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The greenschist–amphibolite transition in the CFM projection

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Abstract

The CFM projection (C = $CaO+Na_2O+K_2O-Al_2O_3$, F = $FeO-Fe_2O_3$, M = MgO) was originally designed for illustrating mineral assemblages in upper amphibolite and granulite facies quartz–feldspar–magnetite-bearing metabasites. By introducing chlorite, the projection can also be used to illustrate mineral assemblages in greenschist facies quartz–feldspar–magnetite-bearing metabasites. The greenschist–amphibolite facies transition takes place in the context of Abbott's (1982) lowest grade CFM topology.

In metabasites, the change from the greenschist facies to the amphibolite facies commonly proceeds with no change in the mineral assemblage other than (1) a change in the compositions of the minerals and (2) a change in the modal proportions of the minerals (Laird, 1980; Thompson *et al.*, 1982; Laird *in* Robinson *et al.*, 1982). The common assemblage is amphibole (Amp) + chlorite (Chl) + plagioclase (Pla) + epidote (Epi) + quartz (Qtz)±Fe^{3+} oxide (hematite or magnetite = Mgt)±Ti-mineral (ilmenite or sphene)±K-mica (muscovite of biotite = Bio)±carbonate (calcite or ankerite)±garnet (Gar). In the greenschist facies, the amphibole is actinolite (Act) and the plagioclase is albite. In the amphibolite facies, the amphibole is hornblende (Hnb) and the plagioclase is oligoclase or a more calcic plagioclase. The whole-rock reaction relating the two facies is polyvariant and has been treated recently in an elegant fashion by Thompson *et al.* (1982) and by Laird *in* Robinson *et al.* (1982). In these works, the changes from actinolite to hornblende and from albite to oligoclase were modelled as continuous reactions.

Abbott (1982) presented a petrogenetic grid for amphibolite and granulite facies metabasites, based on phase relationships in the CFM projection (C = $CaO+Na_2O+K_2O-Al_2O_3$, F = $FeO-Fe_2O_3$, M = MgO). The CFM projection is useful for illustrating mineral assemblages in metabasites containing quartz, magnetite and one or two feldspars. The grid consists of 26 *P–T* regions, each characterized by a distinct CFM topology. Boundaries between the *P–T* regions are mineral reactions involving combinations of four of the CFM minerals hornblende, biotite, garnet, epidote, clinopyroxene, orthopyroxene and fayalite. Quartz, feldspar and magnetite are involved as needed for balancing the reactions.

Some of the lowest grade CFM topologies (*e.g.*, *P–T* regions 1, 5, and 6 in Figure 3 of Abbott, 1982) would be consistent with the greenschist facies if (1) the amphibole were actinolite instead of hornblende, (2) the plagioclase were albite and (3) if the CFM topologies were modified by the addition of chlorite. Actinolites and hornblendes plot in the same part of the CFM diagram and since the change from the former to the latter is, in many instances, continuous, this change has virtually no visible affect on the CFM topologies. Also, because plagioclase does not appear in the CFM projection, the change from albite to oligoclase has no visible affect on the CFM topologies. The purpose of this note is to show that by introducing chlorite in the CFM projection the petrogenetic grid, which I originally designed for amphibolite and granulite facies rocks, applies just as well to lower grades where typical greenschist assemblages are possible.

By several indications (Winkler, 1979; Turner, 1968; Dobretsov *et al.*, 1972) Chl+Epi+Qtz+Mgt+albite is an important greenschist assemblage at temperatures well above the first appearance of amphibole, biotite or garnet in rocks of higher FeO/MgO. In most greenschists, these minerals appear as the result of divariant CFM reactions. The usual order of appearance with increasing grade of metamorphism is actinolite, biotite, garnet (Winkler, 1979; Turner, 1968; Dobretsov *et al.*, 1972). However, garnet may appear at a lower grade than the biotite if the K_2O content of the rock is very low, in which case biotite may not appear at all. Normally the K_2O content is high enough to sustain biotite (or some other K-bearing mineral, Laird, 1980). For the purposes of this note, there is no need to consider CFM topologies without amphibole, biotite and garnet.

The most likely CFM topology for the greenschist facies is shown in Figure 1a. The topology is derived from Abbott's (1982) CFM topology 1, 5 or 6 by the addition of chlorite. All of the three-phase CFM assemblages in Figure 1a are naturally occurring (Abbott, 1982; for the chlorite-bearing assemblages, Winkler, 1979; Turner, 1968; Dobretsov *et al.*, 1972; Spear, 1982). The partitioning of FeO and MgO, X_{FeO} = FeO/(MgO+FeO), between chlorite and other minerals in metabasites is X_{FeO} (Chl) > X_{FeO} (Act), X_{FeO} (Chl) ≥ X_{FeO} (Hnb), X_{FeO} (Chl) < X_{FeO}

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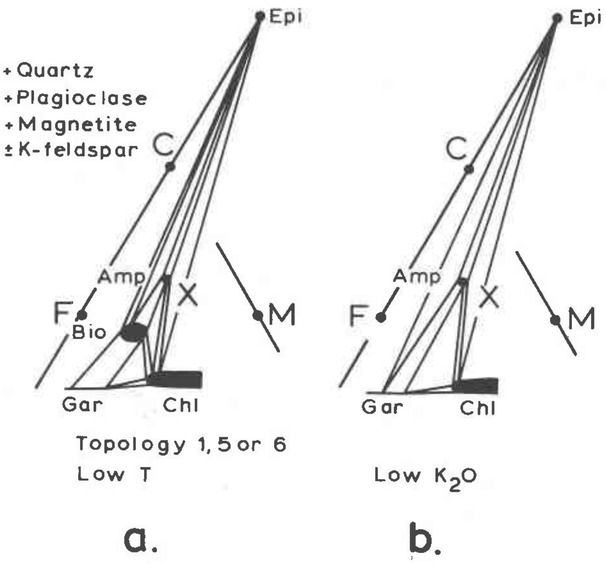

Fig. 1. CFM projections for greenschist and low grade amphibolite metabasites. C = $CaO+Na_2O+K_2O-Al_2O_3$, F = $FeO-Fe_2O_3$, M = MgO. In each projection X marks a bulk composition expressed by the mineral assemblage Chl+Epi. Amp = amphibole, Bio = biotite, Chl = chlorite, Epi = epidote, Gar = garnet. a. Portion of the CFM projection for Abbott's (1982) *P–T* regions 1, 5 or 6 modified by the addition of chlorite. b. Hypothetical CFM projection for low K_2O.

(Gar) and X_{FeO} (Chl) < X_{FeO} (Bio) (Laird, 1980). The epidote in Figure 1 is $Ca_2Fe^{3+}Al_2Si_3O_{12}(OH)$; more aluminous epidotes plot closer to C.

As the temperature increases, X_{FeO} decreases for Gar, Bio and Chl in the various three-phase CFM regions in Figure 1a. Where the amphibole is actinolite, X_{FeO} (Act) for the three-phase CFM region Act+Chl+Epi may increase slightly with increasing temperature (Laird, 1980; Laird *in* Robinson *et al.*, 1982). The three-phase region expands with increasing temperature, such that the Act+Epi join rotates slightly to higher X_{FeO} and the Chl+Epi join rotates to lower X_{FeO}. Where the amphibole in Figure 1a is hornblende, X_{FeO} (Hnb) decreases or remains constant with increasing grade (Spear, 1981), and all three-phase regions move to the right (to lower X_{FeO}) with increasing temperature. With regard to the model assemblage, Amp+Chl+Epi+Pla, of Thompson *et al.* (1982), this change in the CFM projection is accommodated principally by the reaction:

$$\text{Epi} + \text{Chl} = \text{Amp}$$

Quartz, feldspar, Fe^{3+} oxide and H_2O are involved as needed for balancing the reaction. A metabasite, initially in the Chl+Epi field, but with C/(C+F+M) slightly less than Amp (X in Figure 1a and b) will be situated in different fields as the temperature increases. In order from low to high temperature, for Abbott's (1982) CFM topologies 1, 5 or 6 (Fig. 1a), the sequence of assemblages is Chl+Epi, Chl+Epi+Amp, Chl+Amp, Chl+Amp+Bio, Bio+Amp, Bio+Amp+Epi. The chlorite-bearing assemblages are typical of the greenschist facies where the amphibole is actinolite and the plagioclase is albite. The assemblages without chlorite are typical of the amphibolite facies where the amphibole is hornblende and the plagioclase is oligoclase. Very commonly metabasites (metabasalts) are in the Amp+Epi+Chl field when the greenschist-amphibolite transition takes place (Thompson *et al.*, 1982; Laird *in* Robinson *et al.*, 1982). For bulk compositions higher in FeO/MgO, the greenschist–amphibolite transition may occur in one of the chlorite-absent assemblages. For compositions lower in FeO/MgO, the facies transition may occur in the amphibole-absent assemblage Chl+Epi.

I suggest the greenschist–amphibolite transition takes place in Abbott's (1982) lowest grade CFM topology. If the K_2O content of the rock is very low, biotite may not be possible. Under these circumstances, the greenschist-amphibolite transition probably takes place in the context of the CFM topology shown in Figure 1b.

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