The reaction talc + forsterite = enstatite + H₂O revisited: Application of conventional and novel experimental techniques and derivation of revised thermodynamic properties

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ABSTRACT
The reaction 2 talc + 2 forsterite = 5 enstatite + 2 H₂O has been investigated between 1 and 3.5 GPa. Here, we report the results from 2 sets of experiments: (1) “conventional” static quenching experiments performed several years ago in non-end-loaded and end-loaded piston-cylinder apparatus, and (2) a new set of experiments conducted in a novel type of apparatus, a “rocking” piston cylinder. This new technique was employed for the reinvestigation to overcome segregation problems encountered during static experiments. The run-products of the latter experiments are homogenous throughout the entire capsule. The reaction was bracketed to 680–690 °C at 1 GPa, to 660–680 °C at 1.7 GPa, to 650–660 °C at 2.5 GPa, to 600–640 °C at 3 GPa, and to 550–600 °C at 3.5 GPa. The location of the reaction in P-T-space is consistent with low-pressure experimental data of Chernosky et al. (1985), and is in reasonable agreement with the “conventional” high-pressure experiments of this study. The new experimental results were used to refine the existing thermodynamic properties of talc within the framework of the Holland and Powell (1998) database. The standard state enthalpy and entropy amount to \( H_{\text{f}298}^0 = 5912.358 \) kJ/mol and \( S_{\text{f}298}^0 = 239.1 \) J/(K·mol). The refined standard entropy is about 9% lower than the entropy obtained calorimetrically. When the clinoenstatite-orthoenstatite transition is taken into account, \( S_{\text{f}298}^0 \) of talc improves by \( \sim 6 \) J/K. We assume that a further increase of the standard state entropy of talc can be achieved by varying the activity of H₂O in the fluid as a function of pressure and temperature.

Keywords: MgO-SiO₂-H₂O system, experimental petrology, high pressures, uncertainties, thermodynamics, database, entropy, enthalpy

INTRODUCTION
Talc is a phase that commonly occurs in the Earth’s upper mantle and as a major H₂O-bearing phase in subduction zones. Thermodynamic properties of talc, reliable for the conditions predominating in the upper mantle and in subduction zones are essential for the determination of the stable mineral assemblages that form under variable P-T conditions in these regions.

The maximum stability of talc as an end-member occurs at ~ 800 °C at 10–30 kbar (Bose and Ganguly 1995a; Chernosky et al. 1985) and is defined by the reaction:

\[
2\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 = 3\text{Mg}_2\text{Si}_2\text{O}_6 + 2\text{SiO}_2 + 2\text{H}_2\text{O} \tag{1}
\]

talc = orthoenstatite + quartz/coesite + fluid

However, in average mantle compositions, where talc coexists with olivine, the stability of talc is confined to lower temperatures through the reaction:

\[
2\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 + 2\text{Mg}_2\text{Si}_2\text{O}_6 = 5\text{Mg}_2\text{Si}_2\text{O}_6 + 2\text{H}_2\text{O} \tag{2}
\]

talc + forsterite = clino/orthoenstatite + fluid

Reaction 2 is significant as it delimits the stability of talc in peridotite, whereas reaction 1 is significant for Si-enriched veins and for metasomatized, Si-enriched, olivine-absent mantle rocks that can be expected directly adjacent to the subducting slab surface. Here, at the slab surface, talc most probably forms a principal rock-forming constituent that is capable of transporting water to considerable depths, transforming directly into the 10 Å phase that in turn reacts to dense hydrous magnesium silicates (Fumagalli and Poli 2005; Wunder and Schreyer 1997). Under subduction zone conditions, talc is not limited to ultramafic rocks, but also occurs as a major constituent in MORB and, in particular, in Mg-gabbros at >2 GPa (Schmidt and Poli 1998).

Several experimental studies have investigated reaction 2. Chernosky et al. (1985) determined the position of this reaction to 6 kbar. Their results on this reaction as well as on other reactions involving talc form the basis for the determination of the enthalpy of talc within the framework of the Holland and Powell (1998) database. The standard state enthalpy and entropy amount to \( H_{\text{f}298}^0 = 5912.358 \) kJ/mol and \( S_{\text{f}298}^0 = 239.1 \) J/(K·mol). The refined standard entropy is about 9% lower than the entropy obtained calorimetrically. When the clinoenstatite-orthoenstatite transition is taken into account, \( S_{\text{f}298}^0 \) of talc improves by \( \sim 6 \) J/K. We assume that a further increase of the standard state entropy of talc can be achieved by varying the activity of H₂O in the fluid as a function of pressure and temperature.

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