LATE QUATERNARY ICE-SURFACE FLUCTUATIONS OF THE LAMBERT GLACIER

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Abstract: In the area of the Northern Prince Charles Mountains four glacial systems are recognised: land-terminating alpine glaciers in the mountain massifs; large slow-moving outlet glaciers draining from peripheral parts of the ice sheet; the fast-flowing Lambert Glacier ice stream draining from the interior of the ice sheet; the inner part of the Amery Ice Shelf fed by the Lambert and large outlet glaciers. Moraines and drift sheets on Fisher Massif provide a record of fluctuations of these glacial systems and from these features it appears that while the Lambert Glacier surface has declined from its most recent moraines, the alpine glaciers are close to their maximum extents having advanced across the Lambert lateral moraines. Similar patterns occur in the higher moraines and drift sheets. It is interpreted from this that the small alpine glaciers advance out of phase with advances of the large ice sheet fed glaciers. Moraines that are most likely to be of Last Glaciation age occur about 100 m above the present Lambert Glacier surface, and it is probable that during this time the glacier did not expand greatly and thus the Amery Ice Shelf may not have become grounded. This has important implications for Antarctic Ice Sheet volume during the Last Glaciation and its contribution to sea level fall.

Key words: Lambert Glacier, Last Glacial Maximum, ice-surface fluctuations; ice sheet volume

Introduction

The Lambert Glacier is regarded as the world's largest ice stream (Allison, 1979), draining 902,000 km^2 of the East Antarctic Ice Sheet (Swithinbank, 1988). Combined with its adjacent systems some 13.5% of the ice sheet drains into the Amery Ice Shelf, and flowlines extend from far inland at Dome Argus, the major central dome of the ice sheet (Drewry, 1983). It is thus an area of major importance for our understanding of the present and past dynamics of the ice sheet.

A terrestrial record of late Quaternary fluctuations of the Lambert and associated glaciers is preserved on numerous mountain massifs in the Northern Prince Charles Mountains. While there have been some brief descriptions of these features (Crohn, 1959; Trail, 1964; Bardin, 1977, 1982; Derbyshire and Peterson, 1978; Wellman, 1982; Adamson and Darragh, 1991), there has been no attempt to map the glacial deposits, or define the late Quaternary glacial history. In contrast, the Ross Embayment-Transantarctic Mountains region has been intensively studies for many years as reviewed by Clapperton and Sugden (1990), and from this work a general pattern of Antarctic glaciation has been defined. During global glacial cycles the major ice sheet outlet glaciers thicken considerably in their lower reaches due to seaward advance of ice shelf grounding lines caused by eustatic sea level lowering. In addition, the smaller alpine-type, land terminating glaciers advance and retreat out of phase with the large glaciers, as the glacial periods result in reduced precipitation and hence starving of these smaller glaciers (Denton *et al.*, 1989). Reconstructions of the Antarctic Ice Sheet during the Last Glacial Maximum done by Stuiver *et al.* (1981) and Denton *et al.* (1986) are based on this work. They predict ice-level increases of more than 1000 m for the lower reaches of the Lambert and associated glaciers in response to widespread grounding of the Amery Ice Shelf. This paper reports on reconnaissance observations of the glacial geology of Fisher Massif (Fig. 1) and offers a preliminary assessment of the applicability of the Ross Embayment-Transantarctic Mountains glacial model to the Northern Prince Charles Mountains area.

Fisher Massif

In the Northern Prince Charles Mountains region four glacial systems are recognised: alpine glaciers in the mountain massifs; large outlet glaciers draining from the polar plateau west of the mountains; the Lambert Glacier draining from the interior of the East Antarctic Ice Sheet; the inner part of the Amery Ice Shelf, fed by the Lambert and large outlet glaciers (Fig. 1). The Lambert Glacier, which is over 40 km wide, 1.7 km thick, and has surface velocities of around 400 m/y near its grounding line (Allison, 1979), discharges into the Amery Ice Shelf. Near the grounding line the ice shelf is 1.44 km thick (Malcolm and Yates, 1990), and flow rates increase northwards approaching 1200 m/y at the ice front (Swithinbank, 1988). The large outlet glaciers flow generally eastwards through the Northern Prince Charles Mountains to join the Amery Ice Shelf. These are rather slow-moving, the Scylla and Charybdis glaciers having surface velocities of only 70–95 m/y (Malcolm and Yates, 1990). Alpine-type glaciers are confined to the mountain massifs, are usually only a few kilometres long, and are very slow moving cold-based glaciers. Fisher Massif is uniquely situated close to elements of all these glacial systems. Numerous alpine glaciers occur within the massif, it is flanked to the north-west by an unnamed outlet glacier, and the Lambert Glacier flows along its south-east margin. To the east of the massif is the grounding line of the Lambert

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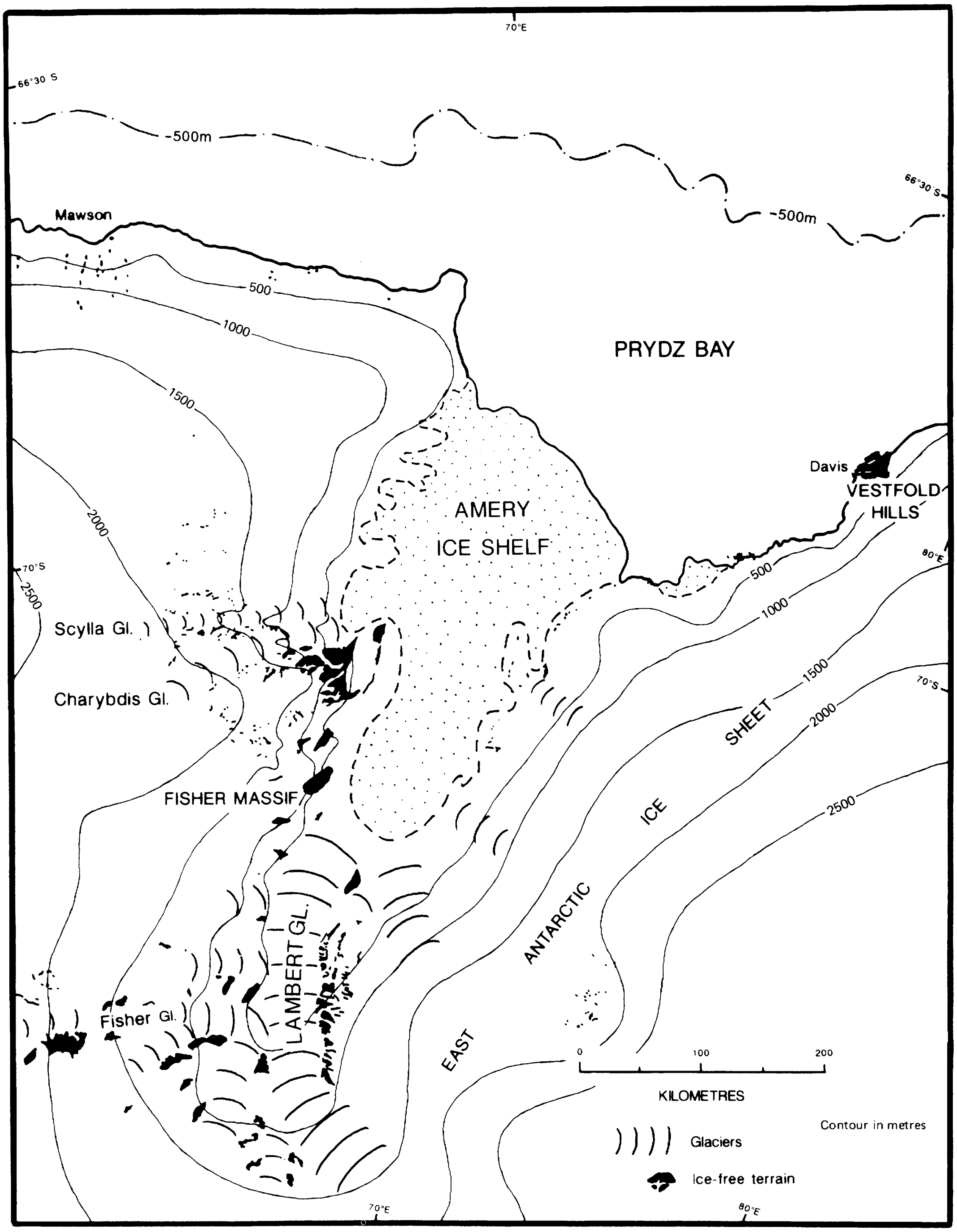

Fig. 1. Prince Charles Mountains, Lambert Glacier - Amery Ice Shelf region.

Glacier marking the inner boundary of the Amery Ice Shelf (Swithinbank, 1988). Past changes to any of these elements of the glacial system are likely to be recorded in the moraines and drift sheets on the massif.

Fisher Massif (71°30′ S, 67°40′ E) is approximately oval shaped, 30 km long, up to 12 km wide, and trends NE-SW parallel to the flow of the Lambert Glacier. The southern third of the massif is heavily glacierized and the highest peak Mt. Johnston (1768 m) is surrounded by numerous alpine glaciers, many of which are tributaries of the unnamed glacier and Lambert Glacier which flow past the NW and SE margins of the massif (Fig. 2). High peaks in the northern part of the massif rise to 1220 m and five smaller alpine glaciers occupy valleys here, but all terminate on the massif. All these high peaks on the massif rise to over 1000 m above the surrounding large glaciers.

The ice-free parts of the massif are extensively mantled by various drift sheets and moraine complexes (Fig. 2). From the nature of their surface form and altitudinal relationships it is apparent that they have been formed during several

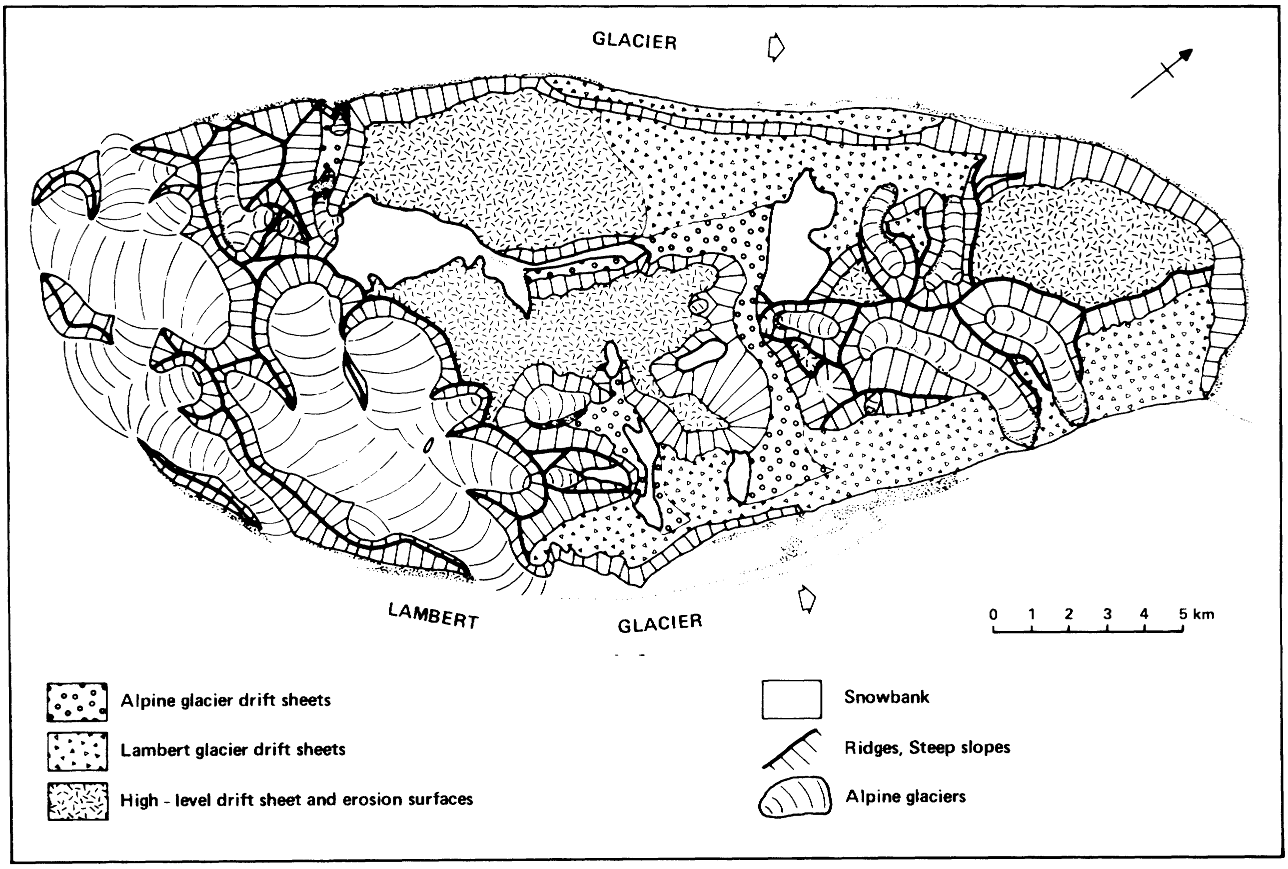

Fig. 2. Glacial landforms of Fisher Massif.

different glacial episodes by a variety of glacial systems, including the local alpine glaciers, the outlet and Lambert glaciers.

Glacial Landforms of Fisher Massif

High-level drift sheet and erosion surfaces

The oldest glacial features occur widely in the upper parts of the massif (Fig. 2). These consist mostly of low-relief remnants of a high-level erosion surface between about 900–1300 m elevation now extensively mantled by felsenmeer. In the south the surface is covered by an area of tillite extending to more than 1450 m above sea level. These features are discussed by McKelvey *et al.* (1991) and are correlated with the Pagodroma tillite of McKelvey and Stephenson (1990). All other glacial deposits and landforms occur at considerably lower elevations, and the local alpine glaciers have incised deep cirques and valleys into these Pagodroma features. The scale of landscape modification that has occurred since the Pagodroma events indicates their considerable antiquity and a pre-Quaternary age is considered appropriate.

Lambert Glacier moraines

Features formed during younger glacial periods can be divided into two groups: those associated with the alpine glaciers, and those formed by the Lambert and the unnamed outlet glaciers (Fig. 2). Lambert Glacier lateral moraines are the best developed along the SE side of the massif and three groups can be differentiated.

The upper belt of Lambert moraines is over 1 km across, rises to about 800 m elevation, and has a subdued surface form with extensive frost polygon development. The middle level Lambert moraine belt rises to about 600 m elevation. It has a moderately irregular surface form and does not exhibit extensive frost polygon development. The lowest Lambert moraines occur up to 200 m elevation, about 100 m above the present ice level, and surface topography is much more irregular than on higher moraine surfaces. From this it is apparent that in the region near its present grounding line the Lambert Glacier has in the past thickened on at least three separate occasions, and lately it has declined about 100 m from the level of its most recent advance. Chronological control on the ages of these advances is lacking. In other parts of Antarctica ice-cored moraines close to the margins of large outlet glaciers have been radiocarbon dated to the Last Glacial Maximum 18,000–21,000 years ago (Stuiver *et al.*, 1981; Bockheim *et al.*, 1989), and thus this age is considered a reasonable estimate for the lowest Lambert moraines on Fisher Massif.

Alpine glacier moraines

Moraines and associated features occur around many alpine glaciers and in two dry valleys in Fisher Massif (Fig. 2). The valleys issue from the eastern side of the central part of the massif as hanging valleys with floors at about 400 m and 700 m above the Lambert Glacier. They are incised through the upper Lambert moraines and thus were cut

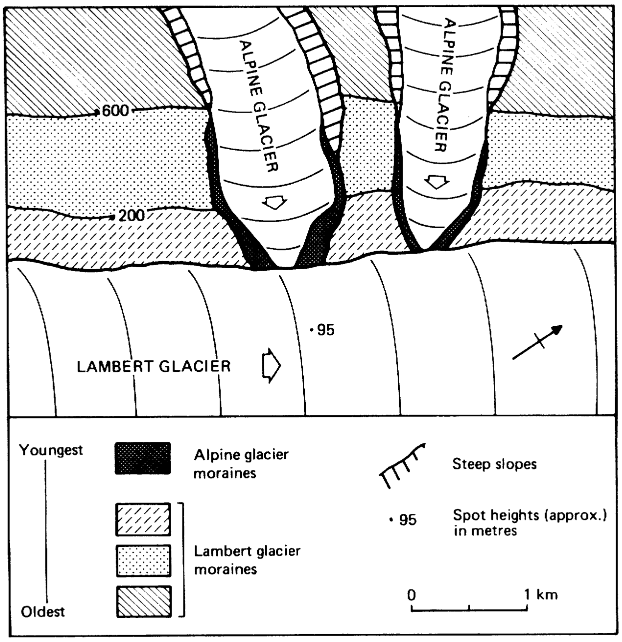

Fig. 3. North-east Fisher Massif moraine complex.

sometime after those moraines were formed (Fig. 2). Drift sheets in the valley floors exhibit considerable frost polygon development and were thus probably formed before the advance that produced the middle level Lambert moraines as these latter moraines do not exhibit extensive frost polygon forms. In the upper reaches of these valleys small alpine glaciers are fronted by younger moraine complexes, an inner ice-cored ridge close to the present alpine glacier margins, and an outer more subdued belt of apparently ice-cored moraines.

At the NE end of Fisher Massif two alpine glaciers extend out of their valleys and down across the Lambert moraine complexes to within a few tens of metres of the Lambert Glacier (Fig. 3). These alpine glaciers are close to their maximum extents and have recently formed moraine complexes that cross all three of the Lambert moraines. Clearly this advance of the alpine glaciers occurred after the Lambert Glacier had retreated from its most recent moraines.

Pattern of glaciation of Fisher Massif

From the above observations a general pattern of glacier behaviour can be proposed. As the large glaciers fed by the ice sheet advanced the small alpine glaciers retreated, and when the large glaciers retreated the alpine glaciers advanced. While this can be interpreted from the geomorphic setting and moraine cross-cutting relationships, these are clearly preliminary findings and much more field data are required. Of particular importance is the absolute dating of ice levels during the Last Glacial Maximum.

This preliminary interpretation of the terrestrial glacial record on Fisher Massif shows a number of similarities with those from the Transantarctic Mountains as described by Denton *et al.* (1989). Large ice sheet outlet glaciers drain through mountains to feed into ice shelves, and small alpine glaciers occur within the mountain massifs. A record of multiple glacial events is preserved and in both areas ice sheet outlet glaciers and the small alpine glaciers fluctuated out of phase with each other. However, a significant difference is apparent. In the Transantarctic Mountains during the Last Glacial Maximum, the large ice sheet outlet glaciers thickened considerably in the region of their current grounding lines reaching 800–1000 m above present ice levels (Denton *et al.*, 1989). In contrast the Lambert Glacier appears to have shown only a minor increase in elevation near its current grounding line reaching only about 100 m above its present level.

Discussion

Denton *et al.* (1986) present a reconstruction of the Antarctic Ice Sheet during the Last Glaciation using as a pattern the style of glaciation observed in the Ross Embayment-Transantarctic Mountains region. This is based on the CLIMAP reconstruction of Stuiver *et al.* (1981), and predicts ice-level increases of more than 1000 m for the lower reachers of the Lambert and outlet glaciers in response to widespread grounding of the Amery Ice Shelf. However, these predications cannot be readily reconciled with the data presented in this paper. On Fisher Massif moraines that are most likely to be of Last Glaciation age occur only about 100 m above the present ice surface, and none of the older lateral moraines occur at such high elevations. Indeed, 1000 m of ice level increase would almost entirely engulf the massif, and this has clearly not happened during the late Quaternary ice ages. It is suggested that during the Last Glaciation the Lambert and other outlet glaciers of the Prince Charles Mountains regions did not expand greatly, and as a consequence the Amery Ice Shelf may not have become widely grounded.

This has important implications for reconstruction of the Antarctic Ice Sheet and its contribution to sea level lowering during the Last Glaciation. The CLIMAP maximum reconstruction of Stuiver *et al.* (1981) has been widely used in studies of post glacial sea level change which assume that melting of the Antarctic ice sheets contributed some 25 m to eustatic sea level rise (Clark and Lingle, 1979; Nakada and Lambeck, 1988; Tushingham and Peltier, 1991). However, Denton *et al.* (1989) have substantially revised the CLIMAP reconstruction of the Ross Embayment area, and suggest that ice sheet fluctuations there may have contributed little to global sea level change. As demonstrated here the same possibility occurs in the Lambert-Amery system. It appears that the large increases in ice volume predicted by the CLIMAP maximum reconstruction have overestimated the Antarctic contribution to sea level fall during the Last Glaciation.

This has ramifications for the study of post-glacial sea level rise which can be shown to be significantly affected by the extent and location of ice sheets during the Last Glaciation (Tushingham and Peltier, 1991). Understanding post-glacial sea level rise is also a necessary part of unravelling present day patterns of sea level change (Peltier and Tushingham, 1991). If Antarctica contributed substantially less than 25 m to post-glacial eustatic sea level rise, then current interpretations of sea level change will need to be revised.

Conclusions

The glacial record of the Lambert Glacier is of major significance as it drains over 10% of the East Antarctic Ice Sheet, and this is one of the few areas from which a terrestrial glacial record of a large proportion of the ice sheet can be established. A terrestrial record of fluctuations of the Lambert Glacier is known to occur on mountain massifs in the Prince Charles Mountains. Observations from Fisher Massif demonstrate that the record contains evidence of multiple glaciations, the large ice sheet outlet glaciers advancing out of phase with the small alpine-type glaciers. This is a similar pattern to that observed in the much-studied Transantarctic Mountains region. However, an important contrast exists: during the Last Glacial Maximum the Lambert Glacier surface apparently showed only a minor increase in elevation near its present grounding line, and widespread grounding of the Amery Ice Shelf may not have occurred. The large increases in Antarctic ice volume predicted by the CLIMAP reconstruction probably did not occur, and this may necessitate reassessment of post-glacial and present day sea level rise calculations.

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