AMPHIBOLE ZONATION IN GLAUCOPHANE SCHISTS, EPIDOTE-AMPHIBOLITES AND ALBITE-GNEISSES AS A GUIDE TO THE METAMORPHIC EVOLUTION OF THE PELAGONIAN ZONE, NE THESSALY, GREECE.

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Abstract: Microstructural investigations combined with the chemical composition and type of zoning in the amphiboles of the tectonometarphic units composing the “Pelagonian Zone” (Ambelakia-Makrynitsa Unit, Pelagonian nappe), Central Greece, revealed major differences, reflecting different metamorphic evolution. The amphiboles of the Ambelakia-Makrynitsa Unit record one HP/LT metamorphism (P>8-10 kbar, T~300-350 ^{0}C) while those of the Pelagonian nappe, show, additionally, relic cores of an albite-epidote-amphibolite facies metamorphism (T~ 500±50 ^{0}C, P~10-11 Kbar).

Key words: amphibole composition, Alpine metamorphism, “Pelagonian Zone”

Introduction

Amphibole has been widely recognized as a monitor of polyphase metamorphic evolution due to its compositional sensitivity to changing pressure and temperature. A considerable amount of research effort over the past several decades has gone towards analyzing the compositional variation of amphiboles with grade of metamorphism (eg. Laird, 1982; Hosotani & Banno, 1986; Ernst & Liu, 1998). Several studies have shown that with increasing metamorphic grade, Ca-amphiboles exhibit an increase in Mg/(Mg+Fe) and Ti, Al, Na and K contents and commensurate decrease in Si and total Fe+Mg+Mn+Ca (Ernst & Liu, 1998 and references therein). Al_2O_3 content of amphibole increases as a function of both pressure and temperature. It is well known that Al tends to replace Si in tetrahedral coordination, with increasing temperature, whereas Al substitutes Mg and Fe in M2 octahedral sites with increasing pressure. Na in M4 site is believed to be a measure of the pressure of metamorphism while (Na+K) in the A-sites is thought to reflect the relative temperature of metamorphism.

In this work, we outline the chemical composition of the amphiboles from glaucophane schists, epidote-amphibolites and albite-gneisses of the polymetamorphic “Pelagonian Zone”, East Thessaly area, Central Greece as it proved to be a valuable key in deciphering the metamorphic evolution of the area.

Geological Setting

East Thessaly is, mainly, composed of various tectonometamorphic complexes that belong to the so-called “Pelagonian Zone”, comprising pre-Alpine and Alpine metamorphic rocks that have experienced several tectonometamorphic events. In the lowermost tectonostratigraphic level a weakly metamorphosed sequence of Triassic-Eocene platform carbonates underlying phyllites is exposed as tectonic windows of the Olympus and Ossa Massifs, tectonically overlain by a HP/LT sequence consisting of orthogneisses, clastic metasediments, metavolcanics and marbles, known as the Ambelakia-Makrynitsa Unit (Kilias et al., 1995). It is thought to extend southward into Southern Euboea and Cyclades with higher peak metamorphic conditions in the latter area. The uppermost unit (“Pelagonian nappe”, Kilias et al., 1995) comprises deformed Paleozoic continental basement gneisses (e.g. Kotopouli et al., 2000 and references therein) overlain by a Permo-Triassic metavolcanosedimentary series and Triassic-Jurassic platform metacarbonates, underlying ophiolites, transgressive Upper Cretaceous carbonates and Upper Cretaceous to Eocene flysch. Controversy has surrounded the tectonometamorphic evolution of the Pelagonian Zone. It has been interpreted *either* as a microcontinental fragment between the Vardar ocean to the east and Pindos ocean to the west that rifted away from the northern margin of Godwana in Triassic and has experienced two major alpine tectonometamorphic events, one of Early Cretaceous age related to the closure of Vardar-Axios, characterized by epidote-amphibolite-facies conditions (e.g Yarwood and Dixon, 1977), and one of Eocene age related to the closure of the Pindos-Cyclades ocean, characterized by HP/LT conditions, *or* as a part of the Apulian plate, that has experienced a continuous HP/LT from Late Cretaceous to Eocene (Lips et al., 1999). In both cases, the HP event was followed by a retrograde metamorphism of greenschist facies conditions. Although much of the evidence of the Early Cretaceous metamorphism has been obscured by later blueschist/greenschist facies metamorphism and tectonism, relics of an albite-epidote-amphibolite facies event (T~ 500±50 ^{0}C and P~10-11 Kbar) have been preserved in certain areas.

Petrography

The metamorphic sequence in the “Pelagonian nappe” is dominated by a *Paleozoic crystalline basement,* predominantly, composed of orthogneisses and migmatitic metapelites, a *Permo-Triassic metavolcanosedimentary series* comprising garnet-mica schists/gneisses, albite-epidote amphibolites with the mineral assemblage Amph+Czo+Phen+Bi+Qtz±Grt±Hem (mineral abbreviations after Bucher & Frey, 1994) and *Triassic-Jurassic marbles.* The blueschist *Ambelakia-Makrynitsa Unit* consists of phengite orthogneisses, marbles and metabasites, the last characterized by the mineral assemblage Ab+Phen+Ep+Amph ±Px+Qtz±Ttn±Lws.

In this paper, only the amphiboles of the "Pelagonian nappe" and the Ambelakia-Makrynitsa Unit are described. They show major differences on their chemical composition and type of zoning reflecting different metamorphic evolution.

The most typical zoning of the amphiboles of the "Pelagonian nappe" is that expressed by sodic-calcic or calcic cores surrounded by sodic rims. In *hematite-bearing epidote amphibolites* from Kalamaki area *(Sample 203)* amphiboles are barroisites armored by riebeckite/magnesioriebeckite rims (Plate I,E). Barroisite shows a slight increase in Al/(Al+Si) ratio (from 0.17 to 0.21, Plate I,F) and Aliv (from 1 to 1.3 a.p.f.u. calculated for 23 oxygens), indicating increasing grade of metamorphism. At the outermost rims, a sharp increase in Fe^{3+} and Na/(Na+Ca) ratio and a decrease in Al^{tot}, are attributed to the riebeckite/magnesioriebeckite overgrowth. The change of barroisite to magnesioriebeckite in hematite-bearing metabasites indicates that barroisite formed at P-T conditions of > 450-480 ^{0}C and 8-9 Kbar and riebeckite/magnesioriebeckite overgrew during cooling at relatively high pressures (Otsuki & Banno, 1990).

In *epidote amphibolites (Sample 32a,* Kalamaki area*)* zoned amphiboles are expressed by actinolite cores rimmed by katophorite, overgrown gradually by magnesiohornblende and actinolite (Plate I,C). Al^{iv} (Plate I,D) increases from ~0.5 a.p.f.u. in the core (actinolite) to ~1.5 a.p.f.u. (katophorite), and decreases towards the rim to ~0.9 a.p.f.u (magnesiohornblende) and ~0.4 a.p.f.u. (actinolite). This zoning pattern indicates that, initially, amphibole grew with rising metamorphic grade (actinolite→barroisite). Magnesiohornblende and actinolite formed successively during decompression and cooling.

In *overprinted pre-Alpine basement migmatites (Sample 148,* Sikourion area*),* the amphibole composition varies from actinolite in the core to glaucophane in the rim via edenite/katophorite and winchite/barroisite (Plate I,A), displaying a multi-stage evolution. Aliv (Plate I,B) increases from ~0.3 (actinolite), to ~1.5 (edenite/katophorite), imprinting increasing temperature, and then decreases to values between 0.6 and 0.2 (barroisite/winchite) and 0.18-0.05 (magnesioriebeckite/glaucophane). A gradual increase in Na^{M4} (Plate I,B) indicates amphibole growth with rising pressure. It should be, noted that Sample 148 represents the lowermost tectonostratigraphic levels of the "Pelagonian nappe" in contact with the underlying Ambelakia-Makrynitsa Unit.

As it was mentioned above, the amphiboles of the Ambelakia-Makrynitsa Unit differ from those of the “Pelagonian nappe” in chemical composition and type of zoning. In the amphiboles of the Ambelakia-Makrynitsa Unit, no calcic or sodic-calcic core was observed. Most of the amphiboles are represented by glaucophane compositions. In some cases, riebeckite cores have been preserved (Plate I,G). Increasing Altot and decreasing X_{Fe}^{3+} towards the rim, record increase in the glaucophane component of the sodic amphibole, suggesting rising pressure and temperature. This is, additionally, supported by Hosotani & Banno (1986) who showed that with rising temperature the univariant reaction Chl+Rbk+Qtz+Ab→Gln+Hem+H_2O, in epidote-glaucophane schists, shifts towards to Al-richer composition. An increase in Al/(Al+Si) and Na/(Na+Ca) ratios (Plate I,H) towards the rims within single crystals, indicates amphibole growth with increasing metamorphic grade (Laird, 1982). In some cases, the outermost rims of the amphiboles are expressed by winchite. Sodic-calcic rims on glaucophane crystals are frequently described (eg. Evans, 1990) from high-pressure terranes having undergone isothermal decompression. Matrix actinolite probably formed during further decompression and cooling.

Conclusions & Discussion

A record of the tectonometamorphic evolution of the “Pelagonian Zone” has been preserved in the form of chemical zoning in the amphiboles. On the basis of microstructural criteria combined with the chemical composition and type of zoning in the amphiboles two different tectonometamorphic units can be distinguished: The Ambelakia-Makrynitsa Unit, showing evidence of only one major alpine metamorphic event and the “Pelagonian nappe”, showing evidence of two metamorphic events. The Ambelakia-Makrynitsa Unit contains blue amphiboles (glaucophanes) typical of HP/LT metamorphism, with increasing Al_2O_3 towards the rim recording prograde metamorphism. Preserved riebeckite cores also affirm the prograde change of the amphibole composition, during subduction. The stable coexistence of Gln+Lws limits peak pressures to >8-10 kbars for T~300-350 ^{0}C, indicated by the calculated reaction Gln+Lws→Ab+Czo+Chl+Qtz+H_2O, while Ttn inclusions in Lws imply even higher-pressure conditions (11-14 Kbar), according to the reaction Lws+Tnt→Ru+Qtz+Czo+H_2O. Winchite rims, in some amphiboles, show that at least the first stages of exhumation were followed by isothermal decompression, while matrix actinolite formed during further decompression and cooling.

Unlikely, most of the amphiboles of the “Pelagonian nappe” are characterized by calcic to sodic-calcic cores, showing growth zoning indicative of prograde metamorphism (actinolite→magnesiohornblende/barroisite), surrounded by sodic-calcic and sodic rims mostly expressed by winchite/riebeckite/magnesioriebeckite compositions. The compositional difference between the core and the rim within single grains may be attributed to different stages of burial and exhumation. Barroisite and hornblende rich in Na, overgrown actinolite, being in equilibrium with epidote, albite, phengite and garnet define an albite-epidote-amphibolite facies metamorphism (Evans, 1990) at T~ 500±50 ^{0}C and P~10-11 Kbar (calculated with THERMOCALC 2.75 using analyzed mineral phases in equilibrium), that may be correlated to the Early Cretaceous event. Cooling during exhumation led to winchite/riebeckite overgrowth. The development of the blue amphiboles varies throughout the “Pelagonian nappe”. It is almost absent in the higher tectonostratigraphic levels, while in the lowermost ones, where the “Pelagonian nappe” tectonically overlies the Ambelakia-Makrynitsa Unit, riebeckite and glaucophane formed, recording the type of the Late Cretaceous-Eocene metamorphic event.

References

Bucher K. & Frey M., 1994. Springer-Verlag
Ernst & Liu, 1998. Amer. Mineral., 83, 952-969
Evans B., 1990. Lithos, 25, 3-23
Hosotani H. & Banno S., 1986. J. metamorphic Geol, 4, 23-35
Kilias et al.,1995: XVth Congress of the Carpatho-Balkan Geol. Assoc. , 4/1, 48-51
Kotopouli et al., 2000. Lithos, 50, 137-152
Laird J., 1982. In Reviews in Mineralogy, Mineral. Soc. of America, 9b, 142-146
Lips A., Wijbrans J. & White S., 1999. Geol. Soc. London, Special Publications, 156, 457-474
Otsuki M. & Banno S., 1990. J. metamorphic Geol, 8, 425-439
Yarwood G. & Dixon J., 1977: 6th Colloq. Aegean Region, Athens, 1, 269-280