Rupturing Continents Exposed Mantle Rocks

Bob Whitmarsh, Southampton Oceanography Centre, UK and the ODP Legs 149 and 173 Shipboard Scientific Parties

Until about 140 million years ago, a narrow shallow seaway lay between Europe and North America. But then a major rift began to separate the European and North American plates, leading to the formation of the Atlantic Ocean. During this process, the continental crust, normally about 35 km thick, was stretched and thinned to breaking point and the intervening space was filled by oceanic crust formed by seafloor spreading at the mid-Atlantic ridge. However, unlike some other continental margins, there is very little evidence that any significant volcanic activity accompanied this rupturing of the Earth's continental crust. A long-standing problem has been to work out how seafloor spreading, itself principally a volcanic process, began. Was it essentially instantaneous or did it begin more gradually and, if so, how?

A combination of geophysical measurements and studies of drill cores obtained by ODP at ten sites off Portugal has now solved the mystery. The geophysicists measured the thickness of the crust from variations in the speed of sound under the continental margin and found that, although the continental crust thinned as expected towards the ocean, it broke up when the crust had been thinned to about 7 km. Oceanward of this point, a crust-free zone up to 170 km wide of the underlying continental mantle layer was exposed at the seafloor. On the landward side of the zone, other geophysical evidence suggests that a number of isolated and relatively small elongated bodies of molten rock were first intruded into the mantle. As the zone of deformation moved oceanwards, more and more molten rock was emplaced until eventually a continuous layer of such rocks, that is oceanic crust, was produced.

The final puzzle was to explain how the broad zone of mantle could be exhumed between the thinned continental crust and the oceanic crust. This puzzle was solved when it was realized that a class of mainly sub-horizontal dislocation surfaces (or faults) from a similarly formed continental margin, now exposed in the Alps, could provide the mechanism whereby mantle was exhumed without producing significant vertical offsets across the faults. Such a concave-downward fault, as well as a diagrammatic representation of how the continental margin off Portugal may have evolved, is shown in the diagram. Many of the rock cores have now been dated using isotopes to demonstrate that the focus of stretching of the crust and mantle migrated from the continent towards the ocean, apparently at an increasing rate.

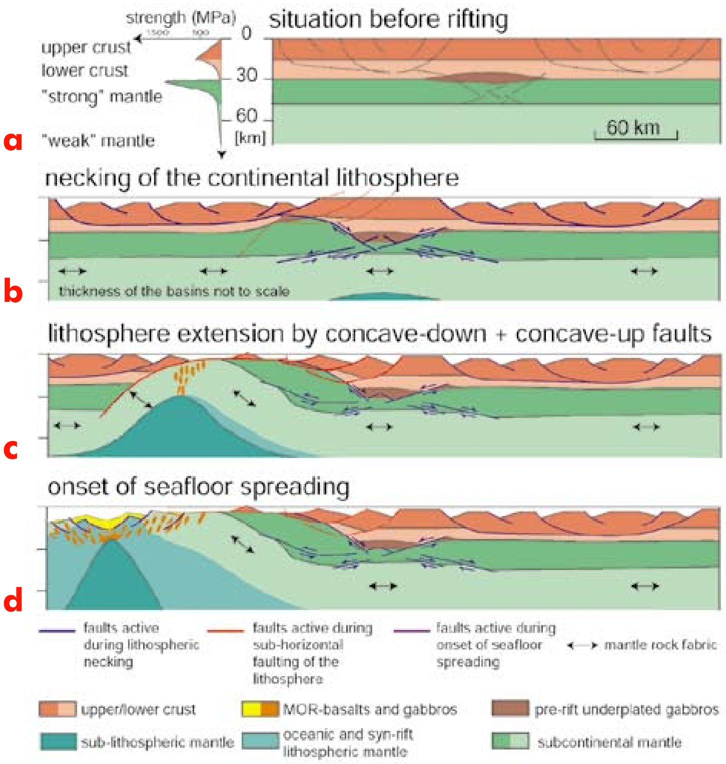

Figure 1. Conceptual lithosphere-scale model of the development of a rifted magma-poor margin relative to a fixed right-hand edge. **a)** Initial situation with crust locally thickened by pre-rift underplated gabbro. **b)** Initially the upper mantle necked beneath the gabbros, allowing the asthenosphere to rise. Elsewhere, ductile flow of the lower crustal rocks determined where rift basins formed at the surface. **c)** Later, the rising asthenosphere started to influence the rifting. Then, rifting was localized at the margin of the relatively weak unextended, or only slightly extended, crust. Note the change in extensional geometry from concave-upward to one or more concave-downward faults. **d)** The asthenosphere ascended close to the surface and melts were intruded into, and even extruded onto, sub-continental mantle. Deeper mantle layers were exhumed oceanward. Eventually, increasing melt production led to the creation of 'continuous' oceanic crust. Seafloor spreading had begun. *(This figure is reproduced from Whitmarsh et al., 2001, Nature, Vol. 413, pp. 150-154.)*