

Glacial history of Marie Byrd Land - from thousands to millions of years

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Continued deglaciation of West Antarctica would have profound impacts on future sea level, and an extensive program of glaciological and remote-sensing research has been devoted to identifying trends in the mass balance of the West Antarctic Ice Sheet [1-5]. Geological studies can provide insight into previous deglaciations of West Antarctica. For example, the work of Scherer et al. [6], which suggests that grounded ice withdrew from the inner Ross Sea Embayment at least once during the late Quaternary, illustrates one possible outcome of further recession. Whether deglaciation to this degree has occurred once, or repeatedly; when it last occurred, and for how long, remain open questions.

In previous work, we used conventional cosmic-ray exposure dating of glacial erratics to document the most recent deglaciation of Marie Byrd Land. Our results showed that: (i) the glacial-maximum West Antarctic Ice Sheet (WAIS) overran peaks in the Ford Ranges, (ii) outlet glaciers traversing the ranges retreated gradually between 10,300 - 1800 yr B.P., and (iii) local icefields surrounding peaks in the ranges have continued to adjust to these changes, exposing fresh deposits as recently as 300 yr B.P. [7]. In order to investigate ice cover prior to the last glaciation, we have measured cosmogenic nuclides in bedrock surfaces throughout the Ford Ranges. These data provide broad constraints on the extent of glaciation in Marie Byrd Land over the past few million years, and show that the present state of West Antarctic (de) glaciation is highly unusual.

Cosmic-ray-produced nuclides such as Be-10, Al-26 and Cl-36 (with half-lives of 1.5, 0.7 and 0.3 Myr, respectively) accumulate in bedrock surfaces at times of deglaciation. During glacial periods when the surfaces are shielded from cosmic radiation, the nuclides decay at different rates, leading to isotopic disequilibrium. Provided bedrock has been protected during glaciation by non-erosive, cold-based ice, the concentrations of these nuclides provide million-year records of exposure and ice cover. Although such measurements cannot be used to date specific glaciations, we can obtain: (i) minimum limits on the total duration of past exposure and glaciation, (ii) a maximum limit on the proportion of time-exposed to time-covered by ice, and (iii) upper limits on total exposure time during the last few half-lives of Cl-36 and Al-26.

Our data show that: (i) All bedrock surfaces, with the exception of ice-scoured pavements at low altitude, retain a memory of intermittent exposure and ice cover ranging from a few hundred thousand years to 3.5 million years. (ii) Mountain transects show that the proportion of "time-exposed" to "time-covered" increases with elevation, as expected. Data from summit surfaces show that, in general, coastal peaks have been ice-free for a greater proportion of the time than inland peaks. (iii) Nevertheless, summits in Marie Byrd Land spend more time buried beneath the ice sheet than exposed. Maximum limits on the fraction of "time-exposed" for the peaks we sampled range from approximately 5% in the eastern Fosdick Mts to 45% for the summit of The Billboard. (iv) Several outcrops, which have been exposed for 2-4 kyr during the present deglaciation, cannot have been exposed for more than 3-30 kyr in the past million years. Thus the least frequently exposed of these surfaces probably did not emerge from beneath the ice sheet more than once or twice in the last 10-15 major interglacials of the late Pleistocene. These data suggest that the present extent of outcrop in the Ford Ranges is unusual, the present-day WAIS in Marie Byrd Land is close to its minimum late-Pleistocene extent, and that the warmth and/or duration of the Holocene rival past interglacials such as Marine Isotope Stage 11 (MIS-11; 400 kyr B.P.) in terms of their effect on the ice sheet. (v) Sites in the Fosdick Mts and Fleming Peaks cannot have been exposed for more than 1-4 kyr and 7 kyr, respectively, during MIS-11, ruling out prolonged, extensive deglaciation of the Ford Ranges at that time. This suggests that the late-Quaternary diatoms found by Scherer et al. (1998) may have been deposited in an earlier interglacial.

We have begun to explore plausible long-term glacial histories that fit these constraints using a calculation that links exposure histories at all our sample sites. In the calculation a single ice-volume parameter

is allowed to vary through time; exposure at each site occurs when ice volume drops below a threshold value, constrained by the Holocene deglaciation sequence. We use genetic algorithms to search for an ice-volume time series, spanning the last 4 Myr, that best reproduces our bedrock Be-10, Al-26 and Cl-36 data. The highly non-linear nature of the model precludes finding a unique solution, but repeated runs of the optimization show several common features. Best-fit models concur in indicating that the most extensive deglaciation of the Ford Ranges occurred ca. 2 Myr ago, and all explain the data with a sequence of 3-4 major deglaciations since 2 Myr B.P., rather than a rhythmic glacial-interglacial sequence resembling the marine oxygen isotope record. These preliminary findings suggest that major deglaciations are not simply linked to climatic and sea-level oscillations, but occur when intrinsic “thresholds” in the ice-ocean-climate system are crossed, as proposed in models like that of Macayeal [8].

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Acknowledgements: Supported by NSF grants OPP9909778 and OPP0229915, and a Lawrence Livermore National Laboratory/Center for Accelerator Mass Spectrometry small grant.