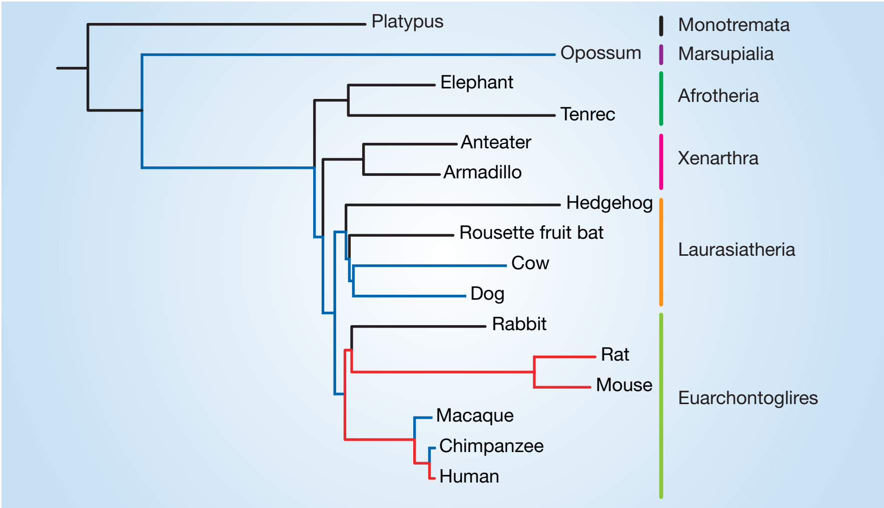

Figure 2 **Mammalian evolution and genome sequencing. This evolutionary tree shows the position of mammals whose genomes have been sequenced and analysed (red) or are being sequenced (blue). Humans, mice and rats come from the same major clade (Euarchontoglires), dogs and cows from a further clade (Laurasiatheria). But two major clades of placental mammals remain unsampled (Xenarthra and Afrotheria). Note also the fast evolutionary rate (represented by a longer branch length) of rats and mice compared with humans.**

genes and pseudogenes (copies of genes that are no longer functional) in the rat genome — possibly because of comparison across the three genomes.

The 10% of genes that are not present as one-to-one pairs between species belong to gene families that have expanded in number in one of the species. Many of these gene families are involved in olfaction, immunology or reproduction, and can easily be associated with biological features that make each species unique; for instance, humans rely less than rodents on their sense of smell, and so have fewer olfactory-receptor genes. Of particular interest for pharmacological studies are the detoxifying P450 genes, of which mice and rats have more than humans. So, it may be more difficult than thought to use the toxicity of drugs in rats as a guide to their toxicity in humans — because rats may be better at removing toxins from their system. Still, having the genome sequence makes it possible to assess whether the P450 genes acting on a specific drug are present in both rats and humans. Moreover, this gene number is more similar between rats and humans than between mice and humans, which could help explain rats' superiority over mice in pharmacology.

In the initial comparison between the mouse and human genomes[2], the high degree of sequence conservation found hinted that some 5% of each genome contains functional elements — genes, regulatory elements and so on. Including the rat genome has significantly increased the resolution of these analyses[1]. The precision of gene prediction (annotation) will continue to increase with each vertebrate genome that is sequenced, and with the availability of other resources, such as the Mammalian Gene Collection[11], that catalogue physical evidence of gene transcription. This is encouraging, because we are far from knowing every gene in the human genome, and even further from knowing how each gene is regulated. Using comparative sequence analysis, researchers can draw on the experiments performed by evolution, where functional elements are conserved and neutral sequences — those sequences that have no particular function — change over time.

To accomplish this in the next few years, a working group[12] has been charged with developing a plan to select the appropriate species and sequencing strategy by which to identify all the functional elements in the human genome. Several other mammalian genomes (those of the chimpanzee, macaque, dog, cow and opossum; Fig. 2) are currently being sequenced, and when completed will further enhance the three mammalian genomes that we already have. The high quality of the rat genome sequence[1], and the speed with which it was produced, leads us to expect great things in the near future. ■

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Earth science

Inside history in depth

David Stevenson

The history of how Earth's interior evolved, and how it accounts for many aspects of our planet's behaviour, remains largely unwritten. Taking water into account could well help to explain a great deal more.

The basic divisions of Earth's internal structure (crust, mantle and core) have been known for a long time. But the evolutionary path that gave us this structure, and that provides the dynamics of plate tectonics, volcanism and magnetic-field generation, remains poorly understood. Why do we have plate tectonics? What is the nature and extent of melting deep within Earth? How does the core manage to keep generating such a richly complex magnetic field?

These were among the questions debated on the first day of a workshop* organized under the auspices of the CSEDI (Cooperative Study of the Earth's Deep Interior), a National Science Foundation programme that is now eight years old. From the talks and ensuing discussions among deep-Earth devotees, it is evident that we need a better knowledge of the processes that govern deep-Earth history, and the material parameters that control those processes, before any kind of 'standard model' can be constructed — much though such a model may be desired by some participants.

A simple view of Earth's evolution invokes the first law of thermodynamics, estimates of radiogenic heat production — that produced by radioactivity — and some straightforward scaling arguments that emerge from our theoretical and experimental understanding of thermal convection. In this view, Earth started hot and cooled through geological time at a rate that closely mimics the decreasing rate at which the radiogenic heat production declines. This decreasing rate arises because the radiogenic heat sources have a variety of half-lives, and the more long-lived sources become increasingly important with time. Earth is

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now presumably shifting to the predominance of ^{232}Th, the longest-lived of the sources. The other parameter of great importance in simple models is the temperature dependence of mantle viscosity, because this dictates the vigour of mantle convection and plate tectonics as the heat flow declines. In this approach, Earth's core has a heat flow that is strongly coupled to mantle evolution through the mantle's ability to cool and accept heat from the core.

Models of this kind are easy to construct and boringly monotonic. Furthermore, they cannot explain the widely accepted factor-of-two ratio for current Earth heat output to current radiogenic heat production. Our planet was more eventful than these simple models allow. Whereas Earth scientists have no desire to repeal the first law of thermodynamics, they are willing to challenge almost everything else. Recently, major disagreements have emerged in attempts to understand the energy budget of Earth's core, and there are still many uncertainties over how to incorporate the effects of plates, water, melting and layering into our picture of mantle circulation.

In the current debate about Earth's core, there is a contrast between low- and high-dissipation pictures of the dynamo responsible for the planet's magnetic field (P. Olson, Johns Hopkins Univ.). These respectively make different assumptions about the geometry of the magnetic fields and associated electrical currents in the core. There is much publication activity on this topic[1–4], but no consensus, because we don't know the full complexity of the field and currents involved. A new study[5] invokes experimental dynamos as well as theoretical ideas, and suggests that dynamos may be less dissipative than some suppose, thereby making a dynamo easier to sustain. Uncertainties about the electrical and thermal conductivity of the core material, and its phase diagram, are also large enough to have a major effect on estimates of dissipation and convective vigour.

For decades, it has been popular to invoke Earth's solid inner core as one of the main contributors to the energy budget available to the dynamo. Latent heat and gravitational energy and buoyancy are released as the inner core grows and excludes some of the light-element components of the outer core (sulphur, oxygen and silicon, for example) from its crystalline structure. Standard evolutionary models have difficulty explaining how the inner core has existed for more than the past billion years or so, yet Earth's magnetic field has existed throughout most of geological time. There is no direct evidence on the age of the inner core, and the dynamo may operate without an inner core. Still, it would be surprising if it were a recent feature of Earth's structure. This is one of several reasons why some scientists wonder whether there is an additional energy source in the core. A possible candidate is radioactive decay of ^{40}K. Although the amount of core radiogenic heating required may be modest compared with Earth's present total energy budget, that amount assumes increasing importance as one goes back in time because of ^{40}K's relatively short half-life of around one billion years. It is not known whether even this modest amount of potassium in the core is assured by elemental partitioning between silicates and iron alloy at the time of core formation. Uranium is also a candidate, and additional non-radiogenic (gravitational) sources cannot be excluded.

Mantle convection driven by thermal buoyancy remains the agreed framework in which to understand plate tectonics and loss of Earth's heat. It is an unfortunate feature of simple models of convection that they can mimic many of the characteristics of plate tectonics, but cannot explain some essential features of plates. The danger of these simple pictures is that they may not provide an adequate predictive framework for how plate tectonics evolves through geological time. Some models[6,7] suggest possible solutions, but the lack of agreement between these various approaches means that we are not close to a final resolution. Water may play a major role through its ability to lower the viscosity of the mantle and possibly the strength of plates. State-of-the-art approaches to elucidating mantle convection include ambitious attempts to describe mantle mixing and accommodate the geochemical constraints (L. Kellogg, Univ. California, Davis).

Partial melting of shallow mantle is the cause of oceanic crust formation, the relatively well-understood and dominant form of volcanism on Earth. But water and carbon dioxide have a major yet poorly understood effect on melting in the mantle (M. Hirschmann, Univ. Minnesota). We do not know the total amount of water in the mantle (although it is at least comparable to that in Earth's oceans), or the rate at which this reservoir is tapped and replenished. Nonetheless, the emergence of provocative ideas[8] on the topic illustrate a growing willingness to tackle the central questions of Earth's interior ocean of water.

Remarkably, these seemingly disparate topics have a common thread. It seems likely that we will not understand the origin of Earth's magnetic field until we know how the mantle controls heat flow in the core. But we cannot understand the mantle side until we have a better understanding of plate tectonics. This may in turn depend on understanding Earth's water cycle. Could it be that magnetism, like life, depends on water? ■

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Entomology

Butterflies at that awkward age

Dick Vane-Wright

Beautifully preserved specimens of butterflies from the Caribbean, caught maybe in the act of egg-laying some 20 million years ago, provide welcome grist to the mill of debate about butterfly history.

Writing in *Proceedings of the Royal Society*, Hall and colleagues[1] describe a new fossil butterfly from examples preserved in amber from Dominica, on the island of Hispaniola. They have called the butterfly *Voltinia dramba*: about 20 million years old, it is the first adult butterfly to be formally described from Dominican or any other type of amber. Its discovery raises key issues about Caribbean biogeography, behavioural evolution (or lack of it), and the origin of butterflies.

The fossil is from the family Riodinidae (the metalmarks), and it belongs to a genus of nine living species now found only on the Latin American mainland (Fig. 1, overleaf). Over 1,000 species of riodinids are known from Central and South America, and in some lowlands they form 20% of the local butterfly fauna. Yet of 300 butterfly species found in the West Indies today, only one is a riodinid, and that species is quite unrelated to the new fossil. So the first issue is how *V. dramba* reached Hispaniola.

With five known fossil examples, beautifully preserved, Hall *et al.*[1] are able to produce good evidence that one of the living species — *V. danforthi* from Mexico — is the closest relative of *V. dramba*. Given that the fossil specimens are 15–25 million years old, Hall *et al.* suggest that the best explanation for the butterfly's presence on Hispaniola is breakup of the 'proto-Greater-Antillean arc', which is postulated to have separated the Caribbean islands from Central America[2]. They date this split, and that between *V. dramba* and