fore chose simply to tabulate the percentage of all bacteria tested towards which a given spice or its extract has consistently shown at least some inhibitory activity, regardless of dose. Four spices are said to be inhibitory towards all bacteria tested — garlic, onions, allspice and oregano — and a total of 15 inhibited 75% of bacteria, or more.

This simple ranking of antimicrobial potencies disguises large differences in the extent to which different spices have been tested. An appendix reveals that in the most inhibitory group, garlic was tested against 29 bacteria, but allspice against only five, and onion against four. Chillies were successful against just four of five bacteria. A review of chemical food preservation concludes that of the 15 spices that Billing and Sherman classify as 'highly inhibitory' and find significantly associated with warm climates, seven, including chillies and allspice, have shown "limited or no activity" towards food spoilage microbes[3]. Even for the apparently inhibitory spices (cinnamon and cloves, garlic, and the Mediterranean herbs), the problem remains that most evaluations have been done *in vitro* rather than *in victu*. The few spices to have been tested in foods show far less activity than they do in microbiological media, probably because food particles sequester the inhibitory compounds[3]. The active sulphur compounds in garlic and onions are formed in disrupted tissue by enzymatic activity, which ordinary cooking procedures limit (but which the Indian practice of grating or grinding probably maximizes). And little is known about the stability of the inhibitory compounds to cooking temperatures.

In short, we don't yet have enough information to say whether spices have significant antimicrobial effects in ordinary cooking. On balance, it looks as though a simpler and more reliable defence against foodborne disease is to heat food well and often, as Indians have long done with highly perishable and unspiced liquid milk.

If Billing and Sherman are unable to make a convincing case for the hygienic hypothesis, their labours are to be valued for reviving an excellent question and demonstrating the need for *in victu* research initiatives. After testing culinarily appropriate spice doses in a model food, one would want to contaminate genuine, pre-refrigeration versions of, say, chicken in a sauce — Chinese red-cooked, Indian curried, Italian *cacciatore*, French *coq au vin*, American pot pie, Mexican *mole* — and follow pathogen growth in each, which will surely be affected by ingredients such as soy sauce, vinegar and wine. Given the worldwide popularity and yet limited antibacterial activity of black pepper, Billing and Sherman's speculative rationale — that pepper acts as a 'bioavailability enhancer' to sensitize bacteria to other spices — needs testing, as does the possibility that common spice combinations bring together complementary antimicrobials.

The strong biological slant of Billing and Sherman's hygienic hypothesis will also help sharpen the thinking of anyone who is intrigued by the complexities of human spice use and its persistence. The past few decades have brought Paul Rozin's rich behavioural analysis of flavourings and the challenges of omnivory[4], fascinating studies of the ceremonial and mythopoetic[5], social[6] and economic[7] aspects of European spice habits — and a continuing boom in per capita spice consumption in the United States. Is the last a manifestation of new selection pressures exerted by *Escherichia coli*, salmonella and campylobacter? Of an immigrant population reverting to type? The chemosensory circuits of my salsa- and vindaloo-loving family are a legacy of unspicy northern Europe, and they suggest not. ☐

Harold McGee is at 14 Chemin Las Crozes, 31450 Pompertuzat, France. He is author of On Food and Cooking: The Science and Lore of the Kitchen, *and* The Curious Cook *(Scribner's/Allen & Unwin).*
e-mail: hjmcgee@alumni.caltech.edu

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Mantle mineralogy

Olivine emerges from isolation

Craig R. Bina

Near a depth of 410 km, the speeds at which seismic waves travel in Earth's mantle rise sharply, an observation long attributed to high-pressure transformation of the mineral olivine to wadsleyite. However, seismological studies of this '410-km discontinuity' reveal wave-speed increases that are smaller and more abrupt than expected from extrapolation of the laboratory behaviour of these minerals to mantle conditions. On page 702 of this issue[1], Irifune and Isshiki show that the hitherto largely neglected exchange of magnesium and iron between olivine and other mantle minerals is an important factor in resolving these apparent discrepancies.

Such discrepancies are significant because they constrain the extent to which mantle discontinuities arise from phase transitions in minerals, such as those in olivine, rather than changes in bulk chemical composition. The mineralogy and chemistry of Earth's mantle, especially that part known as the 'transition zone' between the seismic discontinuities at depths of 410 and 660 km, govern the dynamics of convective

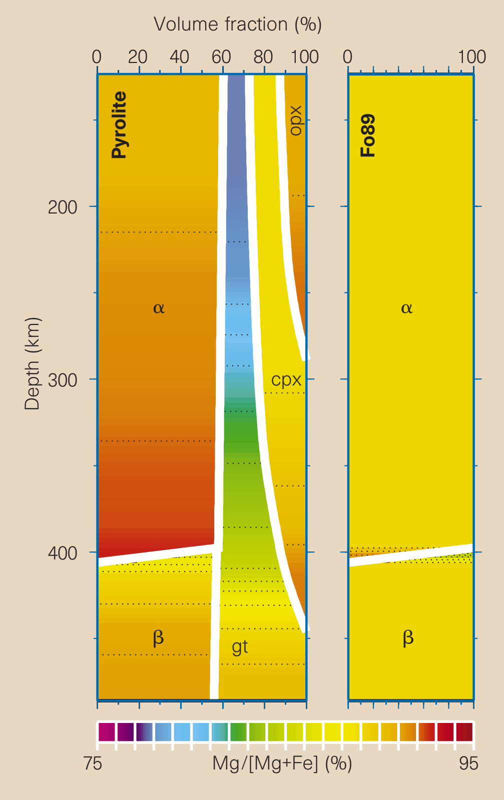


Figure 1 **Equilibrium mineral proportions and compositions as functions of mantle depth, for $(Mg_{0.89}Fe_{0.11})_2SiO_4$ olivine in isolation (Fo89) and for a model (pyrolite) mantle composition. Mineral proportions are as volume fraction, shown by bold white lines; compositions are in terms of Mg/[Mg+Fe], and are shown by colours and by dotted contours at 1% intervals. With increasing depth, olivine (α) transforms to wadsleyite (β) near 410 km, and orthopyroxene (opx) gradually dissolves into clinopyroxene (cpx) which in turn dissolves into garnet (gt). In the pyrolite mantle composition, all phases grow more Mg-rich with increasing depth. (Figure based on data from Irifune and Isshiki[1].)**

flow of heat and matter in the interior[2]. This flow, in turn, drives the tectonic evolution of the surface, including the occurrence of volcanism and seismicity.

Olivine, a solid solution of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4), has the approximate composition $(Mg_{0.89}Fe_{0.11})_2SiO_4$ (called forsterite-89 or Fo89) in samples from the shallow mantle. It transforms from the olivine (α) phase to wadsleyite (β), changing again to ringwoodite (γ) at greater depths and eventually breaking down to a mixture of silicate perovskite and magnesiowüstite. In standard compositional models of the upper mantle such as the pyrolite[3] model, in which a mix of different minerals is taken to account for the rocks and melts erupted at the surface from the interior, olivine accounts for only about 60% of the mantle by volume. Other minerals concerned include orthopyroxene, clinopyroxene and garnet, which gradually dissolve each into the next with increasing depth. Despite a pioneering study nearly 20 years ago, in which Akaogi and Akimoto[4] pointed out that knowledge of element partitioning amongst these minerals is 'indispensable' for understanding the mantle, to this day the olivine polymorphs are treated in isolation from pyroxenes and garnets in most models of the mantle.

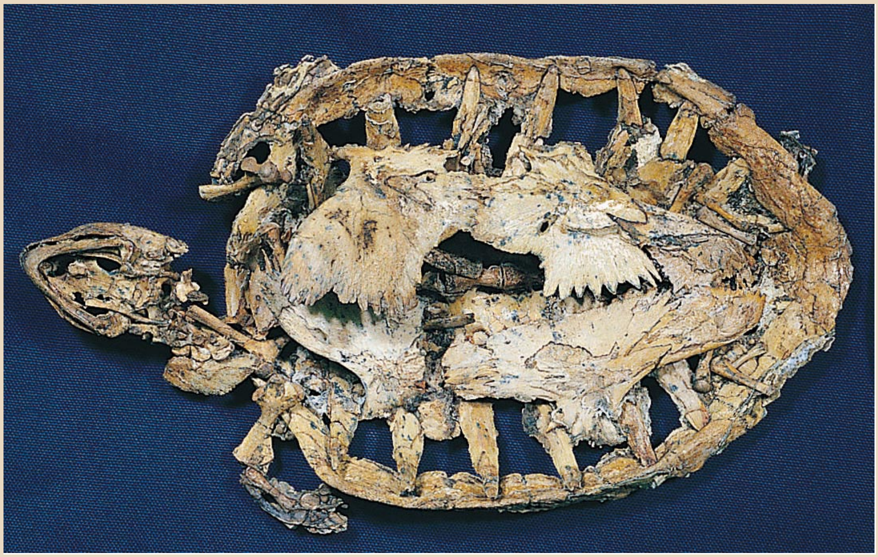
Irifune and Isshiki[1] have shown such artificial separation to be misleading by experimentally demonstrating Mg–Fe exchange between α, β, garnet and clinopyroxene. We have known[5] for some time that the proportions of these minerals vary with depth, as shown by the bold white lines in Fig. 1, but Irifune and Isshiki have now measured the accompanying variations in the compositions of coexisting minerals, shown by the colours. In isolated Fo89 olivine, mineral compositions must remain constant, except in the narrow zone of α–β coexistence. In pyrolite, however, all phases grow increasingly Mg-rich with depth. Given that bulk composition is fixed, this entails an increasing abundance of the most Fe-rich phase, garnet. Indeed, gradual dissolution of the less Fe-rich pyroxenes into the garnet both raises the proportion of garnet and dilutes the garnet to lower Fe levels. However, given constant Mg–Fe partitioning ratios (incidentally confirmed by Irifune and Isshiki), such dilution drives Fe-depletion (that is, Mg-enrichment) of α to maintain equilibrium levels of Fe in garnet. As a result, olivine above the α–β transition in pyrolite becomes enriched in Mg relative to that in Fo89.

Such Mg-enrichment of α shifts the α–β transition to higher pressures (as can be seen in Irifune and Isshiki's Fig. 3 on page 704), so the onset of the transition in pyrolite is postponed to greater depths relative to that in Fo89. On the other side of the phase change, β does not partition Fe into garnet as strongly as does α, so β is not initially Mg-enriched, and the completion of the α–β transition is not postponed relative to Fo89. The net effect of postponing onset but not completion is to concentrate the transition into a narrower range of depths, decreasing the depth-extent of the wave-speed increase by some 6 km relative to that expected for Fo89 ($>$10 km), in better agreement with seismic[6] estimates ($<$5 km).

Furthermore, mineral wave-speeds themselves also vary with composition. Wave-speed increases across the α–β transition in isolated Fo89 can be measured in the laboratory, extrapolated to mantle conditions, and scaled for a mantle model which is about 60% olivine by volume. Although subject to remaining uncertainties[7] in the pressure- and temperature-dependence of mineral wave-speeds, some such analyses[8] yield increases whose magnitudes are rather larger than those inferred for the 410-km seismic discontinuity. In pyrolite, on the other hand, the Mg-

Palaeontology

The eyes have it



Life on land is so challenging that many land vertebrates have taken the plunge and gone back to the sea. From porpoises to placodonts, pliosaurs to pinnipeds, the examples are legion. But life in the sea poses a unique problem for a returning land vertebrate — salt.

A marine vertebrate with a terrestrial ancestry has body fluids that are much less salty than sea water, so an unprotected vertebrate immersed in the sea runs the risk of dehydration. Water can be replaced by drinking sea water. This raises the saltiness of the body with respect to the sea, so there can be no net gain of water unless the salts are excreted in a solution at least as concentrated as that of sea water. The kidneys of marine reptiles, such as turtles, do not have this concentrating power: without other methods of voiding excess salt, a marine reptile cannot eat salty food or drink sea water without becoming dehydrated in the midst of plenty.

Marine life is simply unliveable unless an animal solves the salt problem. This 200-millimetre-long, 110-million-year-old fossil marine turtle, described by Ren Hirayama on page 705 of this issue (*Nature* 392, 705–708; 1998), has taken this lesson on board. The creature, which comes from the Lower Cretaceous Santana Formation of north-east Brazil, extends the fossil record of marine turtles back ten million years. The turtle is primitive in the sense that the bones in its wrists, ankles and digits have not become consolidated into rigid paddles. In other words, its feet would have looked more like those of freshwater terrapins than fully seagoing turtles.

Its salt-excreting arrangements were, in contrast, far less haphazard. Marine turtles have lachrymal glands (each one larger, in some cases, than the brain) modified to excrete a concentrated salt solution. The skull of the Santana turtle shows evidence that it had enormous salt glands around the eyes. In which case, the evolution of salt-excreting glands preceded that of rigid paddles. These salt glands were the turtles' passport back to the sea.

Henry Gee

enriched α is seismically faster than the α in Fo89, but its non-enriched β exhibits the same speeds as β in Fo89. Thus the Mg–Fe partitioning which leads to a narrower transition yields one which is also smaller in magnitude (by about 10% according to Irifune and Isshiki's estimate), in better agreement with seismic estimates.

So Irifune and Isshiki have demonstrated that the olivine polymorphs exchange Fe and Mg with their pyroxene and garnet companions under mantle conditions rather than residing in isolation, confirming Akaogi and Akimoto's early indications that Mg–Fe partitioning relative to garnet differs significantly among the olivine polymorphs. Although other factors, such as mineral hydration or nonlinear variations in wave speed, may also affect the seismic signature of phase changes, Irifune and Isshiki have helped to reconcile the properties of the α–β transition in a pyrolite model mantle with observations of the 410-km seismic discontinuity.

Although their study pertains largely to the top of the transition zone, other work[9] suggests that similar phenomena — Al–Fe exchange involving γ, garnet, silicate perovskite and magnesiowüstite — may in part determine the properties of the 660-km seismic discontinuity at the bottom of the transition zone. Interestingly enough, Akaogi and Akimoto's early study also suggested that Mg–Fe partitioning between garnet and γ should be reversed relative to β in the middle of the transition zone. Future work may or may not show that this behaviour does indeed occur. If it does, it could affect the properties of the broader β–γ transition, too, with implications for our understanding of the enigmatic seismic reflectors[10] that occur at around 520 km depth. □

Craig R. Bina is in the Department of Geological Sciences, Northwestern University, Evanston, Illinois 60208-2150, USA.
e-mail: craig@earth.nwu.edu

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Crop genetics

Reducing transgene escape routes

Alan J. Gray and Alan F. Raybould

Genetically modified crops and the food derived from them have had a bad press, but a rare piece of good news is provided by Daniell *et al.*[1] in this month's *Nature Biotechnology*. They report a development that has profound implications for the risk assessment of genetically modified crops. Most crops are modified by inserting genes into the nucleus, and the genes can therefore spread to other crops or wild relatives by movement of pollen. By engineering tolerance to the herbicide glyphosate into the tobacco chloroplast genome, however, the authors have not only obtained high levels of transgene expression, but, because chloroplasts are inherited maternally in many species, they have also prevented transmission of the gene by pollen — closing a potential escape route for transgenes into the environment.

Glyphosate is the most widely used herbicide in the world. It interferes with 5-enolpyruvyl shikimate-3-phosphate synthase (EPSPS), an enzyme that is encoded by a nuclear gene and catalyses a step in the biosynthesis of aromatic amino acids in the chloroplasts. Conventional strategies for producing glyphosate-tolerant plants are to insert, into the nucleus, an EPSPS gene from a plant or a glyphosate-tolerant bacterium (the bacterial gene is modified so that the enzyme is correctly targeted to the chloroplasts), or a gene that inactivates the herbicide.

But Daniell *et al.* have now achieved maternally inherited glyphosate tolerance in tobacco by particle bombardment of leaves with a vector containing the EPSPS gene of petunia. The gene was modified with border sequences that allow integration into the chloroplast genome by homologous recombination and, using the polymerase chain reaction and Southern blot analysis, the authors confirmed that the gene had inserted into chloroplast DNA of regenerated plants. All of the chloroplasts were transgenic, and the very high copy number of the gene (up to 10,000) resulted in a tenfold increase in glyphosate tolerance compared with transgenic plants that carry the same gene in the nuclear genome[2].

Genes that confer tolerance to herbicides have been the target of genetic engineers for more than a decade. Up to January this year, there were nearly 2,300 experimental releases of herbicide-tolerant crops in OECD countries (about 35% of all genetically modified crop releases up to then)[3]. As well as its agronomic objective, herbicide tolerance has been widely used as a selectable marker, enabling the easy detection of successful transformations.

Herbicide-tolerant crops such as the glyphosate-tolerant soybean *Glycine max* were among the first genetically modified species to be grown commercially in North America. Such crops are also near to market in Europe — for example, both glyphosate- and glufosinate ammonium-tolerant oilseed rape, *Brassica napus*, are undergoing variety trials in the United Kingdom. Tolerance to glyphosate has featured in almost one-third of all herbicide-tolerance field trials and in 20 different crops, ranging from lettuce and tomato to eucalyptus, chestnut and poplar, although the major crop targets have been maize, soybean, oilseed rape, sugar beet and cotton.

The environmental and agricultural implications of the large-scale cultivation


A. J. GRAY

Figure 1 **Off the beeten track — sea beet on a sea wall in Somerset (UK), flowering at the same time as nearby sugar beet. Genes from sugar beet are known to transfer to wild, weedy beets in areas where sugar beet seed is produced[12]. The same process can occur when sugar beet plants flower before harvest in coastal regions where sea beet occurs.**