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Nanoscale study of lamellar exsolutions in clinopyroxene from olivine gabbro: Recording crystallization sequences in iron-rich layered intrusions

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Abstract

Pyroxene exsolutions and associated Fe–Ti oxides and spinels are described in a sample of olivine gabbro representing the Middle Zone of the Panzhihua layered intrusion, Southwest China, part of the Emeishan LIP. High-angle annular dark-field scanning transmission electron microscope imaging, electron diffraction, and energy dispersive spectroscopy reveal complex multi-stage exsolution relationships in the host clinopyroxene. The studied assemblage is common in gabbroic rocks and comprises subcalcic diopside and lamellar clinoenstatite (<1 wt% Ca). Two sets of exsolved clinopyroxene lamellae are observed. Only one is, however, well developed as lamellae oriented approximately parallel to (801) of diopside, making an angle of ~10 to 11° with the (100) planes, or the *c* axis, of both phases. These are the so-called "100" lamellae with a perfect fit along *a*-crystallographic axes when viewed down to [010] zone axis. Crosscutting exsolutions of Fe–(Ti) oxides are relatively common throughout the same host clinopyroxene. Apart from ilmenite and magnetite with variable Ti-content, hercynite is a minor yet ubiquitous phase. The nanoscale study indicates a sequence of fine-scale processes: from higher-*T* (~1030–1100 °C): (I) (clino)enstatite exsolutions in low-Ca diopside; followed by (II) slightly Ca-richer diopside overgrowths and high-*T* titanomagnetite exsolution in diopside; to lower-*T* (<450 °C) (III) titanomagnetite exsolutions into ulvöspinel + magnetite; followed by (IV) sub-solidus re-equilibration in clinopyroxenes and among Fe–Ti oxides + hercynite. Using exact phase boundary theory, pressures of lamellar exsolution within the host diopside are estimated as ~2 GPa with an error of ± ≤1 GPa. The present study of complex exsolutions in clinopyroxene demonstrates that a nanoscale approach can help constrain *P-T-X* evolution during formation of layered intrusions.

Keywords: High-angle annular dark-field scanning transmission electron microscopy, clinopyroxene, titanomagnetite, liquid-magmatic ore deposits, sequence of exsolution