

A quartz–aragonite–talc schist from the lower Skagit Valley, Washington

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Abstract

A thin metaperidotite layer containing the assemblage quartz + aragonite + talc crystallized under blueschist facies conditions in the Darrington Phyllite, northwestern Washington. It is inferred from this occurrence that the stability field of talc + CaCO_3 + quartz extends across the calcite–aragonite phase boundary.

Introduction

On the basis of field evidence, talc was added by Tilley (1948, 1951) to Bowen's (1940) list of minerals to be expected during the progressive metamorphism of siliceous dolomite. Experimental work in the mixed volatile system $\text{CaO-MgO-SiO}_2\text{-H}_2\text{O-CO}_2$ has subsequently confirmed a stability field for the mineral pair talc + calcite (Metz *et al.*, 1968; Gordon and Greenwood, 1970; Skippen, 1971, 1974; Slaughter *et al.*, 1975). At lower temperatures, or higher CO_2 -fugacities, talc + calcite + CO_2 react to form dolomite + quartz + H_2O ; at higher temperatures, talc + calcite + quartz react to tremolite + CO_2 + H_2O , and talc + calcite react to tremolite + dolomite + CO_2 + H_2O .

However, talc is not common in metamorphosed siliceous dolomite (*e.g.* Melson, 1966; Hutcheon and Moore, 1973), and its absence has been ascribed to a number of factors, *viz.* the narrow field of stability for talc + calcite on the $T\text{-}X_{\text{CO}_2}$ diagram (Skippen, 1971, 1974; Slaughter *et al.*, 1975), production of a low-temperature, very CO_2 -rich fluid by buffering along the reaction curve dolomite + potash feldspar + $\text{H}_2\text{O} = \text{phlogopite} + \text{CaCO}_3 + \text{CO}_2$ (Gordon and Greenwood, 1970; Trommsdorff, 1972), low pressures of metamorphism (Skippen, 1974), and high pressures of metamorphism (Slaughter *et al.*, 1975).

This paper describes a rock containing the mineral assemblage talc + quartz + aragonite, from which it is inferred that the field of talc + CaCO_3 + quartz extends across the calcite–aragonite phase boundary.

Regional setting

The quartz–aragonite–talc schist occurs as a 1 to 3 cm wide layer within graphitic phyllite in a small

roadside quarry overlooking the Skagit River, on the South Skagit Highway, 2 1/2 miles east of its junction with Washington State Highway 9 (Clear Lake Quadrangle). The rocks in the vicinity of the quarry belong to the Darrington Phyllite, a unit of pelites, semipelites, and plagioclase-rich psammites, which is conformably overlain by the metabasaltic Shuksan Greenschist, an actinolitic greenschist with blueschist intercalations (Vance, 1957; Misch, 1959, 1966; Bryant, 1955; Jones, 1959). The metamorphism of this sequence was interpreted by Misch (1959) as representing an intermediate P/T range within a comprehensively-defined blueschist facies. Within this sub-facies range, crossite and crossite–glaucophane schists formed under higher, and actinolitic greenschists, under lower oxygen fugacities (confirmed by Brown, 1974). Epidote is abundant, whereas lawsonite occurs sporadically in some phyllites and metapsammites, and jadeite has not been found, although pyroxenes in the chloromelanite range (optically) occur in some metabasalts south of the Skagit (Bryant, 1955; Vance, 1957; Jones, 1959). Aragonite has recently been identified in blueschist ten miles east of the locality here described.

At the quarry, the country-rock graphitic phyllites contain phengite, chlorite, quartz, and albite. Some 100 yards farther west graphitic phyllite contains accessory lawsonite and epidote, as well as what appears to be aragonite being replaced by calcite. The various phyllites contain the record of an S_1, S_2, S_3 sequence. S_1 survives in some panels between S_2 planes. The dominant foliation S_2 parallels the axial plane of tight folds of S_1 , with major transposition of phyllosilicate and graphite layers. Asymmetric open folding of S_2 has led to an oblique incipient S_3 , with

further transposition of graphite and some phyllosilicate.

Quartz–aragonite–talc schist

The thin quartz–aragonite–talc schist forms a flattened isoclinal fold of S_1 . Except in the narrow hinge, all foliation seen in the talc layer represents S_2 , which is marked by strongly aligned talc flakes, mostly much less than 0.5 mm long, accompanied by minor chlorite. S_2 is openly microfolded. This chlorite–talc fabric is partially replaced by 1 to 4 mm quartz and aragonite xenoblasts, commonly elongate parallel to S_2 , and by S_2 -elongate glomeroblastic aggregates of both minerals. Some quartz and aragonite crystals include trains of S_2 chlorite–talc fabric. There is no visible sign of reaction between the talc and the later-formed quartz and aragonite (Fig. 1).

The talc layer is sharply bordered by originally nearly monomineralic chlorite schist several millimeters thick. The chlorite fabric is identical to that of talc and is similarly and extensively replaced by S_2 -elongate quartz xenoblasts which include trains of S_2 fabric of chlorite, openly folded in places. The chlorite selvage clearly represents a tectonically drawn-out blackwall reaction zone between metaperidotite and enclosing metasediment; the talc schist layer, which contains accessory chromite and a variety of sulfides containing Ni, Fe, and Cu, is all that remains

of the metaperidotite at the outcrop. The chlorite selvage lacks carbonate but contains minor tremolite in discrete layers (in one sample, at the talc–chlorite boundary).

Although the replacement quartz and aragonite postdate the talc and chlorite S_2 fabric and its open microfolding, they were nevertheless affected by considerable late-stage deformation. Both show strained extinction, and aragonite has secondary polysynthetic twinning. Moreover, widely spaced S_3 planes oblique to S_2 cut the replacement quartz xenoblasts, which at such shears are locally granulated and annealed as fine-grained mosaic. This feature is best displayed in the chlorite selvage which also shows local transposition and recrystallization of chlorite in S_3 . The same pattern is shown less distinctly in the talc layer, involving transposition of talc into S_3 . An irregular growth of minor amounts of calcite has formed at the expense of some of the aragonite.

Thus, the main growth of quartz and aragonite took place after formation of S_2 but predates S_3 . Talc crystallized during movement on S_1 , recrystallized during formation of S_2 and recrystallized again, in minor amounts, on S_3 . We therefore infer that the intimate association of talc, aragonite, and quartz constitutes a stable assemblage. Tremolite did not form as a reaction phase between talc and introduced

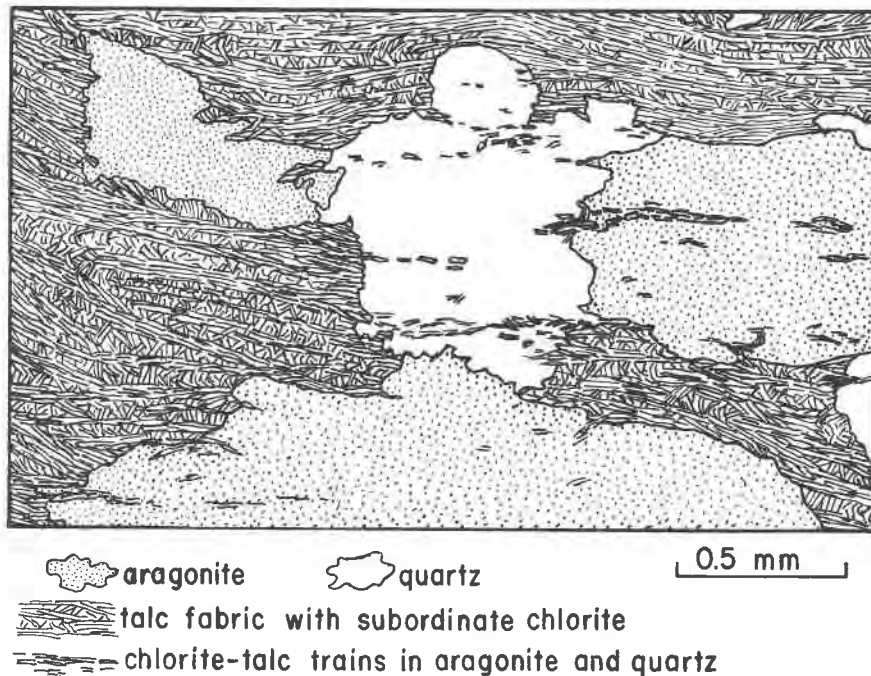


FIG. 1. Chlorite-bearing talc schist partially replaced by aragonite and quartz.

TABLE 1. Microprobe analyses of phases in talc schist

	Chlorite	Talc	Chromite	Aragonite
SiO ₂	29.3	61.6	-	-
TiO ₂	.01	.00	.11	-
Al ₂ O ₃	16.4	.03	12.1	-
Cr ₂ O ₃	3.9†	.05	52.3	.00
FeO*	12.2	4.45	23.6	FeCO ₃ .04
MgO	25.1	28.7	9.47	MgCO ₃ .15
CaO	.06	.01	.09	CaCO ₃ 98.69**
MnO	.19	.03	.54	MnCO ₃ .00
NiO	.33	.16	.09	NiCO ₃ .03
F	.09	.10	-	-
Cl	.02	.02	-	-
			SrCO ₃	1.09
	87.60	95.15	98.30	100.00

* total Fe as FeO † very variable ** by difference

carbonate and silica, although it did grow in minor amounts on S₂ in the chloritic blackwall, where f_{H_2O} was presumably higher than in the talc layer.

Conclusions

Aside from Fe in the talc and Sr in the aragonite, the compositions of the talc, aragonite, and quartz can be rather well expressed by the system CaO-MgO-SiO₂-H₂O-CO₂ (Table 1). The stabilizing effect of Fe in the talc will be more than counterbalanced by Fe in tremolite, the alternate silicate phase, the over-all effect being minimal (Rice, 1975; Thompson, 1975). Similarly, the effect of Sr in aragonite is likely to be counterbalanced by Mg in calcite, the alternate carbonate phase; again, the overall effect on the stability of the assemblage talc-aragonite-quartz will be minimal (see also Skippen and Hutcherson, 1974).

South of the Skagit River, the temperature of the metamorphism of the Darrington Phyllite and Shuksan Greenschist cannot have exceeded $\approx 400^\circ\text{C}$, the upper limit of stability of lawsonite (Crawford and Fyfe, 1965; Newton, 1966; Liou, 1971). Pressures of 7 and 9 kilobars are required to stabilize aragonite at 300°C and 400°C respectively (Johannes and Puhan, 1971). The aragonite formed in the course of the regional metamorphism, and therefore at temperatures most likely high enough to ensure its back-reaction to calcite, had it formed from strained calcite in the calcite stability field (Brown *et al.*, 1962). We therefore conclude that natural talc, aragonite, and quartz are a stable paragenesis at pressures in excess of the calcite-aragonite inversion curve. Even if the talc + calcite stability field contracts with increasing pressure, as claimed by Slaughter *et al.* (1975), it is

still in existence at pressures high enough to convert calcite to aragonite.

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References

- BOWEN, N. L. (1940) Progressive metamorphism of siliceous limestone and dolomite. *J. Geol.* **48**, 225-274.
- BROWN, E. H. (1974) Comparison of the mineralogy and phase relations of blueschists from the North Cascades, Washington, and greenschists from Otago, New Zealand. *Bull. Geol. Soc. Am.* **85**, 333-344.
- BROWN, W. H., W. S. FYFE AND F. J. TURNER (1962) Aragonite in California glaucophane schists and the kinetics of the aragonite-calcite transformation. *J. Petrol.* **3**, 566-582.
- BRYANT, B. (1955) *Petrology and reconnaissance geology, Snow King area, North Cascades, Washington*. Ph.D. thesis, University of Washington, Seattle, Washington.
- CRAWFORD, W. A. AND W. S. FYFE (1965) Lawsonite equilibria. *Am. J. Sci.* **263**, 262-270.
- GORDON, T. M. AND H. J. GREENWOOD (1970) The reaction: dolomite + quartz + water = talc + calcite + carbon dioxide. *Am. J. Sci.* **268**, 225-242.
- HUTCHEON, I. AND J. M. MOORE (1973) The tremolite isograd near Marble Lake, Ontario. *Can. J. Earth Sci.* **10**, 936-947.
- JOHANNES, W. AND D. PUHAN (1971) The calcite-aragonite transition, reinvestigated. *Contrib. Mineral. Petrol.* **31**, 28-38.
- JONES, R. W. (1959) *Geology of Finney Peak area, North Cascades, Washington*. Ph.D. thesis, University of Washington, Seattle, Washington.
- LIU, J. G. (1971) *P-T* stabilities of laumontite, wairakite, lawsonite, and related minerals in the system CaAl₂Si₂O₈-SiO₂-H₂O. *J. Petrol.* **12**, 379-411.
- MELSON, W. G. (1966) Phase equilibria in calcsilicate hornfels, Lewis and Clarke County, Montana. *Am. Mineral.* **51**, 401-421.
- METZ, P., D. PUHAN AND H. G. F. WINKLER (1968) Equilibrium reactions on the formation of talc and tremolite by metamorphism of siliceous dolomite. *Naturwissenschaften*, **55**, 225-226.
- MISCH, P. (1959) Sodic amphiboles and metamorphic facies in Mount Shuksan belt, Northern Cascades, Washington. *Bull. Geol. Soc. Am.* **70**, 1736-1737.
- (1966) Tectonic evolution of the Northern Cascades of Washington State. In: H. C. Gunning, Ed., *A Symposium on the Tectonic History and Mineral Deposits of the Western Cordillera*. *Can. Inst. Min. Metall., Spec.* Vol. 8, 101-148.
- NEWTON, R. C. (1966) Some calc-silicate equilibrium relations. *Am. J. Sci.* **264**, 204-222.
- RICE, J. M. (1975) *Progressive metamorphism of impure dolomite and mineral equilibria in the system CaO-MgO-SiO₂-K₂O-Al₂O₃-CO₂-H₂O*. Ph.D. thesis, University of Washington, Seattle, Washington.
- SKIPPEN, G. B. (1971) Experimental data for reactions in siliceous marbles. *J. Geol.* **79**, 457-481.
- (1974) An experimental model for low pressure metamorphism of siliceous dolomitic marble. *Am. J. Sci.* **274**, 487-509.

- AND I. HUTCHEON (1974) The experimental calibration of continuous reactions in siliceous carbonate rocks. *Can. Mineral.* **12**, 327-333.
- SLAUGHTER, J., D. M. KERRICK AND V. J. WALL (1975) Experimental and thermodynamic study of equilibria in the system CaO-MgO-SiO₂-H₂O-CO₂. *Am. J. Sci.* **275**, 143-162.
- THOMPSON, A. B. (1975) Mineral reactions in a calc-mica schist from Gassetts, Vermont, U.S.A. *Contrib. Mineral. Petrol.* **53**, 105-128.
- TILLEY, C. E. (1948) Earlier stages in the metamorphism of siliceous dolomites. *Mineral. Mag.* **28**, 272-276.
- (1951) A note on the progressive metamorphism of siliceous limestone and dolomites. *Geol. Mag.* **88**, 175-178.
- TROMMSDORFF, V. (1972) Change in *T-X* during metamorphism of siliceous dolomitic rocks of the Central Alps. *Schweiz. Mineral. Petrogr. Mitt.* **52**, 567-571.
- VANCE, J. A. (1957) *Geology of Sauk River area, North Cascades, Washington*. Ph.D. Thesis, University of Washington, Seattle, Washington.

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