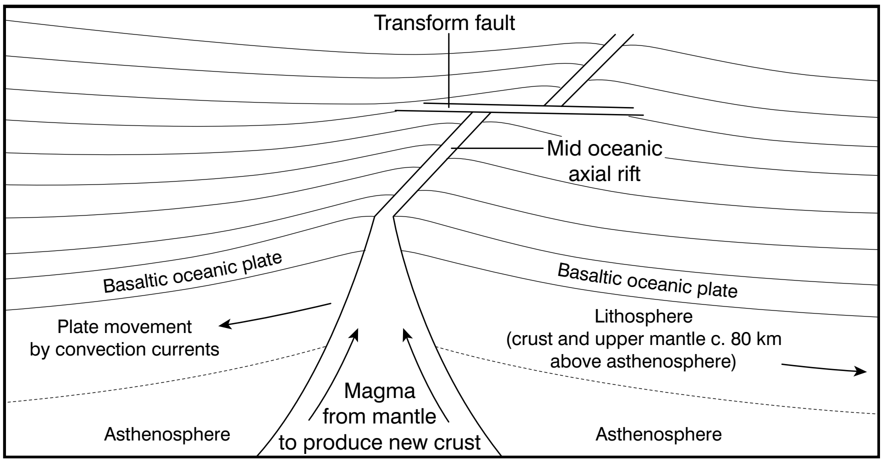
Geofile Online
APRIL 2011
638

MIKE WYNN

OCEAN RIDGES AND RIFT VALLEYS

Figure 1: Sketch diagram to show constructive plate movement at mid-ocean



Introduction

The mid-oceanic ridges are the most fundamental topographic features on the earth's surface, surpassing the largest of the continental mountain ranges. The ridges rise from the deep sea to form underwater mountain ranges up to 4000 metres high, and up to 4000km wide. Some of the highest peaks are active volcanoes and rise above sea level. It is also a zone of shallow earthquakes. The ridges form a virtually continuous feature from north of Iceland, along the middle of the Atlantic Ocean, curving through the Southern Ocean into the Indian Ocean, and are possibly the largest physical feature on earth, at over 60,000km long. In the Indian Ocean there is a major offshoot, called the Carlsberg Ridge, which is linked to rifts in the Gulf of Aden, passing into the Red Sea and so to the East African rift system. From the Indian Ocean the main ridge passes south of Australia and becomes the East Pacific Rise, ending up along the west coast of the USA.

Mid-oceanic ridges

The mid-oceanic ridge is the place where two oceanic plates diverge, at the point where rising convection currents within the earth's mantle spread sideways, forcing the plates apart and creating a rift, through which molten basalt comes to the surface along fissure eruptions and through volcanoes. The pattern of emergence, solidification and outward movement is known as sea floor spreading. At depth the convection currents carry viscous magma but as the convection currents spread from the central rift they cool by conduction and become elastic, moving the overlying plate. This upper part of the mantle is called the lithosphere (Figure 1).

This idea of sea floor spreading was first articulated by Professor Harry Hess in 1960, and later proved by two pieces of evidence:

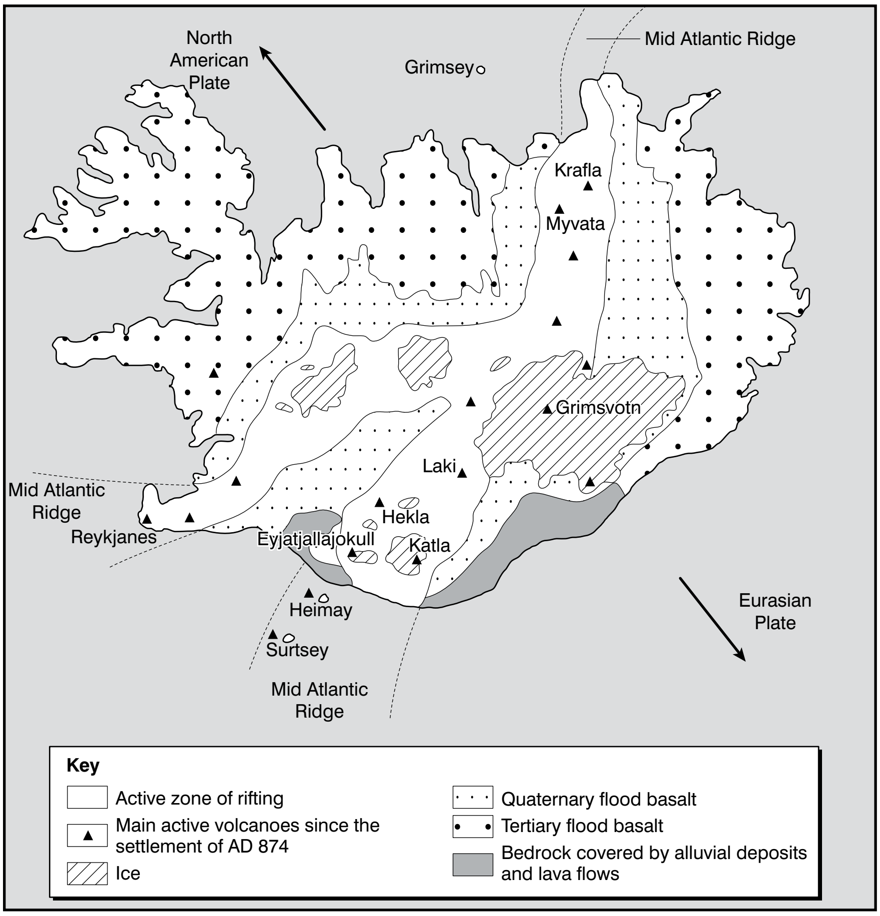
- the dating of the veneer of sediments on the ocean floor, which became older and thicker with increasing distance from the ridge
- the magnetic anomaly patterns of the ocean crust, which are a mirror image of each other on either side of the ridge. As molten basalt flowed out on either side of the ridge it cooled, with the iron particles in the basalt aligned with the earth's magnetic field. As the earth's magnetic field flips every so often, some bands of ocean floor point north, others south, creating a pattern of alternating stripes which are the same on either side of the ridge (symmetry) but get older with increasing distance from the ridge.

Much mid-oceanic ridge activity is recent in geological terms. No ocean floor is older than 225 million years (m.y.), and huge areas have been created in the past 65 m.y. spreading inexorably at just a few millimetres a year. The volcanic islands of the Atlantic increase in age with distance from the ridge. Iceland, Ascension and Tristan da Cunha located on the ridge are all recent and active. Further away the Azores are 20 m.y. old and Madeira is about 90 m.y. old; the Atlantic Ocean did not exist 150 m.y. ago. Movement from the mid-Atlantic Ridge is estimated to be up to 40mm a year, but on the East Pacific Rise, where the Pacific plate and the Nazca plate diverge, 183mm per year. Where the movement is slow, volcanic activity accumulates, so is easy to see, but where the plates move apart more quickly the volcanic activity is carried away and disappears into seamounts (ocean floor mountains, formed from extinct volcanoes, which do not break the ocean surface) and guyots (flat-topped ocean floor mountains). The sea floor subsides on either side of the ridge as it contracts with lateral movement on a slope of about 1 degree.

Either side of the central rift the plates are broken into sections by transform (transcurrent) faults which run at right angles to the line of the mid-oceanic ridge, so the central rift is not a continuous feature. These faults occur because the area between the curvature of the earth between the meridians, and the distance between the lines of longitude, is not the same so plates have to 'give way' and fault in order to be accommodated.

The mid-oceanic ridges are also the location of much hydrothermal activity, where vents eject highly acidic fluids at 370°C. These are mineral chimneys often made of sulphide minerals and referred to as 'black smokers'. Where the crustal plates split, sea water can penetrate one mile down where it reacts with the basaltic rock, causing chemical changes (sulphate ions in sea water reduce to sulphide) and becomes superheated. It shoots back to the surface (the pressure keeps it liquid) and cools rapidly so minerals are precipitated and build chimneys by up to 6 metres a year, which can reach 20 to 30 metres. The black smoke is due to water dissolving the minerals, especially iron and manganese. Here, without light and

Figure 2: Geological map of Iceland – age of volcanism increases from the central active zone outwards



in acidic water animal communities live. They were first discovered on the Galapagos Rise in 1979. These creatures do not depend on sunlight for their primary energy but on symbiotic bacteria that oxidise hydrogen sulphide, ie geochemical not solar energy. Tube worms, mussels, clams and shrimps live in the zone of water at 10° to 40°C between the 370°C of the smoker and 3°C of the surrounding ocean.

As ocean floor investigations become more detailed, places have been discovered where the ocean floor crust appears to be missing and the mantle (peridotite) forms the ocean floor. These areas are referred to as Oceanic Core Complexes, broad domes 10 to 20km across and 1 to 2km high. It is suggested they form where the supply of magma at a ridge is reduced so activity is much reduced but faulting in the crust allows sea water to penetrate deep until it encounters peridotite of the mantle. This reacts to produce soft minerals that lubricate the fault, allowing mantle material to rise to the surface. This situation can last for millions of years until magmatic activity resumes on the ridge.

Iceland

Iceland is a large island of 103,000 sq km; as large as Ireland but smaller than England, positioned between 63° and 66.5°N. Isolated in the Atlantic Ocean on top of the mid-oceanic ridge, Iceland has formed from rising magma as the American and European plates have slowly moved to their present positions.

The geological history of Iceland began in the Tertiary period about 20 m.y. ago. Iceland shared with Greenland, the Faroes and the north west British Isles what was probably a continuous plateau of early Tertiary flood basalt, which became the site of much eruptive activity in the late Tertiary and continues today in Iceland with an intensity that is unrivalled elsewhere in the world. The mid-Atlantic Ridge crosses Iceland from south west to north and is the zone where the island's active volcanoes can be found. This central rift is extended year by year by the opening of fissures. On each side of the active zone rocks get older as they move away at about 25mm per annum from the central zone, further proof of sea floor spreading (but in Iceland, 'on land' spreading) (Figure 2).

Figure 3: An example of one of the fissures within the mid oceanic ridge as it crosses Iceland. Note the chasm-like appearance and uplift that has created steep sides and residual steam activity

Source: Mike Wynn

Figure 4: Krafla caldera, showing a line of fissures, small volcanic cones and a lava field top left. Nine eruptive phases occurred 1975 to 1985 causing the plates to move apart by 4 metres. Magma is just 300 metres below the surface and there is residual volcanic activity visible.

Source: Mike Wynn

Beneath Iceland there appears to be a rising flow of magma through the mantle pushing up the crust; this is called a mantle/volcanic plume, or hot spot, and is the cause of Iceland's volcanic activity. A belt of active volcanoes (200 post-glacially) runs right through the centre of Iceland, so the country is geologically young and is actively developing. The hot spot is central below Grimsvötn, beneath the main ice field of Vatnajökull, and could explain the more intense volcanic activity and earthquakes along the eastern section of the rift. Over the past 500 years, Iceland has accounted for one-third of the earth's total lava flows. In Iceland the magma is basic/basaltic containing mafic (heavy, dark) minerals which make the lava more fluid so it spreads out in large sheets before solidifying. Basaltic columns are a feature throughout Iceland. This basalt erupts through fissure eruptions which are much less violent than volcanic acid cones. Also the magma comes from greater depths than for acid cones.

At various locations throughout the central active zone it is possible to walk over, climb into and scramble through the rifts. It is not one single crack but a whole series of faults spread over many miles. At Pingvellir there is a distinctive cliff marking the edge of the active rift zone (graben) and the start of the American plate. To the east many fissures can be seen and there is occasional earthquake activity. Some of the rifts contain warm, hot or acidic pools of water, in others steam emanates from the depths.

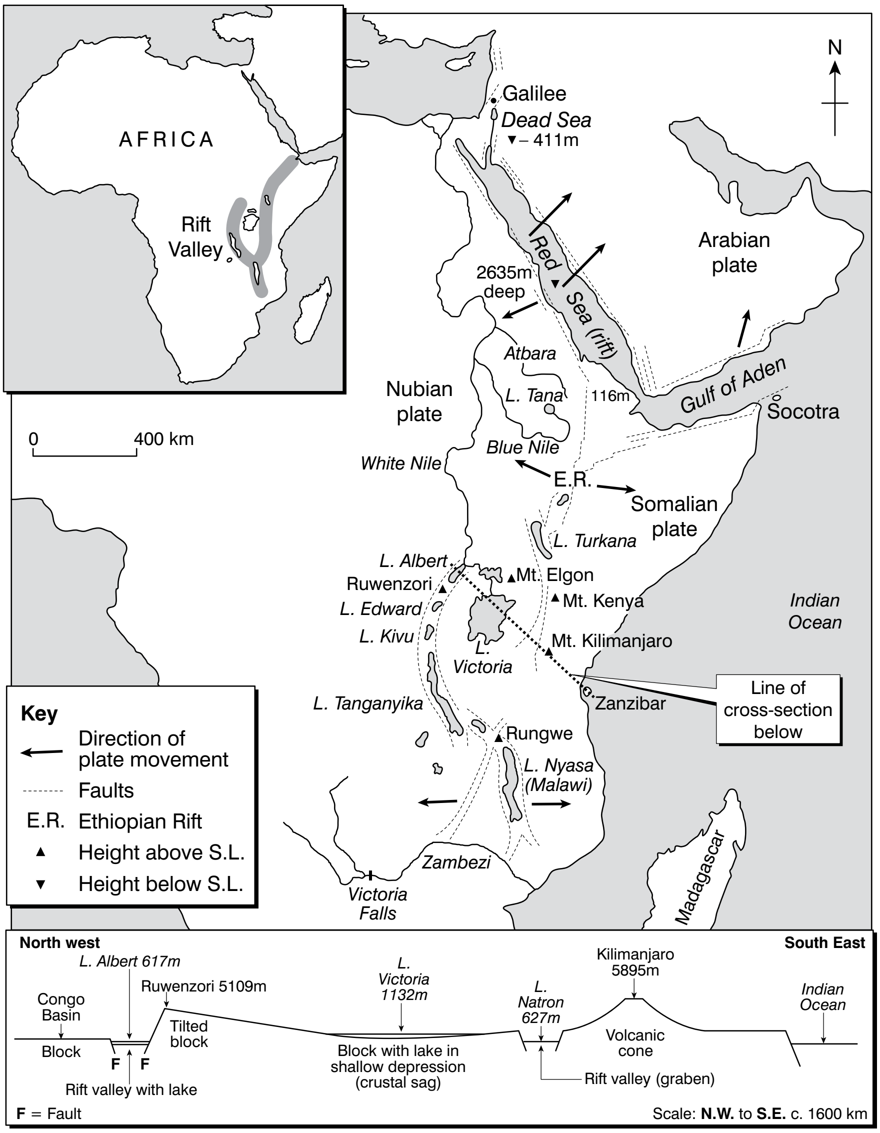
The most momentous and devastating eruption in Iceland's recent history was the eruption of Laki along a 30km fissure between 1783 and 1786, with lava covering 218 square miles of land. This was the largest single volume of lava recorded in historical times. Toxic fumes killed livestock and poisoned farmland, which resulted in a famine wiping out a quarter of the population of Iceland, even affecting harvests in the British Isles.

Beneath the ice caps volcanic activity can create large ice contact lakes. Notably beneath Myrdalsjökull, sub-glacial volcanoes have melted prodigious amounts of ice, up to 300,000 cumecs of melt water then bursting out from the glaciers, notably Katla in 1918. These are jökulhlaups. In 1996 sub-glacial volcanic activity beneath the northern edge of Vatnajökull melted a depth of 500 metres of ice in 30 hours; the meltwater moved south to be impounded as a huge lake in the caldera of Grimsvötn. From here the water escaped south into the Skeidarajökull glacier, eventually breaking through the glacier snout on 5 November discharging 40 to 50,000 cumecs. The water was black with volcanic sediment, creating a wave 3 to 4 metres high and 500 to 600 metres wide, and carrying blocks of ice weighing over 1000 tons 15km towards the sea, destroying some of the bridges and main road across the sandur (outwash plain) and extending the coastline by about 800 metres.

In spring 2010 Eyjafjallajökull initiated activity with minor earthquakes and land uplift of 15cm, then became active again creating lava flows, tephra eruptions and volatile gasses. A second phase of activity produced jökulhlaups and the eruption plume of fine-grained glassy ash, which lasted four days, reached to the top of the troposphere and moved east, severely affecting air traffic throughout Europe. Eyjafjalljökull is a minor volcano but in the past it has triggered neighbouring Katla, a highly active volcano when it erupts.

This active landscape (Figures 3 and 4) provides Icelanders with a great deal of hot water to heat their homes and for swimming pools; some of the latter are natural open-air pools, hot all year round. Hot water is also used to heat greenhouses for vegetable production. Sometimes the problem can be obtaining domestic

Figure 5: East African Rift Valley from the Zambezi to Afar (Ethiopia), the Gulf of Aden, Red Sea and Dead Sea, showing the crustal separation of Africa; inset shows section across the East African Rift Valley



cold water, which has to be brought in by tanker. Tourists are attracted by features of oceanic ridge activity whether it is the general volcanic landscape, waterfalls over eroded lava flows or small-scale residual volcanic features. At Haukadalur there is erupting water. This was the site of the original geyser (Geysir), but it stopped erupting in 1916. Today a smaller but no less spectacular geyser called Strokkur erupts every few minutes. Throughout Iceland, fumaroles give off water vapour and a range of dangerous gases at temperatures from 100 to 900°C. Minerals are deposited around the fumarole vents, including solfatara which produce sulphur. In some areas the mud bubbles, especially after rainy weather. Gas escapes and throws the hot mud into a mini caldera that gradually collapses until the next bubble erupts.

Rift valleys

The East African Rift Valley is a well-known physical feature of world geography but for a long time it has been suggested, tentatively, that it could be a place where a new ocean is beginning:

> 'New research has confirmed that the 56 kilometre rift that opened up in Ethiopia in 2005 as two parts of the African continent move apart is a new ocean in the making' (*Geographical* 82(1), January 2010).

The researchers have proved that 'the processes at work beneath the rift are almost identical to those taking place at the bottom of the world's oceans'.

Possibly the Atlantic Ocean at some time in the past would have looked like a continental rift valley, as in the case of the rift valley that runs from the Jordan Valley, Red Sea and into East Africa, which is already dotted with volcanoes such as Hermon and Kilimanjaro (Figure 5).

The rift faults of Africa create a system of tectonic features that extend from the Zambezi to the Red Sea – over 1800 miles, but 3400 miles if the Red Sea and Dead Sea are included. Mount Kilimanjaro at 5895 metres is the tallest free-standing volcano on earth, just one of a chain of volcanoes. Mount Kenya, 5199 metres, is an eroded lava plug, so at one time it was much higher. Beneath the East African Rift Valley a plume of lava has been rising for millions of years and lifted the crust a mile high, creating cracks/faults on the margins which are the east and west arms of the Rift Valley. Over the past 30 million years enough lava has been poured out to cover Wales 15 miles deep.

The East African Rift Valley consists of four sections:

- in southern Tanzania the east and west rifts converge at Lake Nyasa/Malawi
- the western rift from Lake Tanganyika (up to 550 metres deep, with the floor below sea level) to Lakes Kivu, Edward and Albert, with Mount Ruwenzori in between
- the eastern rift east of Lake Victoria
- Ethiopian section with Lake Turkana and the Afar (Danakil) Depression.

The rift valley and the lakes are characteristically long and narrow, and the sides are clearly defined by normal faulting. The walls of the rift fall between 500 and 800 metres from the plateau on either side and the rift is up to 100km across. The fault scarps are often in a series of steps, indicating that there is a series of parallel fault lines (not just one) that have moved to cause the valley floor to be lowered. The relief is complicated by the escape of volcanic lava within the rift area. The tension created indicates the continental crust of the African plate is separating to produce divergent (constructive) plate boundaries (Figure 5 inset).

The Ethiopian plateau is an on-going volcanism hotspot and such hotspots can initiate continental rifting associated with volcanoes such as Mount Kenya, Mount Kilimanjaro and Mount Fantale (Ethiopia). If rifting continues, new oceanic crust could be generated and the plates would move apart, as seen in the Red Sea. The main Ethiopian rift connects the Afar Depression at the Red Sea, Gulf of Aden junction with the Turkana depression and Kenyan rift to the south. It records all the stages of rift evolution from rift initiation to break up and incipient oceanic spreading.

The Gulf of Aden, Red Sea and Jordanian rift valley has undergone a very different mode of formation. The Red Sea and the Gulf of Aden are where Arabia has separated from Africa, with a near parallel pattern of faults on both the Arabian and African sides, from Suez to Afar and east into the Gulf of Aden. In relation to Africa, Arabia has swung slightly anticlockwise by 6 or 7 degrees. Associated with this the Dead Sea and Jordan Rift Valley wrench (transcurrent) faults have moved the Jordanian (east) side about 107 km northwards relative to the west side, leaving a long, narrow, deep fault-controlled trough that has been occupied in places with lakes such as the Dead Sea and Lake Galilee. The Dead Sea, which is 70km long, is the lowest place on earth at 411 metres below sea level (adjacent Mount Nebo is 833 metres). In summary, the Red Sea is a result of massive crustal separation and the Dead Sea rift is a result of wrench (transcurrent) faulting.

Bibliography

Searle, R. 'Holes in the crust', *Planet Earth* (Autumn 2009), National Environment Research Council.
Little, C. 'Hot stuff in the deep ocean', *Planet Earth* (Winter 2009), National Environment Research Council.
Corti, G. 'Continental Rift Evolution', *Earth Science Review* 96 (2009).
See also **Geofiles** 170, 204 and 477.

FOCUS QUESTIONS

1. Explain why Iceland is such an important location for the study of mid-oceanic ridges.

2. Discuss the assertion that the East African Rift Valley could be the site of a future ocean.

3. Why is knowledge about the mid-oceanic ridge system fundamental to an understanding of plate tectonics?