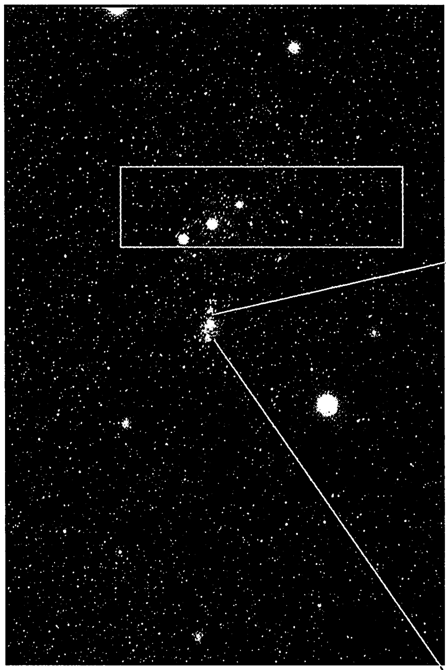

A well-known star nursery. One of the most intensely studied star-formation regions, the Orion Nebula (right), is found in Orion's Sword. Briceño *et al.* have focused on stellar variability in less active regions to gain insights into the early stages of star formation believed to be associated with the generation of planets.

within about 10 million years of their formation that alternative spectral tracers [such as infrared emission from molecular hydrogen (*8*)] may be required to detect any residual material.

Other recent imaging studies of the Orion region have also made use of, or were concerned with, stellar variability. Infrared imaging data collected as part of the Two Micron All-Sky Survey (2MASS) (*9*) demonstrated that about 40% of the roughly 2700 stars in the Trapezium's vicinity are variable, including the well-studied, infrared-luminous Becklin-Neugebauer object (*10*, *11*). The spatial distribution of these infrared variable stars closely follows that of the dense molecular cloud, emphasizing the close relation between intrinsic stellar variability and stellar youth. But the infrared variables detected by 2MASS display a wide variety of temporal behavior, ranging from periodic to random. This suggests that a wide variety of physical mechanisms are responsible for variability in young stars. Potential explanations include rapid rotation of spotty surfaces, short-lived accretion events, and temporary obscuration of stars by orbiting or infalling dust clouds.

Chandra X-ray Observatory high-resolution imaging observations of Orion (*12*, *13*) have established beyond doubt that almost all young stars are prolific sources of x-ray emission. This high-energy emission appears to occur often in the form of relatively short but very strong bursts of hard x-rays. The most volatile x-ray sources appear to be the very youngest, most highly obscured protostars, but almost all sunlike stars in Orion display variable x-ray output (*13*).

The Briceño *et al.* wide-field optical search for variable stars in Orion will continue to cover new ground, and we can expect this work to identify many hundreds of additional young stars. Statistical analyses of these new populations should offer further specifics concerning the time scale for planet formation. Meanwhile, the wealth of imaging data recently collected for Orion suggests that over a remarkably wide range of the electromagnetic spectrum, the one constant of stellar youth is variability.

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PERSPECTIVES: PALEOCLIMATE

Climate Change Across the Hemispheres

Nicholas Shackleton

Ice cores from Greenland have provided evidence that dramatic and rapid changes in air temperature occurred during the last ice age. Temperatures over Greenland changed by as much as 10°C within decades. It is generally accepted that simultaneous changes in temperature must have occurred in the entire North Atlantic region because the Greenland temperature changes were associated with migrations of the Atlantic polar front, the main boundary line between polar and temperate water masses, from near Greenland to as far south as the coast of southern Portugal.

Ice-core records from Antarctica cover a much longer time interval than the Greenland ice cores (Antarctic ice cores document several ice-age cycles, Greenland only a single cycle), and at first the length of the Antarctic records attracted more attention than the finer-scale details. Recently it has become apparent that the Antarctic ice cores also record important temperature variability on millennial and shorter time scales. Comparison of records from the two hemispheres may thus help to answer some of the following questions: Are temperature changes on millennial time scales global in extent? Are changes in the two hemispheres synchronous? Or does a "polar seesaw" operate, with excess warmth flipping from one hemisphere to the other? What causes this enormous variability? The work reported by Blunier and Brook on page 109 of this issue (*1*) is important not so much because it answers all these questions, but because it provides a sound basis for tackling them.

Absolute dating of geological records is notoriously difficult. Thus, in order to interpret an array of geological records of climatic change, it is essential that they are at least expressed on a common relative time scale. Blunier and Brook have used

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the record of abrupt changes in atmospheric methane concentration to synchronize the ice-core records from the two hemispheres. Methane is trapped in air bubbles in the northern and southern polar ice sheets. Because methane is rapidly mixed in the atmosphere, the atmospheric methane concentration should always be almost the same in Greenland and in Antarctica. Thus, matching the two methane sequences can synchronize the air temperature records in the two polar ice caps.

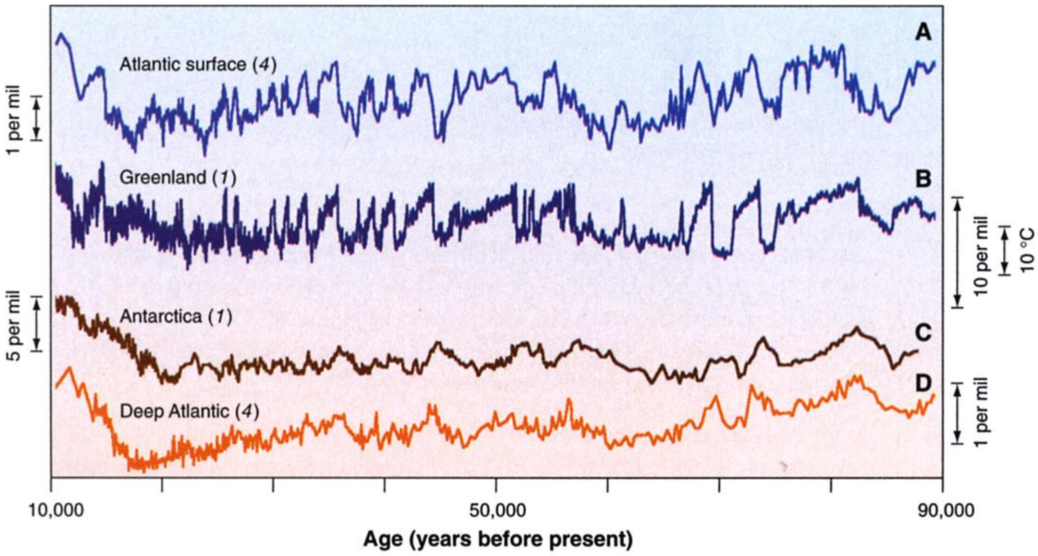
For the Northern Hemisphere, Blunier and Brook (*1*) used the records of methane concentration from the Greenland Ice-core Project (GRIP) and Greenland Ice Sheet Project 2 (GISP2) ice cores. To this composite record from the two northern ice-cores, they correlated a new atmospheric methane data set from the Antarctic Byrd ice core. They used about 20 tie points, most of which have a relative uncertainty of only about 300 years. In their report, they show the records on the time scale developed for the GISP2 core (*2*) but also provide the records on the time scale of the GRIP core (*3*) (see the figure). The GISP2 time scale may be more accurate over the intervals where annual layers can be reliably identified and counted; on the other hand, the GRIP time scale may be more reliable in other intervals. The reason for this is that the GRIP time scale incorporates the assumption that snowfall varied as a function of air temperature (as indeed it must do over the central part of such a large ice sheet, because the colder the air mass over the ice sheet, the less water vapor it carries). In contrast, the GISP2 time scale makes no such assumption; where countable layers cannot be detected, constant snowfall is assumed. As a result, some of the warm events appear relatively shorter on the GRIP time scale (because some of the thickness has been attributed to higher snowfall) than on the GISP2 time scale, whereas cold intervals appear relatively longer on the GRIP time scale. Obviously, this systematic difference between the two approaches to time scale development will have a significant impact on the statistical interpretation of the details of the superb ice-core records, and must be resolved in the future.

Regardless of the exact ages, Blunier and Brook (*1*) demonstrate a consistent pattern throughout the last ice age. Antarctic temperature gradually rises while it is cold over Greenland, and gradually cools while it is relatively warm over Greenland. Over Greenland, the transition from cold to warm conditions typically occurred extremely rapidly (within one or two decades), and it appears that the transition from gradual warming to gradual cooling over Antarctica took place precisely at the time of each sudden warming over Greenland. Blunier and Brook (*1*) thus demonstrate beyond reasonable doubt that temperature does not vary synchronously in the two hemispheres.

Comparison of the resulting polar temperature records with two records from a deep-sea core (*4*) shows that the surface of the North Atlantic changes in synchrony with temperature over the Greenland ice sheet (see the blue curves in the figure). In contrast, the deep waters carry a record that appears to be linked to Antarctic temperature (see the red curves in the figure). In (*4*), it is suggested that the deep-water isotopic record reflects changes in the size of the Laurentide ice sheet, which covered most of Eastern Canada and the northern part of the United States during glacial times. This interpretation implies that atmospheric climate is a slave to the Laurentide ice sheet, at least in those parts of the world that are not dominated by the North Atlantic polar front. On the other hand, it has recently been shown (*5*) that on the 20,000- to 100,000-year scale of orbitally forced climatic variability, the temperature of the deep ocean follows Antarctic temperature and is decoupled from continental ice volume. Thus, the pattern illustrated here may mean that the temperature of the deep ocean was driven by millennial-scale Antarctic variability, as suggested by detailed work in a South Atlantic deep-sea core (*6*). Atmospheric carbon dioxide also appears to vary in concert with Antarctic temperature rather than with Greenland temperature (*7*), although the details of this relation await confirmation.

Another suggestion is that the millennial variability could have been driven from the tropics. Petersen *et al.* (*8*) recently presented a record from the Cariaco Basin that suggests the intriguing possibility that abrupt climate changes in tropical South America could have drastically changed water-vapor transport across the Panama isthmus, affecting Atlantic salinity and heat transport.

Blunier and Brook have provided strong evidence for asynchronous temperature changes in Greenland and Antarctica during the last ice age. The ultimate mechanism behind this climatic see-saw remains, however, uncertain.



Patterns of variability. **(A)** Sea-surface temperature variability off Portugal as indicated by oxygen isotopic composition ($\delta^{18}O$) in planktonic foraminiferal carbonate shells. **(B)** Air-temperature variability over Greenland as indicated by $\delta^{18}O$ in Summit ice (GISP2). **(C)** Air temperature over Antarctica as indicated by $\delta^{18}O$ in Byrd Station ice. **(D)** Variability in extent of North American glaciation and/or of deep-ocean temperature as indicated by $\delta^{18}O$ in benthic foraminiferal carbonate shells. Of these time series, only (B) has been reliably calibrated in terms of temperature (*9*). All data are plotted with reference to age according to the GRIP time scale (*4*).

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