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INSIDE

Stability or Instability of Antarctic Ice Sheets During Warm Climates of the Pliocene?

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ABSTRACT

During the Pliocene between ~5 and 3 Ma, polar ice sheets were restricted to Antarctica, and climate was at times significantly warmer than now. Debate on whether the Antarctic ice sheets and climate system withstood this warmth with relatively little change (stability hypothesis) or whether much of the ice sheet disappeared (deglaciation hypothesis) is ongoing. Paleoclimatic data from high-latitude deep-sea sediments strongly support the stability hypothesis. Oxygen isotopic data indicate that average sea-surface temperatures in the Southern Ocean could not have increased by more than ~3 °C during the warmest Pliocene intervals. A small rise in Southern Ocean temperatures may have caused limited melting of the ice sheets and associated marine transgression, but maximum sea level rise was likely less than 25 m above the present level. Recently discovered evidence from the Antarctic dry valleys indicate relative stability of the Antarctic climate-cryosphere system since middle Miocene time (~14 Ma).

INTRODUCTION

The Antarctic cryosphere is the largest accumulation of ice on Earth and comprises some 30×10^6 km^3 (Fig. 1). If all Antarctic ice melted, sea level would rise by ~70 m. The Antarctic ice sheets are divided at the Transantarctic Mountains into a small (3.3 km^3), marine-based sheet in the west and a larger (26 km^3), continent-based sheet to the east (Fig. 1). The West Antarctic ice sheet is grounded below sea level and may thus be vulnerable to small changes in surface temperatures of the Southern Ocean and in sea level (Mercer, 1978). In contrast, the more stable East Antarctic ice sheet is largely grounded on bedrock above sea level.

The Antarctic ice sheets and adjacent Southern Ocean act together to form the Antarctic ocean-cryosphere system, representing one of the most important components of Earth's climate system, by strongly influencing global atmospheric and ocean circulation (Cattle, 1991). The Southern Ocean is an integral part of the Antarctic environmental system because the cold, circumpolar current maintains thermal isolation of the continent. The ocean is bounded to the north by the Antarctic convergence, or Polar Front zone that separates cold, nutrient-rich Antarctic surface waters to the south from warmer, less nutrient-rich Subantarctic surface water. Upwelling of deep water in the circum-Antarctic links the mean chemical composition of ocean deep water with the atmosphere through gas exchange (Toggweiler and Sarmiento, 1985). The evolution of the Antarctic cryosphere-ocean system has profoundly influenced global climate, sea-level history, Earth's heat budget, atmospheric composition and circulation, thermohaline circulation, and the development of Antarctic biota.

Given current concern about possible global greenhouse warming, understanding the history of the Antarctic ocean-cryosphere system is important for assessing future response of the Antarctic region to global warming. As a result, paleoclimatologists have turned their attention to times when climate was warmer than today. The early Pliocene was one such interval. During that time (4.8 to 3.2 Ma), climate was warmer than at any other time within the past 7 m.y. (Kennett and Vella, 1975; Elmstrom and Kennett, 1986). Did this early Pliocene warmth lead to major deglaciation of the Antarctic ice sheets and significant warming of the Southern Ocean?

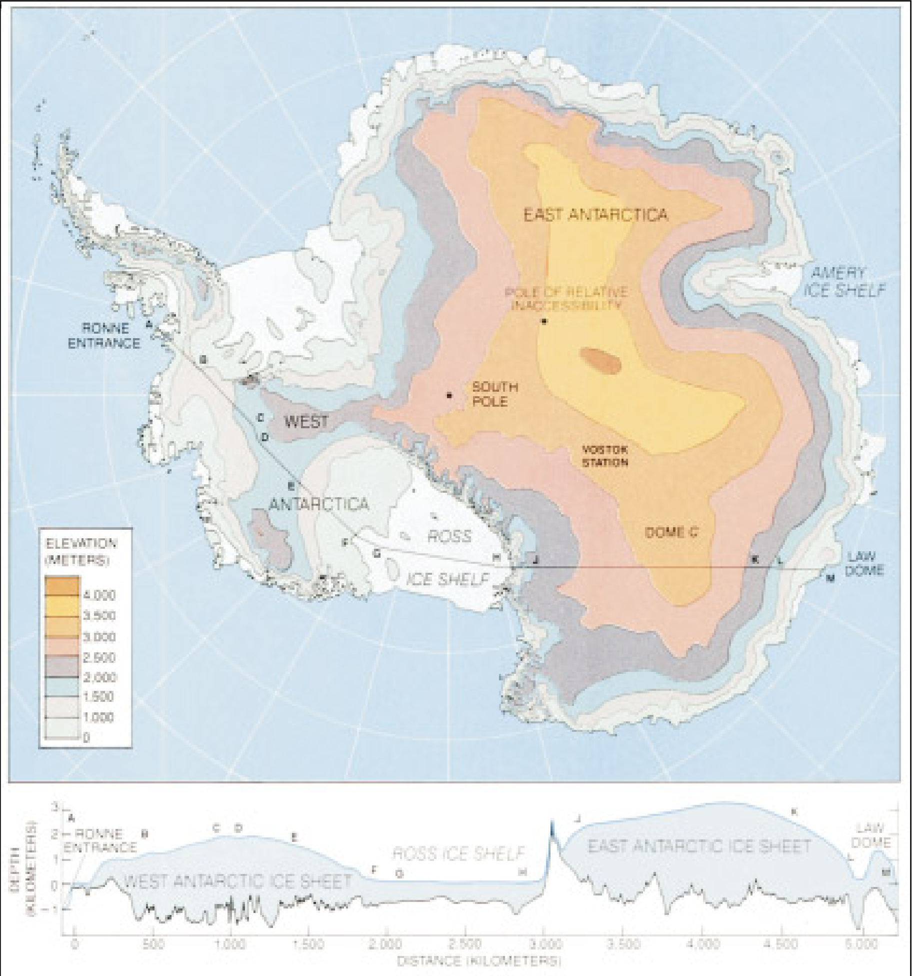

Figure 1. Elevation of Antarctic ice sheets showing the continental ice sheet on East Antarctica and the marine-based ice sheet on West Antarctica that is largely grounded below sea level. The history and stability of these ice sheets differ in that the West Antarctic ice sheet is less stable and developed later (late Miocene) than the East Antarctic ice sheet, which is believed to have developed to its approximate present form by the middle Miocene (~14 Ma). (From *The Antarctic Ice* by U. Radok, copyright ©1985 by Scientific American, Inc. All rights reserved.)

Stability Hypothesis

Until recently, most workers believed that the East Antarctic ice sheet had grown to its approximate present form by the middle Miocene (~14 Ma) and then remained relatively stable under polar desert climate due to continental thermal isolation by the cold circum-Antarctic current ("stability hypothesis"—Shackleton and Kennett, 1975; Kennett, 1977; Clapperton and Sugden, 1990; Kennett and Hodell, 1993). This implies that the Antarctic cryosphere-ocean system is robust and that the ice sheet is difficult to remove because of powerful thermal inertia of the Antarctic circumpolar current and strong negative feedbacks tending to maintain stability. Once tectonic changes such as the opening of the Tasmanian Seaway and Drake Passage permitted circumpolar flow, the Antarctic continent became thermally decoupled from lower latitudes. By 20 Ma, during the early Miocene or shortly thereafter, a vigorous circumpolar current had undoubtedly been established (Kennett, 1977; Lawver et al., 1992). Today the Drake Passage imposes a unique dynamic constraint on poleward transport of warm water because persistent westerly winds in the circumpolar belt deflect warm surface waters northward. Also the position of the Antarctic circumpolar current is fixed partly by seafloor

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Figure 2. Oblique aerial view looking south across the western Olympus Range toward the western Asgard Range in the dry valleys sector of the Transantarctic Mountains, Antarctica. Note detached mesas and buttes, remnants of the upper planation surface. Denton et al. (1993) suggested that these upland landscapes resemble those on the Colorado Plateau and formed under similar semiarid desert conditions. The dry valley landscapes date to the middle-to-late Miocene and exhibit remarkable slope stability, indicating a hyperarid, cold desert environment since that time. This geomorphological evidence argues against major deglaciation and warm Antarctic climates during the Pliocene. Photo from Denton et al. (1993, p. 171; used with permission).

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topography and by the westerly surface wind stress, which is strongly dependent upon land-mass distribution (Gordon, 1988). These critical tectonic factors were not appreciably different during the Pliocene than today (Lawver et al., 1992). Faunal and sedimentological data indicate strong stability in the position of the circumpolar current during the late Neogene; northward and southward migrations of the Polar Front zone have been minor in relation to the vast breadth of the Southern Ocean (Lazarus and Caulet, 1993). The net effect of the relatively stable position of the Antarctic circumpolar current has been long-term thermal insulation of the Antarctic continent and resulting stability of the Antarctic cryosphere.

Deglaciation Hypothesis and the Sirius Group

More recently, workers have proposed a competing hypothesis (“deglaciation”) suggesting that pre-Pleistocene ice sheets were smaller and of lower profile than today and were formed in much warmer conditions (Webb and Harwood, 1991; Barrett et al., 1992). This model also invokes large changes in the volume of the Antarctic cryosphere; reductions to about two-thirds of the present size of the East Antarctic ice sheet during Pliocene intervals, complete loss of the West Antarctic ice sheet, and considerable warming (>5 °C) of Antarctic surface waters. Support for major deglaciation and warming of Antarctica is largely inferred from the presence of reworked oceanic diatoms (as young as late Pliocene age—3.1 to 2.5 Ma; Webb and Harwood, 1991) in sedimentary deposits of the Sirius Group, found at high altitudes (~2000–2500 m) in the Transantarctic Mountains. The Sirius Group consists of lodgment tills interbedded with glaciofluvial, glaciolacustrine, and colluvial sediments containing fossil plant material representing evidence for remarkable warmth, even as close as 500 km from the South Pole (Webb and Harwood, 1991; Hill and Truswell, 1993). The diatoms are inferred to have lived in marine basins within the Antarctic craton and, together with associated basinal sediments, were carried up the Transantarctic Mountains by developing ice sheets after ~2.5 Ma, the age of the youngest diatoms in Sirius sedimentary rock.

Other evidence cited in support of the deglaciation hypothesis includes vertebrate fauna and $\delta^{18}O$ of bivalves from the Vestfold Hills (Quilty, 1993), highstands of sea level during the middle Pliocene (Haq et al., 1988; Dowsett and Cronin, 1990), and warming of Antarctic surface waters inferred from Pliocene planktonic microfossil assemblages (Abelman et al., 1990; Ishman and Rieck, 1992).

The deglaciation hypothesis implies that the Antarctic ice sheets are unstable and susceptible to decay during times of warm climatic conditions such as those reached during the Pliocene. By analogy, Barrett (1991) suggested that the ice sheets may become unstable at elevated CO_2 levels and temperatures predicted to be extant, due to global warming, by the year 2100.

EVIDENCE FROM DEEP-SEA SEDIMENTS

If such major warming and deglaciation occurred during the Pliocene, clear evidence should exist in marine sediments from the Southern Ocean and in glacioeustatic changes on continental margins. Results from deep-sea drilling in the Southern Ocean have led to major advances in the understanding of climate, oceanography, and the biota of the Antarctic continent and surrounding ocean (Kennett and Barron, 1992). Marine sedimentary evidence presented here supports relative stability of the Antarctic cryosphere-climate-ocean system during the late Neogene. Geomorphological evidence from the continent also indicates that hyperarid, cold desert conditions have persisted on Antarctica since about the middle Miocene (Fig. 2; Marchant et al., 1993; Denton et al., 1993), with little temperature increase above modern values.

Pliocene Climatic History: Oxygen Isotopic Evidence

One of the most useful tools for estimating past changes in temperature and global ice volume is the measurement of stable isotopes of oxygen in foraminiferal tests. Since the $\delta^{18}O$ of calcite is dependent on both the temperature and oxygen isotopic composition of seawater (controlled largely by ice volume), separating the temperature and ice volume signals has proven difficult for paleoclimatic reconstructions.

Increased temperature and reduced global ice volume have long been inferred for the early Pliocene from oxygen isotopic values that were lower than today (Shackleton and Kennett, 1975; Hodell and Venz, 1992; Shackleton et al., 1994). Different views exist, however, as to the magnitude of temperature and ice reduction represented by the oxygen isotopic signal. At one extreme, Raymo (1992) suggested major Antarctic deglaciation (50% reduction in ice) during the early Pliocene, whereas Kennett (1977) argued for relative stability of the ice sheets.

Hodell and Venz (1992) provided critical constraints on estimates of the magnitude of Pliocene ice volume and temperature change, using high-resolution oxygen isotopic records of benthic and planktonic foraminifera from Ocean Drilling Program (ODP) Site 704 in the Subantarctic sector (47°S) of the southeast Atlantic (Fig. 3). Compared with earlier results, this record has proven crucial for interpretations of ice-sheet history because both planktonic and benthic foraminifera were analyzed from a high-latitude location. Prior to 3.2 Ma in the Pliocene, benthic $\delta^{18}O$ values were always less than or equal to Holocene values (i.e., 3‰) and fluctuated by only ~0.5‰. The full range of the planktonic oxygen isotopic variations (0.75‰) were slightly greater than the benthic fluctuations, reflecting larger surface-water temperature changes. However, minimum foraminiferal $\delta^{18}O$ values were never more than 0.5‰ to 0.6‰ lower than Holocene values (i.e., 2.3‰). The $\delta^{18}O$ signal from Site 704 can be interpreted to represent *either* a maximum 2.5 °C warming of Subantarctic surface waters *or* a maximum 60% reduction in continental ice volume (Hodell and Venz,

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information will be made available to participants through the World Wide Web on the Internet, or through direct requests to IEE.

At the GSA Annual Meeting in Seattle, IEE sponsored its first workshop on public information and education techniques. The objectives were to provide a group of geoscientists—representing geographic, disciplinary, and affiliatory diversity—with insights and information on such topics as what is newsworthy; how to make news, become news, present news, and distribute news; how to select the most effective medium for a story; news as public information and education; ethical obligations and responsibilities; and establishing credibility with the media.

The workshop in Seattle was led by Victor J. Yannacone, Jr., and Kevin Molloy. Both have extensive experience in media interface training. Yannacone is an environmental lawyer whose past experience includes successful litigation related to banning the use of DDT, saving the Florissant (Colorado) Fossil Beds, and filing the initial class action complaint that later became known as the Agent Orange litigation. Molloy is an award-winning journalist and editor-in-chief of a chain of weekly newspapers on Long Island within the metropolitan New York news area. He has first-hand knowledge about highly controversial news issues and the interface of federal, state, and local political jurisdictions with their concomitant bureaucratic turf wars. Among geoscience topics he covers on a regular basis are ground-water remediation and the effects of pollution on sole-source aquifers, the impact of storms and littoral drift on barrier beaches, and the effects of salinity changes in estuarine environments.

Future Involvement

The success of the Seattle endeavor, as indicated by postworkshop comments of the participants, has led to the planning of four additional media workshops this spring in conjunction with the GSA Section meetings in Hartford, Connecticut, Knoxville, Tennessee, Lincoln, Nebraska, and Bozeman, Montana. Victor Yannacone and Kevin Molloy will again lead the workshops, which will include “hands-on” activity in which participants practice the techniques. Enrollments for the individual workshops will necessarily be limited, but all interested geoscientists are encouraged to submit an application even if they are not available for the currently scheduled workshops. The application form is printed on p. 9 of this issue of *GSA Today.*

If you are interested in participating in the IEE public outreach program on geology and the environment, or simply wish to be kept informed about IEE activities, please complete the GEPOP Network Enrollment Form on p. 9 and 10 and mail or fax it to the address on the form. ■

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☐	☐	Ecosystem management
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☐	☐	Engineering
☐	☐	Hazard mitigation
☐	☐	Land use management
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☐	☐	Remediation
☐	☐	Restoration, ground-water
☐	☐	Restoration, habitat
☐	☐	Waste management
☐	☐	Water resources
		Social Science
☐	☐	Community relations
☐	☐	Decision making
☐	☐	Dispute resolution
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☐	☐	Ethics, environmental
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Ideas

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- ☐ Issue identification
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IEE is interested in your ideas on topics, audiences, and activities for the outreach program, and on your insights regarding obstacles to environmental decision making. Referrals of people or other relevant programs are also welcome. Use a separate sheet if necessary. Thank you.

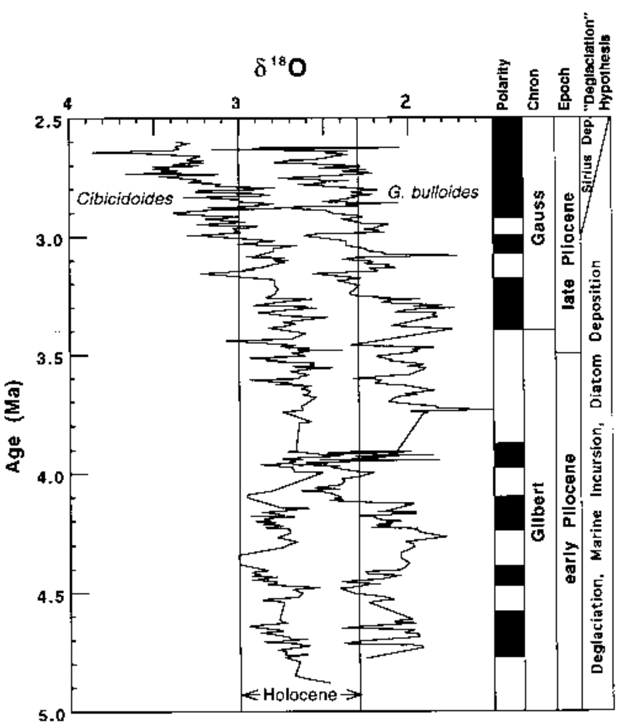

Figure 3. Oxygen isotopic record of benthic *(Cibicidoides)* and planktonic *(Globigerina bulloides)* foraminifers from ODP Site 704 (Hodell and Venz, 1992). The vertical lines represent the present Holocene values at Site 704 for *Cibicidoides* (3.0‰) and *G. bulloides* (2.3‰). Note that during the Pliocene prior to ~3.0 Ma, $\delta^{18}O$ values were generally less than Holocene values, indicating less ice volume and/or higher temperatures in the Subantarctic than today. The minimum $\delta^{18}O$ values, however, are only 0.6‰ less than those of the Holocene, and the amplitude of the signal is dampened, indicating relative climatic stability. The deglaciation hypothesis (see right column) predicts warming of 5 °C and ~60% reduction in Antarctic ice volume, which would result in minimum $\delta^{18}O$ values ~1.85‰ less than those of the Holocene; such low values are not observed in the record.

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1992). The most reasonable interpretation is that the lower $\delta^{18}O$ values reflect both increased temperature and decreased ice volume. This is because it is unlikely that major deglaciation of the East Antarctic and possibly the West Antarctic ice sheets could have occurred in the absence of significant Antarctic warming (Huybrechts, 1992).

A 0.6‰ decrease in oceanic $\delta^{18}O$ might potentially reflect a 60% reduction in Antarctic ice volume, but only in the absence of any increase in temperature, which we believe is untenable. The "deglaciation" hypothesis predicts an increase in high-latitude surface-water temperatures of 5 °C and a two-thirds reduction in Antarctic ice volume (Webb and Harwood, 1991). This amount of warming and deglaciation would result in a decrease of ~1.85‰ in $\delta^{18}O$ values, compared to the observed decrease of only ~0.6‰. The melting of only one-third of the Antarctic cryosphere would cause a decrease of ~0.3‰ in ocean $\delta^{18}O$ values, but the remaining ~0.3‰ decrease would represent a maximum surface-water temperature increase of only ~1.5 °C. The upshot is that the observed oxygen isotopic changes in the early Pliocene of the Subantarctic are insufficient to accommodate both substantial Southern Ocean warming *and* major deglaciation.

The relatively small amplitude of the $\delta^{18}O$ signal during the Pliocene (~±0.25‰) indicates that the Antarctic climate system, as reflected in ocean water temperatures and ice volume, operated within relatively narrow limits during the early Pliocene (Hodell and Venz, 1992). The Pliocene variation in $\delta^{18}O$ (0.5‰–0.6‰) represents only about one-third of the 1.6‰ to 1.8‰ signal observed during the late Pleistocene. The dampened nature of the Pliocene $\delta^{18}O$ signal also is supported by high-resolution records of Pliocene benthic $\delta^{18}O$ variations from an eastern equatorial Pacific drilled site (Shackleton et al., 1994). The minimum benthic $\delta^{18}O$ values during the early Pliocene at this site were also only ~0.6‰ to 0.7‰ less than today's value. This permits major decreases in ice volume only in the absence of warming of deep Pacific waters (Shackleton et al., 1994).

Pliocene Sea-Level History

Evidence for marine transgressions has been widely reported for the Pliocene (Haq et al., 1988; Dowsett and Cronin, 1990). These sea-level highstands were almost certainly glacioeustatic in origin, but the absolute magnitude of the sea-level rise is debated. Haq et al. (1988) estimated the rise to be up to 60 m, a figure considered too high by other workers (e.g., Greenlee and Moore, 1988). Melting of all Antarctic ice would raise sea level by about 70 m, melting of just the West Antarctic ice sheet would raise sea level by 5 m, and melting of the Greenland ice sheet would raise sea level by 7.4 m. We assume that the Greenland ice sheet would not have survived in the case of major melting of Antarctic ice. With the exception of that of Haq et al. (1988), most estimates of sea-level rise would not permit total deglaciation of Antarctica during the Pliocene. A reduction in Antarctic ice volume to two-thirds of present volume, as suggested by Webb and Harwood (1991), would require a sea-level rise of ~54 m (47 m for East Antarctica; 7 m for Greenland).

Stratigraphic studies at Enewetak Atoll indicate early Pliocene sea-level highstands up to 29–36 m above that of the present (Wardlaw and Quinn, 1991). Similarly, Krantz (1991) estimated early Pliocene sea-level highstands up to 25–35 m for the U.S. Middle Atlantic coastal plain. For the same region, Dowsett and Cronin (1990) estimated a sea-level highstand of 35 ± 18 m between 3.5 and 3.0 Ma. The oxygen isotopic records do not necessarily preclude a maximum sea-level rise of 35 m (= 0.35‰ assuming a late Pleistocene $\delta^{18}O$ ice volume calibration), but the amount of warming would be too small (1.4 °C at most or equivalent to 0.35‰) to have caused major Antarctic deglaciation in the first place. Average sea-surface warming of 2 °C at high southern latitudes and sea level 25 m higher than today are conceivable for brief periods during the Pliocene. However, the amount of warming and deglaciation would have been less than these maximum estimates in most of the Pliocene.

Sea-level changes during Pliocene-Pleistocene time led to multiple ice-sheet grounding episodes over the Antarctic continental shelf (Alonso et al., 1992), but these events were not related to major continental deglaciation, nor were they necessarily related to major changes in ice-sheet volume.

Ice-Sheet History: Ice-rafted Detritus

The presence of ice-rafted detritus (IRD) in sediments far to the north of the Antarctic continent in northern Antarctic and Subantarctic waters is a clear indication of major continental ice sheets. IRD is transported far northward when icebergs are common and sea-surface temperatures cold enough to prevent rapid melting. IRD is absent or rare far to the north of the continent during times of reduced continental glaciation and a warmer Southern Ocean. A reduction in Antarctic ice volume by two-thirds and an increase in Southern Ocean sea-surface temperature by more than 5 °C would have led to a major decrease in the flux of IRD and a southward contraction in its distribution.

The stratigraphic distribution of IRD was presented quantitatively by Warnke et al. (1992) for late Neogene Subantarctic sequences of the South Atlantic (50°S). IRD in this area was transported in icebergs from the Weddell Sea area. In the southwest Atlantic (ODP Sites 699 and 701), IRD first appeared at ~6 Ma and has been present continuously, although in varying amounts, up to the present time (Fig. 4). The IRD record in Antarctic

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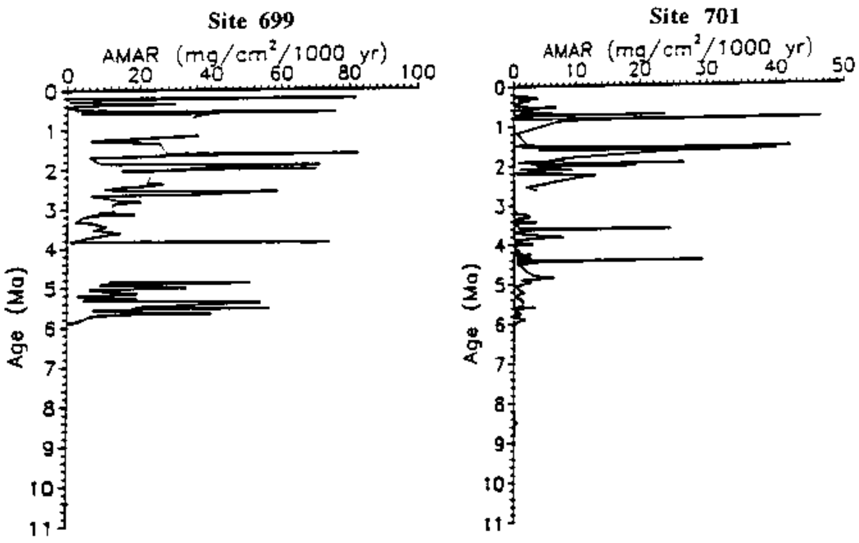

Figure 4. Apparent mass accumulation rate (AMAR) of coarse-grained ice-rafted detritus (IRD) at ODP Site 699 (lat 51°32.5'S, long 30°40.6'W) and 701 (51°9.1'S, 23°12.7'W) from the Subantarctic sector of the southwest Atlantic Ocean (from Warnke et al., 1992). The persistent occurrence of IRD in the Subantarctic throughout the Pliocene argues against major deglaciation of the Antarctic continent.

waters of the Kerguelen Plateau (ODP Site 751; 58°S; Breza, 1992) and Maud Rise (65°S; Kennett and Barker, 1990) shows an upward increase in IRD abundance during the early Pliocene. The Pliocene was marked by persistent delivery of IRD in many parts of the Southern Ocean, with no suggestion of significant reduction in the northward distribution of iceberg sediment transport (Warnke et al., 1992). This almost certainly would have occurred in response to large-scale deglaciation of Antarctica. The records indicate continued existence of major continental ice sheets on Antarctica during the Pliocene.

Pliocene History of the Polar Front (Opal-Carbonate Transition)

The Polar Front zone is marked by a transition from biosiliceous productivity and diatom ooze to the south to dominantly biocalcareous productivity and foram-nannofossil ooze to the north. Deep water wells up south of the zone and creates weakly stratified, chemically homogeneous waters of the Antarctic circumpolar current. The upwelling results in high diatom productivity and formation of the biosiliceous ooze belt. The history of the Antarctic biosiliceous belt is well known from deep-sea drilled sites. Siliceous biogenic sediments appeared in the Antarctic during the late Oligocene–early Miocene, reflecting a progressive increase in upwelling, as a result of the development of circumpolar flow when the Drake Passage opened (Kennett and Barker, 1990). On Maud Rise, for example, sedimentation was almost exclusively biosiliceous from the middle late Miocene to the Quaternary. This and other evidence indicates that the biosiliceous belt, and presumably the Antarctic circumpolar current, has remained well established far north of the Antarctic continent since at least the late Miocene.

A major warming and southward retreat of the Polar Front zone during the Pliocene would have caused a southward retreat of the siliceous-calcareous boundary. Instead, biosiliceous sediments continued to dominate the Southern Ocean, and calcareous microfossils remained rare to absent in Pliocene sediments (Lazarus and Caulet, 1993). Experimental studies indicate that sediment-forming calcareous nannoplankton do not form coccoliths (calcareous platelets) at temperatures below 3 °C (Burckle and Pokras, 1991). Furthermore, coccoliths are almost completely absent in sediments south of the Polar Front today. Absence of calcareous nannofossils in Antarctic Pliocene sedimentary deposits suggests that surface-water temperatures were then also lower than 3 °C. The sedimentologic data provide no compelling evidence to support major southward migration of the biosiliceous belt during the Pliocene, implying that a broad zone of cold Antarctic waters continued to isolate the continent.

Planktonic Microfossils and Antarctic Surface–Water Temperatures

Early Pliocene siliceous planktonic microfossil assemblages in Antarctic waters have long been considered indicative of temperatures warmer than the present day (Ciesielski and Weaver, 1974; Abelmann et al., 1990). However, the amount of warming is debated. Estimates for average Antarctic surface-water temperatures range from >~10 °C, from silicoflagellates (Ciesielski and Weaver, 1974), to ~5 to 10 °C, based on radiolarians and diatoms (Abelmann et al., 1990), to <3 °C, based on an absence of calcareous nannofossils (Burckle and Pokras, 1991). These estimates compare with average modern sea-surface temperatures of ~1 °C in winter and <3.5 °C in summer. In close agreement with Burckle and Pokras (1991), our interpretations of oxygen isotopic data suggest that Pliocene Antarctic sea-surface temperatures were higher than those of today but lower than 3 °C. If $\delta^{18}O$ values in Site 704 are interpreted solely as a temperature signal, then Subantarctic waters were no more than 2.5 °C warmer than today.

The Southern Ocean biota is among the most distinctive on Earth. It contains a very high level of endemism in many taxonomic groups, reflecting relative isolation of the fauna since the formation of the Polar Front zone (Clarke and Crame, 1989). A large fraction of the Antarctic siliceous microfossil planktonic assemblage from the early Pliocene consists of endemic species (Barron and Baldauf, 1989; Abelmann et al., 1990). If significantly warmer waters had displaced cold Antarctic waters far to the south during the Pliocene, the Antarctic biota would have lost much of its endemism. Instead, biotic exchange between Antarctica and lower latitudes has been very limited. For instance, Antarctic waters have been marked by strong endemic radiolarian faunas since the middle Miocene (Lazarus and Caulet, 1993). The modern Antarctic invertebrate and vertebrate fauna contain abundant taxa exhibiting considerable specialization to the environmental extremes, suggestive of long-term environmental stability. Such stability is also suggested by within-site invertebrate diversity as high as anywhere in the world (Clarke and Crame, 1989). Pliocene warming must have been of insufficient magnitude to reverse developing endemism of the Antarctic biota, including plankton (Barron and Baldauf, 1989; Abelmann et al., 1990; Lazarus and Caulet, 1993).

Terrestrial Vegetation: Marine Sediment Evidence

Except for occasional reworked palynomorphs, pollen and spores are absent in late Neogene Southern Ocean sequences (Burckle and Pokras, 1991). If major deglaciation had occurred during the Pliocene, it is likely that vegetation would have been present, at least in coastal areas, supplying pollen and spores to nearby marine sediments. This would be expected especially if the fossil vegetation associated with high-altitude Sirius deposits is of Pliocene age as interpreted by Webb and Harwood (1991). No evidence of terrestrial vegetation has been found in numerous sites drilled close to the continent. The youngest pollen assemblages reported from Antarctica that unequivocally reflect coeval continental vegetation are Oligocene in age (Truswell, 1986; Mildenhall, 1989). The absence of Neogene pollen has generally been interpreted to reflect the demise of continental vegetation during the middle Cenozoic in response to the development of the Antarctic cryosphere (Truswell, 1986).

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Penrose Conference Scheduled

The Argentine Precordillera: A Laurentian Terrane?

October 14–20, 1995

A Geological Society of America Penrose Conference, “The Argentine Precordillera: A Laurentian Terrane?” and associated field trips will be held October 14 to 20, 1995, in San Juan, Argentina, in the foothills of the Argentine Precordillera. It will be followed immediately by a related 1–2-day conference in Jujuy, Argentina, and a 5-day trans-Andean field trip across northern Argentina and Chile sponsored by IGCP Project 376 (Laurentia-Gondwana Connections Before Pangaea). (For information about the Jujuy conference, contact Victor Ramos, Dept. de Geología, Universidad de Buenos Aires, Ciudad Universitaria, 1428 Buenos Aires, Argentina; E-mail: ernesto@geotec.uba.ar.)

The main objective of the Penrose Conference will be to review in the field, and discuss in San Juan, the evidence for the hypothesis that the early Paleozoic age rocks in the provinces of San Juan and Mendoza are parts of an exotic terrane displaced from eastern or southeastern Laurentia during the Ordovician. These rocks represent Cambrian and Early Ordovician age carbonate bank and adjacent slope-facies sediments similar in stratigraphy and faunas to coeval rocks of eastern or southeastern Laurentia. Recently, Grenville ages for the basement of this terrane have been determined, and Ordovician (Iapetus) K-bentonites have been found, further supporting the connection to eastern or southeastern Laurentia. Paleomagnetic data are consistent with a possible collision of eastern Laurentia with western Gondwana in the Ordovician. The Ouachita margin of Laurentia has been proposed as a source for the exotic terrane.

Confirmation of an eastern or southeastern Laurentian source for this terrane and the timing of its transfer to Gondwana will radically alter conventional understanding of global early Paleozoic paleogeography, paleoenvironmental development, and tectonics prior to the assembly of Pangaea.

The conference will bring together an international group of geologists best equipped to evaluate the hypotheses discussed above. This group will include North American geologists familiar with the Cambrian and Ordovician faunas and depositional systems and the early Paleozoic tectonics of the Appalachian and Ouachita orogens, and Argentine and European geologists familiar with the stratigraphy and faunas of the exotic terrane and the tectonics of the early Paleozoic orogen adjacent to its inboard margin.

Participation in the conference will be limited to about 70 persons. The conference fee, which is not yet determined, will include registration, food and lodging, and field trip costs. Limited support is planned for qualified graduate students.

Formal invitations will be mailed in May 1995. Co-conveners of the conference are: ***Ian W. D. Dalziel,*** Institute for Geophysics, University of Texas at Austin, 8701 N. Mopac Blvd., Austin, TX 78759-8397, (512) 471-0431, fax 512-471-8844, E-mail: ian@utig.ig.utexas.edu; ***Allison R. (Pete) Palmer,*** Institute for Cambrian Studies, 445 N. Cedarbrook Rd., Boulder, CO 80304-0417, (303) 443-1375, fax 303 443-1375, E-mail: palmera@spot.colorado.edu; ***Luis H. Dalla Salda*** and ***Carlos A. Cingolani,*** Centro de Investigaciones Geológicas, University of La Plata, calle 1 Nro. 644, 1900 La Plata, Argentina, fax 54-21-25-8696.

Application Deadline: April 1, 1995. To apply for the conference, please provide the following information: (1) name and position; (2) organization and mailing address; (3) phone number, fax number, and E-mail address if available; (4) your field of interest; and (5) a brief statement as to what your interest and experience have been with regard to the conference topic. Send applications to Ian W. D. Dalziel at address above. ■

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CONCLUSIONS

Marine sediments contain a compelling range of evidence indicating that ocean and terrestrial climates of Antarctica and the Southern Ocean remained cold and relatively stable during early Pliocene global warmth and that Antarctica did not experience major deglaciation. We suggest that isotopic and other data from deep-sea sediments are inconsistent with a two-thirds ice volume decrease (= > 47 m sea-level rise) and 5 °C high-latitude surface-water warming advocated by the deglaciation hypothesis (Webb and Harwood, 1991). Antarctic surface-water temperatures are unlikely to have increased by more than ~3 °C. Significant warming in the Arctic during the Pliocene is not matched by equivalent warming in the Antarctic. The relative robustness of the late Neogene Antarctic climate system is supported by modeling experiments by Robin (1988), who suggested that the Antarctic cryosphere expands in steps due to feedback loops that drive the system toward greater stability. Thus, once a large ice sheet is formed, it will not disappear unless climate becomes much warmer than during its formation.

We believe that with the formation of both ice sheets by the end of the Miocene, the modern Antarctic cryosphere-ocean system became well established (Kennett, 1977). The deep-sea sediment record from the Southern Ocean supports relative stability of the Antarctic cryosphere-ocean system since the late Miocene. This interpretation is in conflict with the deglaciation hypothesis. We suggest that an assigned late Pliocene age for the Sirius Group requires reevaluation, since this is the foundation of the deglaciation hypothesis. Studies are also required to establish alternative mechanisms for the emplacement of late Neogene diatoms in Sirius Group outcrops.

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REFERENCES CITED

Abelmann, A., Gersonde, R., and Speiss, V., 1990, Pliocene-Pleistocene paleoceanography of the Weddell Sea—Siliceous microfossil evidence, *in* Bleil, U., and Thiede, J., eds., Geological history of the polar oceans: Arctic versus Antarctic: Amsterdam, Kluwer, p. 729–759.

Alonso, B., Anderson, J. B., Diaz, J. I., and Bartek, L., R., 1992, Pliocene-Pleistocene seismic stratigraphy of the Ross Sea: Evidence for multiple ice sheet grounding episodes: Contributions to Antarctic Research, v. 3, Antarctic Research Series 57, p. 93–103.

Barrett, P. J., 1991, Antarctica and global climate change: A geological perspective, *in* Harris, C., and Stonehouse, B., eds., Antarctica and global climate change: Boca Raton, Florida, Lewis Publishers, p. 35–50.

Barrett, P. J., Adams, C. J., McIntosh, W. C., Swisher, C. C., and Wilson, G. S., 1992, Geochronologic evidence supporting Antarctic deglaciation three million years ago: Nature, v. 359, p. 816–818.

Barron, J. A., and Baldauf, J. G., 1989, Tertiary cooling steps and paleoproductivity as reflected by diatoms and biosiliceous sediments, *in* Berger, W. H., et al., eds., Productivity of the ocean: Present and past (Dahlem Workshop Life Research Report, 44): Chichester, UK, John Wiley & Sons, p. 341–354.

Breza, J. R., 1992, High resolution study of ice-rafted debris, ODP Leg 120, Site 751 southern Kerguelen Plateau, *in* Proceedings of the Ocean Drilling Program, Scientific Results, Volume 120: College Station, Texas, Ocean Drilling Program, p. 207–221.

Burckle, L. H., and Pokras, E. M., 1991, Implications of a Pliocene stand of *Nothofagus* (southern beech) within 500 kilometres of the South Pole: Antarctic Science, v. 3, p. 389–403.

Cattle, H., 1991, Global climate models and Antarctic climatic change, *in* Harris, C., and Stonehouse, B., eds., Antarctica and global climatic change: Boca Raton, Florida, Lewis Publishers, p. 21–34.

Ciesielski, P. F., and Weaver, F. M., 1974, Early Pliocene temperature changes in the Antarctic seas: Geology, v. 2, p. 511–515.

Clapperton, C. M., and Sugden, D. E., 1990, Late Cenozoic glacial history of the Ross Embayment, Antarctica: Quaternary Science Reviews, v. 9, p. 252–272.

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Letter from Washington

Jill Schneiderman

I'm happy to have the opportunity to communicate with my colleagues about my activities and experiences up on Capitol Hill as GSA's 1994–1995 Congressional Science Fellow. For those readers unfamiliar with the program, the American Association for the Advancement of Science has, since 1973, administered the Congressional Science and Engineering Fellowship Program. During the first 20 years of the program, more than 500 scientists and engineers sponsored by 40 professional organizations worked as Fellows on the staffs of approximately 200 personal and committee offices in the House and Senate, and within the Congressional Budget Office, the Congressional Caucus for Women's Issues, the Congressional Research Service, and the Office of Technology Assessment. The purpose of the program is (1) to teach policy making to scientists by providing them an immediate role in legislative processes; (2) to train scientists to participate effectively in policy making; and (3) to bring science expertise to members of Congress.

Societies including the American Geophysical Union, American Veterinary Medical Association, Triangle Coalition for Science and Technology Education, Federation of American Societies of Food Animal Sciences, American Chemical Society, American Society of Mechanical Engineers, Soil Science Society of America, National Society of Professional Engineers, American Psychological Association, American Physical Society, American Institute of Physics, and Institute of Electrical and Electronics Engineers have sponsored 29 Fellows on Capitol Hill this year. We are a diverse lot: recent Ph.D.s, research scientists, educators, engineers, racetrack veterinarians, psychologists, and scientists embarking on careers in science policy.

"Science in the National Interest," President Clinton's August 1994 report that outlines goals for fundamental science and education, quoted Vassar College alumna Vera Rubin of the Carnegie Institution of Washington: "… scientists both in and outside of academia must take seriously their mission to educate in science and science appreciation those who will and will not be scientists." This sentiment prompted me to apply for the GSA fellowship, for I believe that an interdisciplinary science curriculum integrating policy issues with investigations in natural sciences is critical for dynamic undergraduate science education. In my role as Congressional Science Fellow, I see myself as a liaison between government and the geoscience community working toward comprehension of policy and science issues in reciprocal arenas. I am eager to share this year's "insider's" view of the policy-making process with our colleagues and to articulate their potential role in it.

The first eight weeks of the fellowship included a three-week orientation, two weeks of placement interviews, one week at the annual GSA meeting, and two weeks learning my way around my new office. It has been tremendously eye-opening and thought-provoking. The orientation was an exhaustive introduction to the workings of the U.S. government, executive, legislative, and judiciary branches. Top-level policymakers explored with us topics including: domestic and international perspectives on post–Cold War science and technology policy; science and technology as instruments of foreign policy; historical perspectives on White House science advising; mega-science projects and international cooperation; science and technology policy and U.S. economic competitiveness; science, technology, and global environmental issues; intellectual property rights; international security; executive branch and congressional budget processes; legislative process; congressional committees and floor procedures; lobbying the Congress; and communicating science policy news. What we tried to understand could have been at least a semester-long course in science policy. One education resource I recommend from this orientation is the film "An Act of Congress"; narrated by E. G. Marshall, it chronicles the progress of legislation that led to passage of the Clean Air Act and conveys the excitement of science policy-making on Capitol Hill.

We lunched and spoke with Senator Jay Rockefeller (D—W. Va, Commerce, Science and Transportation committee) and Representative George Brown (D—Calif., Science, Space and Technology committee, chair); overloaded on resources available to us from the Congressional Research Service; visited and tried to absorb the mission of the Office of Technology Assessment, General Accounting Office, and White House Office of Science and Technology Policy; and toured the Old Executive Office Building, a magnificent Victorian building with mansard roofing constructed between 1871 and 1888 to house the State, War, and Navy departments.

After entertaining practical suggestions from former science Fellows on how to search for and locate a potentially stimulating office to work in for our fellowship year, we occupied an office in the Hart Senate Office Building and began the job interview process. We'd been advised to take our time and use the opportunity to educate ourselves through interviews about the structure, processes, and goals of Senate and House personal offices and committees. We began this process on September 22, two weeks before the end of the 103rd Congress. The interviews in congressional offices at that frantic moment afforded us a glimpse of the pace and agenda of politics in a waning Congress that we'd not have seen had we been Fellows beginning in an odd year (1993 or 1995). I interviewed with 15 personal offices (House and Senate) and four committees.

After weighing several options (there are always more offices looking for Fellows than there are Fellows to go around), I chose to work for Senator Tom Daschle (D—S. Dak.). He is a second-term Senator, not up for reelection, is co-chair of the Democratic Policy Committee, and serves on the following committees: Finance, Veterans' Affairs, Indian Affairs, Select Ethics, and Agriculture, Nutrition and Forestry. He also chairs the Subcommittee on Agricultural Research, Conservation, Forestry and General Legislation, which has jurisdiction over U.S. Forest Service lands. Since the number of staff in a Senator's office is a function of state population, the number of staff working in Senator Daschle's office is relatively small. That fact guarantees that I will have substantial opportunities to work on a range of issues in a variety of venues. I am working closely with a legislative assistant responsible for environmental issues who is trained as a forest ecologist. Our complementary expertise will serve the Senator well as we work on policy issues grounded in a respectful appreciation of the earth as a system of interacting reservoirs: geosphere, hydrosphere, biosphere, and atmosphere. Though only two weeks into my assignment (as I write this), I've already done substantive work (reading, writing, reporting) on an ecosystem management bill for U.S. Forest Service land, a proposal to form a National Institute for the Environment, and legislation related to interstate transportation of municipal solid waste. We also anticipate working on mining law reform, Superfund, wetlands issues as part of a farm bill, pesticide legislation, and the Clean Water Act when the 104th Congress convenes this month (January 1995).

Campaign rhetoric was mean-spirited, wealthy candidates spent personal fortunes to get elected, and voters were cynical or lazy. Though free television time and postage for bona fide candidates and an election day holiday would alleviate pressures on candidates and voters, such simple measures were not taken. Still, approximately 59 new democracies have started since 1989, and most of them have chosen our system of government or a mixed system that includes substantial aspects of democracy. I look forward to using this forum as a means to engage our colleagues in considerations of the role of geoscientists in policy-making in what Sir Winston Churchill called "the worst form of government, except all those other forms that have been tried from time to time." ■

Jill S. Schneiderman, 1994–1995 GSA Congressional Science Fellow, is serving on the staff of Senator Thomas Daschle (S. Dak.). Schneiderman may be contacted at (202) 224-2321. The one-year fellowship is supported by GSA and by the U.S. Geological Survey, Department of the Interior, under Assistance Award No. 1434-94-G-2509. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. govenment.