Study of Geobarometers in Pelitic Schists from The Pütürge Metamorphites

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Abstract. Pelitic schists from The Pütürge metamorphites contain important minerals, such as garnet, biotite, chlorite, kyanite, and staurolite which are used in the determination of degree of metamorphism. Kyanite in metapelites such as staurolite mica schist, staurolite garnet mica schist, biotite schist and amphibole schist. Kyanite is one from Al₂SiO₅ polymorphs (andalusite, sillimanite and kyanite). Kyanite is approximately ten percent more dense than the other two, and hence formation of kyanite is favoured by high pressures. The metamorphic petrology uses pressure-temperature conditions during metamorphic events and fluids in metamorphic environment. The geobarometers were used to estimate metamorphic conditions of pelitic schistes in metamorphites. The study of garnet–aluminum silicate–plagioclase–quartz (GASP) barometry has a long history. Compositions of staurolite and garnet in the assemblage in samples were calculated from temperature and pressure changes. The calculated temperatures could be due to conditions of P_H₂O < P_total during metamorphism. The equilibrium among staurolite, garnet, quartz and aluminum silicate is only approximately located in pressure-temperature space.

1. Introduction

Metamorphic petrology is to estimate the pressure and temperature conditions during metamorphic events. Metamorphical events are based on pressure, temperature, time and fluids. It is minerals that are used for geothermometer/geobarometers. These minerals are garnet, pyroxene, plagioglace and kyanite. In addition, metamorphosed carbonate rocks from the area contain a variety of geothermometers, calcite-dolomite, plagioclase-calcite-zoisite-amphibole. The some minerals in schist use to calculated pressure, temperature conditions.

In this work, we are investigating geo-barometer for metamorphism of pelitic schists in Eastern Turkey. The pelitic schists in the study area contain garnet-biotite, garnet-plagioclase-quartz-alumina silicate, muscovite-quartz-plagioclase-alumina silicate, staurolite-quartz-garnet-aluminium silicate.

2. Geological Features

Pütürge metamorphite is located on the Eastern Taurus Orogenic Belt and it composed of rocks such as staurolite mica schist, kyanite-mica schist, garnet mica schist, granitic gneiss, amphibolite, marble and quartzite [1, 2]. In these rocks, primary minerals were kyanite, staurolite, garnet, quartz, feldspar, biotite, muscovite, chlorite, serosite, apatite and sphene (Figure 1). Furthermore, a Barrovian like prograde sequence is found in pelitic rocks in study area, SHRIMP U-Pb age of 84.2 -1.1 Ma of
zircons was obtained from the metagranitic genesis of which suggests that the magmatism occurred at the Upper Cretaceous Santonian time [3].

3. Analytical Methods
Samples have been taken from all the rocks in the study area and petrographical characteristics and geochemical analyses determination. Thin sections of samples have been prepared in the geology lab of Firat University. Major and trace element analyses is determined by ICP-MS (Inductively Paired Plasma Mass Spectrometry) in ACTLAB (Canada). Approximately 50 samples of pelitic schist were collected. Mineral assemblages were identified by petrography. Compositions of minerals were obtained by the following electron microprobe analyses in ACTLAB (Canada); data were collected with an automated MAC-microprobe.

4. Petrography
The Pütürge metamorphite are classified as gneiss, mica schiste, garnet-staurolite mica schiste, calcschiste, marble and amphibolite. The mineral assemblages suggest that the regional metamorphis is ascribed to in between upper greenschist to amphibolite facies. Transformation of biotite to chlorite suggest the presence of regressive metamorphism, possibly induced by regional nappe and exhumation processes [2].

In mineralogic investigation of rocks shows quartz, plagioclase, mica minerals (biotite, muscovite, chlorite), staurolite kyanite, garnet and andalusite. Kyanite from this mineral forms as small idioblastic to subidioblastic grains. Biotite mineral is usually not disturbed along the kyanite boundaries. Generally, kyanites, quartz, staurolite, kyanite, garnet and ore mineral consists of as inclusions in andalusite porphyroblasts. Staurolite occur as small subidioblastic generally inclusions (Figure 2). In
some slides, staurolite can be seen as irregular grains, or disseminated throughout the rock. Staurolite is also found as relatively large porphyroblasts containing continuous curved trails of quartz inclusions. In thin section of rocks kyanite with garnet at all occur together in the same rock. It develops as tiny idioblastic crystals in the groundmass.

4.1 Mineralogy and Mineral Chemistry
Pelitic schist belong to Pütürge metamorphite contain staurolite, biotite, plagioclase, andalusite, sillimanite, kyanite, garnet, calcite, amphibole, epidote, chlorite. Compositional parameters of garnet, biotite and kyanite in these rocks therefore are summarized in relative completeness in Table 1.

4.2 Geobarometer
The garnet-plagioclase-quartz-aluminum silicate geothermometer records that temperature during metamorphism in the sillimanite and K-feldspar zones was greater than temperature in the staurolite-andalusite and staurolite-cordierite zones in harmony with calculated biotite-garnet temperatures. Pressure during metamorphism was estimated in this study by mineral assemblages. Nineteen samples from pelitic schiste contain the assemblage biotite-garnet-plagioclase-quartz-kyanite. Pressure was calculated from expressions garnet-plagioclase-quartz-kyanite equilibrium between garnet and kyanite in rocks. The temperature recorded by biotite and garnet as calibrated by [4] shows that the composition of the garnet-biotite for the Garnet-biotite geothermometry must be; $X_{Fe}=0.32-0.90$ (generally 0.60-0.80), $X_{Mg}=0.02-0.44$ (0.10-0.20), $X_{Ca}=0.01-0.29$ (0.10-0.20), $X_{Mn}=0.001-0.60$ (0.10-0.20). Garnet-biotite geothermometry was used in order to determine the temperature of the metamorphites and garnet-biotite geothermometry indicated that metamorphites reached the temperature of 628°C. In 628°C temperature can estimated by geobarometer at >10 Kbar pressure approximately in 25 km depth. Such high calculated temperatures could be due to conditions of $P_{H2O} < P_{total}$ during metamorphism [5]. Further calculations, however, demonstrate that if the staurolite-quartz-garnet-kyanite geothermometer recorded temperatures similar to temperatures recorded by $P_{H2O}$ independent geothermometers in the same specimens during the metamorphic event. The equilibrium among staurolite, quartz, garnet and aluminium silicate is only approximately located in pressure-temperature space.

The calculated that distribution coefficient ($K_D$) = 0.21, $\ln K_D = -1.56$ and $K_D < 1$ in the metamorphites indicated barrovan zone pelitic rocks of the regional metamorphism and the metamorphism temperature developed in the garnet zone. Furthermore, Spear [6] diagram and $\ln K_D = -2109/T(K)+0.782$, accordingly metamorphites shows as a 628°C. Metamict zircons in biotites in rocks can already develop in conditions of temperature greater than 600 °C. The small gap between the two age data (81.53 ± 0.10 and 82.18 ± 0.17) obtained from the Sm-Nd geochronology age analysis conducted on the core and the edge of the garnet, gives the impression that the conditions which
caused the metamorphism of the rocks developed rapidly and that this kind of environment can only be accounted for by the tectonic mobility in the exhumation process [4].

Table 1. EPMA analyses data of Garnet, Biotite and Kyanite

| Gr | SiO₂ | TiO₂ | Al₂O | Cr₂O₃ | FeO | MgO | MnO | CaO | Na₂O | Total |
|----|------|------|------|-------|-----|-----|-----|-----|------|-------|
| 1  | 34.4 | 0.10 | 22.96 | 0.08  | 33.9| 2.91| 0.11| 5.58| 0.03 | 100   |
| 2  | 34.6 | 0.06 | 23.19 | -     | 32.8| 3.16| 0.04| 6.08| -    | 100   |
| 3  | 34.7 | 0.02 | 22.61 | 0.01  | 32.9| 3.32| 0.17| 5.79| 0.03 | 99.6  |
| 4  | 36.1 | 0.01 | 22.05 | -     | 32.3| 3.43| 0.04| 5.71| 0.01 | 99.7  |
| 5  | 35.9 | 0.01 | 22.71 | 0.06  | 31.5| 3.53| -   | 6.27| 0.03 | 100   |
| 6  | 35.5 | -    | 23.01 | 0.01  | 31.7| 3.79| 0.11| 6.17| 0.04 | 100   |
| 7  | 36.6 | 0.04 | 22.79 | 0.01  | 30.9| 3.91| 0.10| 5.72| -    | 100   |
| 8  | 36.2 | 0.9  | 22.46 | -     | 31.2| 3.94| 0.16| 5.76| -    | 99.9  |
| 9  | 37.6 | 0.07 | 22.34 | -     | 29.4| 3.98| 0.03| 6.4  | -    | 99.9  |
| 10 | 38.0 | 0.06 | 21.69 | -     | 30.9| 4.33| 0.24| 5.06| -    | 100   |

| Gr | XFe | XMg | XCa | XMn | Si | Al | Mg | Fe | Mn | Ca | Ti |
|----|-----|-----|-----|-----|----|----|----|----|----|----|----|
| 1  | 0.98| 0.05| 0.13| -   | 11.0| 12.1| 1.74| 26.3| 0.08| 3.98| -  |
| 2  | 0.93| 0.05| 0.13| -   | -   | -   | -   | -   | -   | -   | -  |
| 3  | 0.93| 0.07| 0.13| 0.00| -   | -   | -   | -   | -   | -   | -  |
| 4  | 0.92| 0.06| 0.13| 0.00| -   | -   | -   | -   | -   | -   | -  |
| 5  | 0.92| 0.06| 0.14| -   | 16.7| 12.0| 2.11| 24.5| -   | 4.47| -  |
| 6  | 0.91| 0.07| 0.14| 0.00| -   | -   | -   | -   | -   | -   | -  |
| 7  | 0.91| 0.07| 0.13| 0.00| -   | -   | -   | -   | -   | -   | -  |
| 8  | 0.91| 0.07| 0.14| 0.00| -   | -   | -   | -   | -   | -   | -  |
| 9  | 0.90| 0.07| 0.15| -   | -   | -   | -   | -   | -   | -   | -  |
| 10 | 0.90| 0.08| 0.03| 0.00| -   | -   | -   | -   | -   | -   | -  |

| Ky | SiO₂ | TiO₂ | Al₂O | Al₂O³ | Cr₂O₃ | FeO | MgO | MnO | CaO | Na₂O | Total |
|----|------|------|------|-------|-------|-----|-----|-----|-----|------|-------|
| 1  | 49.76| 0.06 | 14.31| 0.02  | 17.28| 13.45| 0.74| 0.09| 2.58| 0.25 | 98.56 |
| 2  | 49.27| 0.12 | 14.14| 0.04  | 19.63| 11.66| 0.65| 0.13| 2.48| 0.27 | 98.38 |
| 3  | 51.96| 0.56 | 14.80| 0.04  | 11.11| 17.08| 0.38| 0.12| 1.98| 0.65 | 98.67 |
| 4  | 46.44| 0.71 | 13.38| 0.06  | 11.06| 21.44| 0.58| 1.12| 4.58| 0.21 | 99.58 |
| 5  | 46.58| 0.69 | 12.82| 0.00  | 10.98| 21.51| 0.12| 1.07| 4.17| 0.49 | 97.89 |
| 6  | 44.93| 0.72 | 13.06| 0.04  | 13.66| 23.14| 0.51| 0.22| 3.16| 0.30 | 99.74 |
| 7  | 46.24| 0.66 | 11.52| 0.00  | 14.40| 22.31| 0.48| 0.07| 3.02| 0.16 | 98.86 |
| 8  | 46.71| 0.72 | 11.33| 0.02  | 19.24| 19.07| 0.22| 0.02| 2.01| 0.19 | 99.53 |
| 9  | 45.34| 0.69 | 11.28| 0.21  | 19.13| 21.03| 0.20| 0.09| 2.15| 0.15 | 100.27|
| 10 | 50.21| 0.65 | 16.05| 0.10  | 8.84 | 28.52| 0.11| 0.05| 2.56| 0.52 | 97.61 |
| 11 | 50.32| 0.08 | 15.36| 0.03  | 16.12| 15.34| 0.42| 0.05| 2.40| 0.24 | 99.37 |
| 12 | 50.05| 0.58 | 15.53| 0.04  | 15.36| 14.47| 0.07| 0.10| 2.37| 0.53 | 99.01 |
| 13 | 48.19| 0.05 | 15.37| 0.02  | 22.44| 9.52 | 0.61| 0.19| 2.19| 0.32 | 98.90 |

5. Results and Discussions
Pütürge metamorphites went through metamorphism right after ophiolite settlement in the region and this event might be prior to Arabia-Eurasia collision and the closure of the southern branch of Neotetis. In addition, it is also highly probable that metamorphism took place first during Upper
Cretaceous-Santonian [2]. It has been determined that a Barrovian type regional metamorphism has been effective in the massive from green schist to upper amphibolite facies. Traces of regressive metamorphism indicate that rocks have been affected from regressive metamorphism during the surfacing of the Pütürge metamorphites as a result of newer events [2]. The exhumation period of these metamorphites make up the regressive metamorphism of these metamorphites [2]. The mineral paragenesis suggests that rocks underwent amphibolite facies metamorphism. Conditions of amphibolite facies are constrained to 600-700°C and 10-11 Kb [7]. The mineral assemblages (kyanite-almandine-muscovite, staurolite-almandine) observed in the metamorphites and the chemical composition of the garnets indicate that the amphibolite facies of the regional metamorphism reached metamorphism conditions.

Using the Kleemann and Reinhardt [8] calibration of garnet-biotite geothermometry and the Koziol and Newton [9] calibration of GASP barometry, temperature estimates for nine analysed samples from pelitic rocks are plotted along with the three univariant reactions of the Al₂SiO₅ triple point. The calculated temperatures for analysed samples are in very good agreement with the andalusite-sillimanite equilibrium determined by Pattison [10] at 10 kbar. Furthermore, the mineral assemblages such as kyanite-almandine-muscovite and staurolite-almandine observed in the metamorphites and metamictization in zircon at >600 °C have already been documented by [2].

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