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OBSERVATIONS ON SUBMERGED GLACIAL ICE IN McMURDO SOUND, ANTARCTICA

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ABSTRACT. Several large submerged ice masses are described from along western McMurdo Sound, Antarctica. The most important discovery is that Cape Chocolate and the adjacent island that form Salmon Bay are large, grounded ice masses mounted with morainal sediment. Both features are probably remnants of a past expansion of the Ross Ice Shelf. As such, their strata and potential temporal markers may help to unravel the glacial geological chronology of McMurdo Sound. The island was connected to Cape Chocolate during the early British Antarctic expeditions and split away between 1908 and 1956. Large sections of the Ross Ice Shelf have broken out along western McMurdo Sound several times since 1908. Ice walls grounded in shallow water were only observed near large receding ice masses. The location of these walls also corresponds to the recent calving pattern of the Ross Ice Shelf.

RÉSUMÉ. *Observations sur la glace immergée du McMurdo Sound, en Antarctique.* On décrit plusieurs grandes masses de glace immergées le long de la partie ouest du McMurdo Sound, Antarctique. La découverte la plus importante est que le Cape Chocolate et l'île adjacente qui forment Salmon Bay sont de grandes masses de glace reposant sur le fond et surmontées de sédiments morainiques. Ces deux particularités sont probablement des restes d'une expansion passée du Ross Ice Shelf. Comme telles, leur stratification et les datations possibles font espérer que la chronologie géologique de la glaciation du Sound pourra être débrouillée. L'île était reliée au cap lors des premières expéditions britanniques antarctiques et s'en détacha entre 1908 et 1956. De larges portions du Ross Ice Shelf se sont détachées le long de l'ouest du McMurdo Sound à plusieurs reprises depuis 1908. Des falaises de glace ancrées dans des eaux peu profondes n'ont été observées qu'à proximité de grosses masses de glace en cours de recul. La localisation de ces falaises correspond aussi aux récentes zones de vêlage du Ross Ice Shelf.

ZUSAMMENFASSUNG. *Beobachtungen an untergetauchtem Gletschereis im McMurdo Sound, Antarktika.* Einige grosse, untergetauchte Eismassen längs des westlichen McMurdo Sound, Antarktika, werden beschrieben. Die wichtigste Entdeckung besteht in der Feststellung, dass Cape Chocolate und die benachbarte Insel, die die Salmon Bay bilden, aus grossen, aufsitzenden Eismassen bestehen, die von Moränenablagerungen verschüttet sind. Beide Erscheinungen sind vermutlich Überreste eines früheren Standes des Ross Ice Shelf. Falls dies zutrifft, können ihre Schichtung und ihre zeitlichen Stände zur Aufklärung der glazialgeologischen Chronologie des Sundes herangezogen werden. Die Insel war mit dem Kap während der frühen Britischen Antarktis-Expeditionen verbunden; sie wurde zwischen 1908 und 1950 abgetrennt. Grosse Teile des Ross Ice Shelf sind längs des westlichen Sundes mehrere Male seit 1908 herausgebrochen. In seichtem Wasser gestrandete Eiswälle wurden nur in der Nähe von grossen, zurückgehenden Eismassen beobachtet. Die Lage dieser Wälle entspricht auch dem derzeitigen Kalbungsmuster des Ross Ice Shelf.

MORE than 89% of the world's glacier ice is located in Antarctica (Bardin and Suyetova, 1967) and about 10% of the surface area of this massive ice sheet is represented by ice shelves (Thomas, 1973). The most extensive ice shelves are located in the two largest embayments, the Weddell and Ross Seas. The lateral extent of the Antarctic ice sheet is limited by sea-level which determines the position of the grounding line where glaciers begin to float. Consequently, Quaternary expansions of the Ross Ice Shelf appear in phase with major Northern Hemisphere glaciations and attendant lower sea-levels (Denton and others, 1971).

Glacial geological studies in Antarctica are limited by the extensive ice cover and restricted in large part to relatively few ice-free locales. One of the most studied areas is the system of dry valleys in the Transantarctic Mountains that border McMurdo Sound. Marine data have been collected by remote sampling from ships and by drilling from the sea ice (Barrett and others, 1976). This paper is a preliminary description of submarine ice structures observed in McMurdo Sound during the austral summer of 1975. Observations were made during a series of SCUBA dives along the west part of McMurdo Sound from Marble Point to Garwood Valley and along the eastern part of McMurdo Sound from Cape Royds to McMurdo Station (Fig. 1).

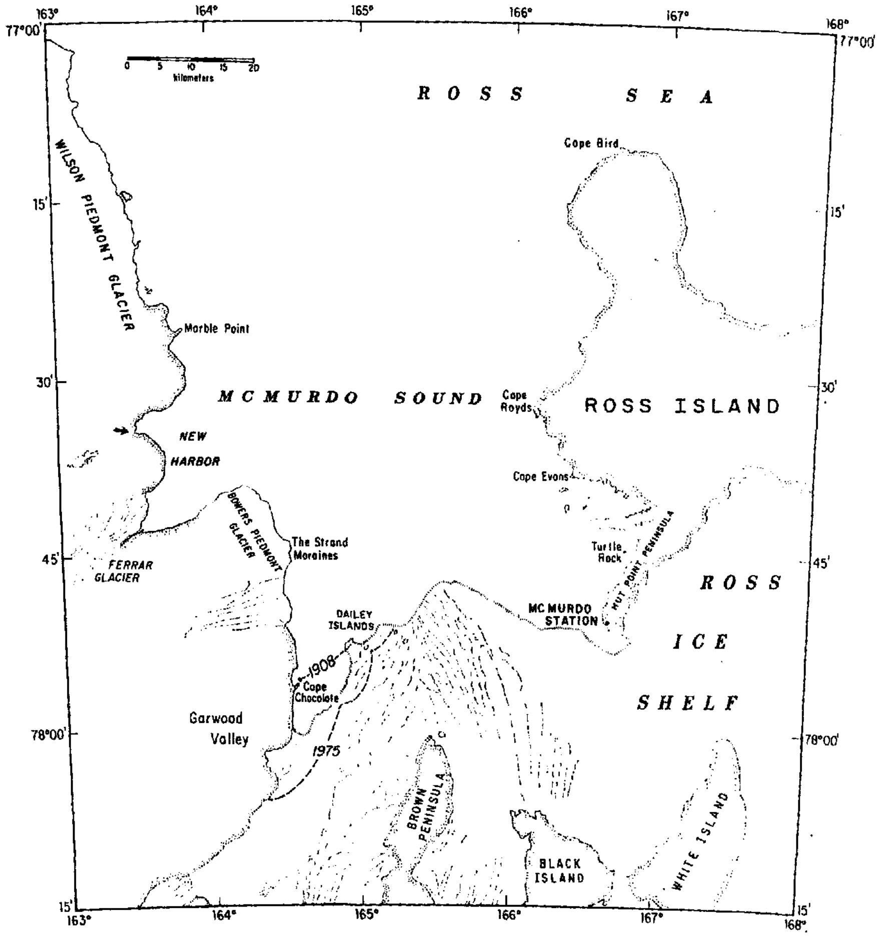

Fig. 1. McMurdo Sound and a part of the Ross Ice Shelf.

The most interesting observations made during this study were at Cape Chocolate. At the tip of the cape there is a small island which proved to be a grounded iceberg mounted with morainal sediment (Figs 1–3). The surficial aspects of the iceberg core are revealed in cracks in the surface deposit and the moraine does not extend below sea-level. The iceberg is grounded in 70–80 m of water. Its submerged sides are nearly vertical in shallow water and gradually slope inward with increasing depth (Fig. 3).

The submarine surface of the ice island has a dimpled texture that resembles the underside of the annual sea ice during its disintegration in late January and the sun cups that develop on the surface of the slowly melting snow (Post and LaChapelle, [c1971], p. 70). The remarkable clarity (rocks are visible 1 m into the ice) of the submerged ice allowed the documentation of the gross vertical stratigraphy (Fig. 3). The top 10 m contain very little sediment and well-dispersed clumps of fresh-water algae. These are not benthic marine algae transported to the under surface of growing sea ice by anchor ice in the manner observed by Dayton and others (1969) nor sea-ice diatoms (i.e. those living on the under-ice surface). A series of very regular, mostly horizontal discrete layers of sediment occur from 10 to 25 m. Some bands dip slightly. The ice from 25 to 50 m is similar to that described in the uppermost layer. A second series of

Fig. 2. Cape Chocolate and the island berg (crosses show diving locations).

discrete sediment layers is present in approximately 50 m of water and extends to an unknown depth (Fig. 3). A small 1–2 cm long luminescent coelenterate burrowed into the ice in water deeper than 30 m.

Cape Chocolate itself is capped with morainal material similar to that occurring on the island berg. Below sea-level there is a vertical ice wall that has the same dimpled texture (Figs 2 and 4). Immediately adjacent to the base of the ice wall there is a distinct zone of marine benthic animals and sediment that is undoubtedly related to anchor-ice formation and scour. Lack of time prevented documentation of the gross stratigraphy and therefore no correlations with the ice island can be inferred.

A brief dive at the northern edge of Salmon Bay revealed only a small ice outcrop in 2 m of water (Fig. 2). This outcrop is probably part of the ice core of the adjacent coastal moraine.

The early maps of Scott (1905) and Shackleton (1909) indicate that Cape Chocolate and the island berg were connected and that the edge of the Ross Ice Shelf was located at or just north of Cape Chocolate during their explorations (Fig. 1). The U.S. Geological Survey (1 : 250 000 series, Ross Island and Mount Discovery) topographic maps are based on U.S. Navy tricamera air photographs taken from 1956 to 1970. They show that the island and cape were separate features in 1956 and that the juncture of the Ross Ice Shelf with the coast north of Garwood Valley (non-dashed line in Figure 1) was stable during this entire period.

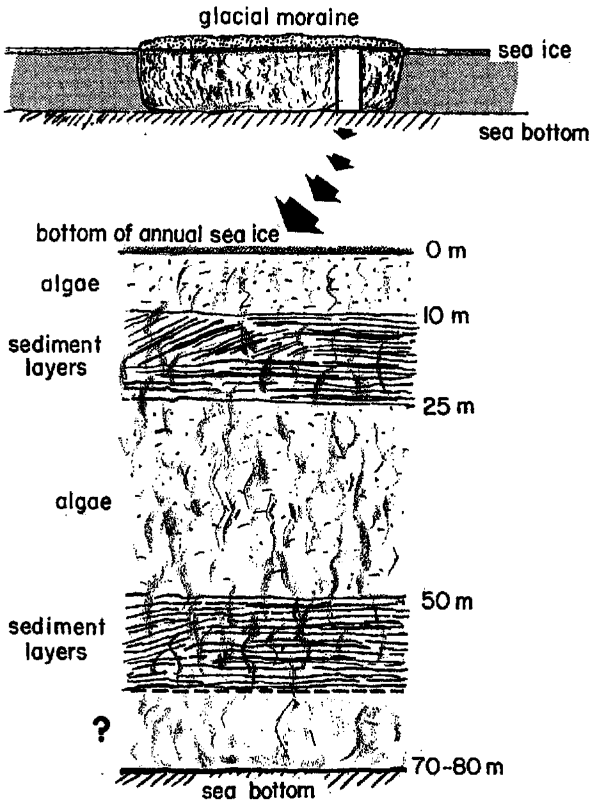

Fig. 3. Vertical strata observed through the side of the island berg. The structure below 60 m is unknown including the exact water depth.

On the other hand, calving did occur along the non-coastal parts of the ice shelf (e.g. an ice-shelf connection to the largest of the Dailey Islands broke away between 1965 and 1970). Between 1970 and 1973, the ice shelf broke out south of Garwood Valley (shown in the 1 : 1 000 000 topographic map of McMurdo Sound, 1974). The position of the ice shelf had not changed in 1975 (Fig. 1).

Air photographs were inadequate to measure northward movement of the island since 1956. The rounded bottom of the island berg is also characteristic of grounded icebergs and is probably caused by lateral movement and bottom scour. Large melt pools have occurred at the intersection of Cape Chocolate and the adjacent coast since at least 1956. These may form the location of a future breaking point should recession continue.

East of the Garwood Valley delta there is an ice mass grounded in 25 m of water. It has a vertical wall with a 10 m thick overhang at the surface. We dived through a tidal crack separating this thick grounded ice from the thinner 5 m thick offshore ice cover. The offshore sea ice has apparently remained intact since the ice shelf calved from the area between 1970 and 1973 because the annual sea ice is only 2 m thick.

A similar ice wall was observed in shallow water along the coast near the southern face of Ferrar Glacier. Both areas are characterized by a slightly uplifted crevasse system in the grounded ice that trends parallel to the coast and is easily seen from the surface. These vertical ice walls do not have the dimpled surface texture, ice clarity or stratigraphy observed at Cape Chocolate. The Garwood Valley and Ferrar Glacier sites are unique from all others

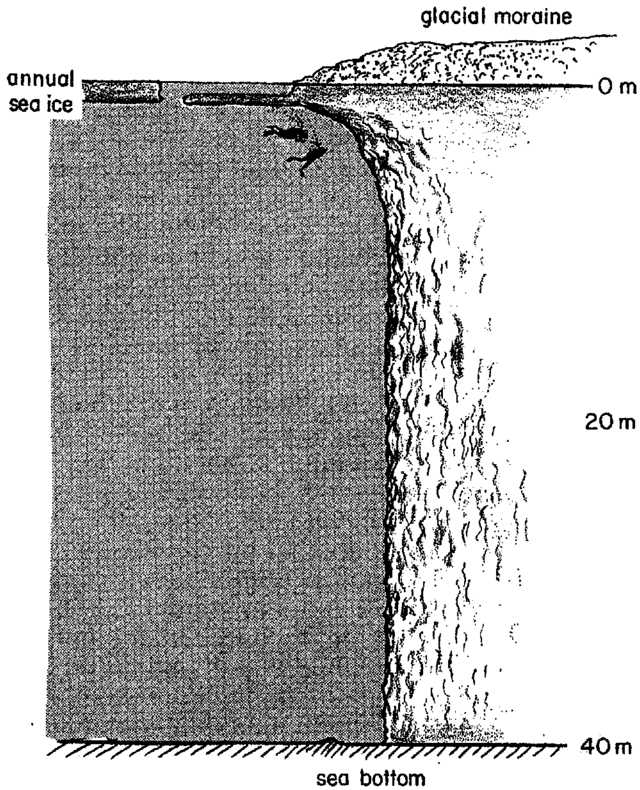

Fig. 4. Cross-section of Cape Chocolate near the distal end.

we dived on in that they are close to large receding ice masses. We do not know when the face of Ferrar Glacier was located at the dive site; however, the composition of the bottom invertebrate fauna indicates that no ice mass was grounded below the ice wall for at least the last 10 years and maybe much longer. On the other hand, the Ross Ice Shelf did cover the Garwood Valley site as late as 1970 and the type of bottom fauna present suggests that the ice shelf was floating quite close to shore.

In summary, we observed relatively young ice walls grounded in shallow water that were exposed by recent glacial recession and an older grounded glacier that was split as the Ross Ice Shelf receded between 1908 and 1956.

The layers of algae and rock in the island berg can be explained by the following growth scheme. The discrete horizontal bands of sediment resemble the thin layers of wind-blown sediment that accumulate on the surface of annual sea ice. During the late summer, these sediments melt into the ice. Such deposits are often present as distinct layers on the bottom of contemporary melt pools. Thus, a series of discrete layers could be deposited as long as there was a net accumulation of ice or snow following melts.

The clear ice observed in the island berg is quite different from the opaque ice formed during the compaction of snow and from bottom freezing (Buynitskiy, 1967). Perhaps melting and refreezing account for the observed clarity. Wind-blown deposition on annual sea ice only occurs very close to the shore and thus to the source of sediment. Heavy snow cover, reduced winds and proximity to an ice-covered shore restrict wind-blown deposition. Large coastal melt pools can be fed from terrestrial and local sea-ice run-off in the absence of wind-blown sediment. Thus, a large sediment-free layer could also develop in an ice sheet growing next to the shore. The occurrence of fresh-water algae in the submarine ice strongly supports a surface growth scheme. The morainal cap may have been formed by plowing coastal sediments over the leading edge of an ice sheet growing close to shore. This apparently explains the mountains of sediment that have accumulated on the Ross Ice Shelf as it flowed into and past Black Island (Fig. 1). On the other hand, the morainal cap may have accumulated as surface ice layers melted. Nevertheless, an ice shelf growing next to the shore could develop the layers shown in Figure 3 and could also become capped by a coastal moraine.

Denton and others (1971) estimated that there were at least four advances of the Ross Ice Shelf in the last 1.2 million years. The last major expansion probably occurred more than 47 000 years ago and the ungrounding of the ice shelf in McMurdo Sound occurred by 5 000 B.P. (Denton and Borns, 1974) as sea-level approached the present level. During growth, the ice shelf extended into the dry valleys along the western part of McMurdo Sound. The ice-cored moraines adjacent to Hobbs Glacier and those that border Salmon Bay, including Cape Chocolate and the island berg, are probably remnants of the Ross Ice Shelf and of the last glacial recession. The growth scheme proposed above is consistent with this hypothesis. Even if the growth of these old ice masses was discontinuous and occurred in a manner other than that suggested, the oldest ice should be located at the bottom. The age of the oldest ice could be determined by simultaneous dating of the bottom ice and its algal contents. Cape Chocolate and the adjacent island may be part of the last major extension of the Ross Ice Shelf and thus date before 47 000 B.P. If eustatic sea-level rose above its present position during the Holocene (Fairbridge, 1976; Pirazzoli, 1976), the ice shelf could have receded south of Cape Chocolate and subsequently advanced northward. An age determination of less than 5 000 years B.P. would support this hypothesis. The dating of these ice masses and the possibility of annual sediment layering may make an important contribution to the unraveling of the glacial geological history of McMurdo Sound.

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