高速拡大軸における深部海洋地殻のマグマ過程および熱水・変質作用

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IODP Exp. 345 successfully drilled lower crustal gabbros generated at a fast spreading ridge (Hess Deep, East Pacific). Among the recovered lithologies, a significant amount of troctolites and other olivine-rich gabbros were present. Beside these primitive rocks, orthopyroxene (Opx)-rich olivine gabbros and large clinopyroxene (Cpx) oikocrysts-bearing troctolites were also recovered (Gillis et al., 2014a, 2014b). All these lithologies were altered and deformed to a certain degree. The purposes of the global study led by the boarding Japanese scientists were to understand the formation of the primitive troctolites, to constrict the origin of the Opx and the large Cpx oikocryst in the troctolites and olivine gabbros, and to understand the alteration and deformation processes affecting the primary rocks.

Troctolites were notably abundant in the base of Holes 345-U1415 J and P, where 3 types were observed: coarse grained (<10mm), fine grained (<2mm) and skeletal olivine-bearing troctolites. Microprobe and Laser-ICP-MS analyses showed that the coarse grained troctolites bear the most primitive composition, which is comparable to the composition of dunites drilled at Hess Deep during ODP Leg 147. Meanwhile, the fine grained and skeletal olivine-bearing troctolites are much evolved in composition than the coarse grained troctolites, and their composition are comparable to that of gabbros and olivine gabbros recovered during ODP Leg. 147. Light rare-earth element (LREE) concentrations in olivine is higher in Hess Deep troctolites than in other areas. Thermodynamic calculations facilitated by rhyolite-MELTS software package (Gualda et al., 2012) and other numerical modelling (Shaw, 2006) showed that fractional crystallisation seems to be the dominant formation process of the coarse grained troctolites, whereas fine grained and skeletal olivine-bearing troctolites may have generated by melt-coarse grained troctolite reaction. These results together with those obtained on other troctolites show that, even for a “simple” lithology as troctolite, its generation process is complex and varies from a region to another.
Chemical mapping of Cpx oikocrysts in fine grained troctolites showed that 3 chemical domain can be distinguished in these large minerals: core, intermediate and rim. The gradational compositional transition from intermediate zone to the rim cover the global chemical scatter observed in Hess Deep Cpx, but the transition from core to the intermediate domains is abrupt. The calculation of the crystallisation pressure according to Nimis's Cpx barometer showed that the core and the intermediate domains crystallised at similar pressure, while the rim crystallised at lower pressure. The chemical composition of olivine in the fine grained troctolitic matrix is in equilibrium with the oikocryst rims and plagioglase chadacrysts included in oikocrysts are slightly more calcic than those in the matrix. These results show a change in the crystallisation conditions during oikocryst formation involving a probable mixing between two melts with different chemical compositions. The Cpx core is more primitive than the troctolitic matrix suggesting a Cpx crystallisation prior to troctolite and from a more primitive melt.
On the other hand, Opx are locally abundant in olivine gabbros without Cpx oikocrysts. 3 types of Opx can be distinguished according to their textures: prismatic, poikilitic or coronæ around olivine. Textural relationships between the 2 types of pyroxenes show that prismatic and poikilitic Opx are partially replaced by poikilitic Cpx, and coronæ around olivine suggest that at least some Opx may have formed during reaction of olivine with a Si-rich melt. Microprobe analysis showed that all Opx are primitive and their Mg# is buffered while their minor and trace elements concentrations present a large scatter. The total Hess Deep Ti range variation is born in each single samples, showing strong local heterogeneities in the parental magma during the crystallisation process. Moreover, increasing TiO_2 from Opx core to rim with constant Mg# shows that Opx generation in Hess Deep gabbros is more likely to be driven by processes like melt-rock reaction or mixing between Si poor and Si-rich melts than by fractional crystallisation.

All Hess Deep samples were hydrothermally altered to a certain degree. Microscopic observations of altered samples have revealed an alteration sequence formed under temperature conditions ranging from amphibolite to zeolite facies with mineral assemblages including amphibole, secondary clinopyroxene, chlorite, talc, serpentine, prehnite, zeolite and clay minerals (Gillis et al., 2014b). Amphibolite-facies alteration is illustrated by the tremolite-chlorite corona textures between primary olivine and plagioclase in primitive olivine gabbro or troctolite lithologies (Nozaka and Fryer, 2011). The abundance of these alteration mineral assemblages within some sampled intervals suggests localized high-temperature fluid flow near the spreading axis. Some of the coronitic amphiboles, particularly those of incipient-stage corona have hornblendic compositions, suggesting a somewhat higher-temperature formation condition than tremolite. In addition, another set of alteration products including Al-spinel, corundum and diaspore occurs in intensely altered parts of the drilled troctolites. The Al-spinel is associated with An-rich plagioclase and pargasitic amphibole, this assemblage points to temperature conditions even higher than in the amphibole-chlorite corona formation. The Al-spinel is partly replaced by corundum, and the corundum, in turn, is pseudomorphically replaced by diaspore. The modes of occurrence and chemical compositions of minerals added to the thermodynamic calculations of the stability conditions for these mineral assemblages show that the highly aluminous phases were formed by localized fluid flow at temperatures ranging from upper-amphibolite to greenschist facies.
Completely altered cores occurred at the bottom of Hole J and, in addition to alteration, they show strong brittle deformation leading to cataclastic and breccia textures. Chemical mapping carried out by SXAM analysis show that cataclasites and breccia can show relatively homogeneous or strongly heterogeneous compositions. In heterogeneous samples, primary plagioclase and Cpx core remained and prehnite were partially transformed into prehnite. On the other hand, homogeneous sample were constituted almost only by prehnite and were probably generated from completely altered gabbros. Whether prehnite created weakness zones in the rock that were subsequently preferred for deformation, or on the contrary, brittle deformation created fractures where fluids could easily percolated and alter the gabbros is still unclear. However, the brittle deformation analysis show a strong influence of fluid percolation in the deformation and these data combined with geomagnetic data show that deformation occurred during the Coco-Nazca rifting following the generation of gabbros at the east pacific Rise.

Our results delineate a succession of complex processes occurred at Hess Deep Rift. Magmatic genesis of the gabbroic rocks probably mostly occurred during EPR expansion and involved several magmatic events leading to the constitution of a petrographically variable gabbroic crust. Secondary events include high temperature hydrothermal alteration at sub-magmatic conditions and low temperature brittle deformation resulting from the propagation of the Coco-Nazca Ridge.

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