GEOSCIENCE

Driving Earth's surface motions

Rinus Wortel and Rob Govers

Density variations within Earth's mantle may be a significant driver of both horizontal and vertical surface movements. The fingerprints of such mantle processes have been found in the Mediterranean region.

Horizontal and vertical motions near Earth's surface are typically stately in pace — some 0.1 to 10 centimetres per year. But their net effects over long periods can be major. After decades to centuries, velocity differences across faults in Earth's crust produce slip deficits of up to a few tens of metres, which are resolved during large earthquakes. On timescales of millions of years, surface movements result in mountain building, in the opening of ocean basins and in the separation of continents. Faccenna and Becker (page 602 of this issue)[1] show that convective action in Earth's mantle, at depths extending from about 100 to 2,900 kilometres, is partly responsible for surface dynamics in one of the most complex tectonic areas in the world — the Mediterranean region.

Almost all scientists now accept that the motion of tectonic plates is part of a sluggish convection system in the mantle that is slowly cooling Earth's interior. But it has been difficult to predict such surface motions as the mechanical part of this heat engine, because we have had only a sketchy knowledge of the distribution and magnitude of density anomalies that drive convective flow.

From studies of the propagation of seismic waves, it has long been known that Earth has largely the same (spherical) structure as an onion. The outer spherical layer is the crust, the layers beneath it being the upper and lower mantle above the spherical core. But knowing this was not enough to understand the dynamics. Convection is driven by relatively small density anomalies within the mantle and core layers, and imaging these anomalies was much more of a challenge. Since the 1980s, the creation of a worldwide network of high-quality seismometers and the development of tomographic mapping techniques have changed this situation drastically[2]. Anomalies that could be tied to upwellings and downwellings were first imaged in the upper mantle, and later in the lower mantle[3].

Another line of investigation — geodynamic flow models[4] — developed in concert with the seismological findings. Historically, three-dimensional information was restricted to crustal levels, and explanations for the three-dimensional crustal structure were sought at crustal levels too. But as tomographic information for the upper mantle became available, complications in plate-tectonic processes were identified, for example in the Mediterranean region[5]. Faccenna and Becker[1] now include the anomalies and flow of the entire mantle in their next-generation geodynamic model.

The idea that flow in the lower mantle contributes to the deformation of Earth's surface is not new. A study[6] of uplift of southern Africa above a wide lower-mantle upwelling convincingly demonstrated such an effect. But not only do Faccenna and Becker bring planetary-scale mantle flow into the picture, they also show that flow driven by smaller-scale anomalies is needed to understand a plate-boundary zone such as the Mediterranean.

The tectonic structure of the Mediterranean is complicated, and especially interesting for that reason. Overall, two major plates, the African and Eurasian, are converging here. This convergence is not simply accommodated in a single subduction zone where one plate is being thrust below the other, however; the region has a number of smaller subduction zones and (micro)plates, the behaviour of which seems to be independent of the convergence dynamics of their larger fellows. From models of mantle flow, Faccenna and Becker demonstrate that smaller-scale convection in the mantle can account for much of that behaviour. Intriguingly, they find that flow beneath the Mediterranean region is significantly affected by the northward inflow of mantle material from beneath the Arabian continent.

We are not yet at the stage at which we have a full appreciation of a plate-boundary region such as the Mediterranean. This work[1] is just one step towards the development of a fully dynamic model that accurately reflects all the observed movement and deformation of tectonic plates, including microplates. Model representations of the connection of surface plates to mantle downwellings need to be improved. Flexing and deforming plates need to become integral parts of flow models to reliably predict dynamic topography. Only then will it be possible to convert the eighteenth-century geologist James Hutton's principle of uniformitarianism, "The present is the key to the past", to "The present is the key to the future" — that is, only then will it become possible to predict the future behaviour of Earth's surface. ■

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ASTROPHYSICS

Young stars in young galaxies

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A fine marriage between galaxy data and theoretical simulations offers an explanation for two apparently conflicting sets of observations on the rate at which stars formed at early cosmic times.

Thanks to a recent surge of multi-wavelength observations and theoretical simulations, an ever clearer picture of the build-up of stars and galaxies in the Universe is beginning to emerge. Writing in *The Astrophysical Journal*, Gnedin and Kravtsov[1] take a significant step in unifying these observations and simulations, and provide a prime illustration of the recent progress in the subject as a whole.

Numerical simulations of galaxy formation and evolution have progressed immensely over the past decade. Remarkably, the same cold dark matter theory that can reproduce the large-scale structure of the Universe also reproduces in broad outline the forms and life histories of the galaxies we observe today. Many of the details within this outline remain unresolved, however, including the structure and build-up of stars, which dominate the visible contents of galaxies. These limitations arise because the evolution of a galaxy is driven not only by gravity, which is readily modelled in what is called an *N*-body simulation, but by a suite of more complicated 'gastrophysical' processes as well: the cooling and accretion of gas, the conversion of the gas into stars, and the 'feedback' of energy and momentum from the stars back into the gas. These latter processes are poorly understood and are far too complex to simulate from scratch. Instead, analytical approximations or physical recipes are melded into the simulations.

Fortunately, nature has provided strong clues to some of these physical recipes, through