

Bulk Rock Compositional Dependence of Metamorphic Mineral Assemblages: Examples from Pelite Pseudosections

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ABSTRACT

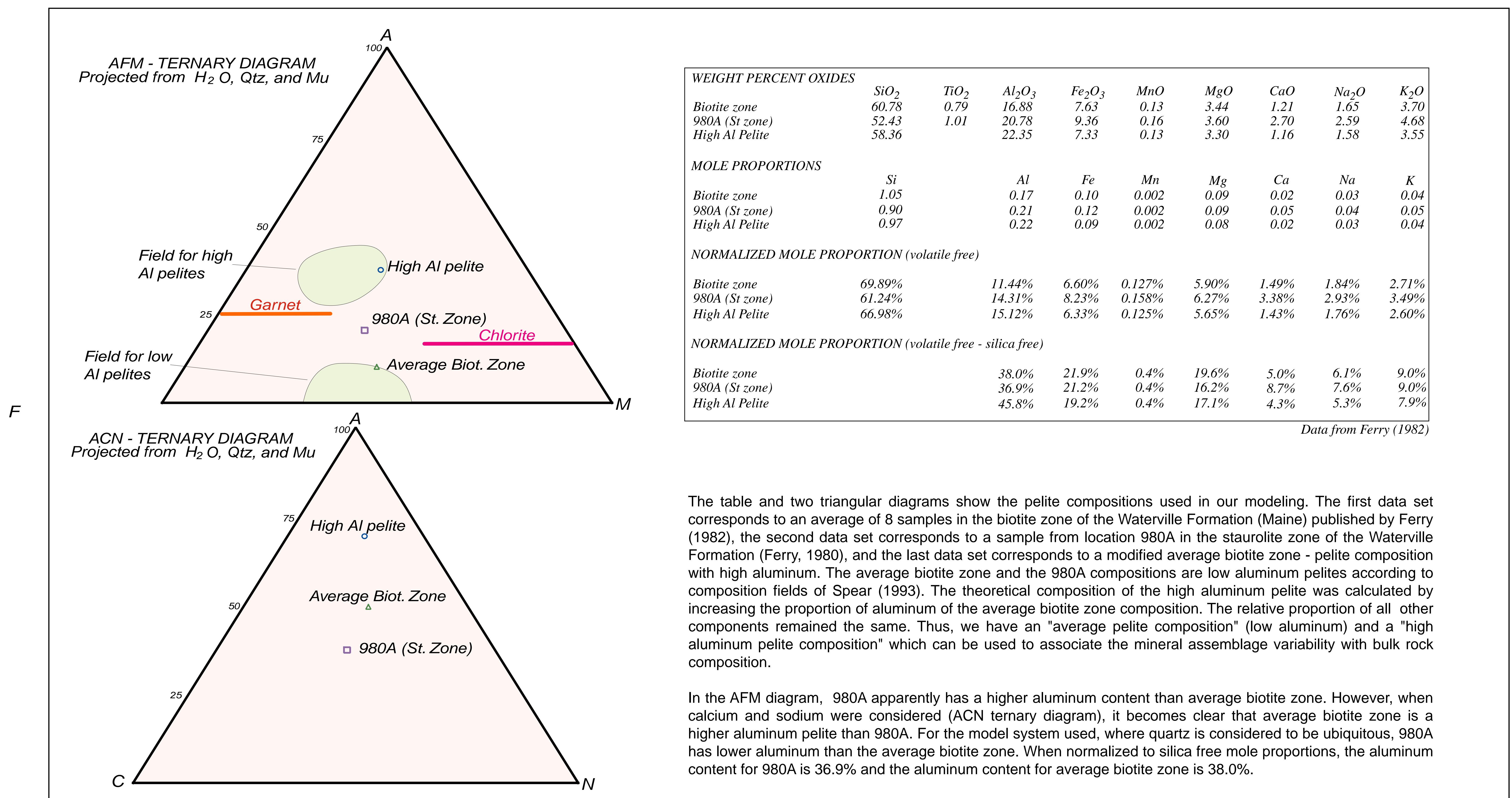
Pseudosections (MnNaCaKFMASH system) were constructed for an average biotite zone pelite and for a sample of the staurolite-andalusite zone of the Waterville Formation, south central Maine using THERMOCALC and the thermodynamic data of Holland and Powell (1998). Activity models were those of Holland and Powell (1998) and those supplied with THERMOCALC, except that some solutions were extended to include Mn. Pseudosections indicate: i) the relevance of these diagrams for predicting parageneses and ii) the control that bulk rock composition exerts on the parageneses.

Predicted mineral assemblages were compared with observed parageneses. Most results from pseudosections are in good agreement with natural assemblages. The biotite-in reaction calculated for the average biotite pseudosection indicates biotite growth at 420 °C and 3.5 kbars. Ferry (1984) estimated that biotite formed ca. 410 °C and 3.5 kbars, in very good agreement with the pseudosection. The most striking discrepancy is that observed staurolite+cordierite is not predicted by the pseudosections. The pseudosections predict staurolite stability above 4.0 and 4.3 kbars, higher than cordierite and/or andalusite stability.

A pseudosection was constructed by proportionally modifying the average biotite zone composition: alumina increased from 16.88% to 22.35%. Comparisons of the three pseudosections show that small variations in bulk rock composition lead to significant changes in mineral assemblages. The biotite-in reaction shifts to higher T and lower P with increased alumina. Increase in alumina concentration drives paragonite stability to lower P (as low as 1 kbar), increases the P-T range of staurolite stability (mainly T range, P range remains above 4 kbars), and causes growth of aluminum silicate before biotite at P < 4 kbars.

The average biotite zone and 980A pseudosections demonstrate the usefulness of pseudosections for predicting mineral assemblages with good (biotite stability) to moderate (staurolite) agreement between natural and predicted assemblages. Results from variation of alumina concentration demonstrate the compositional dependence of metamorphic mineral assemblages.

DATA

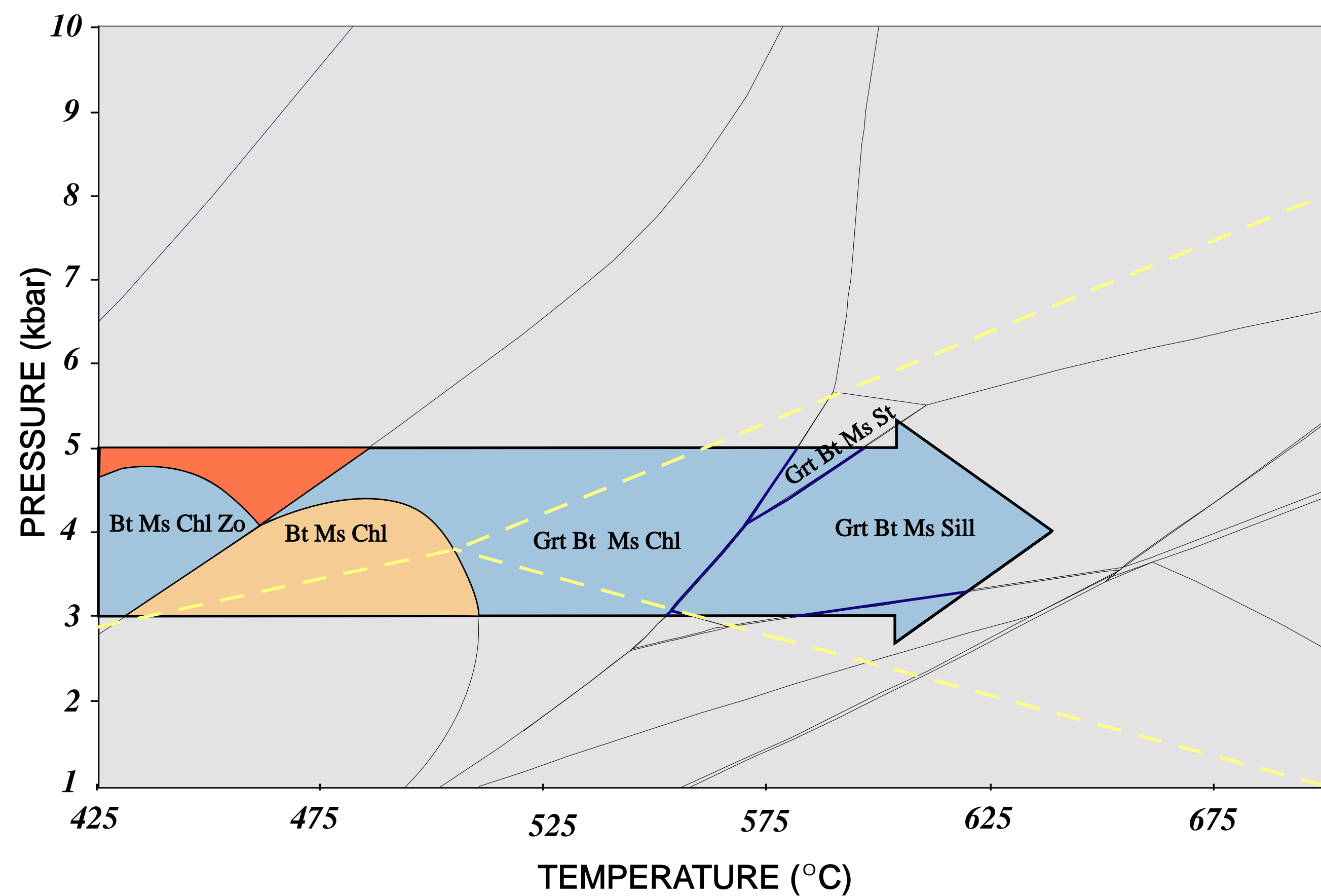


The table and two triangular diagrams show the pelite compositions used in our modeling. The first data set corresponds to an average of 8 samples in the biotite zone of the Waterville Formation (Maine) published by Ferry (1982), the second data set corresponds to a sample from location 980A in the staurolite zone of the Waterville Formation (Ferry, 1980), and the last data set corresponds to a modified average biotite zone - pelite composition with high aluminum. The average biotite zone and the 980A compositions are low aluminum pelites according to composition fields of Spear (1993). The theoretical composition of the high aluminum pelite was calculated by increasing the proportion of aluminum of the average biotite zone composition. The relative proportion of all other components remained the same. Thus, we have an "average pelite composition" (low aluminum) and a "high aluminum pelite composition" which can be used to associate the mineral assemblage variability with bulk rock composition.

In the AFM diagram, 980A apparently has a higher aluminum content than average biotite zone. However, when calcium and sodium were considered (ACN ternary diagram), it becomes clear that average biotite zone is a higher aluminum pelite than 980A. For the model system used, where quartz is considered to be ubiquitous, 980A has lower aluminum than the average biotite zone. When normalized to silica free mole proportions, the aluminum content for 980A is 36.9% and the aluminum content for average biotite zone is 38.0%.

PREDICTED VS OBSERVED PARAGENESIS

Pseudosection for sample 980A



ISOGRAD	Temp (°C)	Chl	Bt	Ms	Qtz	Pl	Grt	St	And	Cd	Sill	Kfs	Zo	Temp (°C)	PSEUDOSECTION FIELDS
BIOTITE	375	XX	XX	XX	XX	XX							X	390-400	Bt Ms Chl Zo Bt Ms Chl
GARNET	460	XX	XX	XX	XX	XX	XX							500	Grt Bt Ms Chl
STAUROLITE ANDALUSITE	490	X	XX	XX	XX	XX	XX	XX	X	X				570	Grt Bt Ms St
SILLIMANITE	550		XX	XX	XX	XX	XX	X		X	XX	X		550-570	Grt Bt Ms Sill

In black: paragenesis observed in the Waterville Formation and temperatures determined using Fe-Mg exchange thermometer for biotite and garnet (Ferry 1980, 1982).

In red: paragenesis predicted by 980A pseudosection and temperatures estimated in the pseudosection at 3-5 kbar.

The colored portion of the 980A pseudosection above shows mineral parageneses in the pressure interval estimated by Ferry (1980) near the sillimanite isograd (3500 ± 200 bars). The table compares mineral parageneses from metamorphic zones described by Ferry (1980, 1982) with those from the pseudosection. In the range 3 to 5 kbar, sample 980A would show the following paragenetic evolution with increasing temperature (all parageneses + quartz and plagioclase):

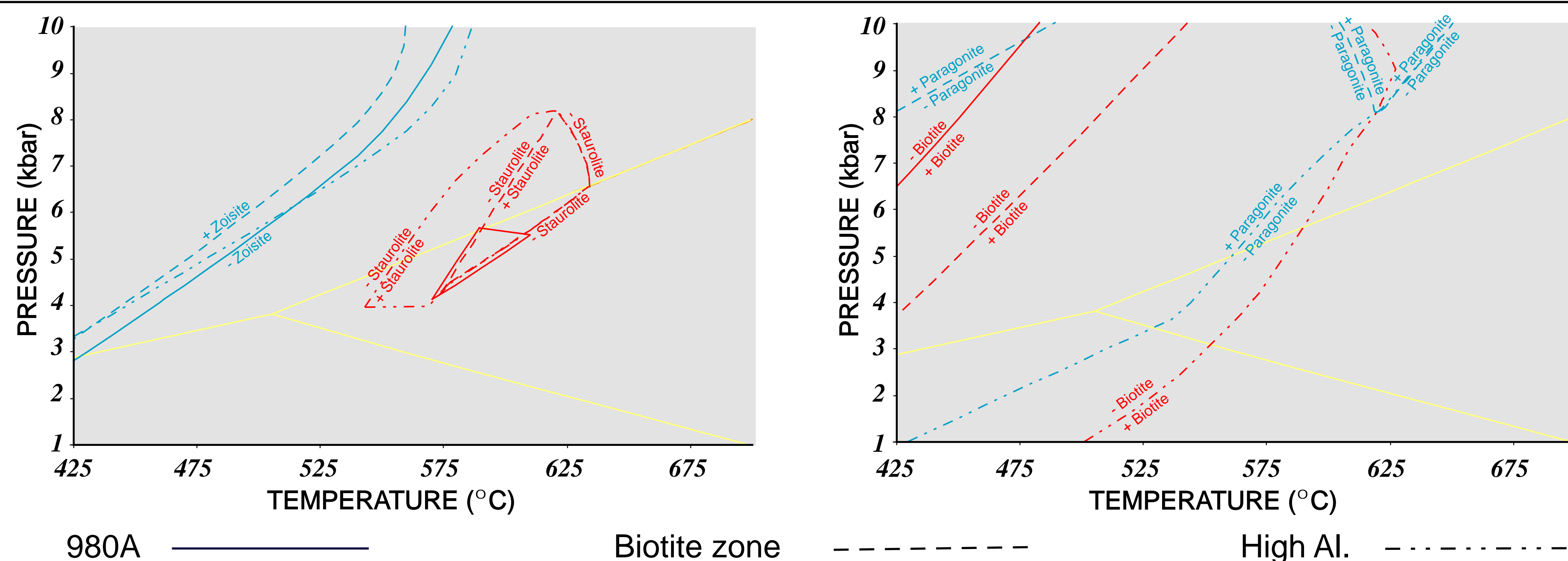
Bt Ms Chl Zo --> Bt Ms Chl --> Grt Bt Ms Chl --> Grt Bt Ms St --> Grt Bt Ms Sill

However, Individual rocks may have followed a variety of P-T paths to their estimated peak P-T conditions.

With the exception of biotite and staurolite zones, the sequence of reactions predicted by this pseudosection is in good agreement with the observed sequence. The pseudosection predicts zoisite stability in the biotite zone which is not observed in the Waterville Formation. Furthermore staurolite+andalusite±cordierite are found in Waterville rocks, but the pseudosection does not predict this assemblage.

If rocks in the biotite zone had been metamorphosed at lower pressure than the 3.5 kbar as inferred by Ferry (1980) near the sillimanite zone, then pseudosection parageneses would match those observed in Waterville Formation.

VARIATION IN PREDICTED PARAGENESIS WITH BULK ROCK COMPOSITION



Some of the variations in topology between the three pseudosections are highlighted here.

- The zoisite-in boundary field does not show significant variations with increased alumina.
- The stability field for staurolite increases with increased aluminum content (progression from smallest to largest P-T stability is: 980A, biotite zone, and high aluminum pelite).
- The biotite-in line shifts to lower pressures and higher temperatures with increased alumina, then, biotite stability is reduced at high pressures - low temperatures.
- Paragonite is not stable in 980A, but is stable in the average biotite zone at high pressures (>8 kbar), and becomes stable at low pressures and low temperatures in the high aluminum pelite.

CONCLUSIONS

Pseudosections can be used to predict mineral parageneses at different P-T conditions for specific bulk rock compositions. Comparison of natural mineral assemblages and pseudosections allows the intensive variables (pressure and temperature) to be estimated.

Predicted mineral parageneses are in good to moderate agreement with natural assemblages in the Waterville Formation. These results were obtained using a nine component system (MnCaNaKFMASH). The most striking discrepancy is the reported natural assemblage staurolite+andalusite±cordierite, which is not predicted by the pseudosections. The biggest stability field for staurolite is found in the high aluminum pelite pseudosection, but this stability field is at high pressures (> 4 kbar) where andalusite and sillimanite are not stable.

The three pseudosections demonstrate the dependence of mineral parageneses on bulk rock composition. In general, high aluminum content will increase P-T stability of paragonite, aluminum silicates, and staurolite. In the case of biotite an increase in alumina will cause a decrease in P-T stability.

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