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mountains preempted possible independent domestications of einkorn elsewhere in its wild range. The rapid diffusion of both einkorn and emmer in turn preempted widespread cultivation of other related domesticable wild grasses, such as Timopheev's wheat. In contrast, the New World's north-south axis required domesticates to adapt to changes of latitude as they spread. The resulting slow spread of crops within Native America permitted numerous independent domestications of the same crop or of related crops (for example, squashes and cottons) in different areas. Within less than 2000 years of the beginnings of domestication in the crescent, its results had been carried east and west to launch the origins of food production over a huge swath of Eurasia (see the figure), from Pakistan to the Balkans (*3*). Food production's expansion over the Americas, Africa, and the Indian subcontinent was much slower because of the north-south axes of those landmasses (*4*).

In short, einkorn domestication in the Karacadağ mountains exemplifies the enormous head start that western Eurasian societies gained from Fertile Crescent biogeography. For history's broad patterns, as for real estate investment, location is almost everything. Plant and animal domestication was prerequisite to the growth of large, dense, sedentary human populations, in which the food-producing activities of part of the population yielded storable food surpluses to feed non–food-producing parts of the population. Hence, food production triggered the emergence of kings, bureaucrats, scribes, professional soldiers, and metal-workers and other full-time craftspeople (*4*). Literacy, metallurgy, stratified societies, advanced weapons, and empires rested on food production. In addition, smallpox and the other crowd epidemic diseases of Eurasia could evolve only in those dense, sedentary human populations living in close contact with domesticated animals, whose own pathogens evolved into those specialized pathogens afflicting us (*4*). Thus, a long straight line runs through world history, from those first domesticates at the Karacadağ mountains and elsewhere in the Fertile Crescent, to the "guns, germs, and steel" by which European colonists in modern times destroyed so many native societies of other continents.

References and Notes

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2. All dates that I cite are so-called calibrated radiocarbon dates, which are corrected for temporal fluctuations in atmospheric carbon isotope ratios and thus correspond to approximate calendar years. The dates in (*1*) are younger because they instead are uncalibrated dates.
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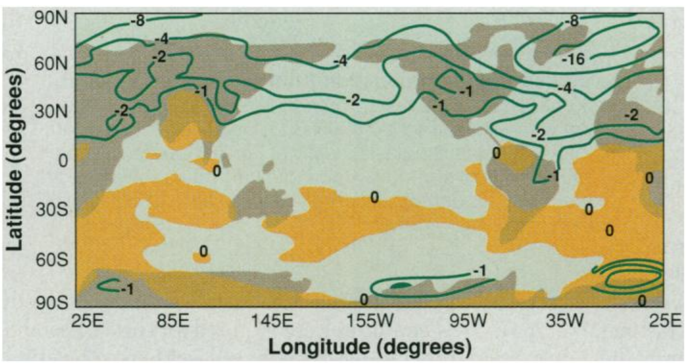
PALEOCLIMATOLOGY

Millennial Climate Oscillations

Delia Oppo

Changes in Earth's orbit around the sun influence the seasonal distribution of energy on Earth, driving the climate system in and out of ice ages in a quasi-predictable manner. As paleoclimatologists struggle to solve remaining mysteries related to the ice ages, they are faced with the prospect of explaining large, rapid millennial climate changes, which are far too frequent to be a linear response to the relatively slow changes in Earth's orbital configuration, known as Milankovitch forcing. Millennial oscillations during the last glaciation are remarkable. The beginning of each cycle is marked by a 5° to 8°C rise in air temperature over Greenland in just decades to centuries. After 1000 to 2000 years of moderate temperatures, the region plunged rapidly back into frigid conditions, only to warm again and start the next millennial climate cycle.



Sensitivity experiments with a coupled ocean-atmosphere general circulation model suggest a widespread response to millennial climate oscillations originating in the North Atlantic. When a strong meltwater pulse is injected into the model's surface North Atlantic, convective overturn ceases, causing cooling, the greatest of which (up to 16°C) occurs in the North Atlantic. The cooling is transmitted to the North Pacific (up to 4°C) primarily by the atmosphere, but the ocean plays an important role by amplifying the response (*15*).

Since the realization that records from North Atlantic sediments can capture the dramatic millennial climate oscillations of the last glacial period (*1*), first seen in ice cores, several research teams have detailed, one-for-one, their marine equivalent (*2*). Millennial oscillations have also occurred closer to the present: The current period of relative warmth, which began about 11,000 years ago (the Holocene), is less stable than generally realized, and the Little Ice Age is only one of several cool events occurring during this time (*3–5*). On page 1257 of this issue, Bond and his colleagues present the first records from the marine realm that are long enough and detailed enough to compare the characteristics of glacial and Holocene millennial oscillations (*6*).

By counting the number of rock fragments in sediments from the Denmark Strait and eastern subpolar North Atlantic, Bond *et al.* identified times of increased iceberg passage over the two sites during the glaciation and Holocene. Compositional changes of this lithic material and variations in the relative abundances of polar and subpolar surface-dwelling fauna suggest that ice-rafting events (that is, the transport of materials by icebergs) were associated with the southward penetration of cooler waters from the Greenland and Iceland seas. Although an order of magnitude smaller than their glacial counterparts, the Holocene oscillations occurred at a similar pace, every 1000 to 2000 years. This rate is indistinguishable from the 1450-year cycle identified by Mayewski and colleagues (*7*) in a Greenland ice-core record of a proxy for the size and intensity of the polar atmospheric circulation. Moreover, Bond *et al.* demonstrate that, like glacial oscillations, Holocene variations in the subpolar North Atlantic are

The author is at Woods Hole Oceanographic Institute, Woods Hole, MA 02543, USA. E-mail: doppo@whoi.edu

associated with ice-core evidence for changing conditions over Greenland.

The origin of millennial-scale climate variability is unclear. The finding of millennial-scale oscillations during the Holocene, in the absence of large ice sheets, rules out ice sheet instability as the primary cause. The interplay between the primary Milankovitch frequencies may account for climate variability at longer suborbital cycles, between 12,000 and 6,000 years (*8*), but it is unlikely that they are responsible for climate cycles of 1000 to 2000 years. Others suggest that variations in solar output may drive these climate oscillations. Bond *et al.* and Mayeski *et al.* favor an ocean-atmosphere mechanism but do not rule out primary forcing by external processes.

In the modern North Atlantic, the process of cooling surface water to form deep water, or convective overturn, provides roughly one-third as much heat as is directly contributed by the sun (*9*). Thus, variations in convective overturn can dramatically influence regional climate (see figure). Broecker introduced the concept of a "salt oscillator"—essentially controlled by the balance between fresh water delivered by melting ice and salt removed from the surface by the export of saline deep waters from the North Atlantic—to explain millennial climate oscillations during glacial times (*1*). Heat released during convective overturn may have promoted the melting of the ice sheets fringing the North Atlantic, delivering fresh water to the surface ocean. Consequently, the density of the surface waters would decrease, eventually to the point where conditions were no longer favorable for deep-water formation. As a result of the reduced heat released in the process of convective overturn, less ice would melt, salinity would rise, and eventually the system would resume the convective phase of the salt oscillator. Marine evidence of linked surface and deep-water variability during glacial and deglacial millennial oscillations is consistent with this hypothesis (*10*).

The recent finding of millennial climate oscillations in the Holocene, when large ice sheets did not surround the North Atlantic, may require modification of the "salt oscillator" hypothesis, but it by no means requires its

UPDATE: PLANETARY SCIENCE

The Early Mars Climate Question Heats Up

James F. Kasting

Recently, Sagan and Chyba (*1*) threw a new log on the smoldering question of early Mars' climate by suggesting that reduced greenhouse gases such as CH_4 and NH_3 might have helped to warm early Mars enough to maintain liquid water on its surface. The greenhouse effect of gaseous CO_2 and H_2O alone had been shown to not be up to the task (*2*). Now, in this issue on page 1273, Forget and Pierrehumbert (*3*) suggest that a CO_2-H_2O atmosphere could indeed have kept early Mars warm—if it was filled with CO_2 ice clouds. Clouds of CO_2 ice differ from water or water ice (cirrus) clouds in that they tend to scatter upwelling infrared radiation instead of absorbing and reradiating it. Thus, they form a partially reflecting layer in the infrared, just as both CO_2 and H_2O clouds do in the visible. Crystals of CO_2 ice are expected to be large (10 to 100 mm diameter), however, which means that they should scatter radiation at thermal infrared wavelengths more effectively than they scatter visible and near-infrared radiation. This variation in reflectivity, combined with the fact that the clouds are expected to form in the upper martian troposphere and not near the planet's surface, allows them to produce a strong warming effect.

In less than 6 months, the number of plausible mechanisms for keeping early Mars warm has gone from zero to two. The idea of CO_2 ice clouds may be more plausible than the CH_4 and NH_3 idea, as calculations indicate that a biological CH_4 source would probably be needed to make it work on its own (*4*). The cloud warming mechanism is complicated, however, because the amount of surface warming depends on such details as particle size, cloud height, cloud optical depth, and fractional cloud cover. These factors, in turn, depend on the details of the atmospheric circulation. As all meteorologists are aware, the realistic simulation of clouds in atmospheric general circulation models is a tricky and still largely unsolved problem for modern Earth, not to mention early Mars. The calculations for Mars point the way to a possible solution to the early Mars climate problem, but it would be a mistake to conclude that the issue is resolved.

Indeed, the hardest part of the early Mars climate problem is understanding what the climate of early Mars was really like. Ever since the Viking mission 20 years ago, a debate has raged as to how warm the martian paleoclimate must have been to form the observed surface features. Some researchers have suggested that the climate was essentially Earth-like, whereas others maintain that the global mean surface temperature was always well below freezing. Progress may be on the horizon in the form of the Mars Global Surveyor spacecraft now orbiting the planet, which should begin returning useful data sometime next spring. The combination of instruments on board, especially the high-resolution camera and the thermal emission spectrometer (which can be used to deduce mineralogy), will hopefully allow better understanding of the climatic conditions under which the martian surface features formed.

The other interesting conclusion from the Forget and Pierrehumbert report is that their calculations imply that the habitable zones around other stars may be significantly wider than thought (*5*). This is good news for ET (extraterrestrial life) enthusiasts because it increases the likelihood that life, including possibly intelligent life, exists outside our own solar system. This question is also one on which progress could conceivably be made in the not-too-distant future: NASA and ESA (the European Space Agency) have tentative plans to construct large space-based interferometers that could return infrared spectra of extrasolar planet atmospheres. It has been argued, quite reasonably, that the signature of the 9.6-μm-wavelength ozone band (which, in turn, implies the presence of photosynthetically produced O_2) could be taken as evidence for extraterrestrial life (*6*). Although such a mission is probably at least 15 to 20 years in the future, the calculations on CO_2 clouds and their effect on planetary climates provide additional reason for hoping that it might meet with success.

The author is in the Department of Geoscience, Pennsylvania State University, State College, PA 16802, USA. E-mail: kasting@essc.psu.edu

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complete abandonment. Ocean-atmosphere interactions may produce a salt oscillator by driving variations in, for example, net precipitation patterns, water vapor transport, or export of ice from the Arctic Ocean to the subpolar North Atlantic. Variation in any of these can affect the surface salinity and, hence, deep-water production (*9, 11*). Bond and his colleagues present the first chemical evidence of deep-water reduction associated with one of the earlier and more prominent Holocene cool events, but as yet, no direct evidence has been found for recurring oscillations in deep-water production associated with Holocene climate oscillations. Circumstantial evidence, however, does exist.

In a subtropical North Atlantic core, Keigwin identified carbonate minima accompanying the two most recent of Bond *et al.*'s cold events and the Little Ice Age (*5*). During the last glacial cycle, carbonate oscillations in this region were associated with chemical evidence for deep-water variability (*12*); thus, Holocene carbonate variations may also reflect deep-water oscillations. Furthermore, the very finding of coeval oscillations in the subtropical and subpolar North Atlantic may suggest deep-water variability, because it is unlikely that cold water from the Greenland and Iceland seas penetrated as far south as 34°N to cause the coolings. Instead, with a reduction in deep-water production, surface cooling might occur because less warm water was drawn northward over the subtropical site to replace sinking waters at higher latitudes. Alternatively, the subtropical coolings may be a consequence of the expanded polar atmospheric circulation, which apparently coincided with the subpolar cool events. But even such atmospheric changes may involve changes in deep-water production. If millennial-scale climate cycles are indeed paced by internal oscillations of the ocean-atmosphere system, then the presence of large ice sheets may provide the amplifying mechanism as originally envisioned (*1*) and recently modeled (*13*).

Several of the Holocene cold events, especially the one 8200 years ago and the Little Ice Age, have been recognized outside of the circum–North Atlantic region (*4, 14*), suggesting that like glacial millennial oscillations they were almost global in extent. Modeling studies suggest that the occurrence in the North Pacific of the larger deglacial and glacial oscillations may be explained by an atmospheric response to variable North Atlantic deep-water production (*15*), but the mechanisms for transmitting the signal almost globally have not been worked out. The importance of deep-water variability in the Holocene must still be confirmed. First, convincing evidence for deep-water variability must be found. Second, the difficulty of explaining the quasi-global nature of large millennial climate oscillations during the last glacial cycle reminds us that explaining the presence of subtle, widespread climate fluctuations during the Holocene will be even more daunting.

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APOPTOSIS

A Myc-Induced Apoptosis Pathway Surfaces

Douglas R. Green

Why is cancer so rare? Simple probability should dictate that in every large complex animal at least one of the huge number of dividing cells will inevitably transform and lead to cancer. Conventional wisdom has it that redundant molecular checks on cellular function, via tumor suppressors, keep the real rates of oncogenesis at low levels. But an emerging view, pioneered by G. Evan at the Imperial Cancer Research Fund Laboratories in London, suggests an additional process at work; that is, that the basic mechanisms of cellular proliferation and transformation are tied to the process of apoptosis: The default for all proliferating cells is to die unless specifically told not to do so.

This concept of an active suppression of death (via specific survival signals) arose from the observation that c-Myc drives apoptosis in fibroblasts unless survival factors are present (*1*). Likewise, the anti-apoptotic effects of Bcl-2 are mediated by the diversion of c-Myc signals toward cell proliferation rather than cell death (*2, 3*).

c-Myc, in association with its partner Max, functions as a transcription factor to drive apoptosis when low amounts of survival factors, such as IGF-1, are present (*4, 5*). But what does Myc-Max induce (or repress) that is responsible for the death of cells? In this issue, Hueber *et al.* on page 1305 (*6*) show that c-Myc–induced cell death in fibroblasts is mediated by the cell surface interactions of Fas (CD95) with its ligand, FasL (CD95L). This effect is due, at least in part, to the ability of c-Myc to sensitize the cells to Fas-mediated apoptosis, an effect of c-Myc that is also seen in tumor necrosis factor–induced apoptosis (*7, 8*). The death pathway induced by c-Myc meanders to the cell surface, where the binding of Fas by its ligand generates a critical apoptotic signal, leading ultimately to the activation of caspase proteases and the death of the cell (see figure).

This "surfacing" of a c-Myc–dependent cell death pathway via Fas-FasL interaction has been described before only in T lymphocytes, during activation-induced apoptosis. Ligation of the T cell receptor (TCR) on previously activated or transformed T cells induces the expression of FasL, which then binds Fas, either on that cell itself or on the surface of a neighboring cell (*9–11*). This induction is dependent on c-Myc expression in the T cells, as demonstrated by the use of antisense or dominant-negative approaches (*12, 13*). That is, activation-induced cell death in T cells occurs by c-Myc–dependent, Fas-FasL–mediated apoptosis.

Perhaps it should not have been surprising to immunologists that the activation-induced cell death pathway in T cells surfaces to allow the engagement of a second receptor-ligand interaction in order for the process to proceed. After all, this is how the immune system often works: Clonal selection occurs when TCR signals affect transcriptional activation of cytokine and cytokine receptor genes, so that the activation pathway again surfaces in the form

The author is in the Division of Cellular Immunology, La Jolla Institute for Allergy and Immunology, San Diego, CA 92121, USA. E-mail: dgreen5240@aol.com