Tectonics

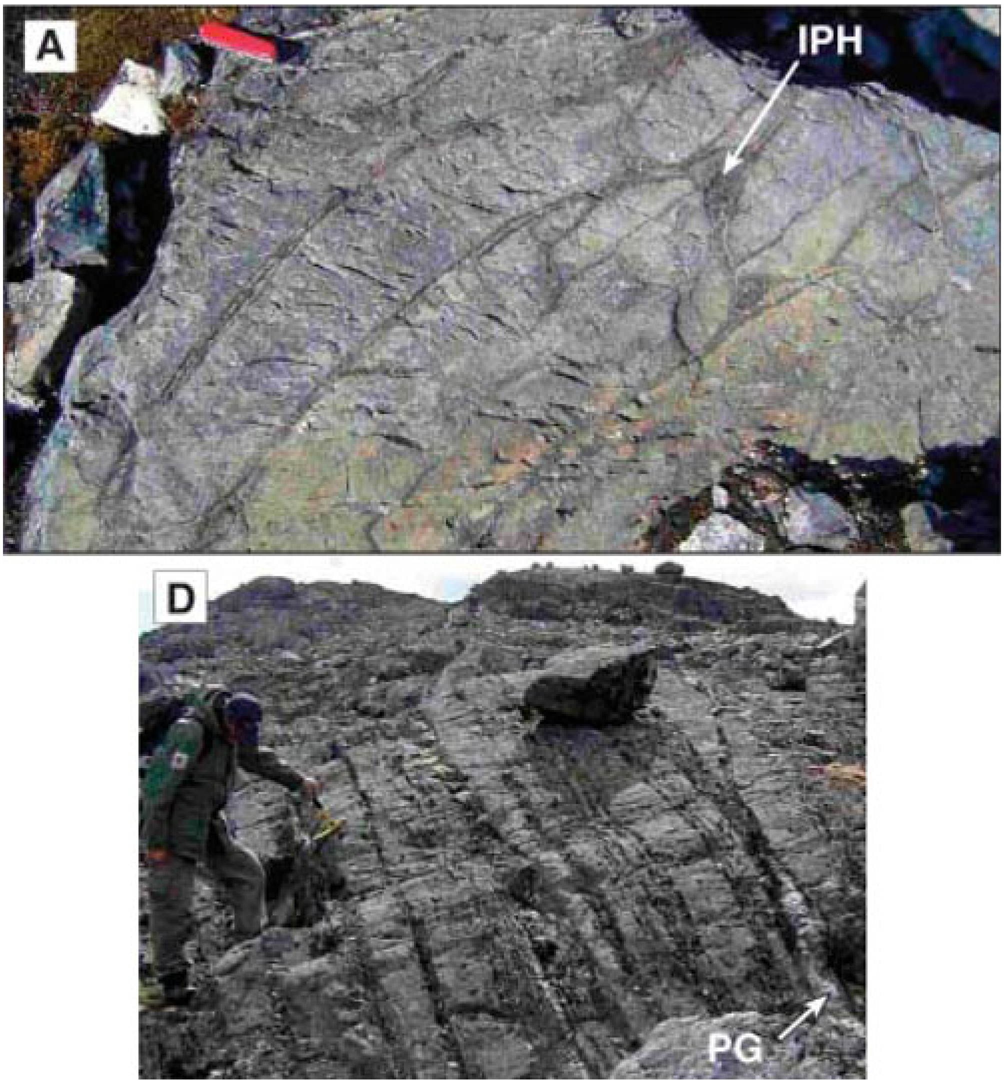
How the asthenosphere loses its strength (*February 2007*)

The Earth is the only tectonically active planet, and indeed its plate movements are astonishingly rapid in a geological sense – about the same rate as toenails grow. Specifically, our planet's activity takes the form of thin, rigid slabs that move on top of a shallow layer of mantle called the asthenosphere (from the Greek *a-sthenos* meaning 'without strength'). The reduced rigidity of the asthenosphere is signified by the low speeds at which seismic waves travel through it. It is tempting to regard this low-velocity zone as mantle 'on the point of melting', perhaps even with isolated pockets of melt. A more widely held view is that it is due to an increased tendency over its range of depth for mantle minerals to contain defects, whose migration gives rise to deformation in the solid state, or creep. Both phenomena are enhanced by water, in the first case if it exists in molecular form, in the second when it dissolves as OH^- in otherwise anhydrous mantle minerals. Experimental work on how mantle minerals behave at different pressures in the presence of water is able to refine models for the asthenosphere (Mierdel, K. *et al*. 2007. Water solubility in aluminous orthopyroxene and the origin of the Earth's asthenosphere. *Science*, v. **315**, p. 364-368; DOI: 10.1126/science.1135422).

Mierdel and her colleagues show that of the main mantle minerals, orthopyroxene shows a sharp decrease in water solubility from high at shallow-mantle pressures to low at depths within the asthenosphere. The dominant mineral, olivine, continuously increases its capacity to dissolve water as depth increases. This makes the depth range of the asthenosphere the least likely for water to be dissolved in the mantle. Instead it must exist in molecular form, able to stimulate incipient melting and therefore weakness. At pressures of the lithosphere, mantle orthopyroxene may 'mop-up' water so that the dominant olivine is dried and thereby becomes stronger.

The oldest ophiolite (*May 2007*)

The Isua area of West Greenland is one of the most prowled over pieces of geological real estate in the world, and is certainly one of the oldest, dated at ~3.8 Ga. Close to the Greenland ice cap, melting bared the fresh rock in the last few thousand years and there is little vegetation, soil or weathering. The area can be mapped and intricate details extracted at scales down to 1:100, and parts of it probably have been examined on hands and knees. The reason for the attention, apart from its antiquity, is that the rocks are recognisably metamorphosed volcanics and sediments, albeit quite highly deformed in places. There are conglomerates that prove deposition by moving water, fine iron-rich cherts that may have formed in submarine hot springs and pillow lavas effused underwater. The cherts would, if unmetamorphosed, be good places to look for signs of early life, and indeed carbon isotopes extracted from apatites in them have been suggested to show signs of life (more recent work failed to find any sign of carbon in such apatites, so the ancient-life aspect of Isua is somewhat tarnished). The lavas and accompanying igneous rocks attract geologists interested in ancient tectonics (Furnes, H. *et al*. 2007. A vestige of the Earth's oldest ophiolite. *Science*, v. **315**, p. 1704-1707; DOI: 10.1126/science.1139170). Furnes *et al*. are not the first to suggest that Isua preserves an ophiolite and evidence for early Archaean plate tectonics, that distinction having gone to a Japanese team 8 years before, who did map on their hands and knees. However, Furnes and colleagues did drive in the final nail – a sheeted-dyke component discovered in the complex – and describe the basalt geochemistry.



Ophiolite indicators at Isua: (top) Pillow lavas; (bottom) sheeted dyke complex. (Credit: Furnes*et al*. 2007; Fig. 2)

Geochemically, the Isua pillow lavas show affinities with both intra-oceanic island arc and mid-ocean ridge settings, their oxygen isotopes indicating extensive involvement of seawater in their alteration. Inevitably, geochemists will have another shot at signs of the earliest life, and perhaps evidence will be found for 'black smokers', the hydrothermal vents which today are colonised by weird and sometimes primitive microbial life forms. Yet Furnes *et al*. report, astonishingly, '…the strain history of these rocks is not yet sufficiently well-known to permit a detailed reconstruction of the Isua ophiolite complex'. On your knees, ladies and gentlemen…

Supercontinents of the past and future (*November 2007*)

Vigorous plate tectonics on the Earth continually drives continents around on the surface. Inevitably, they will clang together sooner or later, along with new sialic crust formed in island arcs that older continental masses sweep up. The more continental crust the more likely it is that all of it will accumulate in a supercontinent. Geologists know three of these for sure : Alfred Wegener's Pangaea (250-200 Ma); Greater Gondwana that clumped together the modern southern continents at 600 Ma and ended up in Pangaea; Rodinia (1100-750 Ma). There are suspicions of earlier assemblies in the Palaeoproterozoic and Archaean, but the crucial method that uses palaeomagnetism for confirming reconstructions breaks down before Rodinia's times. Also, much has happened since 2 billion years ago so that all but shreds of geological evidence have become scrambled.

If plate tectonics is regularly paced over long periods, and that is quite likely as it is driven by continuous heating of the mantle by radioactive decay, maybe there ought to be some kind of cycle of supercontinent assembly. There again, once formed why shouldn't sea-floor spreading in a corresponding super-ocean hold a supercontinent together and still efficiently dissipate the Earth internal heat production? The information to hand indicates that they can last a while (400 Ma in the case of Gondwana) but eventually break up. It has been pretty certain for some time that mantle plumes from the core-mantle boundary don't follow the same motions as do surface plates, so sooner or later one pops up beneath a continent. The bigger the continent the greater the chance that a plume will perturb it, the more so as thick continental lithosphere will act as a thermal 'lid' because of the sluggishness of conductive heat transfer through rigid bodies. It is possible to model the two processes of continental drift/collision and the rise of plumes (Phillips, B.R. & Bunge, H-P. 2007. Supercontinent cycles disrupted by strong plumes. *Geology*, v. **35**, p. 847-850; DOI: 10.1130/G23686A.1). What the US and German co-authors discovered from their model is that planets like the Earth cannot settle into long-term tectonically stable modes. Periodicity is unlikely, and what might look like a kind of regularity – some authors, beginning with J. Tuzo Wilson, have argued for ~400 Ma cycles (dubbed 'Wilson cycles' in his honour) – is merely an artefact of there having been only a few supercontinents in the geological past.

This will come as a bit of blow to the authors of an entertaining speculation about the future of plate tectonics (Williams, C. & Nield, E. 2007. Pangaea, the comeback. *New Scientist*, v. **196** (20 October 2007), p. 36-40). Williams and Nield depend on there really being cyclicity in plate tectonics, and they are not the first to have a shot at predicting a world that will not harbour anything passably human; there has been NovoPangaea, Amasia and Pangaea Proxima (all shown as animations) scheduled for a quarter of a billion years hence. Yes, they would be odd worlds, in the same way as all supercontinents would be alien to those of us used to being no more than 2600 km from the seaside (at the continental pole of inaccessibility in NW China). There would be odd weather patterns, an odd climate overall and mountains where now there are plains and shallow seas. Evolution would slow down both in the seas and on the continents, since all life would potentially interact and there would be fewer ecological niches. A point that ought not to be lost, especially on the authors, is that we can only have such speculative fun by referring to what we do know from the past. I am surprised that a major impact that wipes out all life except for prokaryotes isn't built into Williams and Nield's playful scenario.

Lightened load speeded up India's drift (*November 2007*)

About 140 Ma ago India split from the other Gondwanan continents, and proceeded northwards from its formerly fixed position against what is now Africa, eventually to collide with Eurasia around 50 Ma ago. Its progress was astonishingly fast, as continental drift goes, at around 20 cm per year compared with Australia, Africa and Antarctica at little more than a tenth of that speed (Kumar, P. *et al*. 2007. The rapid drift of the Indian tectonic plate. *Nature*, v. **449**, p. 894-897; DOI: 10.1038/nature06214 ·). Kumar from NGRI in India, and his Chinese and German colleagues, attribute this to the process of Gondwana break-up itself. It probably started when a large mantle plume arrived at the base of the supercontinent's lithosphere; one now represented by the Marion, Kerguelen and Réunion plumes. The sluggish continents have thick lithospheric roots (180-300 km), whereas India (100 km) does not. So, the subcontinent was an especially light load to be dragged northwards by slab pull beneath Asia. The reason suggested for this is that the early Cretaceous plume destabilised the lithospheric root beneath India, causing it to founder. This might also explain another oddity about Southern India. The area is characterised by some of the largest extents of deep-crustal granulites in the world, which are also by far the highest: the Nilgiri granulites reach 2.6 km above sea level. Isostatic rebound from Cretaceous delamination would nicely explain this anomaly of mountains made of the densest continental materials.