Tectonics

Earliest plate tectonics tied down? (March 2020)

Papers that ponder the question of when plate tectonics first powered the engine of internal geological processes are sure to be read widely: tectonics lies at the heart of Earth science. Opinion has swung back and forth from 'sometime in the Proterozoic' to 'since the very birth of the Earth', which is no surprise. There are simply no rocks that formed during the Hadean Eon of any greater extent than 20 km^2. Those occur in the 4.2 billion year (Ga) old Nuvvuagittuq greenstone belt on Hudson Bay, which have been grossly mangled by later events. But there are grains of the sturdy mineral zircon $ZrSiO_4$) that occur in much younger sedimentary rocks, famously from the Jack Hills of Western Australia, whose ages range back to 4.4 Ga, based on uranium-lead radiometric dating. You can buy zircons from Jack Hills on eBay as a result of a cottage industry that sprang up following news of their great antiquity: that is, if you do a lot of mineral separation from the dust and rock chips that are on offer, and they are very small. Given a laser-fuelled SHRIMP mass spectrometer and a lot of other preparation kit, you could date them. Having gone to that expense, you might as well analyse them chemically using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to check out their trace-element contents. Geochemist Simon Turner of Macquarie University in Sydney, Australia, and colleagues from Curtin University in Western Australia and Geowissenschaftliches Zentrum Göttingen in Germany, have done all this for 32 newly extracted Jack Hills zircons, whose ages range from 4.3 to 3.3 Ga (Turner, S. *et al*. 2020. An andesitic source for Jack Hills zircon supports onset of plate tectonics in the Hadean. *Nature Communications, v.* **11**, article 1241; DOI: 10.1038/s41467-020-14857-1). Then they applied sophisticated geochemical modelling to tease out what kinds of Hadean rock once hosted these grains that were eventually eroded out and transported to come to rest in a much younger sedimentary rock.

Artist's impression of the old-style hellish Hadean (Credit : Dan Durday, Southwest Research Institute)

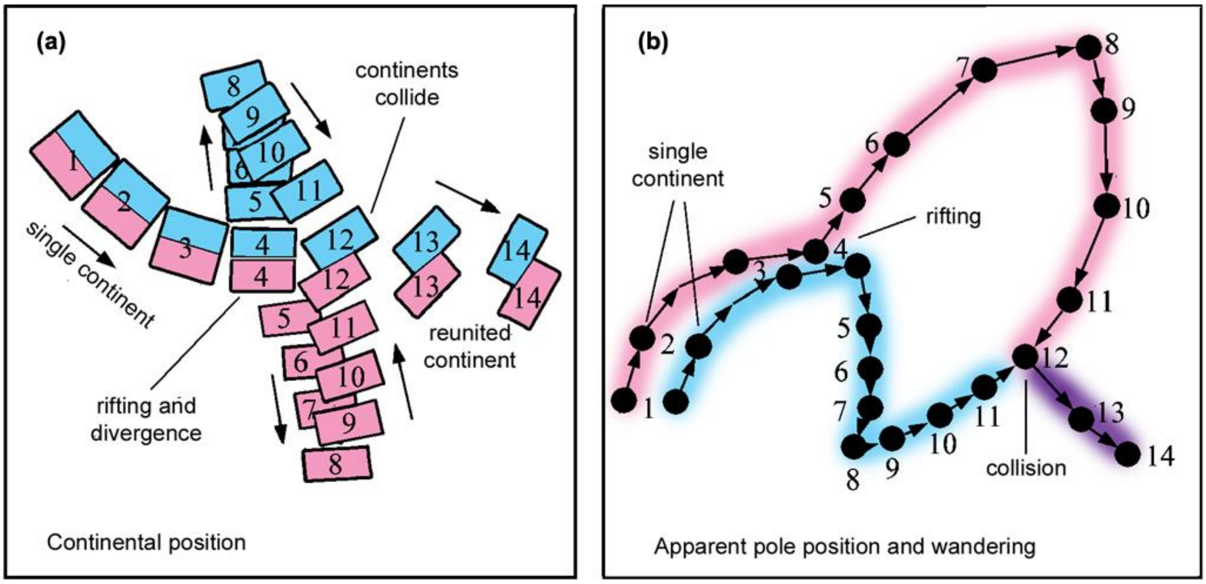
Zircons only form during the crystallisation of igneous magmas, at around 700°C, the original magma having formed under somewhat hotter conditions – up to 1200°C for mafic compositions. In the course of their crystallising, minerals take in not only the elements of which they are mainly composed, zirconium, silicon and oxygen in the case of zircon , but many other elements that the magma contains in low concentrations. The relative proportions of these trace elements that are partitioned from the magma into the growing mineral grains are more or less constant and unique to that mineral, depending on the particular composition of the magma itself. Using the proportions of these trace elements in the mineral gives a clue to the original bulk composition of the parent magma. The Jack Hills zircons mainly reflect an origin in magmas of andesitic composition, intermediate in composition between high-silica granites and basalts that have lower silica contents. Andesitic magmas only form today by partial melting of more mafic rocks under the influence of water-rich fluid driven upwards from subducting oceanic lithosphere. The proportions of trace elements in the zircons could only have formed in this way, according to the authors.

Interestingly, the 4.2 Ga Nuvvuagittuq greenstone belt contains metamorphosed mafic andesites, though any zircons in them have yet to be analysed in the manner used by Turner *et al.*, although they were used to date those late-Hadean rocks. The deep *post*-Archaean continental crust, broadly speaking, has an andesitic composition, strongly suggesting its generation above subduction zones. Yet that portion of Archaean age is not andesitic on average, but a mixture of three geochemically different rocks. It is referred to as TTG crust from those three rock types (trondhjemite, tonalite and granodiorite). That TTG nature of the most ancient continental crust has encouraged most geochemists to reject the idea of magmatic activity controlled by plate tectonics during the Archaean and, by extension, during the preceding Hadean. What is truly remarkable is that if mafic andesites – such as those implied by the Jack Hills zircons and found in the Nuvvuagittuq greenstone belt – partially melted under high pressures that formed garnet in them, they would have yielded magmas of TTG composition. This, it seems, puts plate tectonics in the frame for the whole of Earth's evolution since it stabilised several million years after the catastrophic collision that flung off the Moon and completely melted the outer layers of our planet. Up to now, controversy about what kind of planet-wide processes operated then have swung this way and that, often into quite strange scenarios. Turner and colleagues may have opened a new, hopefully more unified, episode of geochemical studies that revisit the early Earth . It could complement the work described in An Early Archaean Waterworld published on Earth-logs earlier in March 2020.

Earliest direct evidence of plate motions (April 2020)

Published on April 29, 2020 Leave a comment

There are two ways that we recognise the movement of tectonic plates. Since the latter half of the Mesozoic Era, following break up of the Pangaea supercontinent, it bests manifests itself in the magnetic 'stripes' on the ocean floor. They result from alternating polarisation of the geomagnetic field as new oceanic lithosphere is generated at constructive plate boundaries to drive sea-floor spreading. The oldest remaining stripes date back to the early Jurassic. For earlier times geologists have to turn to the continental crust. Lavas and some sedimentary rocks undergo magnetisation at the time of their formation and retained that imprint. Such remanent, palaeomagnetism reveals the original latitude at which it was imprinted, together with the subsequent rotation of a drifting continent relative to an assumed N to S axis joining the opposed magnetic poles. The apparent 'wandering' of the pole through time when successive ancient pole positions of different ages are plotted in relation to the present position of a continent is a good guide to its history of drifting as a result of plate tectonics. Comparing the polar-wander paths of two continents allows the time when they were formerly united to be estimated. So palaeomagnetic pole data makes it possible to reconstruct not just Pangaea but a whole series of earlier supercontinents, ancient magnetic data being supplemented by other geological evidence such as reconnecting the trends on different continents of ancient mountain belts.



Apparent polar wander paths for two continents for a period when they were united then split and were separated by sea-floor spreading, eventually to collide and reunite

The further back in time the fewer palaeomagnetic pole positions have been estimated, and the more uncertain are the apparent polar wander paths and the more complex each continent's accumulated geological history. One of the reasons for such uncertainty is that episodes of metamorphism can reset a rock's remanent magnetisation, hundreds of million years after it originally formed. Thus, the harder it becomes to be certain about early [supercontinents that have been suggested], of which there are quite a few. The earliest that has been proposed is Vaalbara, albeit on grounds of geological similarity, that supposedly united the Kaapvaal and Pilbara Cratons of southern Africa and Western Australia, respectively. Its duration is suggested to have been between 3.6 to 2.8 Ga (billion years ago). The oldest supercontinents with sound palaeomagnetic records date from the end of the Archaean Eon (2.5 Ga). It is the lack or uncertainty of earlier palaeomagnetic evidence that makes the start of plate tectonics the subject of so much debate.

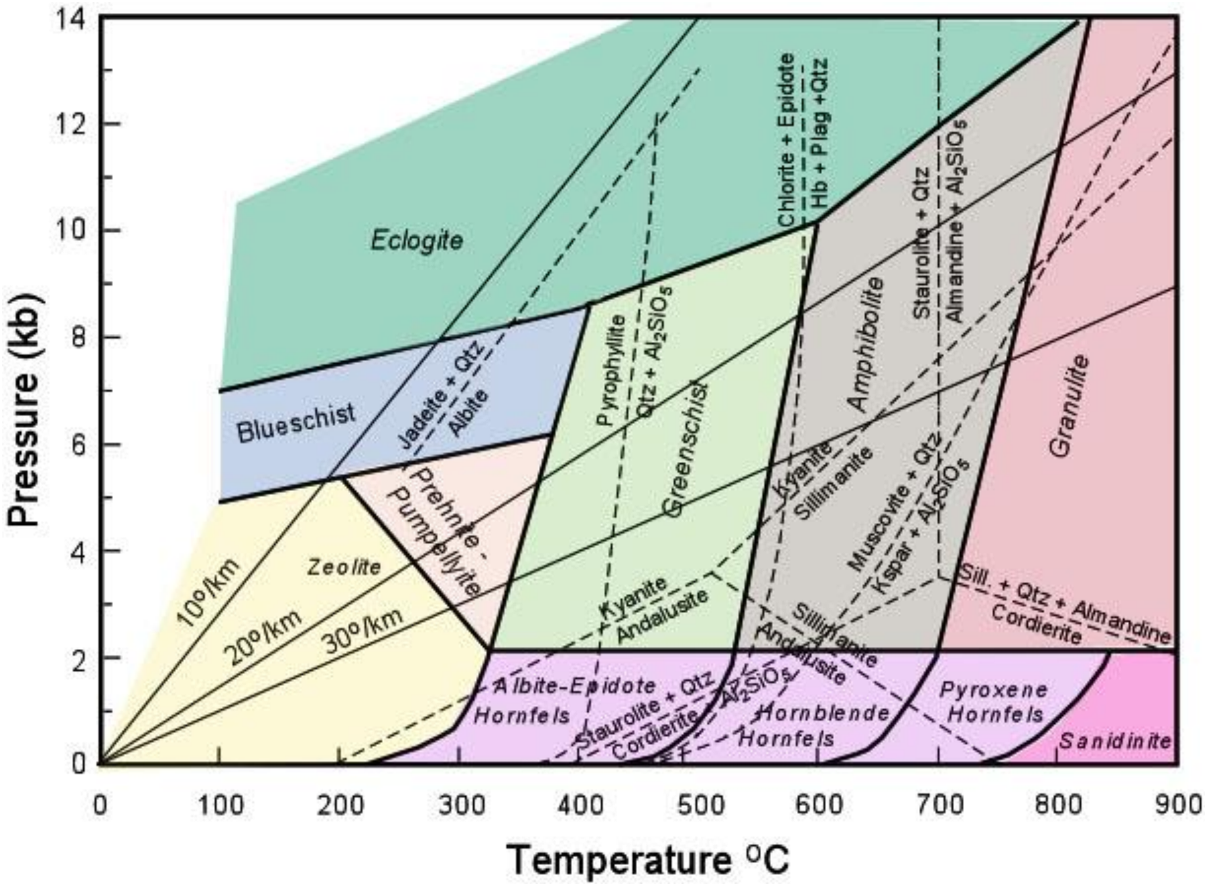
However, geophysicists continually strive to improve the detection of ancient magnetisation, and advances have been made recently to unravel original magnetisation signals from those that have been superimposed later. The fruits of these developments are borne out by a study of a sequence of mafic lavas from the Pilbara Craton that formed about 3.2 Ga ago (Brenner, A.R. *et al*. 2020. [Paleomagnetic evidence for modern-like plate motion velocities at 3.2 Ga]. *Science Advances*, v. **6**, article eaaz8670; DOI: 10.1126/sciadv.aaz8670).

Alec Brenner and colleagues from several US universities measured palaeomagnetism in more than 200 diamond drill cores from two localities in this sequence and combined their data with others from the Pilbara to cover a roughly 600 Ma period between 3.35 to 2.77 Ga. The palaeopoles form a polar wander path that spans roughly 50 degrees of palaeolatitude. From this they have been able to estimate, in considerable detail, the rate at which the Pilbara Craton had moved in Mesoarchaean. In the first 170 Ma the average horizontal motion was about 2.5 cm per year, falling rapidly to 0.4 cm per year over the following 410 Ma. The earlier speed is comparable with the average of modern plate motions. Data from the later period suggests relative stagnation. Motions over the entire ~600 Ma could be due to episodic operation of plate tectonics on the global scale, or a local slowing in the rate of plate growth.

Changing conditions of metamorphism since the Archaean (May 2020)

Metamorphic petrologists have known since their branch of geology emerged that the intensity or 'grade' of metamorphism varies with position in an orogenic belt. This is easily visualised by the sequence mudstone-shale-slate-phyllite-schist-gneiss that results from a clay-rich starting material as metamorphic grade increases. Very roughly speaking, the sequence reflects burial, heat and pressure, and must have been controlled by temperature increasing with depth and pressure: the geothermal gradient. In turn, that depends on internal heat production, geothermal heat flow and the way in which heat is transferred through the deep crust: by thermal conduction or mechanical convection. A particular rock composition gives rise to different metamorphic mineral assemblages under different temperature and pressure conditions.

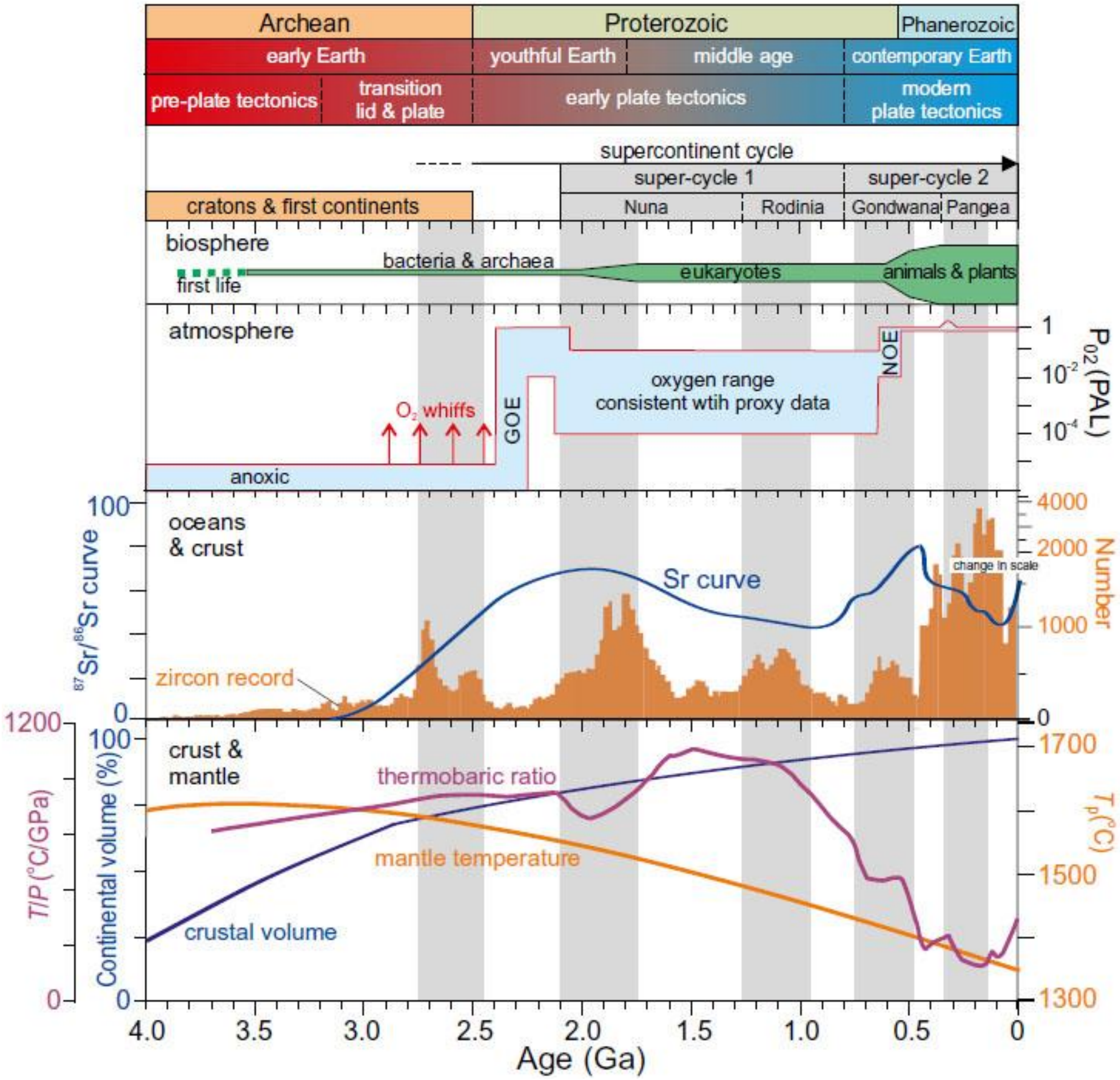
George Barrow was the first to recognise this in the Southern Highlands of Scotland as a series of zones marked by different index minerals. For instance, in once clay-rich sediments he recognised a succession of new minerals in the sequence chlorite; biotite; garnet; staurolite; kyanite; sillimanite in rocks of progressively higher metamorphic grade. Barrow found that once basaltic lavas interleaved with the sediments displayed zones with different characteristic minerals. Other metamorphic terrains, however, revealed different index minerals. Experimental mineralogy eventually showed that Barrow's zones and others reflected a wide range of chemical reactions between minerals that reach equilibrium over different combinations of pressure and temperature. This enabled geologists to distinguish between metamorphism that had occurred under conditions of high-pressure and low-temperature, low-P and high-T and intermediate conditions (see diagram). This suggested that metamorphic rocks can form in areas with different heat flow and geothermal gradients. Geochemical means of assessing the actual temperatures and pressures at which particular rocks had reached mineralogical equilibrium, known as 'thermobarometry', now enable such variations to be assessed quantitatively.



The latest division in pressure-temperature space of different styles of metamorphism (colours) and the main mineral equilibria (dashed lines) that define them

It has long been suspected that the average T/P conditions revealed by metamorphic rocks have varied over geological time, as well as from place to place at any one time. A recent paper has analysed thermobarometric data from the earliest Archaean to recent times (Brown, M. *et al*. 2020, Evolution of geodynamics since the Archean: Significant change at the dawn of the Phanerozoic: *Geology*, v. **48**, p. 488–492; DOI: 10.1130/G47417.1) They conclude that from the Archaean to the start of the Neoproterozoic the average P/T ratio was more than twice as high as it was in the following billion years. At about 2 Ga they suggests a relatively sudden decrease that correlates with what they regard as the first major assembly of continental crust: the Columbia (Nuna) supercontinent. The Mesoproterozoic Era, occupied by the disassembly of Columbia and the eventual creation of the Rodinia supercontinent, retained a high mean T/P. That began to decline with the break-up of Rodinia and a succession of tectonic cycles of ocean opening and closing during the Neoproterozoic and the Phanerozoic. This phase of truly modern plate textonics saw first the assembly of Gondwana and then the all-encompassing Pangaea, followed by its break up as we witness today. There are other correlations with the T/P variations, but they need not detain us.

The raw metamorphic data (564 points spanning 3.5 Ga) are by no means evenly spaced in time, and four dense clusters of points show a very wide spread of T/P – up to 2 orders of magnitude. Yet the authors have used locally weighted scatterplot smoothing (LOWESS) to reduce this to a smoothed curve with a zone of uncertainty that is a great deal narrower than the actual spread of data. Frankly, I do not believe the impression of systematic change that this approach has produced, though I am not a statistician. To a lesser extent than me, it seems that neither does Peter Cawood, who comments on the paper in the same issue of *Geology*: more clearly than do the authors themselves (Cawood, P.A. 2020 [Earth Matters: A tempo to our planet's evolution]: *Geology*, v. **48**, p. 525–526; DOI: 10.1130/focus052020.1).



Peter Cawood's 'take' on the relationship between tectonic development and other important variables in the Earth-system with the estimate by Brown et al. of the mean metamorphic T/P ('thermobaric') variation through Earth history

Cawood's view is that it was all due to a steady fall in mantle temperature and related broad changes in tectonic processes. But metamorphic rocks form in only the outermost 100 km of the Earth. The post-800 Ma examples include a much greater proportion of those formed under high- and ultrahigh pressures – blueschists and various kinds of eclogite – than do the earlier metamorphic belts. This weights the post-800 Ma record to lower mean T/P. Such rocks form in subduction zones and their high density might seem to doom them to complete resorption into the deep mantle. Yet large chunks now end up embedded in continents, interleaved with less extreme materials. Cawood suggests, as do others, that cooling of the mantle has enabled deeper break-off of subducted slabs to meet their end at the core-mantle boundary. The retained low T/P lithosphere since 800 Ma may have been sliced into the continents by increased underthrusting during continent-continent collisions that dominate the more modern orogenic-metamorphic belts.

What controls the height of mountains? (June 2020)

'Everybody knows' that mountains grow: the question is, 'How?' There is a tale that farmers once believed that they grew from pebbles: 'every year I try to rid my field of stones, but more are back the following year, so they must grow'… Geoscientists know better – or so they think[!] – and for 130 years have referred to 'orogeny', a classically-inspired term (from the Ancient Greek óros and *geneia* – high-ground creation') adopted by the US geologist Grove Gilbert. It incorporates the concept of crustal thickening that results from lateral forces and horizontal compression. Another term, now rarely used, is 'epeirogeny' (coined too by G.K. Gilbert), wherein the continental surface rises or falls in response to underlying gravitational forces. That could include: changing mantle density over a hot, rising plume; detachment or delamination into the mantle of dense lower lithosphere; loading or unloading by ice during glacial cycles. Epeirogeny is bound up with isostasy, the maintenance of gravitational balance of mass in the outermost Earth.

A small part of the High Himalaya (credit: Access-Himalaya)

In 1990, Peter Molnar and Philip England pointed out that the incision of deep valleys into mountain ranges results in stupendous and rapid removal of mass from orogenic belts, which adds a major isostatic force to mountain building (Molnar, P. & England, P. 1990. Late Cenozoic uplift of mountain ranges and global climate change: chicken or egg? Nature, v. 346, p. 29–34; DOI: 10.1038/346029a0). In their model, the remaining peaks are driven higher by isostasy. They, and others, coupled climate change with compressional tectonics in a positive feedback that drives peaks to elevations that they would otherwise never achieve. Molnar and England's review saw complex interplays contributing to mountain building, accompanying chemical weathering even changing global climate by sequestering atmospheric CO_2 into the minerals that it produces. As well as the height of peaks in active zones of crustal shortening and thickening, such as the Himalaya, Molnar and England's theory explained the aberrant high peaks at the edge of high plateaus that are passively subject to erosion. Examples of the latter are the isolated peaks beyond the eastern edge of the Ethiopian Plateau that locally have the greatest elevation than the flood basalts that form the plateau: unloading around these peaks has caused them to rise isostatically.

Thirty years on, this paradigm is being questioned, at least as regards active orogens (Dielforder, A. *et al*. 2020. Megathrust shear force controls mountain height at convergent plate margins. *Nature*, v. **582**, p. 225–229; DOI: 10.1038/s41586-020-2340-7). Armin Dielforder and colleagues at the German Research Centre for Geosciences in Potsdam and The University of Münster consider that overall mountain height is sustained by interactions between three forces. 1. They are prevented from falling apart under their own weight or being pushed up further against gravity by lateral tectonic force. 2. Climate controlled erosion limits mountain height by removing material from the highest elevations. 3. Isostasy keeps the mountains 'afloat' above the asthenosphere. The authors have attempted to assess and balance all three major forces that determine the overall elevation of mountain belts.

At a convergent plate margin where one plate is shoved beneath another, the megathrust above the subduction zone behaves in a brittle fashion, with associated friction, towards the surface. At depth this transitions to a zone of ductile deformation dominated by viscosity. A major assumption in this work is that stress in the crust below a mountain belt is neutral; i.e. horizontal, tectonic compression is equal to the weight of the mountains themselves and thus to their height. So, the greater the tectonic compressive force the higher the mountain range that it can support. The test is to compare the actual elevation with that predicted from plate-tectonic considerations. For 10 active orogenic belts there is a remarkable correspondence between the model and actuality. the authors conclude that variation over time of mountain height reflects log-term variations in the force balance, in which they find little sign of a climatic/erosional control. But that doesn't resolve the issue satisfactorily, at least for me.

The study focuses on the mean elevation, and this leaves out the largest mountains; for instance, their maximum mean elevation for the Himalaya is about 5.46 km (in fact for a narrow NE-SW swath that may not be representative of the whole range). Yet the Himalaya contains 10 of the world's highest mountains, all over 8 km high and 50 peaks that top 7 km, adjacent to the Tibetan Plateau. The mean elevation of the whole Himalayan range is 6.1 km. Consequently, it seems to me, the range's *maximum* mean elevation must be somewhat higher than that reported by Dielforder *et al*. The difference suggests that non-tectonic forces <u>do</u> contribute significantly to Himalayan terrain

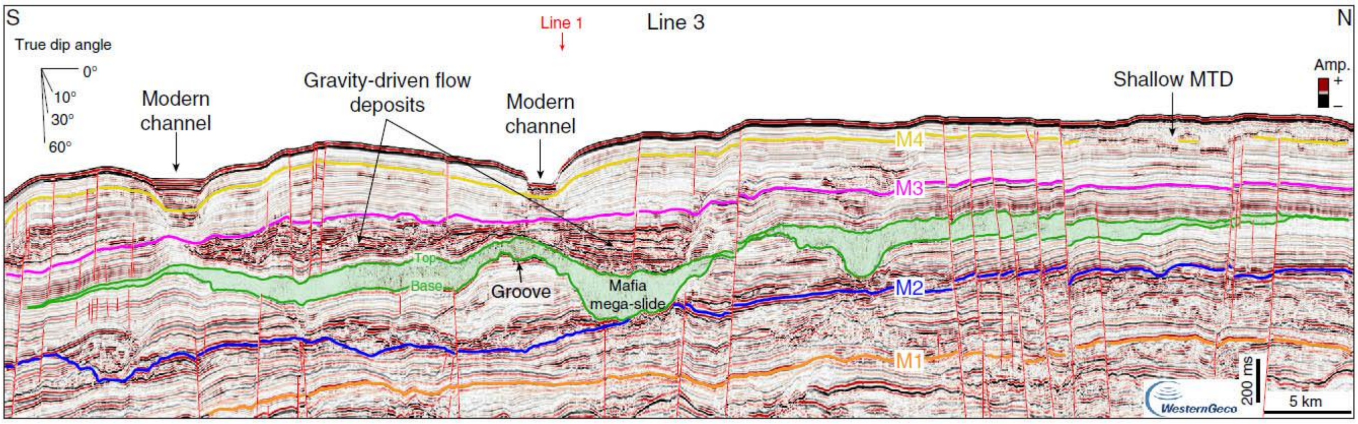
See also: Wang, K. 2020. [Mountain height may be controlled by tectonic force, rather than erosion](). *Nature*, v. **582**, p. 189-190; DOI: 10.1038/d41586-020-01601-4

Submarine landslides and formation of the East African Rift System (July 2020)

East Africa is traversed from the Afar Depression in the north to Malawi in southern Africa by several great depressions bounded by active normal fault systems: grabens in the old terminology. They are regions of active crustal extension and thinning decorated by chains of active volcanoes. The last 50 years has witnessed more than 3400 major earthquakes (magnitude 4 to 7); unsurprising for the Earth's largest active continental rift system. In Afar, the East African Rift system links to two others that have extended sufficiently to create oceanic crust: the Red Sea and the Gulf of Aden rifts. Afar is the site of the best documented tectonic triple junction. In Ethiopia, the rifting began after the whole of the Horn of Africa and Yemen had been smothered by continental flood basalts 30 Ma ago, during the Oligocene Epoch. The East African rifts are repositories for younger sediments that contain a continuous record of hominid evolution from about 5 Ma ago. This is no coincidence, for adjacent bulging of the continental crust resulted both from its unloading by thinning along the rifts and the buoyancy conferred by high heat flow in the mantle beneath. The uplifted areas have risen as high as 4 kilometres elevation (in Ethiopia), and present some of the world's most spectacular land forms. This N-S barrier disrupted earlier climatic patterns that had much of tropical Africa blanketed by dense woodland and resulted in a strongly seasonal climate during the last few million years and the development of open savannah land. Put simply, open grassland with widely spaced trees was no place for diminutive forest apes to scamper on all-fours. Being able to leg-it nimbly on two gave the apes that developed such a gait a decisive evolutionary advantage: the rest, as they say, is human evolutionary history.

The East African Rift System (Credit: P.C. Neupane, M.Sc thesis 2011; Fig. 1)

The extension and rapid uplift along the rift flanks to this day pose severe risk of landslides. Indeed, some are so large as to resemble fault blocks in their own right. Vast amounts of the upper crust have been stripped off by rapid erosion driven by the uplift. The debris has not only ended-up on the rift floors as sedimentary fill but far more has made its way eastward to be deposited on the Indian Ocean continental shelf. Until recently, piecing together the history of rifting and uplift has been restricted to the rifts themselves and their adjacent flanks. Such terrains have extremely complex and usually discontinuous geological sequences, so signs of the onset of extensional tectonics and uplift may differ from region to region. Agreement is limited to some time between 25 and 17 Ma. The whole tectonic process may, in fact, have begun at different times along the length of the rift. A clearer picture should emerge from studies of the post-30 Ma sedimentary pile along the Indian Ocean continent shelf. A sure-fire way of getting the needed data is from offshore areas that are prospective for oil and natural gas. Such is the case off the Tanzanian coastline at the southern limit of the rift system.



Seismic reflection profile parallel to the Tanzanian coastline with the Mafia mega-slide highlighted in green (Credit: Maselli et al. 2020; Fig. 5) Click to view full resolution

The Tanzania Petroleum Development Corporation and Shell have conducted seismic reflection surveys and drilled some test wells to the SE of Zanzibar Island, an area of major deposition from the eastward flowing Ruaha–Rufiji and Rovuma Rivers. Vittorio Maselli of Dalhousie University in Halifax Nova Scotia and colleagues from the UK, Italy and the Netherlands analysed a wealth of data from these surveys, to discover one of the biggest landslides on Earth (Maselli, V. and 10 others 2020. Large-scale mass wasting in the western Indian Ocean constrains onset of East African rifting. *Nature Communications*, v. **11**, article 3456; DOI: 10.1038/s41467-020-17267-5). The Mafia mega-slide is represented in seismic profiles by a sedimentary unit, up to 300 m thick. It has a highly irregular base that cuts across strata in late-Oligocene to early-Miocene (25-23 Ma) sediments. It covers an area of more than 11,600 km^2 and has a volume of at least 2500 km^3. The unit's upper surface is also irregular, suggesting that the unit's thickness varies considerably. Younger sediments are draped across the irregular top of the slide body. In other, parallel sections the deposit is absent. Unlike the clearly bedded nature of sediments above and below it, the seismic response of the slide deposit is featureless, except for zones of chaotic stratification that reveal slump-folds. Nor is this the only sign of major submarine slides: there are others of lesser extent that predate the base of the Pliocene (5.3 Ma).

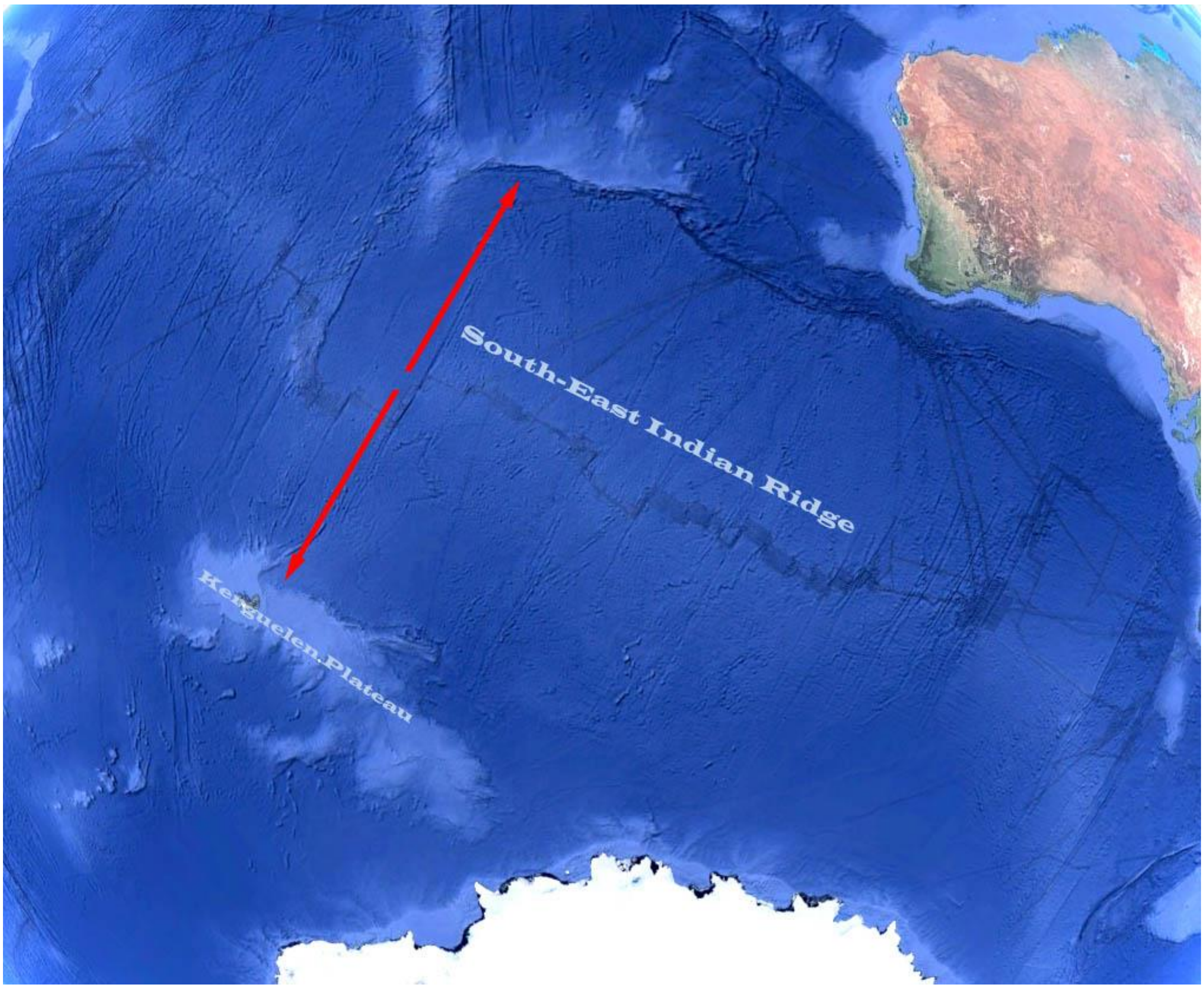
A mass movement of this magnitude would have generated a tsunami larger than that which possibly wiped out Mesolithic habitation on the east coast of Britain 8200 years ago due to the even larger Storegga Slide at the edge of the Norwegian continental shelf. The

Mafia slide event would have flooded wide tracts of the East African coast. Its estimated age, between 22.9 to 19.8 Ma, is roughly coeval with the initiation of volcanism in the Tanzanian segment of the East African Rift and the onset of rifting and uplift of its flanks. It was probably launched by a major earthquake (>7 on the Richter scale). Such is the pace of current deposition and the thickness of sedimentary build-up since the Pliocene, there is a danger of future slides, albeit of lesser magnitude: the system continues to be seismically active, with recently recorded quakes offshore of Tanzania.

Kerguelen Plateau: a long-lived large igneous province (November 2020)

It's easy to think of the Earth's largest outpourings of lava as being restricted to the continents: continental flood basalts with their spectacular stepped topography made up of hundreds of individual massive flows and intervening soil horizons. The Deccan Traps of western India are the epitome, having been so named by natural scientists of the late 18th century from the Swedish word for 'stairs' (*trappa*). Examples go back to the Proterozoic Era, younger ones still retaining much of their original form as huge plateaus. All began life within individual tectonic plates, although some presaged continental break-up and the formation of new oceanic spreading centres. They must have been spectacular events, up to millions of cubic kilometres of magma belched out in a few million years. They have been explained as manifestations of plumes of hot mantle rock rising from as deep as the core-mantle boundary. Unsurprisingly, the biggest continental flood-basalt outpourings coincided with mass extinction events. Otherwise known as large igneous provinces (LIPs), they are not the only signs of truly huge production of magma by partial melting in the mantle. The biggest LIP, with an estimated volume of 80 million km^3, lies deep beneath the Western Pacific Ocean. To the northeast of New Guinea, the Ontong Java Plateau formed over a period of about 3 Ma in the mid-Cretaceous (~120 Ma) and blanketed one percent of the Earth's solid surface with lavas erupted at a rate of 22 km^3 per year. Possibly because this happened on the Pacific's abyssal plains beneath around 4 km of sea water, there is little sign of any major perturbation of mid-Cretaceous life, but it is associated with evidence for global oceanic anoxia. Ontong Java isn't the only oceanic LIP. Bearing in mind that oceanic lithosphere only goes back to the start of the Jurassic Period (200 Ma) – earlier material has largely been subducted – they are not as abundant as continental flood-basalt provinces. One of them is the Kerguelen Plateau 3000 km to the SE of Australia, which is about three times the area of Japan and the second largest LIP of the Phanerozoic Eon. The Plateau was split into two large fragments while sea-floor spreading progressed along the Southeast Indian Ridge.

Long regarded as a microcontinental fragment left when India parted company with Antarctica – based on isolated occurrences of gneisses – there is evidence that during the formation of the Kerguelen LIP the basalts rose above sea level. Because earlier radiometric dating of basalts from ocean-floor drill cores were of low quality, an Australian-Swedish group of geoscientists have re-evaluated those data and supplemented them with 25 new Ar-Ar dates from 12 sites (Jiang, Q. *et al*. 2020. Longest continuously erupting large igneous province driven by plume-ridge interaction. *Geology*, v. **48**, online; DOI: 10.1130/G47850.1). Rather than a cluster of ages around a short time range as expected from the short life of most other LIPs, those from Kerguelen span 32 Ma during the Cretaceous (from 122 to 90 Ma). The magmatic pulse began at roughly the same time as that of Ontong Java, but continued for much longer. Smaller oceanic LIPs do seem to have lingered for unusually lengthy periods, but all seem to have constructed in several separate pulses. Large-volume eruption at Kerguelen was continuous for *at least* 32 Ma; the drilling did not penetrate the oldest of the plateau basalts. It seems that the Kerguelen LIP is unique in that respect and requires an explanation other than simply a mantle plume, however large.



Bathymetry of the Indian Ocean south-west of Australia, showing the Kerguelen Plateau and South-east Indian Ridge. The red arrows show the amount of sea-floor spreading on either side of the Ridge since it began to open. The pale blue area at the NE end of the arrow was formerly part of the Plateau (credit: Google Earth)

Jiang *et al*. suggest a model of continuous interaction between a long-lived plume and the development of the Southeast Indian Ridge oceanic spreading centre. Their model involves the line of continental splitting between India and Antarctic taking place close to a major deep-mantle plume at around 128 Ma. There is nothing unique about that; incipient ocean rifting in the Horn of Africa and formation of the Red Sea and Gulf of Aden ridges is currently associated with the active Afar plume. This was followed by a kind of tectonic shuffling of the Ridge back and forth across the head of the Kerguelen plume: not far different from the Palaeogene North Atlantic LIP, where the mid-Atlantic Ridge and the still-active Iceland plume, except the ridge and plume seem more intimately involved there. However, there are probably many subtle relationships between plumes and various kind of oceanic plate margins that are still worth exploring. Since the first discovery of mantle plumes as an explanation for volcanic island chains (e.g. the Hawaiian chain) where volcanism becomes progressively older in the direction of plate movement, there is still much to discover.

See also: Magma .conveyor belt' fuelled world's longest erupting supervolcanoes (*Science Daily*, 4 November 2020)