Abiotic synthesis of both ribose and bases is problematic, and linking the two into nucleotides is more difficult still (*18*). Increasing acceptance of an RNA world has actually stimulated research into plausible models for a pre-RNA world (*1*). Could translation have arisen even before RNA? Ribozyme relics argue against such a model: If translation evolved in a pre-RNA biosphere, why would the subsequent evolution of RNA introduce functional RNA components into preexisting (proteinaceous) ribosomes?

Finally, if proteins evolved in an RNA world, then this informs theories about the fixation of the canonical genetic code. RNA templates are significantly more error-prone (in terms of point mutation) than their DNA equivalents (*5*). An RNA-world origin for the genetic code thus adds significance to the finding that the arrangement of canonical codon assignments appears to minimize the phenotypic impact of errors (*19*).

References

1. R. F. Gesteland, T. R. Cech, J. F. Atkins, Eds., *The RNA World* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 1999).
2. E. Szathmáry, *Trends Genet.* **15**, 223 (1999).
3. S. A. Benner, A. D. Ellington, A. Tauer, *Proc. Natl. Acad. Sci. U.S.A.* **86**, 7054 (1989).
4. I. Hirao and A. D. Ellington, *Curr. Biol.* **5**, 1017 (1995).
5. J. Maynard Smith and E. Szathmáry, *The Major Transitions in Evolution* (Freeman, Oxford, 1995).
6. P. E. Leon, *J. Mol. Evol.* **47**, 122 (1998).
7. F. H. C. Crick, *J. Mol. Biol.* **38**, 367 (1968); C. R. Woese, *The Genetic Code* (Harper and Row, New York, 1967); L. E. Orgel, *J. Mol. Biol.* **38**, 381 (1968).
8. H. B. White, *J. Mol. Evol.* **7**, 101 (1976).
9. A. Lazcano, R. Guerrero, L. Margulis, J. Oro, *ibid.* **27**, 283 (1988).
10. P. Reichard, *Science* **260**, 1773 (1993).
11. G. Olsen and C. R. Woese, *Trends Genet.* **12**, 377 (1996).
12. D. T. Logan, J. Andersson, B.-M. Sjoberg, P. Nordlund, *Science* **283**, 1499 (1999).
13. J. T.-F. Wong and P. M. Bronskill, *J. Mol. Evol.* **13**, 115 (1979).
14. J. H. Cate, M. M. Yusupov, G. Zh. Yusupova, T. N. Earnest, H. F. Noller, *Science* **285**, 2095 (1999).
15. B. Alberts *et al.*, *Molecular Biology of the Cell* (Garland, New York, ed. 3, 1994), chap. 9.
16. A. Jordan and P. Reichard, *Annu. Rev. Biochem.* **67**, 71 (1998).
17. G. Sawers and G. Watson, *Mol. Microbiol.* **29**, 945 (1998).
18. A. Lazcano and S. L. Miller, *Cell* **85**, 793 (1996).
19. D. Haig and L. D. Hurst, *J. Mol. Evol.* **33**, 412 (1991); D. H. Ardell, *ibid.* **47**, 1 (1998); S. J. Freeland and L. D. Hurst, *ibid.*, p. 238; *Proc. R. Soc. London Ser. B* **265**, 2111 (1998).

PERSPECTIVES: GEOPHYSICS

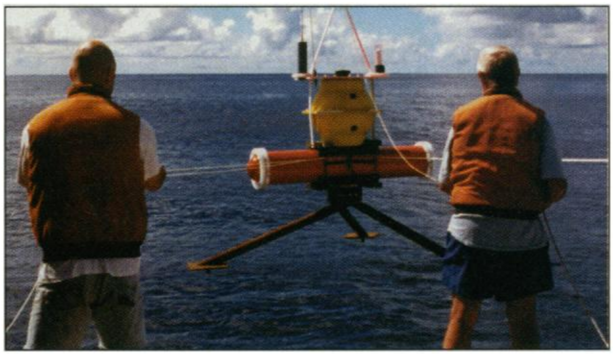
Mapping Mantle Melting

Roger Buck

Most of the volume of Earth, or any of the terrestrial planets, is a mantle made of silicate. Yet we see little of it at the surface because early in Earth's evolution a crust of lower density material floated to the top of the mantle. Present-day partial melting and differentiation of the mantle mostly occur in the upwelling region below mid-ocean ridges. On page 752 of this issue, Evans *et al.* (*1*) present results from the last phase of a major collaborative experiment to pull back the veil obscuring our view of this crucial geophysical process.

In the picture provided by plate tectonics, ridges are now seen as primary sites of mantle upwelling, whereas subduction zones are centers of downward flow. We know more about the downwelling regions because earthquakes occur within the brittle subducting plates and the seismic activity allows us to track the plate position. At the same time, seismic velocities are very different in the cold plates and the hotter mantle through which they plunge. Our view of the region of upwelling is not so clear; no deep seismicity marks the upwelling of hot weak mantle, and lateral temperature gradients there are small.

Whereas ~100-km-thick plates move down at subduction zones, the region of upwelling and pressure release melting under ridges could be as much as a thousand kilometers wide according to simple "passive" models of mantle flow driven by plate motion. The crust produced by that subridge melting forms essentially at the ridge axis (*2*), implying either that melt generated by wide upwelling has to flow toward the ridge axis or that the mantle flow itself is focused under the axis. One of the primary goals of the recent MELT (Mantle Electromagnetic and Tomography) Experiment was to see if a region of partial melting could be detected and if so to map the size of that region. This involved the largest deployment of ocean bottom instruments for the purpose of answering geological questions. It was centered on the fastest spreading and straightest part of the global mid-ocean ridge system—the East Pacific Rise around 17°S.



Data from the deep. Magnetometer being deployed in the area of the MELT Experiment from the research vessel *Thompson* showing Rob Evans (of Woods Hole Oceanographic Institution) on the left and Helmut Moeller (of Scripps Institution of Oceanography).

CREDIT: J. BAILEY/WHOI

Evans *et al.* (*1*) report results from the MELT Experiment involving interpretation of electromagnetic measurements. The new results build on what was learned from the earlier seismic part of the experiment, presented in a series of articles in 1998 (*3*). The two methods should indicate different things about melt in the mantle. Seismic velocities depend on melt volume and on the aspect ratio of melt inclusions. The electromagnetic experiments measure conductivity and are sensitive to how interconnected pockets of melt are, as well as to the water abundance in mantle minerals. The deployment of one of the magnetometers used in the experiment is shown in the figure.

Both the seismic and the electromagnetic experiments indicate the presence of a small amount (perhaps less than a few percent) of melt over a region several hundred kilometers wide and more than 100 km deep under the ridge. The inferred region of partial melt is very asymmetric, extending much farther to the west than to the east, under this roughly north-south–oriented ridge. The seismic low-velocity region extends more than a hundred kilometers to the east of the ridge with a gradual change to higher velocities. In contrast, the electromagnetic results show a sharper transition between a very conductive, inferred melt-rich region to the west and less conductive regions to the east of the ridge axis. The conductivity transition occurs at the spreading axis.

The MELT results preclude even moderate focusing of upwelling as predicted by some "dynamic" mantle flow models (*4*). They imply that melting-related density changes do not drive substantial mantle upwelling and that most flow is "passive" or driven by plate motion. Dynamic flow, driven by buoyancy, may be insignificant

The author is in the Department of Earth and Environmental Sciences and the Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA. E-mail: buck@ldeo.columbia.edu

because melt flows out of the mantle too fast to build up lateral variations in melt concentration and so density. Alternatively, the viscosity of the shallow mantle may be so high as to slow dynamic flow.

The asymmetry in the pattern of inferred partially molten mantle may be related to asymmetric spreading of the ridge (*3*). The Pacific Plate on the west side of the ridge is moving about twice as fast to the west, in the hot-spot reference frame, as the Nazca Plate is moving to the east. The mantle to the west appears to be hotter than the mantle to the east, based on the slower rate of subsidence of the ocean floor with age on the west side of the ridge. The combination of asymmetric spreading and lateral variations in mantle thermal structure may mean that most upwelling and melting take place on the west side of the ridge.

The more sharply defined lateral variation observed in conductivities compared with the variation in seismic velocities may reflect the fact that electromagnetic and seismic methods measure different things. Evans *et al.* (*1*) note that as melt gets out from the mantle, the melt fraction may drop below the point at which the melt pockets are interconnected. There may be enough melt in the mantle to the east of the ridge to lower the seismic velocities but not enough to affect the conductivity. Geodynamic models treating melt fractions retained in mantle upwelling below an asymmetrically spreading ridge are now being carried out by several groups.

The results reported by Evans *et al.* will spark much effort to refine and test competing models for lateral flow of melt toward the ridge axis (*5*). Studies of slices of oceanic crust and mantle pushed up on land and exposed in complexes called ophiolites are drawing more attention from people interested in understanding how melt gets out of the mantle. There is encouraging improvement in petrologic and geochemical methods for estimating how fast melt flows through the solid mantle matrix and how fast that matrix moves up.

An interesting offshoot problem involves the origin of axial highs along fast spreading mid-ocean ridges such as the part of the East Pacific Rise where the experiment was conducted. One can argue that these narrow highs, which look like a fairly continuous dorsal fin along thousands of kilometers of ridge axis, are the longest topographic feature on our planet for which the basic mechanism of formation is disputed. The first models for this feature involved a deep root of low-density, probably melt-rich region below the axis. The MELT Experiment does not show the existence of such a root so other explanations are now being sought (*6*).

References

1. R. L. Evans *et al.*, *Science* **286**, 752 (1999).
2. E. E. Vera *et al.*, *J. Geophys. Res.* **95**, 15529 (1990).
3. The MELT Seismic Team, *Science* **280**, 1215 (1998).
4. D. R. Scott and D. J. Stevenson, *J. Geophys. Res.* **94**, 2973 (1989); W. Su and W. R. Buck, *ibid.* **98**, 12191 (1993).
5. J. Phipps Morgan, *Geophys. Res. Lett.* **14**, 1238 (1987); M. Spiegelman and D. McKenzie, *Earth Planet. Sci. Lett.* **105**, 368 (1991); D. W. Sparks and E. M. Parmentier, *ibid.* **105**, 368 (1991).
6. M. Eberle and D. W. Forsyth, *J. Geophys. Res.* **103**, 12309 (1998).

PERSPECTIVES: ASTROPHYSICS

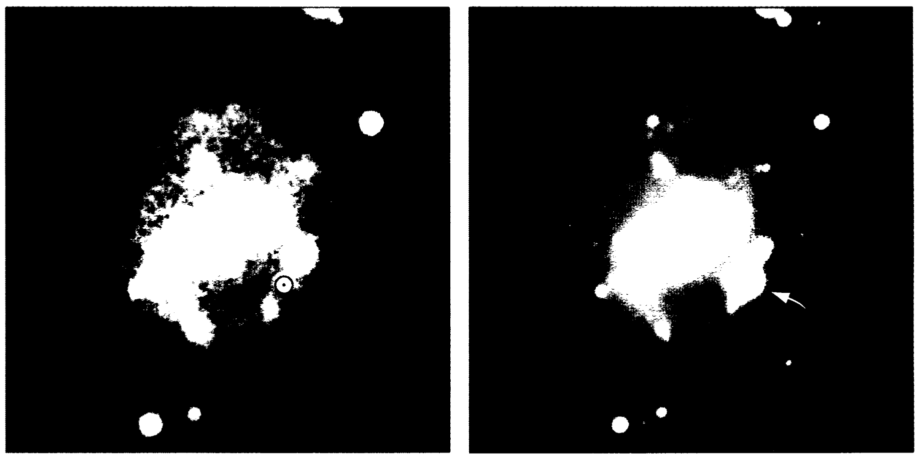
From Gamma-Ray Bursts to Supernovae

Jan van Paradijs

Gamma-ray bursts (GRBs) (*1*) are energetic astronomical events that last from tens of milliseconds to tens of minutes, with energies of up to 1 million electron volts. During the peaks of the brightest events, their flux is similar to that of the brightest stars that are visible to the naked eye. First observed in 1967, GRBs have been the focus of the recent Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory (CGRO) (*2*). These new observations confirm earlier indications that the bursts are uniformly spread out over the sky and exclude the possibility that they occur in our galaxy, as previously thought by most astrophysicists. The wealth of new data is providing clues to the origin of these events and, in a striking twist, reviving an old idea (*3*) that links GRBs to supernovae (*4*).

Distances to GRBs were measured for the first time in 1997, after the detection of long-lived x-ray, optical, and radio wavelength afterglows of GRBs (*5*). The ability to measure these afterglows was the direct consequence of the rapid availability of accurate GRB positions, measured with the wide-field camera on the Italian-Dutch satellite BeppoSAX. Many afterglows were found in faint host galaxies, and redshift determinations (which reflect the expansion of the universe) unambiguously established that the distance scale is cosmological (that is, GRBs come from very far away in space and time) (*6*).

GRBs are by far the most luminous photon emitters in the known universe, with peak luminosities of up to several 10^{52} erg/s (that is, 10^{19} solar luminosities). Their optical afterglows are also extraordinarily luminous. For instance, at its redshift of 0.835, the peak magnitude of the optical afterglow of GRB970508 corresponds to an optical luminosity about two orders of magnitude higher than that of a luminous type Ia supernova, one of the brightest extra–solar system objects in the sky. Even brighter was GRB990123, the only GRB for which optical emission was



Before and after. The galaxy ESO 184-G82 several years before the supernova 1998bw (**left**) and within a day of gamma-ray burst GRB980425 (**right**), which occurred at or near (**arrow**) SSN1998bw. [The circle in the left panel indicates the future position of SN1998bw.]

CREDIT: T. J. GALAMA; PUBLISHED IN (*10*)

The author is in the Astronomical Institute "Anton Pannekoek," University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, Netherlands and the Physics Department, University of Alabama, Huntsville, AL 35899. E-mail: jvp@astro.uva.nl

http://www.jstor.org

LINKED CITATIONS

You have printed the following article:

Mapping Mantle Melting
Roger Buck
Science, New Series, Vol. 286, No. 5440. (Oct. 22, 1999), pp. 692-693.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819991022%293%3A286%3A5440%3C692%3AMMM%3E2.0.CO%3B2-G

This article references the following linked citations:

References

[1] **Asymmetric Electrical Structure in the Mantle Beneath the East Pacific Rise at 17°S**
R. L. Evans; P. Tarits; A. D. Chave; A. White; G. Heinson; J. H. Filloux; H. Toh; N. Seama; H. Utada; J. R. Booker; M. J. Unsworth
Science, New Series, Vol. 286, No. 5440. (Oct. 22, 1999), pp. 752-756.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819991022%293%3A286%3A5440%3C752%3AAESITM%3E2.0.CO%3B2-3

[3] **Imaging the Deep Seismic Structure Beneath a Mid-Ocean Ridge: The MELT Experiment**
The MELT Seismic Team
Science, New Series, Vol. 280, No. 5367. (May 22, 1998), pp. 1215-1218.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819980522%293%3A280%3A5367%3C1215%3AITDSSB%3E2.0.CO%3B2-P

NOTE: *The reference numbering from the original has been maintained in this citation list.*