

Crustal Growth

Prof. John Tarney¹

TARNEY, J. (1984). Crustal Growth. *Proceedings of the Shropshire Geological Society*, **4**, 12-14. The ocean floor is composed largely of basalt, whereas the continents are formed of lighter material of approximately the composition of granite. So where does the acid rock come from? One of the common models proposes that granites are derived from partial melting of the deeper part of the crust, the 'liquid' portion formed migrates upwards, forming diapirs, intruding into the upper crust as granites. The implication is that the dry rock left behind is richer in dark mafic minerals - pyroxenes, hornblendes, etc. However, the isotopic characteristics of the granites don't always concur with an origin in the crust; they must be derived from the mantle.

In zones of crustal generation, particularly in a subduction zone where water is taken down, wet magmas are formed, which get stuck in the lower crust and remain there in a ductile condition for a long time. Being very viscous, they flow over a long time period, but fracture easily. Thus they open up and are cut by basaltic dykes. Then, over time, the viscous tonalite intrudes the basic rock, splitting it up, stretching it and spreading it around, forming the veined appearance of black and white rock.

¹Shrewsbury, UK. E-mail: editor@shropshiregeology.org.uk

The Earth is quite different from the other planets in having relatively little crust. It used to be thought that when the Earth formed, it differentiated very early into core, mantle and crust. Yet this leaves the problem of why only one third of the planet is crust, and why no rocks have been found which are older than 3.8 billion years, although zircons found recently in Australia have been dated at approximately 4.1 billion years. So there are 500 million years of Earth history quite unknown. In the next few years much effort will be put, into trying to ascertain this early history, e.g. NASA programme, and major conferences in March and April 1984.

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with an origin in the crust; they must be derived from the mantle.

In Scotland, the Mountain of Suilven, a type area for lower crustal material, is formed of late Precambrian sediments, practically horizontal red Torridonian sandstones, overlying unconformably the basement of the Lewisian, which here is granulite facies. This is a very old land surface, at least 700 million years old.

The Lewisian granulites, at 2.9 billion years old, are the oldest crustal rocks in Britain. The rock is a bimodal suite, characteristic of the Archean. It is a black and white rock, a mixture of two rocks, an ultrabasic rock in a matrix of tonalite gneiss. In east Greenland, these same bimodal gneisses, or agmatite, appear over many square miles. With these rocks, sediments occur - these are brown weathering because of the pyrite and biotite present. Some of these sediments have large blue crystals of kyanite. In India, temples are built with lower crustal granulite. The dark colour is characteristic of lower crustal rocks. This is thought to be because this is the highest grade of metamorphism, when the rock is very dry, and is flushed through with CO₂ fluids from the mantle. Although appearing uniform in colour, in detail the rock is a mixture of basic rock, pegmatite, tonalite, quartz veins, all heavily folded, forming bimodal gneisses.

Moving on to the Pacific Ocean, the eastern margin is characterised by very extensive formation of granite over the last 400 million

years. It is this margin which is close to the mid-ocean ridge, which has been over-ridden by the American plate. However, on the western margin, the plate is very old, extending for some 12,000 miles from the mid-ocean ridge, before it starts to go down under the Marianas and Japan. There is very little granite in the region of this subduction zone, but it is characterised by the presence of island arcs.

There are very few places where the plate is subducting under continental crust, but there is evidence of changing subduction patterns. More usual is the occurrence of island arcs, some submarine, with basins behind. These can be divided into three types - inactive basin with low heat flow, inactive basin with high heat flow and an active basin with a high heat flow. The high heat flow indicates that the mantle has been rising in some way and producing basalt.

The Glomar Challenger has been involved in sample drilling around the margin of the Pacific. The samples obtained enable a reconstruction of the history of the region - why are the arcs where they are, what is the age sequence, what is the composition and what does subduction do? Evidence from this exploration suggests that up to 35-40 million years ago there was a spreading ridge in the area of Hawaii, and that the ocean floor was spreading north and south from this. However, most of the ocean floor is 150-180 million years old, so there must have been a junction between fairly old Pacific floor and newly formed floor in this region. The direction of the line of volcanic islands of the Hawaiian group supports this. This chain of islands has been formed by the plate passing over a hot spot forming volcanoes which are then carried by the plate. The change in direction of the chain, indicates the change in plate movement. The island arc system only began to form just after the Pacific Plate changed motion.

The subduction zone can be very shallow and earthquakes are associated with this type. At other places, the zone can be almost vertical and in this instance, island arcs are formed. There are variations between these two extremes. Thus, it is plain that the western Pacific has steep subduction, whereas the eastern margin must be a much shallower subduction. Japan is somewhat more intermediate. There are various models to explain the formation of the back-arc basins. One is that as asthenospheric material is dragged down the

subduction zone, then other material rises and if the crust is thin enough, will break through to form the basin.

Another model proposes that as the material left behind after the formation of basalt is relatively lighter than the rest of the mantle, it rises up to form the basin. One other possibility is that the hinge of the subduction zone retreats and then the mantle flows in behind. The opposite of this is found at the other margin, where the plate is difficult to push under because it is light - it therefore bulges up and sediments are scraped off. There is much folding along the margin and earthquakes are common because there is a large contact zone between the two plates, which requires a great deal of force to secure movement.

The Deep Sea Drilling Programme shows that in the western margin of the Pacific, the series of arcs and basins - Iwo Jima Ridge, West Philippine Basin, Marianas, Kyushu-Palau Ridge, Parace Vela Basin, form an evolutionary series, with no one system of arc and basin remaining active for more than 15 million years. The system seems to be that where there is steep subduction, it is pulling down too fast and causes the hinge to roll back, leaving the area weak. The mantle then uprises, splits the arc and continues to uprise and spread in the back-arc region. This extensional process can also lead to basin formation in continental crust.

One of the most popular models for the formation of continental crust is one of accretion of arcs on the continent, i.e. volcanic arcs are formed and subsequently a continent collides with it, "scraping" the "new" material onto its edge. Evidence for this can be seen in the Himalayas.

Moving on to Antarctica, it is possible to show by the age of the ocean floor, that active subduction of the Pacific Plate was taking place up until about 40 million years ago. At that time, the actual spreading ridge was pushed under the continent and subduction stopped, as did the granite intrusion. This correlates with the change in motion of the Pacific Plate mentioned earlier.

In Southern Chile, which is deeply eroded, all the granite intrusions were formed in the Mesozoic; even the basement is late Palaeozoic sediments, so there are no very old rocks. The dominant rock type in the Andes is tonalite, full of mafic inclusions which have been pulled apart by the acid rock, and therefore similar to the bimodal Precambrian gneisses. This material is only found in the deeper uplifted parts of the crust, where

there has been an extension to form a basin, which has been compressed back again, developing a thrust which pushes up the deep crust. This is a very common feature in Chile and British Columbia. There is a change from low grade high level rock to very deep level rocks in only a few tens of metres. This type of activity was very common in the Miocene epoch of the Tertiary.

These bimodal rocks are very common throughout the world, so how are they formed? One possibility is that when rocks that are wet are intruded, they cannot rise to the upper part of the crust; only dry magmas can do this, because if water is added to a rock, it melts at a lower temperature than if it were dry, as the pressure is lower higher in the crust, water comes off and the magma solidifies. In zones of crustal generation, particularly in a subduction zone where water is

taken down, wet magmas are formed, which get stuck in the lower crust and remain there in a ductile condition for a long time. Being very viscous, they flow over a long time period, but fracture easily. Thus they open up and are cut by basaltic dykes. Then, over time, the viscous tonalite intrudes the basic rock, splitting it up, stretching it and spreading it around, forming the veined appearance of black and white rock.

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D.M. Jones