

SPECIAL COLLECTION: GLASSES, MELTS, AND FLUIDS, AS TOOLS FOR UNDERSTANDING VOLCANIC PROCESSES AND HAZARDS

Role of volatiles (S, Cl, H₂O) and silica activity on the crystallization of haüyne and nosean in phonolitic magmas (Eifel, Germany and Saghro, Morocco)[†]

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ABSTRACT

To constrain the crystallization of alkaline and volatile-rich lavas present in intraplate settings, we studied the petrological features and the geochemical composition of major, trace, and volatile elements of mineral and bulk-rock of two sodalite-bearing phonolites: (1) haüyne-plagioclase-bearing Si-K-rich phonolite from Laacher See (Germany) and (2) nosean-nepheline-bearing Si-poor phonolite from Saghro (Morocco). In haüyne-bearing phonolites (55–59 wt% SiO₂, K > Na, Na+K/Al = 0.96–1.08), we found that the low silica and low sodium activity promoted the early crystallization of S-rich haüyne (13.7–13.9 wt% SO₃, 0.4 wt% Cl) + S-rich apatite (0.7–0.9 wt% SO₃), titanite, and rare pyrrhotite followed by clinopyroxene-plagioclase-sanidine at relatively low pressure and temperature ($P = 250$ MPa and $T = 850$ °C) and oxidized condition ($\Delta\text{NNO}-\text{NNO}+1$, where NNO is nickel-nickel oxide buffer). The crystallization of haüyne occurred at fluid-undersaturated conditions from a silicate melt with 6 wt% H₂O, 0.17–0.23 wt% Cl, 0.11–0.4 wt% S, and 0.07–0.14 wt% F. Nosean-bearing phonolites from Saghro are silica-poor and peralkaline (52–54 wt% SiO₂, Na > K, Na+K/Al = 1.2) and crystallized at higher P and T (300 MPa and 950 °C) and more reduced conditions (NNO) compared to haüyne-bearing phonolites. The incongruent reaction to form nosean requires high silica and Na₂O activity. The mineral assemblage and composition suggest early crystallization of nepheline followed by nosean (7.8–8.8 wt% SO₃; 1–1.1 wt% Cl). The sequence of crystallization is: clinopyroxene + nepheline + S-poor apatite (<0.04 wt% SO₃) + pyrrhotite followed by nosean and titanite. Nosean-bearing magmas are fluid-undersaturated with relatively low volatile content (4 wt% H₂O, <0.25 wt% Cl, <0.056 wt% S, 0.08–0.1 wt% F), although Cl may have exsolved during ascent and formed a fluid phase (NaCl-bearing).

Both haüyne- and nosean-bearing phonolites are last equilibrated at relatively low pressure and high temperature. Haüyne and nosean crystallized at oxidized and volatile-rich pre-eruptive conditions. They record the volatile concentrations at depth and may be used as oxybarometer. The incongruent reactions involved to form haüyne and nosean suggest that phonolitic magmas became more oxidized during crystallization. The initial volatile concentrations in basanite/nepheline magmas, from partial melting of volatile-bearing K₂O-rich mantle rock, should have been one important factor influencing the crystallization of haüyne-bearing Si-K-rich phonolite and nosean-bearing Si-poor phonolite in intracontinental setting.

Keywords: Phonolite, sodalite, haüyne, nosean, volatile elements, pre-eruptive conditions