Plate tectonics

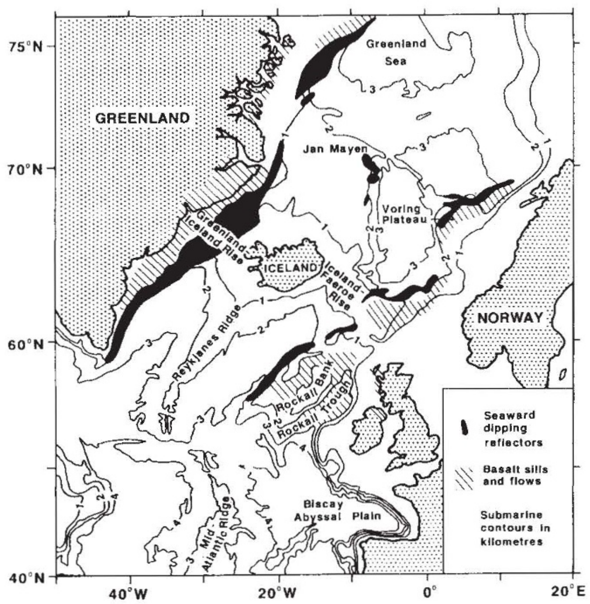
When continents rift

Robert S. White

THE Tertiary volcanic region in the north-east Atlantic is a classic area for detailed petrological studies of magmatic processes. It is also important for detailed studies of large-scale geodynamic processes that lead to the generation of new ocean basins. When Greenland rifted away from Europe to form the north-east Atlantic, there was an immense outburst of volcanic activity both on the rifted continental margins and in the hinterland, creating the Tertiary igneous province of Greenland, the Faeroes, north-west Scotland and Ireland. The full extent, timing and magnitude of the offshore volcanism that occurred became apparent at a recent conference*.

The north-east Atlantic is a superb natural laboratory in which to study the birth of an ocean. The rifted margins mostly have little sediment cover, so that their deep structure is not obscured. Both sides of the rifted basin can be studied in a way not possible on many other margins and there is good control on the dating of major events. In the early 1980s it was realized that there are extensive volcanic flows on some rifted margins. Although the volcanic flows are offshore and therefore inaccessible to the geological hammer, they can be readily identified on seismic reflection profiles. They produce a series of layered reflections that dip seawards (Hinz, K. *Geol. J.* E**22**, 3-28; 1981). Dipping reflectors have now been recognized around the entire north-east Atlantic (see figure) and are known from drilling to be formed of basalt extruded near or above sea level. It is widely accepted by analogy with similar stacks of dipping lavas now forming in Iceland (Palmason, G. *J. geophys. Res.* **47**, 7-18; 1980) that the dipping-reflector sequences were created by basalt flows from fissures to seaward of the margin (J. Mutter, Columbia University, USA).

There is considerably less agreement on the location of the continent–ocean boundary. According to Mutter, the dipping reflectors are formed entirely by seafloor-spreading processes with the continental boundary to landward. Others think that they overlie stretched, intruded continental-crust (D. Roberts, British Petroleum, London), a view supported by isotope evidence of continental contamination of the lavas (L. Parson, Institute of Oceanographic Sciences, UK; R. Merriman, British Geological Survey). Research by my group, along with colleagues at Birmingham and Durham Universities, shows that in the Rockall area often an upper set of the reflectors overlies stretched continental crust but a seaward set occurs in the oceanic crust. Numerous schemes for defining the location of the continent–ocean boundary have been proposed: midway beneath the innermost dipping wedge (J. Skogseid, University of Oslo); at the seaward margin of the innermost wedge (D. Smythe, British Geological Survey) at the landward margin of the innermost wedge (Mutter); and where the lowest of the dipping reflectors stops onlapping (H. Larsen, Greenland Geological Survey).



Distribution of basalt flows forming seaward, dipping-reflector sequences and early Tertiary volcanism around the region of the north-east Atlantic.

Much of this debate on the exact location of the continent–ocean boundary is sterile because it revolves around poorly defined terminology. Between the unstretched, continental crust and the new, oceanic crust there must be a region where the percentage of igneous rock in the crust increases due to both intrusion and extrusion. It is meaningless to try to identify a precise boundary in this intermediate region of fragmented continental-blocks and newly emplaced igneous rock.

The timing of the volcanism is becoming increasingly constrained by many new studies, including biostratigraphy around ash layers in the North Sea (R. Noble, British Geological Survey), radiometric dating (A. Mussett, University of Liverpool; I. Meighan, Queen's University, Belfast), palaeomagnetic measurements, magnetic-anomaly identification and seismic-reflection stratigraphy. The entire margin split very rapidly, with the bulk of the magmatism occurring in 2–3 million years or less.

Huge volumes of igneous rock were generated during rifting. According to Roberts, the dipping reflectors alone account for 1–2 × 10^6 km^3 of basalts; this is about the same as the entire Deccan volcanic province in India. Furthermore, new seismic-refraction data of Mutter and co-workers from the Voring Plateau, and our own from the Rockall margin show that up to five times more igneous rock is emplaced beneath the dipping reflectors, giving a total volume of 5–10 × 10^6 km^3.

Why should there have been such intense and rapid igneous activity along this particular 2,000-km-long segment of continental rift? Mutter proposes small-scale convection under the evolving rift as the mechanism for producing thick igneous crust on some rifted margins. My view is that the large quantities of igneous rock on the rifted margin are due to anomolously hot material in the ductile asthenosphere that lies roughly below 100 km. As the rigid lithosphere above is stretched and thinned in the initial stages of rifting, the hot asthenosphere wells up to fill the space, generating partial melt as it rises and decompresses. D. McKenzie and M. Bickle (University of Cambridge) have shown that 15–20 km of melt can be produced by upwelling asthenosphere that is only 100–150°C hotter than normal. These sorts of anomalous temperature in the asthenosphere are created across 1,500–2,000-km-wide regions by hot spots such as the one at present centred under Iceland. M. Bott (University of Durham) introduced a global perspective by postulating that the Icelandic hot spot is driven from the lower mantle by the return flow of material subducted into the lower mantle at the edge of the Pacific plate.

It appears that the entire Tertiary igneous province and elevated, volcanically active, continental margins of the north-east Atlantic can be explained by a relatively small (~ 100°C) increase in the asthenosphere temperature. □

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