dination sites, thus enabling a greater overall system relaxation. This effect is analogous to step proliferation, a well-known stress relief mechanism in strained heteroepitaxial films on surfaces (*2*). The relaxation achieved by CO tilting at steps can be likened to the reason why some of us have a preference for the aisle seat. The advantage that CO has is its ability to force a rearrangement of seats that allows more molecules to reside at the coveted aisle.

The initial stage of the surface rearrangement reported by Tao *et al*. is similar to the oxygen-induced step doubling observed previously on vicinal surfaces of Pt and other metals in UHV (*3*–*7*). If this behavior is indeed general, then we may expect to find CO-induced nanocluster formation at step edges of many vicinal metal surfaces under ambient conditions.

The results of Tao *et al*. help to bridge the gap between UHV studies of step morphology and dynamic catalytic particle changes under ambient conditions (*8*, *9*). A crystalline particle changes its shape by mass transport over its surface. Because steps are the mass sources and sinks for this process, shape changes must involve step motion. Experiments providing correlated chemical and morphological information, such as those of Tao *et al*., can elucidate the atomic mechanisms that lead to particle shape changes.

Changes in step morphology that may occur as catalytic reactions progress must now be considered in studies of catalytic behavior. However, better understanding of catalyst behavior requires knowledge not only of the structures—as provided by Tao *et al*.—but also the kinetics of nanocluster formation. Entropy also reduces step free energies on clean surfaces, resulting in equilibrium fluctuations of step shape that become more pronounced as temperature is increased (*10*). To explore the possible impact of these effects on catalysis, the methods used by Tao *et al*. should be extended to even higher pressures and temperatures.

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CLIMATE CHANGE

Ice Age Rhythms

Evidence for high sea level ~81,000 years ago provides new insight into ice age history.

R. Lawrence Edwards

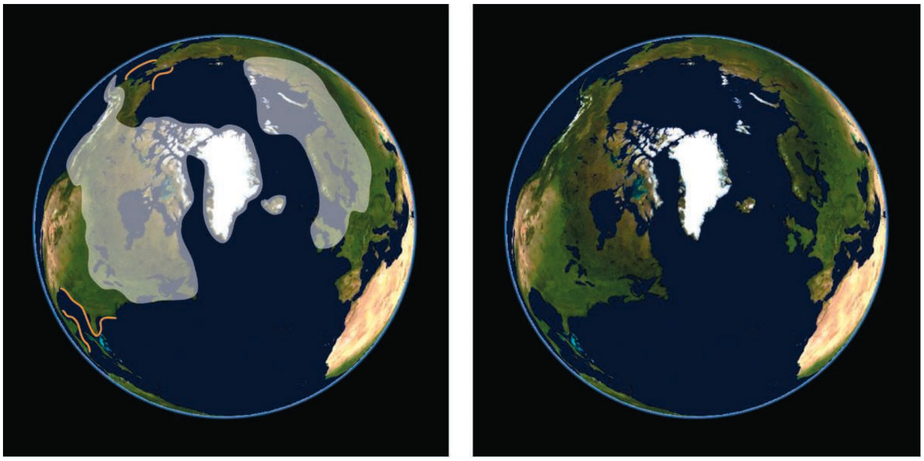
What caused the series of more than 20 ice ages that have come and gone during the past 2 million years of Earth history? On page 860 of this issue, Dorale *et al*. (*1*) reveal a new twist in the most recent ice age cycle and demonstrate once again the rapidity with which large ice sheets can come and go.

The great Northern Hemisphere ice sheets of past ice ages have sculpted the surfaces of much of the northern continents and shifted positions of shorelines worldwide (see the figure). The changing climates of the ice ages provided the environmental backdrop for the last episode of human evolution. Advancing and retreating shorelines modified migration routes for humans and other species. Some of today's most productive soils in the American Midwest, central China, and southeastern Europe developed on wind-blown silt (loess) deposited during glacial times. The waxing and waning of ice sheets thus shaped much of today's world, and knowledge of their causes may help us understand some of the challenges that we face in the coming decades and centuries of climate change (*2*).

Given that climate differs widely from region to region, reconstructing hundreds of thousands of years of climate history would seem to be an impossible task. Earth scientists have therefore sought measuring sticks that integrate climate. One such measure is sea level, an inverse measure of the volume of ice stored above sea level on continents. As the continental ice sheets grew and decayed, sea level dropped and rose, falling to as low as ~130 m below present levels and rising as high as several meters or more above present levels. Sea level is thus a good (but not perfect) measure of the waxing and waning of the ice sheets.

For this reason, accurate sea-level reconstruction is a central goal of climate research. The gross features of the curve are now known (*3*), but there is still a need to improve resolution, accuracy, and precision, both in time and elevation, and to resolve discrepancies. Seemingly small errors can have major implications: An error of 6 m in sea-level elevation is equivalent to the presence or absence of all the ice currently on Greenland.

Early work on sea-level history (*4*, *5*) found a strong link between sea level and the inten-



Whither the 100,000-year cycle? Previous data suggested that each of the last several ice age cycles took ~100,000 years. If this were the case, then ~81,000 years ago, Earth's ice cover should have been intermediate between the glacial (*14*) and the modern state. Dorale *et al*. present evidence that instead, ~81,000 years ago, ice cover was similar to today's. Orange lines indicate shoreline positions in the ice age world. Sea ice is not depicted.

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sity of Northern Hemisphere summer sunlight (insolation), the latter calculated from known changes in the geometry of Earth's orbit and rotation axis. This observation provided support for the Milankovitch (*6*) or astronomical theory of the ice age cycles. However, the early data also posed a serious problem. Calculated sunlight variations have periods of ~23,000, ~41,000, and ~100,000 years, with the latter periodicity much weaker than the others. The ice age cycles contain the same periodicities, but for the last several cycles, the dominant period is ~100,000 years, the least significant in the sunlight calculation (*4*). A generation of scientists has strived to explain this "100,000-year problem" through nonlinear responses of Earth's climate to changes in the seasonal distribution of sunlight (*7*, *8*) or to processes not related to the sunlight calculation at all.

Dorale *et al.* provide evidence for high sea level at ~81,000 years ago, in the middle of the most recent 100,000-year cycle. This result challenges the observational basis for much of the discussion over recent decades. A high sea level at ~81,000 years ago is not consistent with a 100,000-year beat, but it does coincide with calculated high Northern Hemisphere summer sunlight, and thus supports a simple version of the Milankovitch theory. If verified, this sea-level high may be considered an exception to the 100,000-year cycle, in which high summer sunlight caused the ice sheets to melt—an exception with precedent, given evidence for another off-beat event ~229,000 years ago (*7*).

Dorale *et al.* dated layers of the mineral calcite, which were deposited like bathtub rings from pools of water in Mallorca caves, in the western Mediterranean. Because the pools are connected to the sea through underground passages, the layers record sea level at the time they formed. Using this approach, Dorale *et al.* inferred sea levels similar to modern values ~81,000 years ago. They estimated maximum rates of sea level rise of ~2 m per century. This rate is high, but not unprecedented in the geologic record. It exceeds by several times those predicted for the next century (*9*).

Others will likely test Dorale *et al.*'s inference of low ice volume 81,000 years ago. A major question relates to the flow and bend of the solid Earth, such that sea level is not solely dependent on ice volume. Earth's shape, mass distribution, and gravitational field change continually in response to the redistribution of water between the ice sheets and oceans during the ice age cycles (*10*, *11*). Because of the high viscosity of Earth's mantle, the solid Earth responds slowly (over thousands of years) to the rapid redistribution of water and ice on the surface. The physics of this process is well known, but the calculation requires knowledge of the elastic properties of the lithosphere (Earth's rigid outer shell), the viscosity structure of the mantle and the history of ice and water distribution on Earth's surface, which are difficult to quantify. Nevertheless, the process has been modeled for different times in the ice age cycle (*10*, *11*). Dorale *et al.*'s findings should spur further studies, with an eye toward the Mallorca region.

A number of previous studies have estimated sea level ~81,000 years ago. Some of these estimates appear to agree (*12*) with Dorale *et al.*'s findings, whereas others appear to disagree (*13*). One problem with comparing these studies is the possibility—and in some cases probability—that discrepant sea-level elevations may represent different sea levels at different times, given plausible dating errors. Future studies that determine sea levels at different times at the same place may help to resolve the discrepancies. Regardless of the ultimate verdict on sea level ~81,000 years ago, Dorale *et al.*'s findings will stimulate ideas, discussion, and new studies of ice age history and causes.

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GENETICS

Genetic Control of Hotspots

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Both chromatin and DNA sequence account for individual differences in the location and frequency of genetic recombination.

With the exception of identical twins, individuals have different genetic makeup, which results from two key processes. During meiosis, maternal and paternal homologous chromosomes assort randomly to form daughter cells (gametes), thus generating different combinations of maternal and paternal chromosomes. Additional variation is generated by recombinations or crossovers, in which parts of homologous chromosomes are exchanged, resulting in a new combination of parental alleles. On pages 835, 836, and 876 of this issue, Parvanov *et al.* (*1*), Baudat *et al.* (*2*), and Myers *et al.* (*3*) report the identification of a mammalian gene—PR domain containing 9 (*PRDM9*)—that controls the extent to which crossovers occur in preferred chromosomal locations, known as "hotspots" (see the figure).

In addition to contributing to genetic variation, recombination is critical to the success of meiosis. A physical bridge that is built around the point of exchange—the chiasma—ensures correct assortment of chromosomes into gametes. The location of a chiasma is important because an exchange that occurs too close to the telomere or centromere of a chromosome can confer instability and lead to abnormal chromosome segregation (*4*). In humans, this type of error is startlingly common. Aneuploidy [either monosomy (only a single copy of a chromosome, rather than a pair) or trisomy (three copies of a chromosome)] is estimated to occur in 10 to 25% of all conceptions and is the leading cause of pregnancy loss as well as developmental disabilities (*5*).

Even though meiosis and meiotic recombination are fundamental cellular processes, the genes and mechanisms involved are poorly understood. In mouse recombination hotspots, histone proteins are often modified by methylation or hyperacetylation (*6*),

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