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RECONSTRUCTION AND DISINTEGRATION OF ICE SHEETS FOR THE CLIMAP 18 000 AND 125 000 YEARS B.P. EXPERIMENTS: RESULTS

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Abstract. Late-Wisconsin ice sheets were reconstructed for the CLIMAP 18 000 years B.P. experiment. This experiment modeled the ice-age steady-state climate using boundary conditions that differed from present ones mainly in Earth-surface albedos, sea-surface areas, and land-surface topography. These required determinations of the area, volume, and elevation of Late Wisconsin ice sheets. An initial-value finite-difference numerical model for ice-sheet reconstruction was developed from a recursive formula which gave ice thickness for known variations of bed topography and theoretical variations of basal shear stress. Ice thicknesses were calculated in 50 km to 100 km steps along flow lines from margins to domes of late-Wisconsin ice sheets. We assumed that terrestrial margins were along the furthermost moraines, marine margins were along the present 500 m bathymetric contour, domes were centers of maximum post-glacial isostatic rebound, and flow lines were along glacial lineations (eskers, striations, drumlins, etc.) connecting margins to domes. At various locations ice-sheet margins were verified by dated moraines for terrestrial margins and Egga-type moraines for marine margins. Ice-sheet elevations and thicknesses were contoured from profiles reconstructed for 40 Antarctic flow lines and 137 Northern Hemisphere flow lines for a maximum ice-sheet extent, and 86 Northern Hemisphere flow lines for a minimum ice-sheet extent.

Maximum and minimum Northern Hemisphere ice-sheet reconstructions were necessary because glacial geological studies in the Arctic are inconclusive (Hughes and others, in press). One body of work favors ice sheets which extended to the margins of the Arctic continental shelf, but another body has these ice sheets terminating near present Arctic shorelines. Ice sheets were reconstructed assuming isostatic equilibrium and rock–ice density ratios of 3 and 4. For the maximum reconstruction, a density ratio of 3 requires removing 172 m of ocean water, Laurentide ice up to 3 230 m high with 2 930 m mean thickness, Scandinavian ice

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up to 2 710 m high with 2 700 m mean thickness, and Antarctic ice up to 4 050 m high with 2 330 m mean thickness; whereas a density ratio of 4 requires removing 164 m of ocean water, Laurentide ice up to 3 800 m high with 2 920 m mean thickness, Scandinavian ice up to 2 520 m high with 2 190 m mean thickness, and Antarctic ice up to 4 050 m high with 2 310 m mean thickness. By contrast, for the minimum reconstruction with a density ratio of 4 only 126 m of ocean water was removed, Laurentide ice was up to 3 480 m high with 2 690 m mean thickness, and Scandinavian ice was up to 2 520 m high with 2 190 m mean thickness.

During the last interglaciation 12 000 years ago mean global sea-level was about 6 m higher than at present. This sea-level rise could have resulted from complete collapse of the Greenland ice sheet or the Antarctic ice sheet west of the Transantarctic Mountains, or partial collapse of an Antarctic ice-sheet drainage basin east of the Transantarctic Mountains. Since the West Antarctic ice sheet is mostly grounded on a continental shelf that is permanently below sea-level, it is a marine ice sheet and is believed to be inherently unstable. For this reason, we chose to collapse it for the CLIMAP 125 000 years B.P. experiment using our marine ice-sheet disintegration model.

Two West Antarctic ice-sheet disintegration histories were modeled, both starting with a maximum West Antarctic ice sheet which extended to the continental shelf margin during the previous ice age (Stuiver and others, in press). Disintegration was triggered and maintained by rising sea-level during the glacial–interglacial transition. Isostatic rebound was assumed to nearly keep pace with disintegration so that approximate isostatic equilibrium was maintained. Both disintegration histories began with ice-stream grounding lines retreating from sills at the continental shelf margin as sea-level rises. Initially the ice-sheet calving fronts and grounding lines nearly coincided because a confined ice shelf cannot form beyond the continental-shelf margin.

In the ice-shelf disintegration history, the West Antarctic grounding lines retreated faster than the calving fronts so that floating ice shelves were created in the Ross, Amundsen, Bellingshausen, and Weddell Seas. The grounding line in the Amundsen and Bellingshausen Seas temporarily halted along the barrier of volcanos and mountains extending from the Edsel Ford Range to the Antarctic Peninsula, but the calving ice-shelf front continued to retreat. When this ice shelf no longer effectively buttressed Thwaites and Pine Island Glaciers, their grounding lines retreated over the barrier and an ice shelf was created in the Byrd Subglacial Basin. This ice shelf, together with the Ross and Filchner–Ronne Ice Shelves, completed the ungrounding of the West Antarctic ice sheet. These ice shelves remained intact during the last interglaciation, so surface albedos did not change dramatically even though surface elevations did.

In the calving-bay disintegration history, the West Antarctic grounding lines and calving fronts retreated at the same rate so that extensive floating ice shelves never formed. Instead, calving bays migrated up surging ice streams and carved out the heart of the West Antarctic marine ice sheet. Seasonally open seas replaced the West Antarctic ice sheet so both surface albedos and surface elevations changed dramatically. Our modelling results pinpoint Pine Island Bay, where Thwaites and Pine Island Glaciers now terminate, as an active calving bay that may control the Holocene and present-day collapse of the West Antarctic ice sheet, provided that high bedrock sills are not present.

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