

and cetaceans. Vocal learning is common in birds but has arisen in three separate lineages (songbirds, parrots, and certain hummingbirds), and is not known for more basal birds.

Do these independently evolved behaviors share common neural pathways? At least in songbirds and humans, some of the forebrain pathways implicated in vocal learning share homologous components (6, 7). Also, calling is controlled by a midbrain system that may be common to that of vertebrates (8, 9). It may be that all forebrain

mechanisms controlling vocalizations have to interact with the same midbrain system. Such commonalities increase confidence that animal studies can give insight into human vocal learning (10, 11). The story of the evolution of vocalizations is still being written, both for its deep ancestral roots and for its most modern developments.

References

1. A. H. Bass, E. H. Gilland, Robert Baker, *Science* **321**, 417 (2008).
2. A. M. Simmons, A. N. Popper, R. R. Fay, Eds., *Acoustic*

3. M. Zhu, *Nature* **410**, 81 (2001).
4. L. C. Rome, D. A. Syme, S. Hollingworth, S. L. Lindstedt, S. M. Baylor, *Proc. Natl. Acad. Sci. U.S.A.* **93**, 8095 (2006).
5. N. Shubin, *Your Inner Fish* (Pantheon Books, New York, 2008).
6. A. Reiner *et al.*, *J. Comp. Neurol.* **473**, 377 (2004).
7. M. A. Farries, D. J. Perkel, *J. Neurosci.* **22**, 3776 (2002).
8. T. J. Seller, *Trends Neurosci.* **4**, 301 (1981).
9. J. M. Kittelberger, B. R. Land, A. H. Bass, *J. Neurophysiol.* **96**, 71 (2006).
10. A. J. Doupe, P. K. Kuhl, *Annu. Rev. Neurosci.* **22**, 567 (1999).
11. Zeigler, P. Marler, Eds., *Behavioral Neurobiology of Bird Song* (New York Academy of Sciences, New York, 2004), vol. 1016.

10.1126/science.1161775

CLIMATE

Was the Younger Dryas Global?

Thomas V. Lowell¹ and Meredith A. Kelly²

The Younger Dryas cold event, which lasted from 12,900 to 11,600 years ago, was a rapid return to near-glacial conditions during the transition from the Last Glacial Maximum to the current Holocene warm period. Similar rapid climate reversals have been identified during earlier glacial-to-interglacial transitions (1). Such millennial-scale climate events may thus play an important role in the transition from glacial to interglacial periods.

The mechanisms that caused the Younger Dryas are not yet fully understood. An important step in understanding these mechanisms is to determine the geographic extent of Younger Dryas-related climate conditions. On page 392 of this issue, Ackert *et al.* (2) suggest that Younger Dryas cooling did not influence eastern outlet glaciers of the Southern Patagonian Icefield. Instead, they argue that these glaciers advanced in the early Holocene, likely as a result of changes in southern westerly wind circulation. The absence of Younger Dryas-related cooling in this southern mid-latitude location would have implications for the driving mechanisms of the event.

Uncertainties in dating techniques continue to make it difficult to determine whether mid-latitude locations in the Southern Hemisphere experienced Younger Dryas-related climate changes. To illustrate these uncertainties, consider prior studies and that by Ackert *et al.*, which examine past glacial extents in southern mid-latitude locations. Past glacial extents pro-



Advance and retreat. According to Ackert *et al.*, eastern outlet glaciers of the Southern Patagonian Icefield, such as the Perito Moreno Glacier shown here, retreated after the Younger Dryas had ended.

vide a sensitive proxy for past temperatures (3). In general, these extents are dated using either radiocarbon or surface-exposure dating. The latter method is based on the measurement of cosmogenic nuclides in the upper surfaces of boulders on moraines.

However, in New Zealand and South America, where both radiocarbon and surface-exposure methods have been applied to date certain moraines, a distinct offset exists between the resulting ages. Radiocarbon ages in these southern mid-latitude locations indicate that glacial advances occurred before the Younger Dryas. For example, in New Zealand, numerous radiocarbon ages of vegetation overrun by the Franz Josef Glacier show that the Waiho Loop moraine formed prior to, or at the beginning of, the Younger Dryas (4). A later study at the same site reports radiocarbon

Determining the geographical extent of a 1300-year cold event that occurred just before the current warm period requires accurate chronologies.

ages that indicate a pre-Younger Dryas glacial advance (5). Similarly, in Argentina, one preliminary radiocarbon age indicates that the Perito Moreno Glacier, an eastern outlet of the Southern Patagonian Icefield (see the figure), advanced prior to the Younger Dryas (6). In contrast, recently reported surface-exposure (¹⁰Be and ³⁶Cl) ages of boulders atop moraines in New Zealand and South America have been interpreted to indicate glacial recession well after the Younger Dryas (2, 7). Both studies conclude that local glacial advances in the southern mid-latitudes were influenced by changes in southern westerly wind circulation in the early Holocene and not by Younger Dryas-related cooling.

There are at least two possible explanations for the offset between radiocarbon and surface-exposure ages of past glacial extents.

¹Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA. ²Geochemistry Division, Lamont-Doherty Earth Observatory, Palisades, NY 10964, USA. E-mail: thomas.lowell@uc.edu

First, ages from the two dating techniques may yield accurate ages of different stratigraphic levels. That is, the radiocarbon ages discussed above yield dates of glacial advances, whereas surface-exposure ages yield the time of glacial recession and moraine stabilization. Therefore, an interpretation of the reported ages is that local glaciers in New Zealand and South America advanced prior to the Younger Dryas, remained in extended positions, and receded in the early Holocene. This hypothesis could be tested using temperature and precipitation data from other paleoclimate records as input for glacier modeling studies.

Second, the offset may result from uncertainties associated with the dating techniques. For example, because of plateaus in the radiocarbon calibration curve, reported radiocarbon ages may be uncertain by a few hundred years. Moreover, the uncertainties in cosmogenic nuclide production rates are substantial (as much as 10% at the locations discussed here). One means to address these uncertainties is to use independent dating methods to calibrate site-specific cosmogenic nuclide production rates.

Once again, understanding Earth history hinges on accurate chronologies. As long as these dating issues are unresolved, determin-

ing the presence or absence of a Younger Dryas-related climate change at mid-latitudes in the Southern Hemisphere will remain a challenge.

References

1. H. Cheng *et al.*, *Geology* **34**, 217 (2006).
2. R. P. Ackert Jr. *et al.*, *Science* **321**, 392 (2008).
3. J. Oerlemans, *Science* **308**, 675 (2005); published online 3 March 2005 (10.1126/science.1107046).
4. G. H. Denton, C. H. Hendy, *Science* **264**, 1434 (1994).
5. C. S. M. Turney *et al.*, *Quat. Sci. Rev.* **26**, 3037 (2007).
6. J. A. Strelin, E. C. Malagnino, *Quat. Res.* **54**, 339 (2000).
7. T. T. Barrows, S. J. Lehman, L. K. Fifield, P. De Deckker, *Science* **318**, 86 (2007).

10.1126/science.1160148

MATERIALS SCIENCE

Tracking Corrosion Cracking

Andreas Stierle

The corrosion of steel-based mechanical components is an unwanted everyday phenomenon, which destroys about 3% of the annual world gross domestic product (*I*). At the beginning of the 20th century, it was discovered that steels that contained more than 10% chromium are highly resistant to corrosion. Since then, the story of stainless steel has been a surpassing success as a material combining chemical inertness and high mechanical strength for use in applications ranging from kitchen sinks to steam generators. During fabrication and operation, many stainless steel components are exposed to mechanical loads that create high strains inside the material, which results in mechanical failures at unexpectedly low loads in the presence of corrosive agents. As discussed on page 382 of this issue, King *et al.* (2) shed light on the microscopic origin of environmental corrosion by studying crack formation in situ, characterizing the effects of stress and corrosive media, such as an acidified solution of $K_2S_4O_6$, on the polycrystalline grain structure of samples in an electrochemical cell.

Grain boundaries are the key players for the combined mechanical and corrosion properties of a material: They serve as sinks for the segregation of impurities inherently included in or added during the manufacturing process. The challenge of studying real polycrystalline samples, as opposed to simpler model samples that are single crystals, is enormous. The internal structure of a polycrystalline material

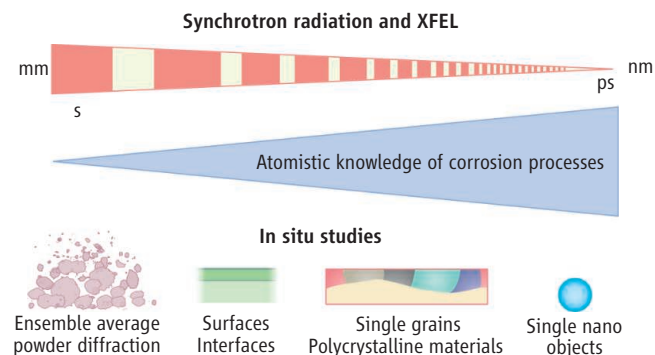
is a nightmare for scientists because it is made up by a three-dimensional (3D) arrangement of individual, more or less randomly oriented crystalline grains of variable size, which interact through their grain boundaries. Conventional (text book) x-ray powder diffraction experiments average over such an ensemble of orientations, which leads to a characteristic, anisotropic broadening of the sharp Bragg diffraction peaks. Retrieving the grain-grain interaction from such Bragg profiles remains a challenge in materials science (3). Nevertheless, it is a prerequisite for a full understanding of the mechanical properties of the material at hand.

Only recently has it been shown that highly brilliant, high-energy x-ray synchro-

tron radiation can be used to analyze the local grain structure of a polycrystalline material, including the local strain state and individual grain orientation under variable external mechanical stress (4–6). Such a 3D grain structure reconstruction is reported for austenitic stainless steel by King *et al.* (2). Synchrotron radiation tomography also allowed King *et al.* to combine grain structure reconstruction with an in situ localization of corrosion processes inside the sample. In these studies, the spatial resolution is limited by the detection system to about 1 μm . The future development of synchrotron beams that are focused to widths of 50 nm (7) with stroboscopic methods is expected to deliver even higher-resolution 3D information and a

time resolution on the order of 100 fs (8) versus 50 to 100 ms at present (see the figure).

During steel welding, a thermally activated carbon segregation process can occur. King *et al.* have found that the grain boundaries in stainless steel, which are structurally less perfect (or where crystallographic planes with high Miller indices meet), are more sensitive to carbon segregation and the formation of chromium carbides, which makes them more sensitive to corrosion.



A road map for understanding corrosion. Studies performed on technologically relevant materials under realistic conditions in various media (O_2 , SO_2 , N_2 , plasmas, acids, and water) will create a database for improving corrosion resistance. The use of highly focused synchrotron and x-ray free-electron laser (XFEL) radiation should improve both the spatial and temporal resolution of structural studies. The kinetics and dynamics of the corrosion processes can then be revealed at the level of nanocrystalline grains and their atomic interfaces.

Max-Planck-Institut für Metallforschung, Stuttgart
D-70569, Germany. E-mail: stierle@mf.mpg.de

CREDIT: ADAPTED FROM ANDREAS STIERLE