EENS 2120	Petrology
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Metamorphic Mineral Assemblages

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The mineral assemblages that occur in metamorphic rocks depend on four factors:

- The bulk chemical composition of the original rock.
- The pressure reached during metamorphism.
- The temperature reached during metamorphism.
- The composition of any fluid phase that was present during metamorphism.

If a rock is taken to some higher pressure and temperature then the mineral assemblage that develops should represent stable chemical equilibrium if the conditions are held for a long enough period of time that equilibrium can be achieved. Since metamorphism usually involves long periods of geologic time, most metamorphic rocks represent an equilibrium mineral assemblage.

The Phase Rule for Metamorphism

Recall that the phase rule states that

$$F = C + 2 - P$$

where F = the variance of the system or number of degrees of freedom,

C = the number of components in the system,

and P = the number of phases present.

the 2 stands for the two independent variables, Pressure and Temperature.

If you think about it, in metamorphic rocks where temperature and pressure can both vary during metamorphism, the most likely case would be to find a divariant ($F=2$) assemblage of phases. A univariant assemblage ($F=1$) would be less likely to occur, and an invariant assemblage ($F=0$) would represent equilibrium at a fixed point in temperature and pressure, and would thus be even less likely to occur.

So, for $F=2$, $C=P$, the number of phases present in a rock for the more common divariant assemblage will be equal to the number of components. If P is greater than C, then one of three possibilities exist for the mineral assemblage.

1. The assemblage represents a non-equilibrium assemblage (perhaps due to incomplete chemical reactions or due to the presence of retrograde minerals that developed during cooling, uplift, or unroofing of the metamorphic rock).
2. The assemblage represents univariant or invariant equilibrium, as discussed above.
3. The number of components have not been chosen correctly.

If possibility (1) is the reason for the lack of correspondence with the phase rule, it can usually be determined by close inspection of the rock. Reaction textures present in the rock might indicate incomplete reaction. Known retrograde minerals, i.e. those stable at lower pressures and temperatures than the rest of the minerals in the rock, could be identified. These retrograde phases could then be subtracted from the number of phases being considered and the phase rule could be reapplied to only the phases known to be in equilibrium. (For example, the presence of chlorite in amphibolite and granulite facies rocks would be indicative that the chlorite is a retrograde mineral or mineral produced during weathering, and thus would not be considered in the application of the phase rule.)

Possibility 2 could always occur, and if the number of components is chosen correctly and retrograde minerals are not considered, then this may be the case.

The number of components, as stated in the phase rule, must be chosen so as to represent the minimum number necessary to form all phases possible in the rock. Recall that the number of components is not strictly the number of oxide components or the number of elements as reported in a chemical analysis of the rock. If we just consider the major phases that make up metamorphic rocks and consider that some ions freely substitute for one another in solid solutions, then the number of components can often be reduced to 7 or 8. For example:

1. $K_2O{\cdot}Al_2O_3$ (based on the ratio of K to Al in the alkali feldspars)
2. $(Ca,Na_2)O{\cdot}Al_2O_3$ (based on the ratio of Ca and Na to Al in the plagioclase)
3. $(Si,Ti)O_2$ - based on the common substitution of Ti into tetrahedral sites in most silicates)
4. (Fe,Mn)O - based on the common substitution of Mn for Fe in minerals.
5. MgO - usually needed because Fe-Mg solid solution compositions are both temperature and pressure dependent. (although sometimes these two are combined, which would reduce the total number of components by 1).
6. $(Al,Fe^{+3})_2O_3$ - based on the commonly observed substitution of Fe^{+3} for Al^{+3}Al in minerals.
7. H_2O - usually present in a fluid phase, but also an important component of hydrous minerals.

8. CO_2 - also usually present in a fluid phase, but also an important component in carbonate minerals.

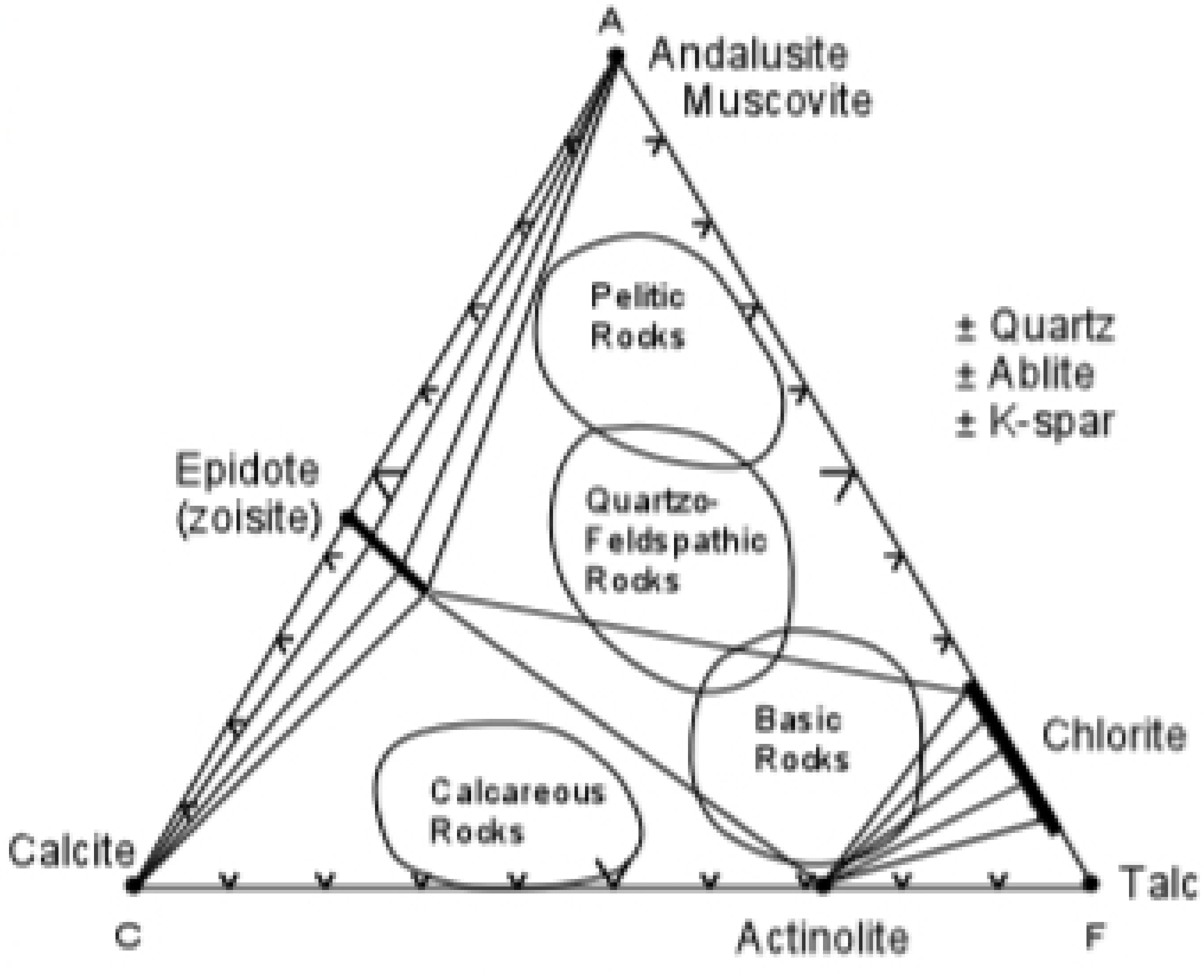
If H_2O and CO_2 are assumed to be always present and available to form hydrous and carbonate minerals, then the number of components can be reduced to 5 or 6. Thus for a divariant assemblage (F=2) we would expect to find 5 or 6 different mineral phases present in a metamorphic rock, or up to 8 phases if the assemblage is invariant.

This is the basis for the construction of the AKF and ACF diagrams discussed previously, where the number of components have been reduced to 4, by making assumptions like quartz and alkali feldspar can always be present. Still, you are cautioned that the above analysis is not always generally applicable, and each rock must be considered on a case-by case scenario.

Example of Progressive Metamorphism

Progressive or ***prograde metamorphism*** occurs as the temperature and pressure are increased on the rock. As the pressure and temperature increase, a rock of a given chemical composition is expected to undergo a continuous series of chemical reactions between its constituent minerals and any fluid phase present to produce a series of new mineral assemblages that are stable at the higher pressures and temperatures. We here illustrate how the mineral assemblages might change in a hypothetical set of rocks, starting with a low grade mineral assemblage as shown in the ACF diagram below.

First, consider the compositions of various types of rocks. Pelitic and quartzo-feldspathic rocks are relatively aluminous, calcareous rocks are relatively rich in the C component, and basic rocks are relative rich in the F component. At some low temperature and pressure typical of low grade metamorphism, pelitic and quartzo feldspathic rocks in this example would consist of epidote, chlorite, andalusite, muscovite, and possibly quartz, k-spar, muscovite, and albite. Calcareous rocks would contain epidote, calcite, actinolite, and possibly quartz, albite, and k-spar. Basic rocks would consist of epidote, chlorite, actinolite, and possibly, quartz, albite, and k-spar. Ultramafic rocks would consist of actinolite, chlorite and talc.



Low Grade Rocks