Tectonics

Pacific plate about to split? (*March 2008*)

The world's largest lithospheric plate lies to the west of the East Pacific Rise spreading axis, and extends from 60˚N to 60˚S. A string of volcanic islands connects Easter Island, which is close to the East Pacific Rise, to Samoa on the northern end of the Tonga Trench. Each lies above a small hot spot, which collectively define the most densely packed area of active within-plate volcanism on the Pacific Plate. Associated with it is an area of anomalously shallow ocean floor: the South Pacific Superswell. North of this zone the plate velocity has been faster than that of the southern part of the Plate for the last 7 Ma. One explanation for the hot-spot cluster is that it lies above a 'tear' that is starting to develop in the Pacific lithosphere (Clouard, V. & Gerbault, M. 2008. Break-up spots: Could the Pacific open as a consequence of plate kinematics? *Earth and Planetary Science Letters*, v. **265**, p. 195-208; DOI: DOI: 10.1016/j.epsl.2007.10.013). Others dispute this conjecture, but Clouard and Gerbault have modelled strain patterns across the Plate, using plate speeds derived from magnetic stripes and GPS measurements, to predict where volcanism might arise in relation to a focussed shear zone in the lithosphere. The model points directly at the linear cluster of hot spots. Maybe this is the site of a future division of the Pacific Plate into two, the current magmatism perhaps to generate a new, E-W spreading axis. That would be 5 to 20 Ma off, so there is plenty of time to discuss the processes going on.

See also: Reilly, M. 2008. Is the Pacific splitting in two? *New Scientist*, v. **197** (26 January 2008 issue), p. 10.

Is plate tectonics a turn-on or a turn-off? (*March 2008*)

The dominant force that helps to drive plate motions is the pull exerted by dense cold lithosphere descending subduction zones. If the total length of subduction zones were to increase or decrease, or some other factor affecting the global rate of subduction changed then plate movements overall would be affected. Yet it is plate tectonics that actually removes the bulk of heat continuously generated in the deep Earth by radioactive decay. The amount changes very slowly over periods of tens to hundreds of million years. Should plate movements slow or stop, that heat would either build up at depth or would emerge in a way unrelated to the motion of plates, perhaps as within-plate magmatism.

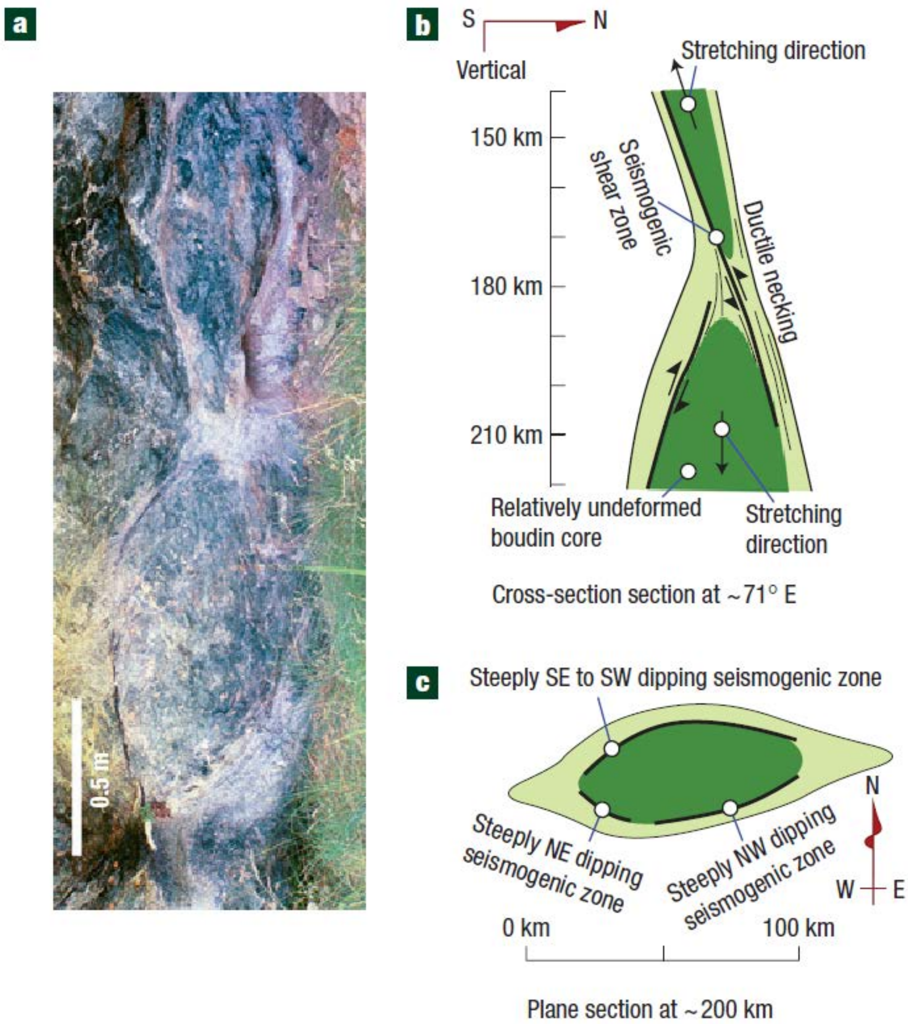
Should the Pacific Ocean close, then a large proportion of modern subduction would stop, and some kind of thermal and mechanical compensation would cut-in. There were times in the past when vast oceans did close as supercontinents formed: the formation of Rodinia in the late Mesoproterozoic; the Pan African orogeny of the late Neoproterozoic; the mid-Phanerozoic assembly of Pangaea. Each would have resulted in an order-of-magnitude fall in the rate of subduction. Paul Silver and Mark Behn of the Carnegie Institution of Washington and Woods Hole Oceanographic Institution have attempted to judge what kind of thermal and mechanical compensation may have taken place (Silver, P.G & Behn. M.D. 2008. Intermittent plate tectonics. *Science*, v. **319**, p. 85-88; DOI: 10.1126/science.1148397). They look at geochemical parameters that ought to act as proxies for subduction processes – the way certain element and isotope proportions in the mantle (Nb/Th and $^{4}He/^{3}He$) are affected by the productivity of arc magmatism. Another proxy for subduction intensity is the rate of production of continental crust, assuming reasonably that most is produced from magmas generated at volcanic arcs.

It has become clear, as the number of absolute ages from the crust has steadily increased, that the continents have formed in a stop-start fashion. Convincingly, Silver and Behn's synthesis of Nb/Th and $^{4}He/^{3}He$ ratios in basalts also shows a marked fluctuation in the rate of the mantle's chemical depletion. It peaked at the end of the Archaean, declined to a minimum around 1 Ga and rose again with the formation of Pangaea at about 300 Ma. The link with supercontinent formation is not simple, although a pattern emerges. Pangaea and the suspected Nuna supercontinent of the Palaeoproterozoic link to peaks in mantle depletion rate, whereas the supercontinents Rodinia and Pannotia (arising from the Pan African) formed while depletion rates were low. Silver and Behn ascribe the differences to two kinds of closure of Pacific-sized oceans following their origination by rifting and drifting of supercontinents. One scenario involves closure of the ocean that once surrounded the supercontinent, as seems to be on the cards, eventually, for the modern Pacific; P-type closure. The other when the ocean formed passively by break-up is 'outgunned' by sea-floor spreading in the once surrounding ocean. That would be the case had the spreading on the East Pacific Rise not involved double subduction around the Pacific margins – the Atlantic would have opened only for both its margins to become subduction zones; A-type closure. Pangaea and possibly Nuna resulted from A-type closure. On the other hand Rodinia and Pannotia seem to have involved circumnavigation of drifting continents to collide at roughly the antipode of the split in a preceding supercontinent by P-type closure.

The conclusion is that plate tectonics was active in the early Earth, becoming intermittent in its middle life and rose again since a billion years ago. From an examination of the deep thermal consequences of changes in plate motions in the outer Earth, it appears that mantle temperature has fluctuated markedly through time, albeit with a net decrease due to decayed radioactivity. This may have partially 'switched off' the conditions for mantle convection that favours plate formation and motion to a more sluggish form. By way of confirmation of their theoretical work, Silver and Behn point to the vast emplacement in most modern continents of granitic and anorthositic plutons under tectonically quiescent conditions that characterised the Grenvillian events preceding the formation of Rodinia between 1.6 to 1.3 Ga.

A drop off the old block? (*May 2008*)

It is not so long ago that detachment and foundering of material from lithospheric blocks began to be visualised as a means to explain large areas of recent, rapid uplift of the continental surface. Chunks falling from the subducted slabs beneath Tibet and Kamchatka (see *Evidence for slab break-off in subduction zones* September 2002) may have generated unusual magmatism or stopped volcanism respectively. Massive Himalayan uplift and that of areas such as the Sierra Nevada in the western US seem to indicate foundering of large masses of mafic rocks from the base of thickened lower crust (see *Mantle dripping off mountain roots* October 2004). Even the end-Miocene Messinian salinity crisis in the Mediterranean has been ascribed to uplift resulting from delamination (see *When the Mediterranean dried up* May 2003). Yet convincing evidence from seismic data are conspicuous by their rarity. A necking, or monstrous boudinage of the subducting slab beneath the Hindu Kush region of the Himalayan chain is convincingly demonstrated by geophysicists from the Australian National University (Lister, G. *et al*, 2008. [Boudinage of a stretching slablet implicated in earthquakes beneath the Hindu Kush]. *Nature Geoscience*, v. **1**, p. 196-201; DOI: 10.1038/ngeo132).



Lister *et al*.'s interpretation of ductile necking on a subduction zone beneath the Hindu Kust (B – cross section; c – plan view) compared with an exposed, kilometre sized megaboudin of high P/T gneisses in Italy (a) (Credit: Lister *et al*.; Fig. 6)

The setting for this remarkable 'caught in the act' phenomenon is where a minor ocean basin closed when the Kohistan arc was accreted to Asia during the closure of the Tethys ocean, and is in the process of vanishing. Wherever such minor basins have been caught up in major destructive-margin tectonics they seem to coincide with markedly arcuate orogens characterised by high-P metamorphism and repeated stacking of thrust slices. Once school of thought seeks a solution by some kind of ductile 'dripping' of mantle, which the authors sought to test by looking at seismicity beneath the most prominent of these arcuate mini-orogens. What they found was a zone of 'necking' defined by clustered earthquakes on either side. Detailed analysis suggests that a drop-shaped mass is in the process of detaching itself by a combination of brittle and ductile deformation –a boudin several orders of magnitude larger than any that have previously been described.

Refined seismic tomography of North American subduction (*September 2008*)

Relics of the Farallon plate that was subducted beneath North America during its late Mesozoic and Cenozoic westward drift have been known for some time from seismic tomography, but only in a blurred form. Advances in computation from many seismic records are steadily improving the resolution of this revolutionary technique, and a more finely tuned picture of the mantle beneath the North American continent has now emerged (Sigloch, K. *et al*. 2008. Two stage subduction history under North America inferred from multiple-frequency tomography. *Nature Geoscience*, v. **1**, p. 458-462; DOI: 10.1038/ngeo231). The American-German-French team reveal several pieces of the 'lost' plate in an astonishingly complex 3-D representation of the North American mantle down to 1800 km. There are two main blocks: one still active and connected to the active subduction zone between British Columbia and northern California that dips steeply to about 1500 km depth, the other inactive and stranded beneath the eastern part of the continent. The authors believe that the two separated around the end of the Mesozoic. They suggest that the break coincided with the within-plate deformation and volcanism known as the Laramide era that lasted from 70-50 Ma, which probably coincided with low-angled subduction of the Farallon plate. After the break, the flat subduction 'rolled-back' westwards, leaving a track on volcanism across the western part of the continent. The authors also ponder on the relationship between the changed style of subduction and the thermal event that produced the Columbia River continental flood basalt event at 17 Ma.

The ocean that tried to swallow itself (*September 2008*)

Wegener's famous supercontinent Pangaea lasted for about 200 Ma from the mid Carboniferous to the late Triassic, and formed a 'slice world' extending almost from pole to pole. Yet it had a vast spreading embayment on its eastern side, around which wrapped two 'horns' of continental lithosphere: an ocean dubbed 'Palaeotethys'. Another peculiarity is that at its core Pangaea is marked by a huge, orogenic belt that seems to have been buckled on a continental scale: the Iberian-American Arc. Such refolded mountain chains are sometimes referred to as 'oroclines', and there is considerable debate about how they might have formed. The latest notion is that slab-pull at a north-dipping subduction zone at the northern edge of Palaeotethys not only caused its spreading centre to be consumed, but thereafter continued to suck at the remaining ocean lithosphere (Gutiérrez-Alonso, G. *et al*. 2008. Self-subduction of the Pangaean global plate. *Nature Geoscience*, v. **1**, p. 549-553; DOI: 10.1038/ngeo250). The stresses involved in attempted closure of the wedge-shaped ocean spur on the otherwise elliptical supercontinent would explain several roughly radial rift systems with voluminous magmatism that formed in Pangaea in Permian times, such as the Oslo graben. Ever ready for a bit of fun, *New Scientist* has referred to Pangaea in terms of an aged, but well-known computer-game object that apparently turned on itself after consuming all lesser objects (Palmer, J. 2008. Pac-Man supercontinent ate itself to pieces. *New Scientist News Service*, 6 July 2008.

Tibetan Plateau reviewed (*September 2008*)

The roughly 5 km high Tibetan Plateau is not only the largest area of high elevations on Earth, it helps generate the monsoons of southern and SE Asia. Some have argued that it is a major climatic driver and may have been responsible for overall cooling of the Northern Hemisphere by diverting wind patterns once it had reached its present extent. Tibet may even have influenced global cooling through the Cenozoic by encouraging extraction of CO_2 from the atmosphere by liberating enormous quantities of silicate minerals for chemical weathering. From a tectonic standpoint the Plateau is especially fascinating. In the mid-1970 Molnar and Tapponnier proposed that the near-doubling of Tibet's crustal thickness had created unstable conditions and that crust was being extruded eastwards as a result of gravitational collapse: an evolving example of escape tectonics. There are hundreds of papers on or relating to the Tibetan Plateau, its origin and evolution, so a succinct review is welcome (Roydon, L.H. *et al*. 2008. The geological evolution of the Tibetan Plateau. *Science*, v. **321**, p. 1054-1058; DOI: 10.1126/science.1155371).

Royden and colleaguescentre on the development over 3 decades of the escape tectonics idea, and offer an important regional insight. Widening the context to include the evolution of the West Pacific oceanic lithosphere reveals a link between the timing of plate tectonic events there and changes in crustal collapse far to the west in eastern Tibet and adjacent lands. Soon after India began to collide with Eurasia in the Eocene, the subduction zones of the West Pacific and Indonesia migrated ridgewards, away from Eurasia as a result of trench rollback. This created space into which crustal collapse could spread as the Himalaya and Tibetan Plateau were thrown up. This trench migration stopped during the Miocene, severely interfering with the gravitational possibilities for escape tectonics. Effectively, the escape from Tibet was 'dammed', and it is from that date that the phenomenal rise to 5 km elevation has taken place. The authors even link this hindrance to the development of seismically hazardous conditions throughout western China, such as the Longmenshan mountains where the magnitude 7.9 12 May 2008 Wenchuan earthquake occurred (Burchfiel, B.C. *et al* 2008. A geological and geophysical context for the Wenchuan earthquake of 12 May 2008, Sichuan, People's Republic of China. *GSA Today*, v. **18** (July 2008), p. 4-11; DOI: 10.1130/GSATG18A.1)

See also: Kerr, R.A. 2008. Pumping up the Tibetan Plateau from the far Pacific Ocean. *Science*, v. **321**, p. 1028-1029; DOI: 10.1126/science.321.5892.1028a.