Science Spot

Brian submitted his article on plate tectonics prior to the earthquake and tsunami in Japan that has unfolded so dramatically on our TV screens and radio this past month. Therefore it's important to acknowledge the human tragedy caused by this natural disaster and our prayers continue to go out to all those who have been affected and continue to be affected.

Editor

THE EARTH'S TECTONIC PLATES

Since the early 1960s it has been recognised that the outermost shell of the Earth, the ‘lithosphere’, to a depth of about 150km, has split into a series of semi-rigid ‘plates’ of complex rock components and structure. There are about a dozen major plates, as well as many smaller ones (Fig 1), and these are known to be more or less continually moving, relatively to each other, at a rate of a few centimetres per year—the rate at which our finger nails grow!

The boundaries of these plates are of three types—1) ‘Constructive’ margins, where the plates pull apart and new lithosphere is formed in between, 2) ‘Destructive’ margins, where plates collide such that one plate overrides another and lithosphere is carried down into depths, where it merges into deeper levels of the Earth, and 3) ‘Conservative’ margins, where plates slide past each other without formation or destruction of lithosphere.

The major constructive margins occur along the mid-ocean ridges in the Atlantic, Indian and Pacific oceans. New oceanic lithosphere is formed along these ridges, and volcanic islands such as Iceland sometimes form on the ridges. Major destructive boundaries occur around the margins of the Pacific, and give rise to the ‘Ring of Fire’—volcanic activity and mountain ranges of Japan, Indonesia, New Zealand, Alaska, Central America and the Andes. An example of a major conservative margin is the San Andreas fault along the boundary of the Pacific and the west coast of the United States. Earthquakes occur along all plate margins, especially the destructive and conservative boundaries. Some tectonic plates are composed almost entirely of oceanic lithosphere, which is largely of dense basaltic volcanic rock, eg the Pacific plates, but other plates are made of both oceanic and continental lithosphere. Continental lithosphere is relatively light granitic rock and sedimentary material which is carried along with the oceanic lithosphere when the plates move. As a result, from time to time continents collide, with the formation of mountain ranges such as the Alps and Himalayas.

Beneath the largely rigid lithosphere occurs a layer of partially molten rock which is ductile (able to flow, like very thick treacle), down to a depth of about 250km, known as the asthenosphere. It is the presence of this ductile layer which makes it possible for the rigid lithospheric plates to move around the Earth. Underneath the asthenosphere, the mainly solid Earth's mantle, consisting of high pressure silicate minerals, continues to a depth of 2,900km. Beneath that is the Earth's molten nickel-iron core, which continues to 4,980km, and then a solid nickel-iron core, forming the centre of the Earth to a depth of 6,370km. So the lithospheric plates are only just over one fiftieth of the Earth's radius in thickness. Rock which is partially to completely molten rises to the surface from various depths, to produce volcanoes which are often, but not always, related to plate margins, eg the Hawaiian volcanoes.

The Earth was formed about 4.6 billion years ago and its interior has remained hot (about

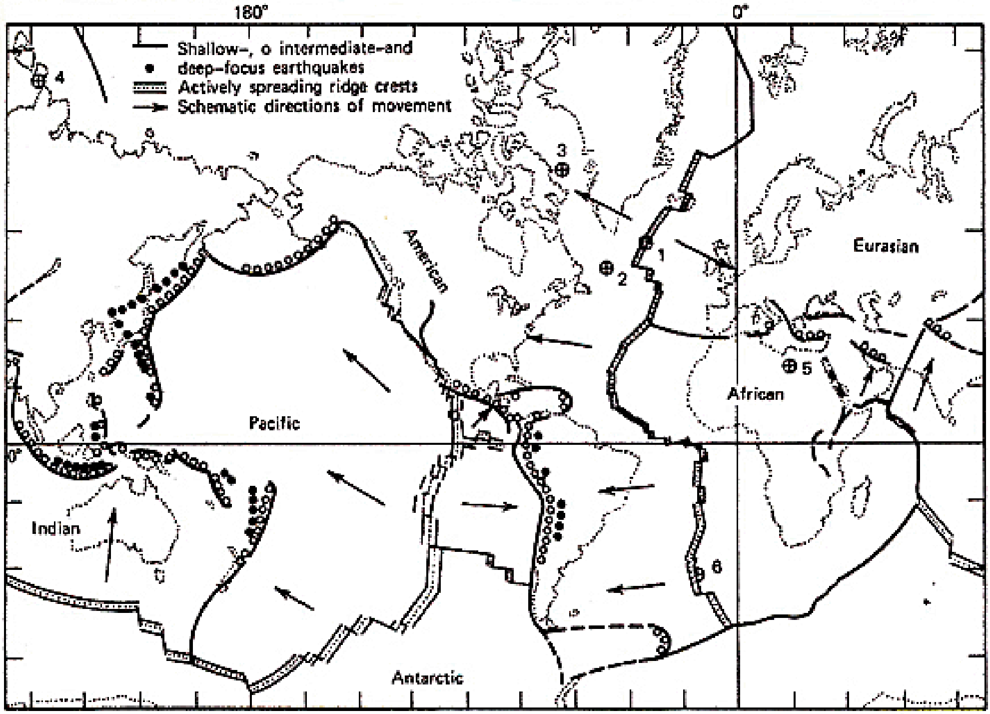

Fig 1: The Earth's major tectonic plates, showing directions of relative movement, plate boundaries and earthquake zones (after Vine and Hess, 1970)

5,000°C at the centre) mainly due to heat generated by radioactive decay. It is this heat which causes the asthenosphere to be partially molten and so allows the mainly rigid lithospheric plates to move around above it. The fundamental causes of plate movement are still uncertain. Most geologists think that convection currents within the Earth are responsible, dragging the plates across the surface, but there are many problems with this idea. Although molten rock can rise from the asthenosphere, and from greater depths, possibly even from the core/mantle boundary, most of the Earth's interior is solid, making convection currents difficult to envisage. If they do exist, the most likely candidates are two large ones, rising near the equator on opposite sides of the Earth, beneath the Pacific and beneath Africa, respectively. These could be related to the rotation of the Earth, which is also responsible for the Earth's magnetic field in the molten iron core.

My own preference is for an idea which has been suggested by a minority of geologists, and might be called the ‘Lithospheric Inertia’ hypothesis. Most lithospheric plates show a tendency to move in a westerly direction relative to each other, albeit at varying rates so that they sometimes pull apart and sometimes collide. This relative westerly movement may be the result of the plates tending to lag behind, riding on the ductile asthenosphere, as the Earth rotates in an easterly direction at a rate of 1,600km/hr at the equator. The fastest rates of relative plate movement occur near the equator. In the past Earth rotated faster, which would have increased this effect. Drag on the lithosphere caused by the gravitational attraction of the Moon could reinforce this, especially bearing in mind that the Moon was closer to the Earth in the past than it is now—the Moon is moving away from the Earth at a rate of a few cm/year.

Although these effects would be very slight, over great periods of geological time the results could be dramatic. Amusingly, I was reminded of this idea while watching a rather plump belly-dancer in Tunisia, whose tummy tended to lag behind as she gyrated from side to side! It is not certain exactly when the Earth's lithosphere became stable enough and rigid enough for plate tectonics to operate. No doubt it was a gradual process, but there are clear signs that by at least three billion years ago this was the case. Certainly, plate tectonics has been responsible for the evolution of all the major, and many of the minor, features of the Earth's surface as well as having a profound influence on the evolution of life and of the Earth's climate. It is highly significant that plate tectonics does not operate on any other planets of the solar system. The recent severe earthquakes in Christchurch, New Zealand, and in Japan, are a reminder of how active these processes are today.

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