusing on special aspects of drilling operations, drilling problems, and possible solutions. The paper also includes the brief introduction of the challenging Coulman High Project, which proposes to use the fast-moving Ross Ice Shelf as a drilling platform. Finally, recommendations are given for future planners regarding (1) operating and logistical problems in Antarctic harsh environment; (2) drilling complications in permafrost; (3) drill bit design; (4) possible land, sea ice and ice shelf platforms; (5) sea riser structure, and (6) drilling fluid composition.

1. Introduction

The Antarctic continent, which is nearly completely covered by a thick ice sheet, and the surrounding ocean with its fringing belt of sea ice, ice shelves, and drifting icebergs, offers challenges to geological investigations that seek to unravel the history of one of Earth's last frontiers (McKay et al., 2016). The history of this region is recorded in rocks deposited in and around Antarctica. These rocks, formed during times that witnessed past climate changes and the associated growth and retreat of ice sheets, offer clues to help us understand the interplay of Earth's dynamic processes that control and respond to the Antarctic cryosphere.

The region of the McMurdo Dry Valleys and McMurdo Sound is crucial for better understanding of the ice dynamics as it records the evolution of both the East and West Antarctic Ice Sheets, whose variations are a direct response to climatic changes. This has been one of the main reasons for the intensive research in this area in the past decades, especially within the successful offshore drilling projects. McMurdo Sound lies at the southwestern corner of the Ross Sea, between the Transantarctic Mountains in southern Victoria Land and volcanic Ross Island, and at the southern end of the Victoria Land Basin, one of the four major extensional basins forming the Ross continental shelf.

In the 1950–60s, drilling in bedrock in this region had been limited to ~20 m for foundation studies for the nuclear power plant at McMurdo Station and foundation studies at Scott Base.

Geological drilling on the Antarctic continent started with the Dry Valley Drilling Project in the early 1970s, resulting in 15 boreholes ranging 4 to 381 m deep (Fig. 1). The last hole, DVDP-15, was drilled in 1975 from the local fast sea-ice covering McMurdo Sound. Since then, eight offshore sites (MSSTS, CIROS-2, CIROS-1, CRP-1, CRP-2/2A, CRP-3, AND-1B, AND-2A) have been cored in the McMurdo Sound region, and much experience has been gained in both operational support and drilling procedure. Over the years, penetration depth in the offshore drill holes has increased from 64.6 m (DVDP-15, 1975) to 1284.9 m (AND-1B, 2006) below the seafloor (Fig. 2). Drilling results have provided access to critical knowledge on the climatic and tectonic history of the Victoria Land margin of Antarctica, giving us new understanding

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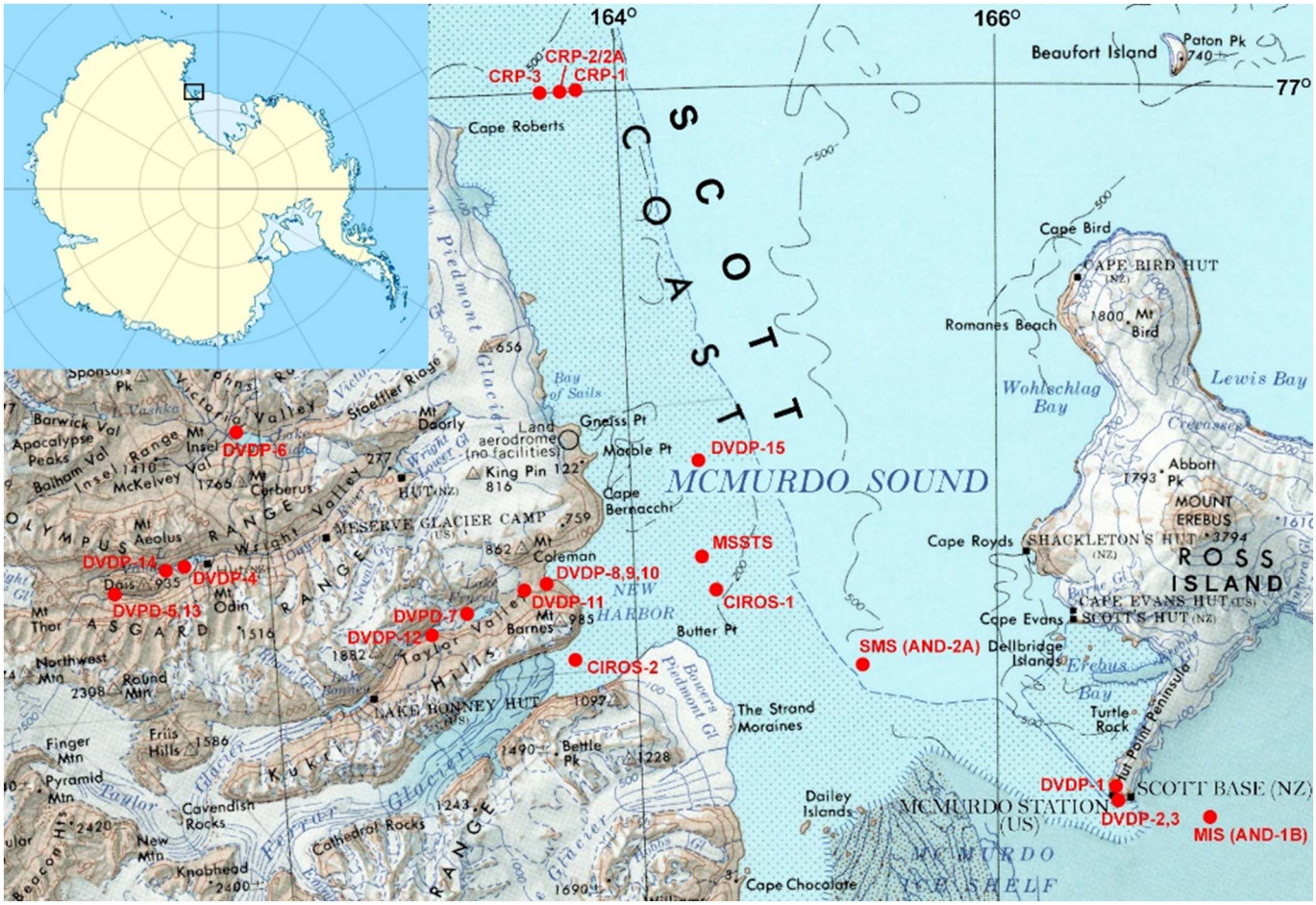

Fig. 1. Locations of the drilled boreholes at McMurdo Dry Valleys and McMurdo Sound, Antarctica.

of the history and behavior of the Antarctic ice sheet in this region over the last 34 million years (Barrett, 2007).

In the 1970s–1980s, the seafloor of the Southern Ocean was explored by the Deep Sea Drilling Project (DSDP) using the Glomar Challenger and later the JOIDES Resolution research drill ships equipped with a drilling platform and scientific laboratories. To date, ten ship-based expeditions have drilled cores from the Southern Ocean. Although the penetration into seabed sediments near the Antarctic continent by drill ship is a very effective way of recovering long cores, we do not include it in this review for two reasons. First, drill ships are poorly suited for work in ice-covered waters, and second, the closest area investigated by the Glomar Challenger in the Ross Sea (Leg 28, sites 270–274) in early 1973 (Hayes et al., 1975) is quite a distance from the area described here.

This review also does not include subglacial till and bedrock drilling with hot water and electromechanical cable-suspended drill systems, even though some of these drill sites were located in the McMurdo area. For example, in January 1994, the borehole reached bedrock at a depth of 554 m using the PICO-5.2″ drill in an *n*-butyl-acetate-filled hole in the central part of Taylor Dome, a local ice dome just inland of the McMurdo Dry Valleys (Steig et al., 2000). Hot water and electromechanical drilling is quite different from conventional geological drilling, and were discussed recently in a separate review (Talalay, 2013).

During the last decades, some shallow drilling projects were carried out in the McMurdo Dry Valleys for specific purposes such as the study of microorganisms preserved in Antarctic permafrost (Gilichinsky et al., 2007), observations in rock-covered glaciers (Green et al., 2007), and a microbiological study of lake sediment beds (Karr et al., 2005). However, this review confines itself to the both onshore and offshore ***geological drilling*** in the McMurdo Dry Valleys and McMurdo Sound, focusing on special aspects of drilling operations, drilling problems, and possible solutions. This is particularly significant for planning and designing future geological drilling projects in Antarctica.

2. Dry Valleys Drilling Project (DVDP)

The Dry Valleys Drilling Project (DVDP) conducted in 1971–1975 was an international project involving collaboration between scientists from the US, New Zealand, and Japan, that drilled 14 holes in Antarctica—in the Dry Valleys, on Ross Island, McMurdo Sound, and with test holes near McMurdo Station (Torii, 1981). In fact, 15 holes were drilled (Table 1), but hole DVPD-5 failed at a depth of < 4 m and is usually not counted in official statistics. The areas investigated were also subject to a series of independent analyses of Antarctic geochronology, paleoclimatology, and paleomagnetism. The results furthered the understanding of glacial and geological history at that time.

According to the original plan, the target was to drill through crystalline rock to maximal possible depth in the time available or through sediments following penetration to several meters of crystalline rock, supposedly to 300 m, with maximal depth in McMurdo Sound from sea ice to ~1500 m (Project Coordinators, 1972). In reality, the penetration depths of most of the boreholes did not exceed 100–200 m because of technical and logistical problems.

The US National Science Foundation has purchased a diamond-bit, wire-line, rock coring Longyear 44 rig capable of drilling a 64-mm (2.5″) borehole to 1500 m. Where necessary for geophysical logging (e.g., heat flux), holes remained cased with steel pipes. The rig could be