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CRYSTALLIZATION IN TONALITIC MAGMAS: EXPERIMENTAL DATA
AND THE RECORD FROM THE GESINIEC TONALITE
(STRZELIN CRYSTALLINE MASSIF, SW POLAND).

Abstract: Phase equilibria experiments were established for two natural tonalite types from the Gesiniec Intrusive (Strzelin Crystalline Massif, SW Poland) in the range 750–850°C, 1–2 kbar, at NNO buffer and mole fraction of water X_{H_2O} from 0.6 to 1.0. Tonalites differ by major element chemistry and mineral composition. Cummingtonite occurs in one type. Experimental assemblage at 2 kbars and $X_{H_2O} > 0.8$ reproduced natural one plus orthopyroxene and magnetite. Cummingtonite crystallized in both tonalite types at 2 kbar, water saturation and at temperature $< 780^\circ\text{C}$. This mineral is a possible magmatic phase for those conditions. Therefore the Gesiniec tonalities equilibrated in different, magmatic conditions.

Keywords: tonalite, phase equilibria, experiments, crystallization, cummingtonite

INTRODUCTION

Tonalites are widespread and chemically varied group of rocks. They occur in lower continental crust and in shallow, late- to postorogenic settings (e.g. Roberts et al. 2000). The small tonalite stock forming the essential part of the Gesiniec Intrusive (Strzelin Crystalline Complex, Fore-Sudetic Block, SW Poland) belongs to the second of the mentioned tonalite groups (pressure estimation below 2 kbar, based on occurrence of magmatic andalusite in two-mica granite crosscutting the tonalites). It exhibits low Si content typical for unevolved diorite – tonalite plutons in orogenic, calc-alkaline suites (e.g. Roberts et al. 2000).

The information about crystallization conditions and processes controlling differentiation can be obtained from mineral composition and zonation patterns occurring in those minerals. Composition of mineral phases in plutonic rocks is often altered during subsolidus processes and records late stage fluid induced crystallization. The range of subsolidus re-equilibration is often difficult to assess and natural mineral compositions cannot be unambiguously used as the record of magmatic processes. For example cummingtonite is supposed to be either of magmatic (e.g. Nicholls et al. 1992) or subsolidus origin (e.g. Roberts et al. 2000).

Therefore as the case study of low silica tonalities from orogenic calc-alkaline suites, experiments were performed on two different tonalite types. The

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cummingtonite bearing and cummingtonite free compositions provide new information on the conditions of differentiation, crystallization and origin of cummingtonite in tonalitic rocks.

EXPERIMENT: STARTING MATERIAL AND GENERAL TECHNIQUE

Experiments were performed on two natural tonalites (F06 and M20) occurring in the Gesiniec Intrusive (Strzelin Crystalline Massif). Tonalite is the dominating rock type in the intrusive (Oberc-Dziedzic 1999). Both tonalites consist of plagioclase, amphibole, biotite, quartz and accessories apatite, zircon, titanite and ilmenite. Cummingtonite occurs only in sample M20 as mantles on hornblende crystals. Tonalites differ in the bulk composition, compositions of minerals and the mode. M20 tonalite is richer in MgO (8.4 wt. %), FeO^{TOT} (9.69 wt. %) and K_2O (2.59 wt. %) and impoverished in Al_2O_3 (13.41 wt. %) and CaO (5.26 wt. %) comparing to F06 (MgO–3.0 wt.%, FeO^{TOT} –7.83 wt.%, K_2O –2.0 wt. %, Al_2O_3 –17.88 wt.% and CaO–6.4 wt.%). The F06 composition is typical of unevolved tonalities from orogenic settings (e.g. Roberts et al. 2000) and experiments were performed in 10 and 15 kbar for similar composition (Johannes & Holtz 1996). The crystallization sequence as seen in rock texture is: plagioclase, hornblende, \pm cummingtonite, biotite, quartz. The chosen rocks represent dominating tonalite types in the intrusive.

Crystallization experiments were performed in Cold Seal Pressure Vessel with water as the pressure medium. For each composition (M20 and D06), phase equilibria were established in the temperature range 750 - 850°C, at 1 and 2 kbar and under oxygen fugacity controlled by NNO buffer (NiO and Ni powders loaded into the bomb). Mole fraction of water XH_2O varied between 0.6 and 1.0 (initial XH_2O loaded into capsule). Experimental products (crystals and melt) were analyzed by electron microprobe.

RESULTS

Experiments have been carried out to determine low-temperature phase equilibria in tonalitic system. Equilibrium composition of crystals and coexisting melt as a function of crystallization conditions (mole fraction of water, temperature and pressure) were determined. Crystalline phases identified in run products were plagioclase, hornblende, orthopyroxene, clinopyroxene, biotite, cummingtonite, ilmenite and magnetite. Magnetite occurred only in experiments with F06 composition. In several runs, apatite and zircon were observed. Therefore, crystallization experiments were successful in reproducing the natural phase assemblage plus orthopyroxene, clinopyroxene and magnetite. Resulting stability fields of minerals are presented in Fig 1.

Hornblende stability field is restricted to $\text{XH}_2\text{O} > 0.8$ at 2 kbar. Cummingtonite occurs only in water saturated experiments and temperatures $<780^\circ\text{C}$ in M20 and $<770^\circ\text{C}$ in F06 composition. Stability of hornblende decreases to water saturated conditions with decreasing temperature (Fig 1). Hornblende was not detected by EDX (energy dispersive X-ray analysis) in runs where cummingtonite occurs.

Amphiboles did not crystallized at 1 kbar. Orthopyroxene is the dominating ferromagnesian phase for water-undersaturated conditions and it is not stable for water-saturated conditions below 780°C. The amount of orthopyroxene decreases with decreasing temperature for water saturated conditions. For two-step experiments with decreasing temperature from 850 to 800°C, rounded orthopyroxene occurs in euhedral hornblende crystals.

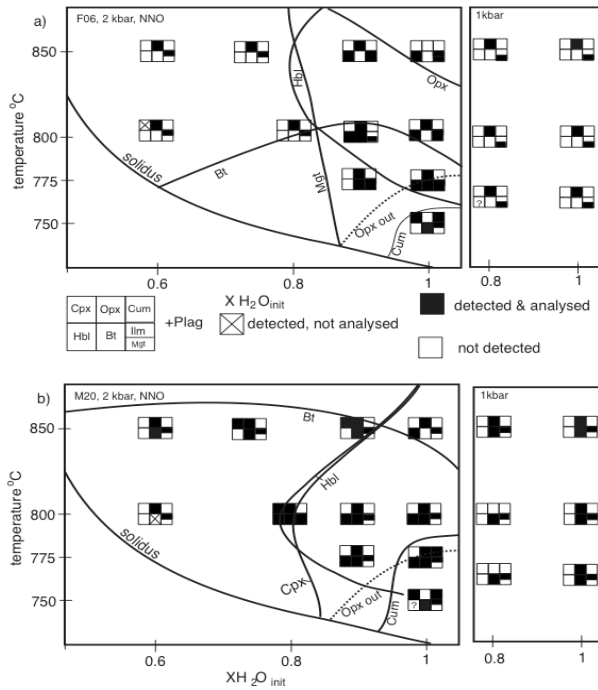


Fig 1. Isobaric T-XH₂O phase diagram at 2 kbar (left) and 1 kbar (right) for (a) poikilitic tonalite F06 and (b) dark tonalite M20.

$$XH_2O_{init} = \frac{H_2O}{H_2O + CO_2}$$

mol% - initial composition of fluid phase in the experiments.

Table 1. The composition of natural and experimental plagioclase and hornblende.

	plagioclase	plagioclase	hornblende	hornblende	hornblende
	natural	experiment. XH ₂ O=1	natural	ex. 850°C	ex. 775°C
Dark tonalite M20	An ₂₅₋₆₅	750°C: An ₅₄	Na _A - 0.04-0.36	Na _A - 0.47	Na _A - 0.28
		800°C: An ₆₂	AlIV - 0.5-1.04	AlIV - 1.78	AlIV - 1.22
Poikilitic tonalite F06	An ₂₅₋₅₇	800°C: An ₅₅	Na _A - 0.37-0.53	Na _A - 0.56	Na _A - 0.44
		850°C: An ₆₄	AlIV - 1.24-1.75	AlIV - 1.67	AlIV - 1.85

Natural Mg/(Mg+Fe) ratios of hornblende and biotite were reproduced for M20 composition suggesting that oxygen fugacity under which rock was equilibrated was similar to experimental one. Mg/(Mg+Fe) ratios in minerals from F06 composition were lower than for M20 but higher than in natural sample indicating lower oxygen fugacity during F06 crystallization and/or late stage equilibration. The same can be concluded from absence of magnetite in natural sample.

Comparing the hornblende composition from experimental runs and natural rocks it can be seen that compositions in terms of Si, Al^{IV}, Na and Ti are reproduced at 850-800°C for F06 hornblende and 775°C for M20 hornblende.

CONCLUSIONS

- (1) Mineral assemblage and chemical composition of phases (Al, Na+K, Ti, Si in amphibole and An in plagioclase) in natural rocks were reproduced in experimental products in water saturated conditions and at temperatures ~800°C for F06 tonalite and ~775-750°C for M20 tonalite.
- (2) Orthopyroxene is an important phase during crystallization of tonalitic magmas at low pressures and should be considered to model the evolution of magma during crystallization. Differences in chemical composition of the two tonalites types may be explained by the orthopyroxene accumulation in M20.
- (3) The lack of orthopyroxene in both compositions indicates that it reacted out supposedly due to reaction with melt involving formation of hornblende and biotite. It is confirmed by the experimentally observed phase proportions. The amount of orthopyroxene decreases concomitantly with increase in hornblende+biotite proportions. Cummingtonite was supposedly formed due to breakdown of hornblende, which is in agreement with the M20 tonalite texture.
- (4) Cummingtonite can be late magmatic phase indicating water saturated conditions of crystallization and reequilibration of rock composition in temperatures below 780°C.

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