

Ti-GARNETS FROM THE MIĘDZYRZECZE SILL NEAR BIELSKO-BIAŁA (THE OUTER WESTERN POLISH CARPATHIANS)

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Abstract: Garnets from the picrite sill and pectolite endoskarn from Międzyrzecze were investigated. According to Deer's nomenclature, the garnets studied belong to the andradite-titanian andradite series with predominant schorlomite substitution. Ca-Na metasomatism associated with tectonic deformation was responsible for the development and chemical differentiation of the Ti-garnet.

Key words: glimmerite, andradite, schorlomite, pectolite skarn.

INTRODUCTION

Ti-bearing garnets were found in a strongly altered, olivine glimmerite sill in Międzyrzecze Górne near Bielsko-Biała (Fig. 1). The small, 12 m thick sill was emplaced into the Cieszyn limestones and suffered intensive fracturing and shearing. In exocontact zones (up to 0.3 m in thickness), metamorphic alteration is restricted to recrystallization of limestones into marbles without the development of garnet. There are two main zones in a vertical section through the picritic sill. The *wall effect* played a significant role in producing olivine-free zones, up to 1.5 m thick, of glimmerite composition along both contacts. Progressive chilling of magma at the margins was associated with inward migration of olivine phenocrysts towards the centre of the sill resulting in the development of a central plug of phenocrysts. That part of the Międzyrzecze sill consists of phlogopite (26.0 vol.%), olivine (21.0 vol.%), diopside (20.0 vol.%), spinel (5.3 vol.%), apatite (1.6 vol.%) and perovskite (1.2 vol.%). A pale green chlorite-rich matrix, much of which was originally olivine and phlogopite, forms up to 25.0 vol.% of the rock. This matrix comprises a mixture of chlorite (clinochlor), serpentine (mainly antigorite) and smectite.

During post-magmatic alterations, the chilled margins (up to 0.2 m thick) of the sill were carbonatized. The olivine-free zones show considerable enrichment in elements such as

Na, Ca and P in comparison to the core of the sill. The increased Na, Ca and P in the outer parts of the sill could be the result of the introduction of these elements by hydrothermal fluids emanating from neighbouring sediment. The occurrence of Ti-bearing garnet is restricted to the olivine-free zones of the sill, one of which contains a lenticular body of pectolite endoskarn.

RESULTS AND DISCUSSION

There is a spatial relationship in the olivine-free zones of the Międzyrzecze sill between garnet occurrence and the cooling-fracture system. This mineral is only found within intensively altered blocks of picrite where it is associated with hydrothermal alterations of Fe-Ti spinel, phlogopite and perovskite. A secondary mineral assemblage comprising Ti-bearing garnet, pectolite, analcime, natrolite, fluoroapatite, titanite, diopside and calcite characterises the strongly altered parts of the sill. Secondary fluorapatite with abundant liquid inclusions is a typical mineral in this assemblage.

In the olivine-free zone, the colour of garnet crystals varies from colourless to yellow and brown-black while their morphology changes from euhedral to anhedral. They occur among phlogopite flakes, where garnet crystals of 0.05-0.4 mm diameter may form irregular or small, rounded agglomerations which often enclose black inclusions of unaltered glimmerite. The brown to yellow anhedral garnets (up to 0.6 mm in diameter) poikilitically include numerous crystals of secondary fluoro-apatite or occur as interstitial grains between phlogopite and diopside. Large poikilitic crystals seldom display oscillatory zoning.

The second occurrence of Ti-garnet is associated with the pectolite endoskarn which occurs in the olivine-free zone near the top of the sill. This lenticular body is up to 2 m thick, 5 m wide and 12 m long. It contains abundant carbonate veins (up to 30 cm thick). There is a marked similarity between the mineralogy of the pectolite skarn and the assemblage of secondary minerals in the olivine-free zone of the picrite sill. The skarn consists mainly of elongated (up to 2 mm long and to 0.5 mm wide) pectolite crystals which poikilitically enclose abundant inclusions of Ti-garnet, diopside and analcime. Poikilitic biotite crystals with inclusions of Ti-garnet, in some cases, coexist with minerals such as natrolite, calcite, apatite and titanite. In the pectolite skarn, two types of Ti-bearing garnet can be distinguished:

1. brown-black euhedral crystals (<0.02 mm) forming inclusions in pectolite, biotite and diopside or filling open spaces in veins.

2. larger (up to 0.7 mm across) atoll-shaped garnets showing narrow black-light brown rims completely distinct from cores consisting of spicular aegirine and a cryptocrystalline mixture of natrolite and analcime. These garnets are clearly a metasomatic type of Ti-garnet.

The chemical compositions of the garnets studied are presented in Table 1 and Figure 2. Poikilitic and interstitial grains of garnet from strongly altered picrite exhibit the greatest and most continuous (Figure 2a) variations in TiO₂ content (0.1 to 15 wt.%). Contrasting with the garnet from the picrite, both types of garnet from the pectolite skarn show very restricted ranges in TiO₂ between 12-15 wt.% (Figures 2b and 2c). Additional compositions (indicated by arrows) plotted on these diagrams indicate reaction between previously crystallized garnet and later hydrothermal solutions. Textural and chemical evidence shows that the atoll garnets reflect replacement, mainly by analcime and natrolite, progressing from the garnet interior towards the garnet margins. The garnet compositions plotted on the schorlomite (2R⁴⁺) – andradite (2R³⁺) – morimotoite (R²⁺R⁴⁺) diagram (Figure 3) show that most of them are titanian andradites according to the nomenclature of Deer et al. (1982); only some plot in the morimotoite field.

According to recent findings, e.g., those of Peterson (1995) and Armbruster *et al.* (1998), Ti- andradites can show two different substitution mechanisms in the tetrahedral site:

1. the schorlomite substitution, $Ti^{4+} \rightarrow Si^{4+}$ where Ti^{4+} fills the octahedral site while Fe^{3+} with substantial Fe^{2+} occupies the tetrahedral vacancies ($[6]Ti + [4]Fe^{3+} \leftrightarrow [6]Fe^{3+} + [4]Si$; $[6]Ti_2 + [4]Fe^{2+} \leftrightarrow [6]Fe^{3+}_2 + [4]Si$). These garnets show very limited hydrogarnet substitution $(O_4H_4)^{4-} \leftrightarrow (SiO_4)^{4-}$.

2. the morimotoite substitution, $Fe^{2+} + Ti^{4+} \leftrightarrow 2Fe^{3+}$ in the octahedral site is linked with significant hydrogarnet substitution affecting the tetrahedral site. The data presented above support the conclusion that the schorlomite substitution was the major factor in the formation of Ti-bearing garnet in the Międzyrzecze sill. Intensive Ca-Na metasomatism, associated with tectonic deformation was responsible for the formation of the garnet. The abundance of fluorapatite suggests that fluorine complexing was a major factor in Ti mobility (Baalen 1993).

References

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Table 1. Chemical compositions (wt.%) of Ti-garnet from the Międzyrzecze sill.

Fig. 1. Location map for rocks of the teschenite association in southern Poland and the Czech Republic (from Smulikowski 1930 and Šmíd 1978).

Fig. 2. Ti-garnet compositions plotted in $Ti^{4+}-Fe^{3+}-(Cr^{3+})-Al^{3+}$; a - garnet from strongly altered picrite, b - small (<0.02 mm) euhedral garnet crystals from pectolite skarn, c - atoll-shaped garnet from pectolite skarn.

Fig. 3. Triangular compositional diagram for Ti-garnet from the Międzyrzecze sill.

Table 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| SiO ₂ | 35.69 | 34.99 | 34.50 | 33.41 | 32.81 | 31.16 | 30.69 | 29.79 | 29.76 |
| TiO ₂ | 0.56 | 1.96 | 4.25 | 5.96 | 7.77 | 10.30 | 12.27 | 14.05 | 15.15 |
| ZrO ₂ | 0.03 | 0.29 | 0.01 | 0.15 | 0.28 | 0.15 | 1.09 | 0.24 | 0.19 |
| Al ₂ O ₃ | 1.20 | 1.72 | 1.01 | 0.72 | 0.62 | 0.43 | 0.26 | 0.37 | 0.33 |
| V ₂ O ₃ | 0.39 | 0.19 | 0.49 | 0.49 | 0.28 | 0.38 | 0.74 | 0.35 | 0.33 |
| Cr ₂ O ₃ | 0.05 | 0.05 | 0.18 | 0.13 | 0.10 | 0.11 | 0.12 | 0.06 | 0.05 |
| Fe ₂ O ₃ | 28.65 | 26.28 | 25.91 | 24.44 | 22.81 | 20.27 | 18.70 | 16.68 | 15.69 |
| MgO | 0.25 | 0.68 | 0.90 | 0.99 | 1.06 | 1.11 | 0.64 | 1.23 | 1.38 |
| CaO | 33.24 | 33.22 | 33.16 | 32.98 | 33.07 | 32.62 | 31.73 | 32.80 | 32.56 |
| MnO | 0.04 | 0.18 | 0.06 | 0.11 | 0.16 | 0.08 | 0.29 | 0.04 | 0.14 |
| FeO | 0.00 | 0.00 | 0.15 | 0.64 | 1.08 | 2.66 | 3.52 | 3.69 | 3.81 |
| Na ₂ O | 0.03 | 0.02 | 0.06 | 0.10 | 0.12 | 0.17 | 0.57 | 0.28 | 0.29 |
| Total | 100.14 | 99.58 | 100.69 | 100.13 | 100.16 | 99.44 | 100.62 | 99.58 | 99.70 |
| Si | 5.978 | 5.873 | 5.736 | 5.604 | 5.505 | 5.295 | 5.180 | 5.060 | 5.038 |
| Ti | 0.070 | 0.248 | 0.531 | 0.752 | 0.981 | 1.316 | 1.557 | 1.794 | 1.929 |
| Zr | 0.003 | 0.024 | 0.001 | 0.012 | 0.023 | 0.013 | 0.090 | 0.020 | 0.015 |
| Al | 0.237 | 0.34 | 0.198 | 0.143 | 0.122 | 0.086 | 0.051 | 0.074 | 0.067 |
| V | 0.053 | 0.026 | 0.066 | 0.065 | 0.037 | 0.052 | 0.100 | 0.048 | 0.045 |
| Cr | 0.006 | 0.007 | 0.024 | 0.018 | 0.013 | 0.014 | 0.016 | 0.009 | 0.007 |
| Fe ^{3+#} | 3.611 | 3.319 | 3.241 | 3.085 | 2.880 | 2.592 | 2.375 | 2.132 | 1.999 |
| Mg | 0.062 | 0.171 | 0.224 | 0.248 | 0.265 | 0.281 | 0.161 | 0.310 | 0.349 |
| Ca | 5.966 | 5.974 | 5.907 | 5.927 | 5.945 | 5.938 | 5.739 | 5.970 | 5.904 |
| Mn | 0.006 | 0.026 | 0.008 | 0.015 | 0.023 | 0.012 | 0.041 | 0.006 | 0.020 |
| Fe ²⁺ | 0.000 | 0.000 | 0.020 | 0.089 | 0.151 | 0.379 | 0.497 | 0.524 | 0.539 |
| Na | 0.010 | 0.005 | 0.021 | 0.031 | 0.040 | 0.056 | 0.187 | 0.092 | 0.094 |
| | 16.002 | 16.013 | 15.977 | 15.989 | 15.985 | 16.034 | 15.997 | 16.039 | 16.006 |

Amount of Fe³⁺ was estimated by assuming that 16 cations are balanced by 24 oxygens

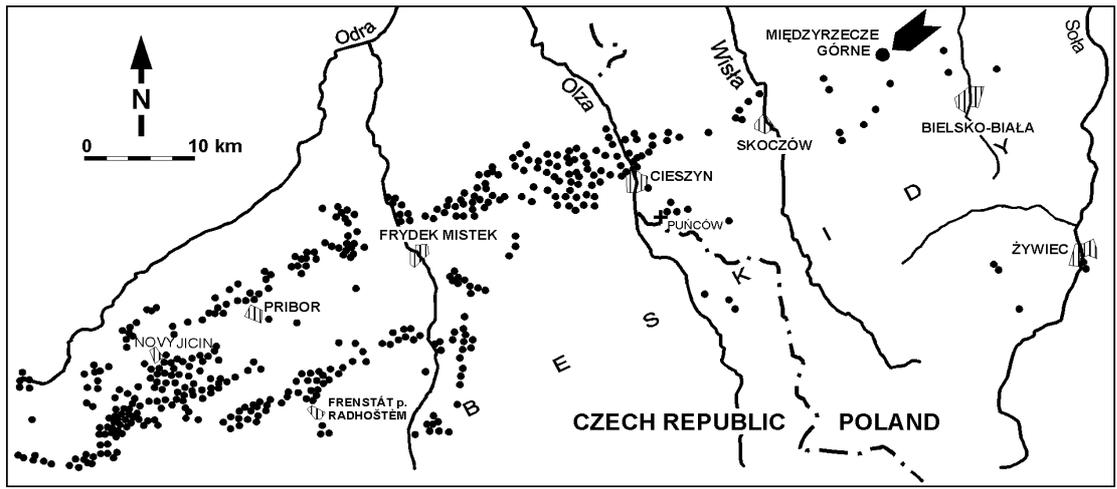


Fig. 1.

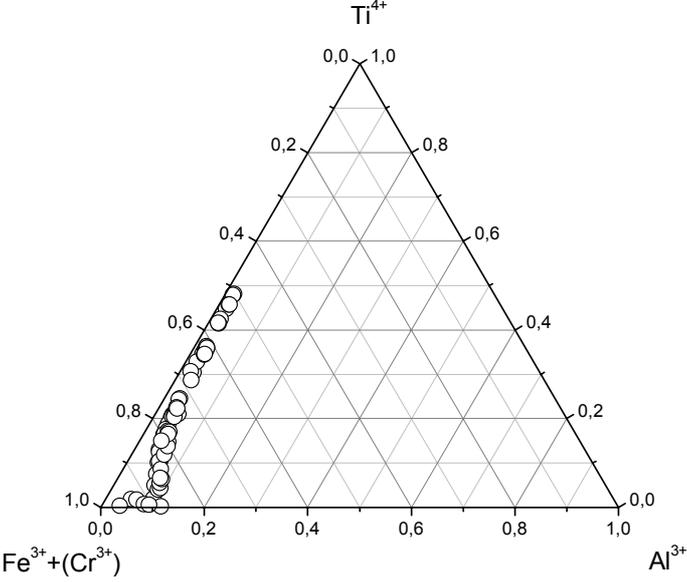


Fig. 2a

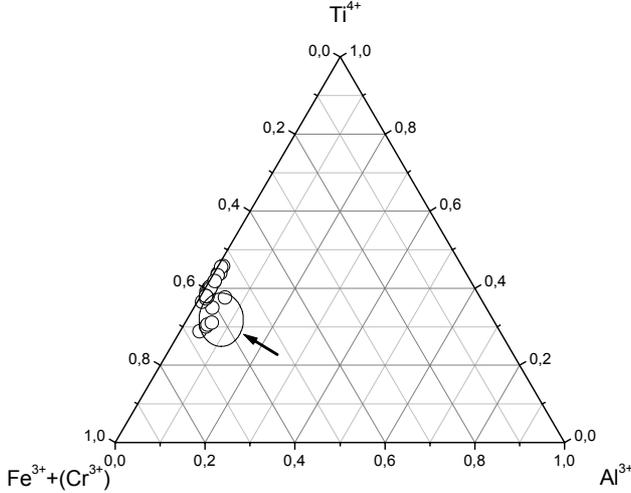


Fig. 2b

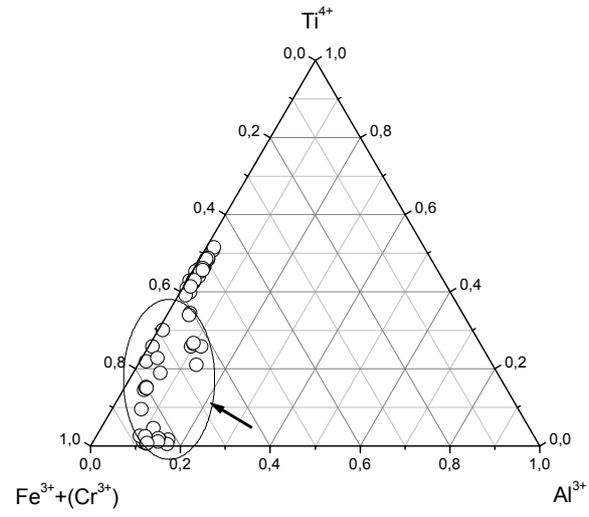


Fig. 2c

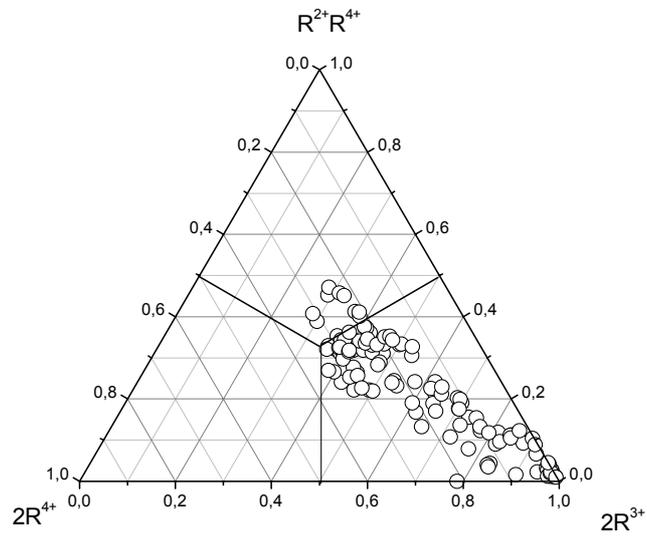


Fig. 3