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Titanium in calcium amphibole: Behavior and thermometry

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Abstract

Thermometry of high-grade metamorphic rocks is difficult due to fast cationic diffusion during slow cooling, but the titanium content of calcium amphibole (Ti-Amp) can retrieve amphibole-forming temperature as high as ~1000 °C. Based on pseudosection modeling and past research survey, we find that Ti-Amp is controlled by temperature under the conditions of oxygen fugacity <2 log units above the Ni-NiO oxygen buffer (ΔNNO+2), in subalkaline systems, and with the presence of Ti-phases (rutile, ilmenite, or titanite). We apply available experimental data to calibrate a new Ti-Amp thermometer for such conditions:

$$T\left(^{\circ}\mathrm{C}\right)=\frac{2400}{1.52-\log \mathrm{Ti}^{\mathrm{Amp}}}-273$$

where T is temperature and log $\mathrm{Ti}^{\mathrm{Amp}}$ is the Ti content of amphibole in atom per formula unit (apfu) expressed in the logarithm to base 10. The standard error of the calibration experiments is ±35 °C. This thermometer can be applied only if the aforementioned conditions are fulfilled. Besides, caution should be taken when applying the thermometer to rocks under subsolidus water-unsaturated conditions, which can be observed as non-equilibrium textures or low bulk-rock water content (<1–1.5 wt%). The results of this thermometer may be underestimated if applied to rocks that are equilibrated above 850 °C and contain rutile and a significant amount of water (>3.5–4 wt%).

The new thermometer can be successfully applied to amphibole-bearing natural igneous and metamorphic rocks. In addition, we propose the Si vs. Ti in amphibole diagram that roughly demarcates the boundaries among the high amphibolite, high-temperature granulite, and ultrahigh-temperature granulite facies. Although pseudosection modeling provides details of the *P-T* evolution of studied rocks, the Ti-Amp thermometer is quick and easy to apply. However, further research is needed to improve our knowledge of the behavior and stability of amphibole and to improve the accuracy of both pseudosection modeling and conventional thermometry.

Keywords: Thermometer, titanium in calcium amphibole, granulite, amphibolite, igneous rocks, pseudosection