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EVIDENCE FOR A FORMER LARGE ICE SHEET IN THE ORVILLE COAST–RONNE ICE SHELF AREA, ANTARCTICA

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Abstract. The Orville Coast area of the Antarctic Peninsula was extensively glacierized in the past. Striations, polished rock surfaces, and erratics on nunatak summits indicate that this area was covered by a broad regional ice sheet whose grounded ice margin was on the continental shelf, in the present-day Ronne Ice Shelf area. If the glacial history of Antarctica has been controlled by eustatic sea-level changes, the destruction of this ice sheet would have been contemporaneous with that of the Ross Sea ice sheet due to the world-wide rise of eustatic sea-level at the end of the Wisconsin glaciation.

Résumé. *Preuves de l'existence passée d'une vaste calotte glaciaire dans le secteur de la Orville Coast et de la Ronne Ice Shelf en Antarctique.* La Orville Coast dans la Antarctic Pensinsula a été, dans le passé fortement englacée. Des roches striées et des surfaces polies, et des blocs erratiques en haut de nunataks indiquent que cette zone était couverte par une grande calotte glaciaire régionale, dont le front reposait sur le sol du socle continental, dans la zone de l'actuelle Ronne Ice Shelf. Si l'histoire de la glaciation antarctique a bien été contrôlée par des fluctuations marines eustatiques, la destruction de cette calotte devrait être contemporraine de celle de la calotte de la Ross Sea au moment du soulèvement eustatique mondial du niveau de la mer, à la fin de la glaciation du Wisconsin.

Zusammenfassung. *Nachweis eines früheren grossen Eisschildes im Gebiet Orville Coast–Ronne Ice Shelf, Antarktis.* Das Gebiet der Orville Coast auf der Antarktischen Halbinsel war früher stark vergletschert. Riefen, polierte Felsoberflächen und erratisches Material auf den Gipfeln von Nunatakkern weisen auf eine Bedeckung dieses Gebietes durch ein breites, regionales Eisschild hin, dessen Aufsetzlinie am Kontinentschelf im Bereich des heutigen Ronne Ice Shelf lag. Wenn das glaziale Geschehen auf Antarktika durch eustatische Meerespiegel-schwankungen gesteuert wurde, dann müsste die Zerstörung dieses Eisschildes gleichzeitig mit der des Ross Sea-Eisschildes infolge des weltweiten, eustatischen Meeresspiegelanstiegs am Ende der Wisconsin-Eiszeit erfolgt sein.

Introduction

At least four times during the last 1.2 Ma West Antarctic ice expanded to form a grounded ice sheet, more than 1 000 m thick, on the continental shelf in the present-day Ross Sea area (Denton and others, 1971; Denton and Borns, 1974). Radiocarbon ages suggest that the latest Ross Sea glaciation was contemporaneous with the late Wisconsin (Würm) glaciation in the Northern Hemisphere, and that the recessional phase of this glaciation was contemporaneous with the world-wide rise of eustatic sea-level at the end of late Wisconsin time (Denton and others, 1971).

An explanation for the former expansion of a grounded ice sheet on the continental shelf of the Ross Sea area was proposed by Hollin (1962). Hollin suggested that at times of extensive glaciation in the Northern Hemisphere, the world-wide lowering of eustatic sea-level lowered the grounding line and displaced it northward, allowing the Antarctic ice to expand on the present continental shelf. Hollin (1962) estimated that a lowering of sea-level by 150 m would advance the grounding line 550 km. He concluded that the glacial history of Antarctica is governed primarily by sea-level changes, rather than by climatic changes. As these eustatic sea-level lowerings are thought to have been responsible for expansions of West Antarctic ice into the Ross Sea area, a similar history might exist for the continental shelf area of the Weddell Sea (Denton and Borns, 1974).

Field evidence found in the course of reconnaissance geologic mapping during the austral summer of 1977–78 indicated that the Orville Coast area of the Antarctic Peninsula was extensively glacierized in the past. Data from the Behrendt, Hauberg, Merrick, Sweeney, and Wilkins Mountains, and Sky-Hi Nunataks (Fig. 1) indicate that a large ice sheet whose grounding line was on the present-day continental shelf, at least 65 km and perhaps several hundred kilometers from the present coast, existed in the past.

Almost the entire study area (30 000 km²) is located in the accumulation area of a large ice field. Blue ice was encountered only in areas where wind erosion is common. The few mountain ranges and isolated nunataks comprise approximately 1% of the study area.

The present-day ice field was superimposed upon a pre-glacial topography and has modified the mountain ranges and nunataks into arêtes, horns, and broad cols. In the Hauberg Mountains, a number of valleys trend nearly due north, approximately parallel to a major joint system. Pre-glacial valleys

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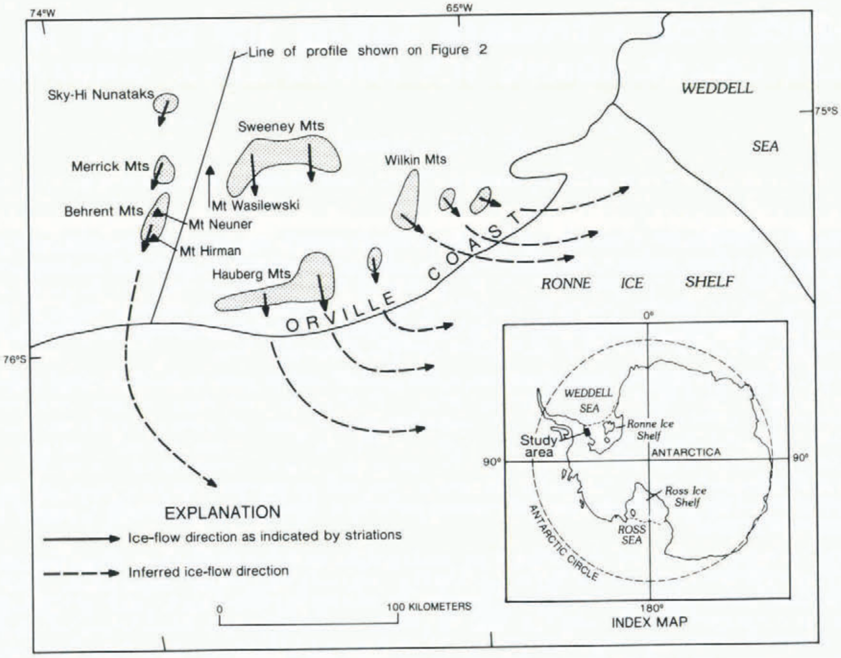

Fig. 1. Sketch map of the Orville Coast area showing mountain ranges and nunataks where striations were identified and the inferred direction of ice flow.

were developed parallel or sub-parallel to this joint system, and with the onset of glaciation the valleys were widened and deepened, and today serve as major outlets for ice from the interior. At present, ice is diverted around the various nunataks and ranges and funneled into these outlet valleys. However, field observations indicate that at one time all the nunataks and ranges were covered by a large ice sheet that flowed into the Ronne Ice Shelf area of the Weddell Sea.

The geology of the Orville Coast is similar to that of the Lassiter Coast area, to the north-east, and to that of eastern Ellsworth Land to the south (Rowley, 1978). The oldest exposed rocks are those of the Middle to Upper Jurassic Latady Formation, a thick sequence (>5 000 m) of black slate, shale, siltstone, and sandstone with minor amounts of coal, locally interbedded with intermediate volcanic rocks. The Latady Formation comprises all of the Hauberg and Wilkins Mountains and parts of the Behrendt, Merrick, and Sweeney Mountains. The Latady Formation and associated volcanic rocks have been folded along west-north-west to east-north-east axes and have been intruded by stocks that produced contact metamorphic aureoles as much as 1 km in width. The stocks range in composition from granodiorite to gabbro and are similar to the Andean stocks and batholiths in other areas that are late Cretaceous in age. These stocks comprise large areas of the Behrendt, Merrick, and Sweeney Mountains.

Evidence of a former ice sheet

Evidence that the Orville Coast area had at one time possessed a greater ice cover consists of erratics, polished rock surfaces, and striations on virtually every summit and ridge inspected.

Erratics, although uncommon, were found on a number of nunataks; most were pebble or cobble in size. Boulder-size erratics were very uncommon and this sparsity may be due to the close spacing of joints and to the intense frost-shattering of nunatak bedrock before the material was incorporated into the ice. In many cases, erratics could be identified even when deposited on a nunatak of an identical lithology because the sub-rounded, and sometimes striated and/or oxidized appearance of the erratics contrasted strongly with the unoxidized angular frost-shattered bedrock it was deposited on.

Although rare, glacially polished surfaces were noted on fine-grained rocks, although best preserved on the Latady Formation near an intrusion where the rock had been metamorphosed. Polish was not noted on any intrusive rocks. These rocks appear to be so readily grussified that polish, if originally present, is quickly destroyed.

Striations, although not abundant and in many cases poorly preserved, were noted on the majority of nunataks inspected. As with polish, the best-preserved striations were found on the fine-grained facies of the Latady Formation. At several localities, well-defined striations were noted on clay galls in sandstone, although no striations were found on the surrounding coarser-grained sandstone. Well-preserved striations were also identified on fine-grained volcanic rocks (dacite?) but were extremely rare on the coarser-grained intrusive rocks. Nichols (1960) noted that coarse-grained igneous rocks on the Antarctic Peninsula are not easily striated and that striations are not preserved on these rocks as long as on other rock types.

Striations along ridges, summit areas, and broad cols were analyzed in order to determine the direction of past regional ice flow. Based on the data, it appears that the regional ice flow was generally southward over the Sweeney and Hauberg Mountains into the present area of the Ronne Ice Shelf (Fig. 1). To the east, the regional ice flow was to the south-east (S. 50° E.), across the Wilkins Mountains and into the present Ronne Ice Shelf area. The regional ice-flow direction in the Behrendt and Merrick Mountains, and the Sky-Hi Nunataks to the west of the Sweeney Mountains, was to the south-west (S. 35° W.). Once in the present-day Ronne Ice Shelf area, the ice flow would have been diverted in a northerly direction to the Weddell Sea area. Backward projection of these striation directions indicates a center of ice dispersal approximately 75 km north of the Sweeney Mountains, near the present ice divide of the Antarctic Peninsula. Cross-cutting relationships of striations in the Sweeney Mountains suggest that there may have been an eastward shift in the ice-sheet center by several tens of kilometers; however, data are quite scarce.

Extension of the former ice sheet beyond present-day limits

Ice-surface altitudes from the Antarctic Peninsula Traverse, 1961–62 (shown on the U.S. Geological Survey Antarctica Sketch Map, Ellsworth Land–Palmer Land, scale 1 : 500 000), were used to reconstruct the present ice-surface profile (Fig. 2). The profile was taken from the relatively nunatak-free area between the Behrendt and Merrick Mountains on the west and the Sweeney Mountains on the east (Fig. 1).

Mount Neuner (1 421 m), on whose summit striations were noted, lies approximately 60 km inland from the present ice margin. Sea-level during the Wisconsin glaciation has been estimated between 100 and 135 m lower than present (Andrews, [c1975]). Using the lesser estimate of sea-level, Mount Neuner would have been at an altitude of 1 521 m in the Wisconsin. Presently, the ice surface attains this same altitude about 130 km inland (Fig. 2). If the former ice sheet that overwhelmed Mount Neuner had a similar surface profile to that of the present ice, we may assume that the position of the grounded ice margin was at least 70 km beyond its present position (Fig. 2). Similarly, Mount Wasilewski (1 616 m), about 90 km inland from the present ice front (Fig. 2), shows evidence of having been overridden by

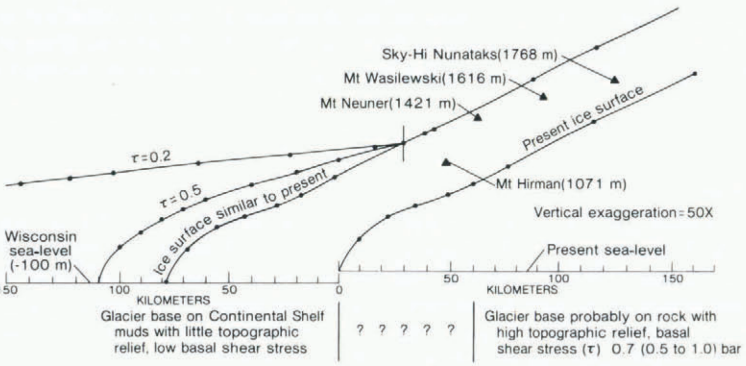

Fig. 2. Profile between the Behrendt and Merrick Mountains on the west, and the Sweeney Mountains on the east, showing projected ice-surface profiles discussed in the text.

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glacial ice (personal communication from T. S. Laudon, 1978). Allowing for the 100 m lower sea-level during Wisconsin time, the present ice surface attains an altitude of 1 716 m about 155 km inland (Fig. 2). Hence, when this mountain was covered by ice from the interior, the grounded ice margin was at least 65 km beyond its present position. These glaciated peaks provide only a minimal value of former ice thickness; as the ice surface may have been much higher than the summits, the actual grounded ice front may have been much farther than 65–70 km beyond its present-day margin.

In Figure 2 it has been assumed that ice from the inland mountainous area possesses common basal shear stresses of 0.5–1.0 bar. When the present ice-surface profile is projected so that Mount Neuner is overridden by 100 m of ice, the result is an extension of the former ice sheet about 80 km out on to the continental shelf. It is almost certain, however, that once ice expands on to the low-relief marine muds of the continental shelf there will be a reduction in basal shear stress. Hollin (1962) developed an equation to explain the observed surface profiles of ice sheets:

$$h = 4.7d^{\frac{1}{2}} \tag{1}$$

where h is the ice thickness and d is the distance from the ice-sheet edge; both h and d are expressed in meters. This equation assumes a basal shear stress of 1 bar. A modification of Hollin's equation for a basal shear stress of 0.5 bar yields the following:

$$h = 3.35d^{\frac{1}{2}} \tag{2}$$

(personal communication from J. T. Hollin, 1979). Application of this relationship at a point where the basal topography may change (Fig. 2) results in an extension of the former ice sheet 110 km beyond its present margin (Fig. 2).

Low basal shear stresses, based on reconstruction of the Pleistocene ice limits for several lobes in the south-western part of the Laurentide ice sheet, were obtained by Mathews (1974). Mathews suggested that, for those lobes moving over nearly horizontal ground, the basal shear stress may be only a small fraction (7–21%) of the 1.0 bar considered normal. Assuming Mathews' upper limit (0.2 bar) and again modifying Hollin's (1962) equation for this basal shear stress ($h = 2.12d^{\frac{1}{2}}$), the former ice sheet would extend approximately 320 km beyond its present margin (Fig. 2).

The present-day Ronne Ice Shelf is grounded in places and other areas are underlain by shallow water (Behrendt, 1962). Thomas and Bentley (1978) believed that a partially grounded ice shelf is a prerequisite for maximum ice-sheet growth out to the edge of the continental shelf. Extensive glaciation in the Northern Hemisphere with the accompanying eustatic lowering of sea-level would ground even more of the Ronne Ice Shelf, increasing the buttressing effect allowing ice from the Orville Coast area to expand on to the continental shelf area.

Unfortunately, no material was found on any of the nunataks that might provide a minimum age of deglaciation. However, if the assumption that the glacial history of Antarctica is controlled by sea-level changes is correct (Hollin, 1962), one would expect similar glacial histories for both the Ross Sea and Ronne Ice Shelf areas, i.e. that both areas were covered by large ice sheets during the world-wide eustatic lowering of sea-level during the Wisconsin glaciation. The limited nature of the field observations from the Orville Coast area do not prove that Hollins's hypothesis is correct, nor do they prove that the chronologies of glaciation and deglaciation in the Ross and Ronne Ice Shelf areas were similar. However, the data are certainly compatible with both theories and indicate that at some past time the grounded ice front advanced many kilometers beyond its present position on to the continental shelf in the Ronne Ice Shelf area.

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