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Eclogite Facies Metamorphic Rocks of the Worcester Mountains, Stowe, Vermont, USA II

John Mark Brigham, Suzanne L. Baldwin, Jay B. Thomas

Department of Earth and Environmental Sciences, Syracuse University, Syracuse, New York, USA

jbrigham@syr.edu

Syracuse University

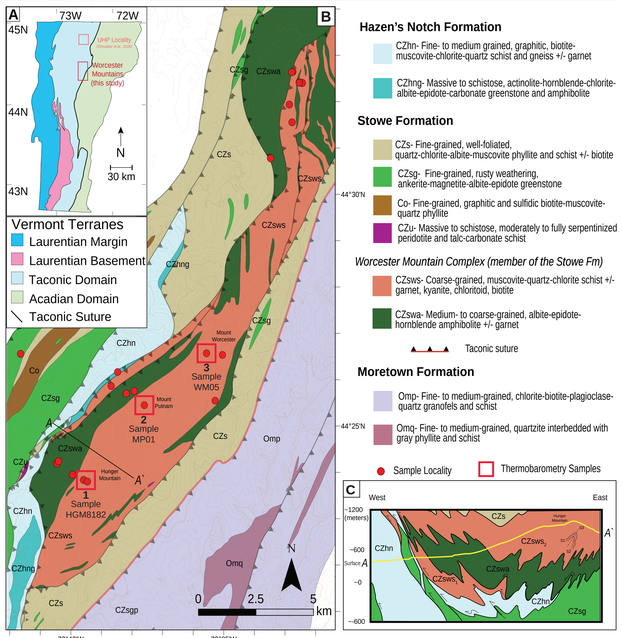
Introduction

A recent study in the northern Appalachian Mountains showed that one locality within the Ordovician Taconic orogenic suture zone recorded ultra-high-pressure (UHP) metamorphic conditions, equating to depths of >75 km (Gonzalez et al., 2020). **However, the extent of Taconic UHP and HP metamorphism is not well documented.**

The Worcester Mountain Complex occurs at a similar structural level to the UHP rocks ~30 km to the north. It is composed of variably altered mafic and pelitic schist. These lithologies contain garnet, which can host mineral inclusions that record the conditions during garnet growth.

We present electron microprobe Ti-in-quartz and Zr-in-rutile data from inclusions in garnet and garnet composition isopleth calculations from kyanite-garnet-mica schists from the Worcester Mountains (map unit CZsws). **Our results indicate mineral crystallization at eclogite facies pressures of 14–20 kbar (~45–65 km) and temperatures of 625–685°C .**

Geologic Setting



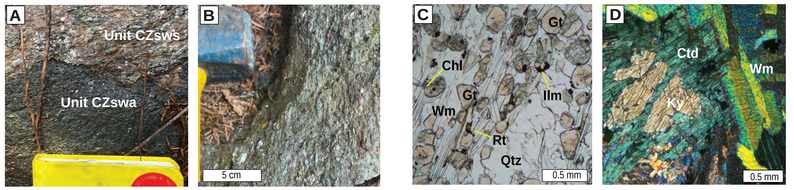
(A) Simplified tectonic map of Vermont after from Gonzalez et al., 2020.

(B) Bedrock geology of the Worcester Mountains area (after from Ratcliffe et al., 2011). This study focused on unit CZsws (garnet-kyanite-mica schist). Three samples used for thermobarometry are highlighted in red boxes.

(C) Cross section (after Gale et al., 2006) showing the structural relation of the Worcester Mountain Complex (units CZsws and CZswa) compared to surrounding lithologies.

Results

Outcrop, Hand Sample, and Thin Section Observations



(**A**) Contact between amphibolite (CZswa) and retrogressed pelitic-schist (CZswa).

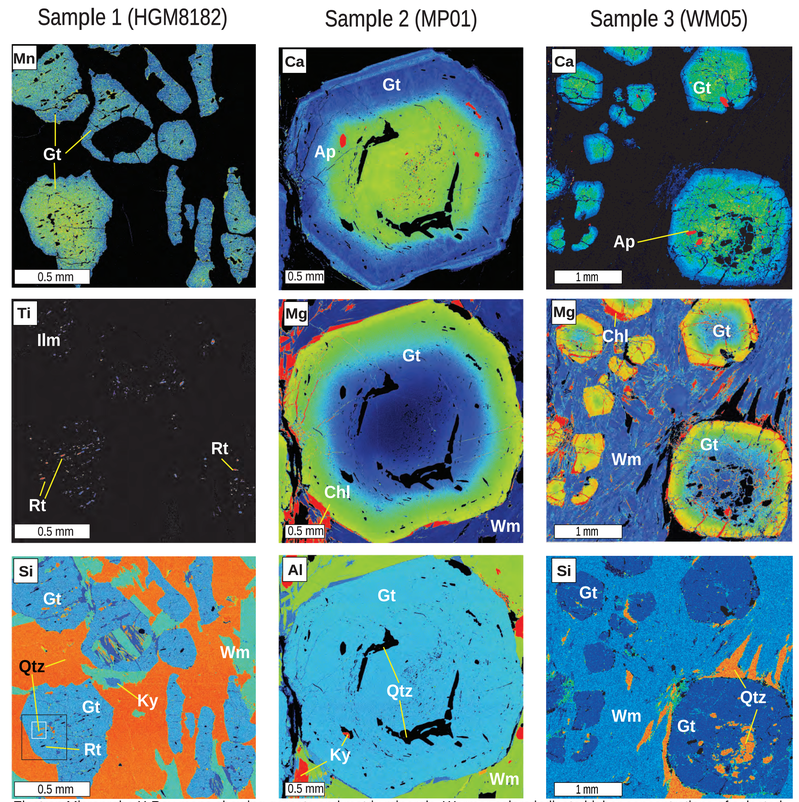
(**B**) Photograph of sample 2 (MP01) with relatively unaltered garnet, kyanite, and white mica.

(**C**) Photomicrograph (PPL) of sample WM05 showing garnet partially altered to chlorite.

(**D**) Photomicrograph (XPL) of sample HGM8182 showing kyanite partially altered to chloritoid.

Abbreviations: Gt, garnet; Wm, white mica; Qtz, quartz; Ilm, ilmenite; Rt, rutile; Ctd, chloritoid; Ky, kyanite;

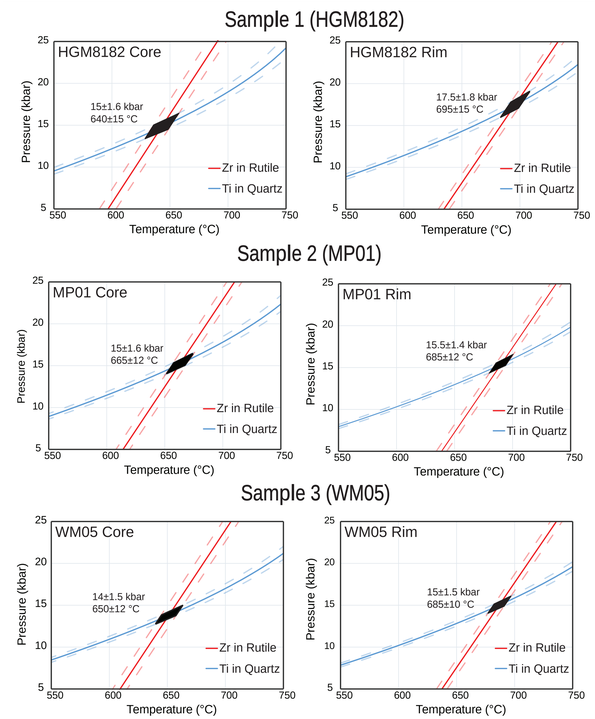
Electron Microprobe Observations



Electron Microprobe X-Ray maps showing garnets and matrix minerals. Warmer colors indicate higher concentrations of selected elements. Gt, garnet; Qtz, quartz; Rt, rutile; Ky, kyanite; Wm, white mica; Chl, chlorite; Ap, apatite; Ilm, ilmenite.

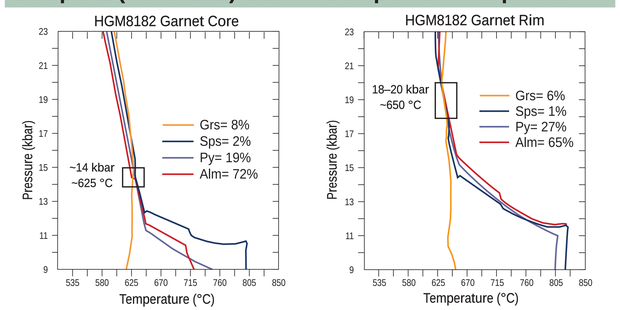
Targets for garnet inclusion trace-element thermobarometry analyses are highlighted in boxes in the HGM8182 Si Map. White box shows a quartz inclusion and black box shows a quartz + rutile pair near the garnet rim.

Trace-Element Thermobarometry



Pressure-temperature diagrams summarizing results from electron microprobe Ti-in-quartz and Zr-in-rutile analyses (using solubility models from Osborne et al., 2022; and Tomkins et al., 2007. Isopleth intersections (approximate conditions of mineral growth) are highlighted by black polygon.

Sample 1 (HGM8182) Garnet Composition Isopleths

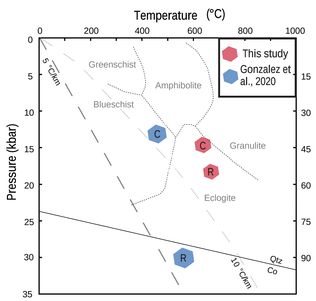


Pressure-temperature diagrams (modelled using program GIBBS [Spear and Menard, 1989]) showing garnet core and rim composition isopleths for each garnet endmember composition. Isopleth intersections approximate conditions of garnet growth.

Abbreviations: Alm, almandine; Py, pyrope; Grs, grossular; Sps, spessartine

Interpretations

- Trace element thermobarometry and garnet composition models record different parts of a prograde metamorphic history.
- Garnet composition models estimate conditions of garnet nucleation and final garnet growth, whereas inclusions estimate conditions during garnet growth.
- Significant overstepping of the metamorphic reactions to nucleate garnet is suggested by conditions reported from garnet cores.
- No along-strike variation (within error) in pressure-temperature estimates suggests that eclogite facies conditions were reached throughout the Worcester Mountain Complex.
- Temperature estimates for the Worcester Mountains pelitic schist are higher than those reported for garnet cores at the UHP locality where coesite was found in a garnet rim. Pressure estimates are similar.



Pressure-temperature diagram (after Gonzalez et al., 2020) highlighting the metamorphic facies and the quartz/coesite (Co) transition.

Red hexagons show the locations of garnet core (C) and rim (R) growth inferred in this study. Blue hexagons show garnet growth for the Taconic UHP locality 30 km north of our study area.

Summary and Future Work

Our results show that garnet in pelitic schist from three localities in the Worcester Mountain Complex grew at eclogite facies metamorphic conditions (625–685 °C, 14–20 kbar).

Performing analyses on mineral inclusions in garnet from other rocks along the Taconic Suture may reveal additional localities that preserve Ordovician eclogite facies metamorphic conditions, which may improve tectonic models for the Taconic Orogeny.

Additional studies are needed to identify a mechanism for the exhumation of high-pressure metamorphic rocks in this region.

Acknowledgments

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References

Gale, M., Kim, J., King, S., Montane, P., and Orsi, C., 2006, Bedrock Geologic Map of the Southern Worcester Mountains Watershed, Middlesex and Stowe 7.5' Quadrangles, Vermont: Vermont Geological Survey, scale 1:24,000, 1 sheet(s).

Gonzalez, J.P., Baldwin, S.L., Thomas, J.B., Nachlas, W.O., and Fitzgerald, P.G., 2020, Evidence for ultrahigh-pressure metamorphism discovered in the Appalachian orogen: Geology, v. 48, p. 947–951, https://doi.org/10.1130/G47507.1.

Osborne, Z.R., Thomas, J.B., Nachlas, W.O., Angel, R.J., Hoff, C.M., and Watson, E.B., 2022, TitaniQ revisited: expanded and improved Ti-in-quartz solubility model for thermobarometry: Contributions to Mineralogy and Petrology, v. 177, p. 31, https://doi.org/10.1007/s00410-022-01896-8.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.J., 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, 3 sheets, scale 1:100,000, https://doi.org/10.3133/sim3184.

Spear, F.S., and Menard, T., 1989, Program GIBBS: A generalized Gibbs method algorithm: American Mineralogist, v. 74, p. 942–943.

Tomkins, H.S., Powell, R., and Ellis, D.J., 2007, The pressure dependence of the zirconium-in-rutile thermometer: Journal of Metamorphic Geology, v. 25, p. 703–713, https://doi.org/10.1111/j.1525-1314.2007.00724.x.