References

1. R. Mirsky, K. R. Jessen, *Brain Pathol.* **9**, 293 (1999).
2. J. M. Cosgaya, J. R. Chan, E. M. Shooter, *Science* **298**, 1245 (2002).
3. J. R. Chan, J. M. Cosgaya, Y. J. Wu, E. M. Shooter, *Proc. Natl. Acad. Sci. U.S.A.* **98**, 14661 (2001).
4. M. Pruginin-Bluger, D. L. Shelton, C. Kalcheim, *Mech. Dev.* **61**, 99 (1997).
5. E. J. Huang, L. F. Reichardt, *Annu. Rev. Neurosci.* **24**, 677 (2001).
6. S. S. Scherer, J. L. Salzer, in *Glial Cell Development*, K. R. Jessen, W. D. Richardson, Eds. (Oxford Univ. Press, London, 2001), pp. 299–330.
7. C. A. Bentley, K. F. Lee, *J. Neurosci.* **20**, 7706 (2000).
8. B. L. Hempstead, *Curr. Opin. Neurobiol.* **12**, 260 (2002).
9. J. C. Nickols *et al.*, *Society for Neuroscience Abstr.* **819**, 15 (2002).
10. T. Yamashita, K. L. Tucker, Y. A. Barde, *Neuron* **24**, 585 (1999).
11. A. Cellerino, P. Carroll, H. Thoenen, Y. A. Barde, *Mol. Cell. Neurosci.* **9**, 397 (1997).
12. H. Yan, P. M. Wood, *J. Neurosci. Res.* **62**, 329 (2000).
13. D. M. McTigue, P. J. Horner, B. T. Stokes, F. H. Gage, *J. Neurosci.* **18**, 5354 (1998).
14. J. Y. Zhang *et al.*, *Eur. J. Neurosci.* **12**, 4171 (2000).
15. D. E. Syroid *et al.*, *J. Neurosci.* **20**, 5741 (2000).
16. M. S. Beattie *et al.*, *Neuron* **36**, 375 (2002)
17. R. Lee, P. Kermani, K. K. Teng, B. L. Hempstead, *Science* **294**, 1945 (2001).

PERSPECTIVES: PALEOCLIMATE

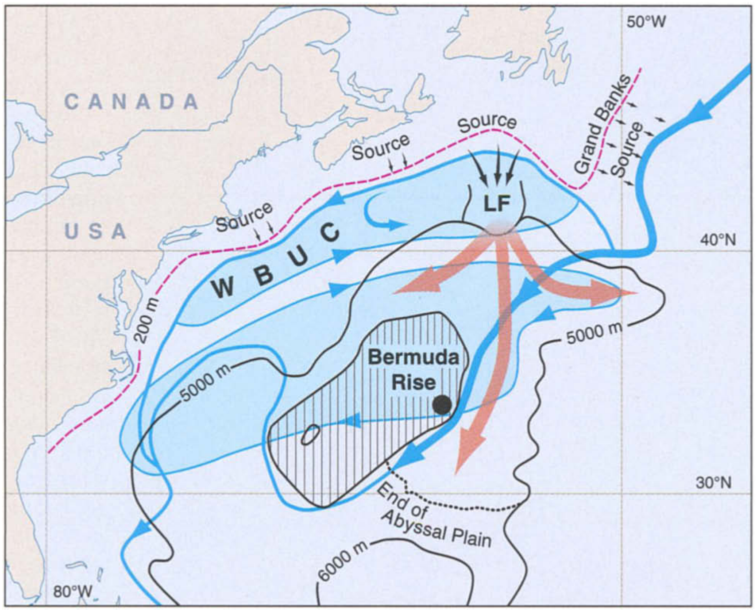
A Poisoned Chalice?

I. Nick McCave

Like King Arthur's knights searching for the Holy Grail, marine geologists search for areas with high sedimentation rates, because only cores drilled in these areas can provide high-resolution records of past climate. But on page 1224 of this issue, Ohkouchi *et al.* (*1*) show that this Grail may be a poisoned chalice.

High sedimentation rates—ideally, 50 to 100 cm per 1000 years—are necessary for high resolution because most marine sediments are mixed by bottom-dwelling organisms on a scale of a few centimeters. In the North Atlantic, average rates are about 2 to 4 cm per 1000 years away from continental margins (*2*), and about 10 cm per 1000 years on continental margins. In the North Pacific, they are even lower (less than 1 cm per 1000 years). High sedimentation rates are thus anomalous. The question is whether cores with anomalous rates of deposition are also anomalous in other ways—for example, in the climatic signals they contain.

Of course, one person's anomaly is another's signal. Whether a core is interpreted correctly depends on which assumptions are made with regard to the sedimentation process. We can envisage three main scenarios for sediment deposition.



Sediment transport at Bermuda rise. The fine plumes of turbidity currents (gray) from the Laurentian fan (LF) are entrained by deep-ocean flows (blue lines) and trapped in regions of recirculation (pale blue areas) (*14*). Material eroded by storms from the eastern Grand Banks may be carried to Bermuda Rise by the North Atlantic Deep Water (NADW) (thick blue arrow). Resuspension from the upper continental margin of Nova Scotia and the northern United States feeds into the recirculating gyre and may find its way to Bermuda Rise, especially when sea levels are low during glacial periods. The core of Ohkouchi *et al.* (*1*) (black spot) lies under the NADW, in the recirculation and near the turbidity current flow path. WBUC, Western Boundary Undercurrent.

First, material sinking to the seafloor may consist entirely of material from the upper ocean, comprising both biological material and wind-blown dust. In such a pelagic (upper ocean) setting, the material is presumed to be static once it has landed on the seafloor. It is a mixture of sand-sized (>63 μm diameter) components, mainly shells of foraminifera, and fine particles (<63 μm diameter), mainly dust and the detritus of phytoplankton. The fine particles form aggregates and sink rapidly to the seafloor, where they fall apart. This scenario applies to most of the deep ocean (away from continental boundaries), where bottom sediments reflect the material leaving the upper ocean and its processes and properties. However, sedimentation rates are extremely low, so this is not where Grail hunters go.

Second, the thickness of the sediments bearing pelagic signals may be increased by laterally transported material that does not carry a temperature or other signal of interest. In areas where current-controlled rapid deposition creates sediment drifts, foraminifera are quickly buried and hence relatively immobile, providing good time markers. This scenario is envisaged, neglecting the likely mobility of the fine particles, when records are interpreted as though they were pelagic, with high resolution conferred by added sediment. The laterally transported material comprises clay (<2 μm diameter) and silt (2 to 63 μm diameter) carried in suspension.

The third scenario is the same as the second, but focuses attention on the properties of the laterally supplied silt and clay. These fine materials may carry information on their source or on how vigorous the bottom flow is. The pelagic input then provides material on which to base stratigraphy and inference of age. (Reprehensibly, many paleoceanographers simply throw the fine material away!) In most sediment drifts, the third scenario is correct—the lateral input is not signal-free—nevertheless, the first two scenarios are often assumed for interpretation (*3*).

Ohkouchi *et al.* (*1*) demonstrate elegantly the interpretative pitfall in assuming the second scenario when the third applies. They show that at the same level in their sediment core from Bermuda Rise, the radiocarbon ages of unsaturated alkenones [fine-grained organic compounds synthesized by plankton in the upper ocean from which estimates of sea surface temperature (SST) are obtained] greatly exceed those of foraminifera (*1*).

Keigwin has argued that the foraminifera at this location show SST changes associated with the Little Ice Age (late 15th to late 19th century AD) (*4*). If the first or second

The author is in the Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK. E-mail mccave@esc.cam.ac.uk

scenario is correct, then the fine and coarse components should be the same age. If they are not the same age, as is the case here, then the most likely explanation is that the filler is not inert. Instead, it carries a signal similar to, but older than, that sinking from the overlying waters.

In this case, some aspects of the fine material at a location cannot be interpreted as a time history of events at the sea surface directly above that location. It is contaminated by displaced records of events at a different place with different characteristics. Support for this interpretation comes from Benthien and Müller (*5*), who showed that modern bottom sediments in the Argentine Basin record temperatures that are 2° to 6°C colder than the sea surface. Strong bottom currents transport material from the south into this region (*6*).

Most sediment drifts lie under deep boundary currents downstream from a major source of sediment (*7*). In contrast, Bermuda Rise, a mud-covered plateau at 4000 to 4500 m depth, is separated from the adjacent continent by a 5500-m-deep abyssal plain that is not a regular current-controlled sediment transport pathway.

Because of its midocean setting, Bermuda Rise might have been thought free of the signal contamination associated with resuspension and transport on continental margins. The sediment cover is derived from pelagic fallout, turbidity-current material from the Laurentian Fan swept over the rise by deep currents (*8*), and resuspended sediment from the Grand Banks and United States/Canada margins entrained in the deep circulation (see the figure). On the basis of expected pelagic sedimentation rates, the latter two components must dominate by a factor of at least 5, although it remains unclear which of them is more important (*8–10*).

Ohkouchi *et al.* show that the thick sediment on Bermuda Rise is more likely to come from resuspension of relatively young (a few thousand years) sediment on continental margins than from wholesale mixing of material accumulated over several hundred thousand years, as would be typical of turbidity currents (*9*). This argues against the turbidity current model of Laine and Hollister (*8*) as the only transport path.

Bermuda Rise is an important location from which key palaeoclimatic results have emerged. What is true for one millennial-scale oscillation—the Little Ice Age—may well be true for other such oscillations 30,000 to 60,000 years ago.

For example, Sachs and Lehman (*11*) have argued that alkenone-based SSTs matched temperature variations in the Greenland ice cores. They established their sediment core's age by correlating variations in sediment lightness with the calcium carbonate variations in a nearby sediment core previously dated by radiocarbon and oxygen isotopic stages. They noted that "this method produced ages for the SST events that were 2000 to 5000 years older than their apparent counterparts in Greenland paleotemperature ... records" (p. 758).

They attributed this surprising (for believers in the second scenario) result to radiocarbon dating errors and uncertainties in the oxygen isotopic age scale. They therefore devised a new age scale that maximized the correlation between Bermuda Rise SSTs and oxygen-isotope variations in the Greenland ice core. This approach, of course, produced a close relation between temperature at Bermuda and Greenland. It looks as though their earlier interpretation may have been strikingly, but perhaps less interestingly, correct.

The report by Ohkouchi *et al.* illustrates that the size dependence of sediment transport processes must be considered carefully in sediment core interpretations. Age models should not be based on highly mobile material. This stricture could also apply to sediment color, which is dominated by the highly mobile fine particle fraction. (In a single transport system, color may still be useful.) Alkenones provide excellent records of SSTs, but sediment records will be most credible when the second scenario is fulfilled.

Continental margins, with high resuspension and lateral sediment supply from diverse sources, are particularly prone to problems associated with sediment core interpretation. One way of checking for the potential error is to date foraminifera and fine-grained cocolith carbonate from the same core level. These dates should be the same [after checking that the fine carbonate is not limestone ground up by glaciers (*12*)]. The Grail may not always be poisoned, but one should not drink from it indiscriminately.

References and Notes

1. N. Ohkouchi *et al.*, *Science* **298**, 1224 (2002).
2. W. L. Balsam, F. W. McCoy, *Paleoceanography* **2**, 531 (1987).
3. In all of these cases, there is an important difference in behavior between the foraminifera used for analysis (generally >250 μm diameter), whose sinking speed of >1 cm s^{-1} requires currents of more than ~25 cm s^{-1} for suspension, and the silt- and clay-sized material, whose sedimentation rate of <0.2 cm s^{-1} (and mostly <0.01 cm s^{-1}) requires currents of only 1 to 2 cm s^{-1} to maintain suspension. This fine-grained material has long residence times and is susceptible to long-distance transport (*13*).
4. L. Keigwin, *Science* **274**, 1503 (1996).
5. A. Benthien, P. J. Müller, *Deep-Sea Res. I* **47**, 2369 (2000).
6. M. T. Ledbetter, *Nature* **321**, 423 (1986).
7. I. N. McCave, B. E. Tucholke, in *The Geology of North America*, vol. M, *The Western North Atlantic Region*, P. R. Vogt, B. E. Tucholke, Eds. (Geological Society of America, Boulder, CO, 1986), pp. 451–468.
8. E. P. Laine, C. D. Hollister, *Mar. Geol.* **39**, 277 (1981).
9. P. P. E. Weaver, *Sedimentology* **41**, 1025 (1994)
10. R. F. Anderson *et al.*, *Deep-Sea Res. II* **41**, 669 (1994).
11. J. P. Sachs, S. J. Lehman, *Science* **286**, 756 (1999).
12. W. L. Balsam, D. Williams, *Mar. Geol.* **112**, 23 (1993).
13. I. N. McCave, *Spec. Publ. Geol. Soc. London* **15**, 35 (1984).
14. W. J. Schmitz, M. S. McCartney, *Rev. Geophys.* **31**, 29 (1993).

PERSPECTIVES: NEUROSCIENCE

Freeing the Brain from the Perineuronal Net

Kevin Fox and Bruce Caterson

You can't teach an old dog new tricks, or can you? On page 1248 of this issue, Pizzorusso *et al.* (*1*) provide new data indicating that the brain of an adult animal can be persuaded to respond like a young brain to changes in visual experience. They use an enzyme known as chondroitinase ABC to alter the biochemical composition of the perineuronal net that surrounds neurons in the visual cortex. Degrading the glycosaminoglycan components of this perineuronal net restores the ability of cortical neurons to alter their synaptic connections. Normally, neurons in the visual cortex of rats only retain their plasticity for 4 to 5 weeks after birth, before the perineuronal net matures. Remarkably, injecting chondroitinase ABC into the visual cortex of adult rats restores this plasticity.

Enhanced online at www.sciencemag.org/cgi/content/full/298/5596/1187

The visual cortex receives two images of the world, one from each eye. The images are combined in the binocular zone of the cortex, which makes up most of the visual cortex in humans and a smaller component in rats because their eyes lie on either side of the head. But if one eye is forcibly closed early in development (monocular deprivation), the open eye takes over control of the binocular zone (*2*). At the cellular level, this means that neurons that would have developed connections to both eyes lose synaptic input

The authors are in the Neuroscience Research Group and the Connective Tissue Biology Labs, Cardiff School of Biosciences, Cardiff University, Cardiff CF10 3US, UK. E-mail: foxkd@cardiff.ac.uk