Deformation of crystal-liquid mush and the formation of the lower oceanic crust

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In a paper little remembered today, N.L. Bowen [1920] postulated that crystallization differentiation could be driven not only by gravitational movement of crystals, but also by deformation of partially molten masses of igneous rock. He termed the process "differentiation by deformation," and predicted that the process should result in the formation of almost pure monomineralic rocks, called adcumulates, the occurrence of crosscutting granophyres, primary banding or foliation, and segregation of late-stage melts into cavities formed by stretching of a crystalline mesh.

The gabbroic rocks drilled at ODP Hole 735B, Atlantis II Fracture Zone, Southwest Indian Ridge exhibit all of these features. There are two intervals of primitive olivine-bearing gabbros, each about 200 m thick and with similar trends of downhole variation in mineral chemistry, separated by a 73-m interval of moderately to intensely deformed, gneissic and porphyroclastic, oxide-bearing and oxide-rich ferrogabbro cut by local veinlets of highly fractionated liquids (trondhjemite). Numerous small deformed oxide gabbros also obliquely cut primitive gabbros near the top and the bottom of the hole. The 73-m zone of oxide gabbros represents crystallization of highly fractionated mafic liquids, rich in iron and titanium, which penetrated along an inclined active fault zone along which the two blocks of primitive gabbros were being juxtaposed at the time. Gradients in mineral compositions with depth suggest that the iron-rich melts mixed with local, more primitive, pore melts as they penetrated along the fault, with the densest, most iron- rich liquids resting on a breccia zone at the base of the fault. Here, the most extreme differentiation by deformation took place, leading to immiscible separation of siliceous (trondhjemitic) and iron- rich liquids.

Formation of extraordinarily pure adcumulates requires extreme modification of original contacts between cumulus minerals, here envisaged to have formed in a channelized porous- flow matrix which reached from the mantle to the top of gabbroic cumulates. Textures suggest that pressure solution was the main mechanism of grain-boundary dissolution, reprecipitation, and porosity reduction among these adcumulates.

Similarly deformed and lithologically diverse gabbros were cored on the dipping surface of a rift-valley master fault at 23°N on the Mid-Atlantic Ridge during ODP Leg 153. The oxide- rich gabbros at Hole 735B may be a similar master fault encountered at depth. Concentrations of oxide-rich gabbros along such master faults may explain dipping reflectors seen in seismic profiler records of the lower ocean crust at slow-spreading ridges. Among dredged samples, deformed oxide gabbros are sometimes found in peridotites, indicating that highly fractionated melts penetrate faults which intersect the mantle.

Reference:

Bowen, N.L., Differentiation by deformation, *Proc. of the National Academy of Sciences, 6,* 159-162, 1920.