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METAMORPHIC EVOLUTION OF THE AMPHIBOLITES FROM THE POLISH PART OF STARE MĚSTO ZONE (SUDETES, SW POLAND)

Abstract. The Stare Město Zone is the lowermost part of Lugicum, marking out the main boundary between the East and West Sudetes. Small part of the unit is exposed in Poland, in the vicinity of Bielice village. This area consists mainly of banded amphibolites, intruded by syntectonic granitoids. The banded amphibolites are medium — to coarse grained. Main constituents are segregated into alternating, light — plagioclase rich, and dark — amphibole rich layers. Quartz and K-feldpars are subordinates. Accessories are: zircon, apatite, titanite, and locally garnet, biotite; secondary minerals are: chlorite and prehnite. Banded amphibolites underwent progressive M_1 amphibolite facies metamorphism, with PT peak conditions at 650–720°C and 8.0–9.5 kbar. This was followed by M_2 and M_3 regressive metamorphism, accompanied by rapid uplift, regional mylonitization and metamorphism under the greenschists and sub-greenschsits facies conditions.

Key-words: Stare Město Zone, banded amphibolites, metamorphic evolution

INTRODUCTION

The Stare Město Zone is situated in the eastern part of the Orlica-Śnieżnik Dome (Sudetic part of the Bohemian Massif), immediately to the west of the Ramzova thrust. The latter separates East (Moravo-Silesicum) and West (Lugicum) parts of the Sudetes. The Stare Město Zone is located mostly in Czech Republic (Fig. 1), its small part belongs to Poland (Fig. 2).

The Stare Město Zone consists of, tectonically separated, NE-SW trending zones of different lithology. From the west to the east these are: (1) mica schists and metavolcanites of the Hranična Unit, (2) leptyno-amphibolite complex, composed mainly of banded amphibolites, mylonitic gabbros with intercalations of gneisses, quartzites and calc-silicate rocks (Skácel 1979, Štipská et al. 1995, Parry et al. 1997, Štipská et al. 1998) with spinel peridotites at the base (Fig. 3). The latter mark supposedly the boundary

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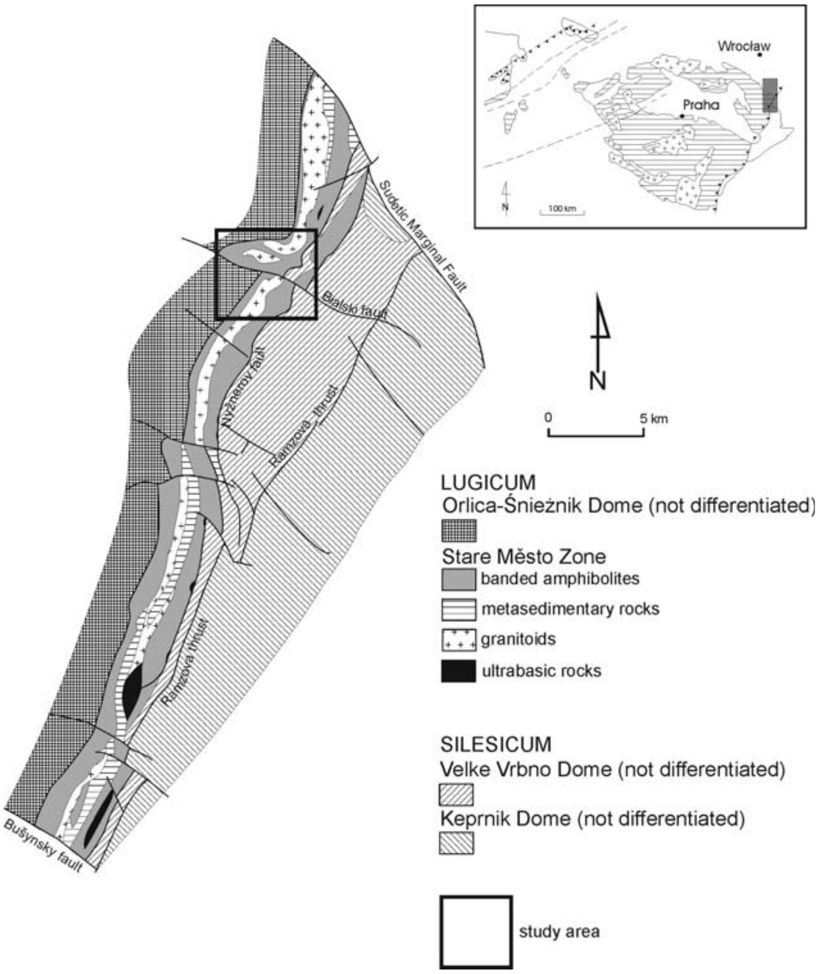

Fig. 1. Geological sketch map of Stare Město Zone and adjacent areas (after Štipska et al. 1998, simplified)

between the West and East Sudetes (Parry et al. 1997). The leptyno-amphibolite complex was intruded by Variscan granitoids, dated at 339±7 Ma (Parry et al. 1997).

Floyd et al. (1996) considered the amphibolites to be metamorphosed, low-Ti or main series tholeiites with MORB or IAB affinities, contaminated by upper continental crust and/or pelagic sediments. Wichrowski (1973a, b), and Narębski and Wichrowski (1979) suggested sedimentary protolith of amphibolites.

Parry et al. (1997) distinguished three tectono-metamorphic events, which affected the Stare Město Zone. The first one (D_1) occurred during Cambro-Ordovician rifting of continental crust, under the conditions corresponding to those of granulite low-pressure facies. It was followed by Variscan metamorphism under the conditions of amphibolite facies (D_2) and greenschists facies (D_3). D_2 and D_3 events were accompanied by strong mylonitic deformation (Parry et al. 1997).

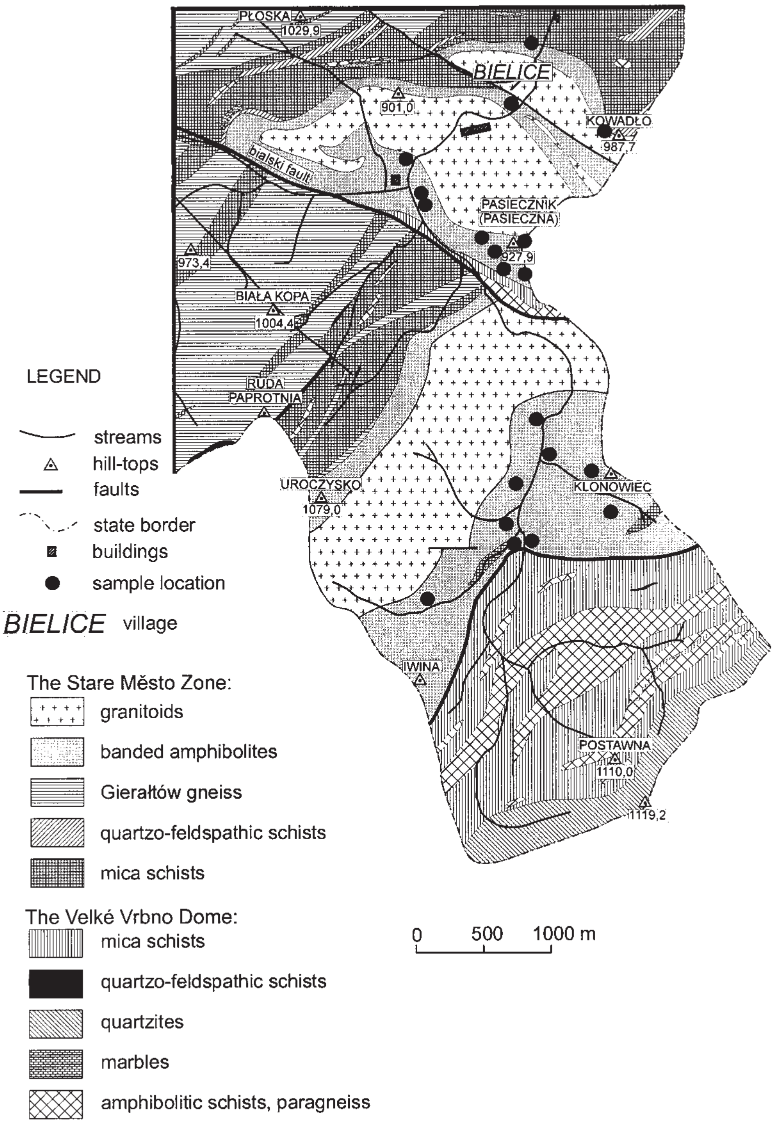

Fig. 2. Geological sketch map of the Polish part of the Stare Město Zone with adjacent areas.
Based on geological maps: Nowa Morawa (L. Kasza 1958),
Strachocin-Bielice (Z. Cymerman, S. Cwojdziński 1984); simplified

PETROGRAPHY AND MINERAL CHEMISTRY

The amphibolites of Polish part of the Stare Město Zone are medium-grained. The coarse-grained varieties, significantly enriched in amphibole, form layers up to several centimetres within the medium-grained ones.

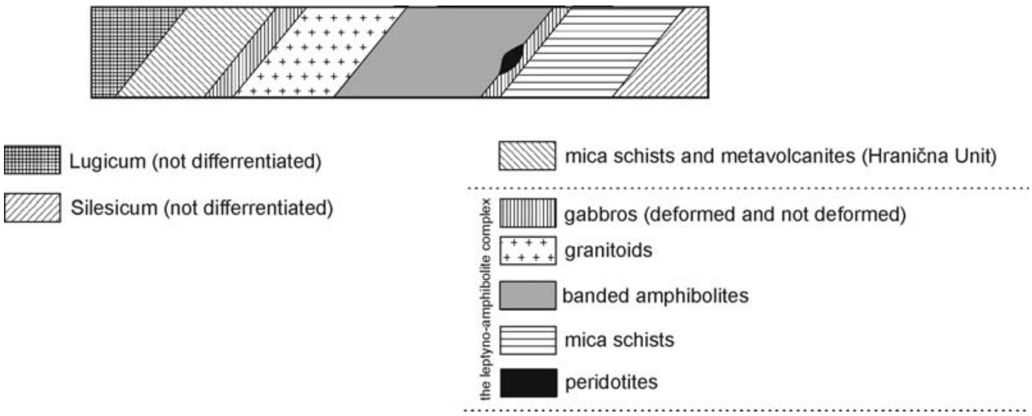

Fig. 3. Schematic cross-section through the Stare Město Zone (after Parry et. al. 1997)

The amphibolites are composed of alternating dark, amphibole dominated layers and light, leucocratic ones (Phot. 1). Locally, the light material occurs in irregular patches and nests disrupting layering. The banding of amphibolites is strongly variable. The banded amphibolites as well as the uncommon homogenous ones (Phot. 2), with entire spectrum of transitional types occur. The foliation is defined by the banding and parallel arrangement of amphibole prisms. It dips under moderate angles in directions changing from NW to E.

The amphibolites from the Polish part of the Stare Město Zone are mylonitized to a different degree. Sharply contacting zones of different strain and thickness up to tens of centimetres are present. Strongly mylonitized amphibolites display well developed S-C fabric and grain-size reduction (Phot. 3). Kinematic indicators (asymmetric pressure shadows, porphyroclast's tails) document non-coaxial character of deformation, indicating a top-to-NE sense of shear. Amphibole, biotite and feldspars are partly replaced by chlorite and prehnite, respectively. Strongly mylonitized amphibolites contain sericitized feldspars (Phot. 3.).

The banded amphibolites show high variation in chemical composition*. The most common are quartz normative tholeiites compositions (*sensu* Yoder and Tilley 1962), whereas olivine tholeiites and alkali-basalts are subordinate (Table 1). Both alkali--basalts and olivine tholeiites compositions occur only in the vicinity of the granitoids/amphibolite contact zone (*c.f.* Table 1, Fig. 2).

Amphibole and plagioclase, quartz and locally K-feldspar occur within the amphibolites. Accessories are zircon, apatite, titanite, and locally garnet plus biotite.

The amphibole layers (thickness 0.5–1.5 cm) are composed of pale to olive-green amphibole prisms and less abundant, subhedral plagioclase. Amphibole tends to form elongated aggregates, up to several mm in thickness. Anhedral quartz and K-feldspar occur subordinately among the amphibole aggregates.

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* Analyses were done by wet method at the laboratory of the Institute of Geological Sciences, University of Wrocław, Poland.

Amphibole has the composition** of tschermakite or hornblende (Leake et. al. 1997; Fig. 4, Table 2). Insignificant part of grains are zoned. Part of them have cores impoverished in Si and enriched Al (Fig. 4A, B), others have cores impoverished in Al and

TABLE 1

Representative analyses and CIPW norms of banded amphibolites from the Polish part of the Stare Město Zone

Component	W1503	W1508	W1577
SiO_2	52.26	49.72	56.87
TiO_2	0.85	0.80	0.75
Al_2O_3	15.78	14.08	15.56
Fe_2O_3	2.51	2.86	3.35
FeO	7.52	8.34	5.74
MnO	0.20	0.20	0.11
MgO	5.70	8.94	5.17
CaO	7.48	9.33	6.89
Na_2O	6.27	3.28	3.23
K_2O	0.78	0.63	0.86
P_2O_5	0.04	0.06	0.06
LOI	0.81	1.30	1.52
Total	100.20	99.54	100.11
Q	—	—	11.39
Or	4.64	3.79	5.16
Ab	37.65	28.22	27.69
An	12.67	22.20	25.75
Ne	8.49	—	—
Di	20.00	19.89	6.92
Hy	—	5.98	16.58
Ol	11.17	14.02	—
Mt	3.66	4.22	4.93
Il	1.62	1.55	1.45
Ap	0.09	0.13	0.13

W1503, W1508 — medium-grained amphibolites from the vicinity of granitoides/amphibolite contact zone (the slope of Pasieczna),

W1577 — medium-grained amphibolite from the top of Klonowiec.

** Analyses of minerals were done at microprobe laboratories of the University of Wrocław, the University of Hannover (Germany) and the University of Bochum (Germany).

TABLE 2

Representative chemical analyses of amphiboles (13-CNK) from banded amphibolites of the Polish part of the Stare Město Zone

Compo-nent	1	2	3	4	5	6	7	8	9	10	11
	core	→	rim	core	rim	core	rim	core	rim	core	rim
SiO_2	45.34	44.56	45.08	46.06	44.57	43.73	42.45	43.74	47.20	42.81	43.92
TiO_2	1.35	1.65	1.45	0.71	0.68	1.09	0.75	1.49	0.41	1.09	1.00
Al_2O_3	9.83	10.61	9.84	10.07	10.70	11.95	13.27	9.22	6.50	12.08	11.36
Fe_2O_3 a)	7.64	8.54	8.47	7.65	5.20	5.77	5.02	10.00	8.82	7.10	6.26
FeO a)	8.68	7.65	7.45	7.73	11.51	12.09	12.94	11.37	11.48	10.91	10.94
MnO	0.40	0.39	0.30	0.44	0.38	0.27	0.23	0.42	0.40	0.33	0.26
MgO	11.77	11.84	11.94	12.21	11.12	9.99	9.25	9.43	10.79	10.11	10.59
CaO	10.72	10.52	10.45	10.77	11.92	11.46	11.64	10.41	11.02	11.34	11.51
Na_2O	1.73	1.91	1.52	1.56	1.45	1.63	1.62	1.73	1.01	1.67	1.40
K_2O	0.22	0.26	0.29	0.31	0.43	0.37	0.52	0.28	0.18	0.41	0.36
H_2O a)	2.05	2.05	2.04	2.06	2.03	2.03	2.01	2.01	2.02	2.02	2.03
Total	99.73	99.99	98.83	99.57	99.98	100.39	99.70	100.11	99.84	99.87	99.03
Si^{4+}	6.64	6.50	6.63	6.71	6.57	6.44	6.33	6.52	6.99	6.35	6.49
Ti^{4+}	0.15	0.18	0.16	0.08	0.07	0.12	0.08	0.17	0.05	0.12	0.11
Al^{3+}	1.70	1.82	1.71	1.73	1.86	2.08	2.33	1.62	1.13	2.11	1.98
Fe^{3+} a)	0.84	0.94	0.94	0.84	0.58	0.64	0.56	1.12	0.98	0.79	0.70
Fe^{2+} a)	1.06	0.93	0.92	0.94	1.42	1.49	1.61	1.42	1.42	1.35	1.35
Mn^{2+}	0.05	0.05	0.04	0.05	0.05	0.03	0.03	0.05	0.05	0.04	0.03
Mg^{2+}	2.57	2.57	2.62	2.65	2.45	2.20	2.05	2.10	2.38	2.23	2.33
Ca^{2+}	1.68	1.64	1.65	1.68	1.88	1.81	1.86	1.66	1.75	1.80	1.82
Na^{+}	0.49	0.54	0.43	0.44	0.42	0.47	0.47	0.50	0.29	0.48	0.40
K^{+}	0.04	0.05	0.05	0.06	0.08	0.07	0.10	0.05	0.03	0.08	0.07
Total	15.21	15.23	15.13	15.18	15.38	15.34	15.43	15.22	15.07	15.36	15.29
mf b)	0.71	0.73	0.74	0.74	0.63	0.60	0.56	0.60	0.63	0.62	0.63

a) Calculated by stoichiometry according to 13-CNK method,
b) mf = Mg/(Mg + Fe^{2+}).
Analyses 1, 2, 3 — large amphibole grain from dark layer,
analyses 4, 5 and 8, 9 — small amphibole grains from dark layer,
analyses 6, 7 and 10, 11 — small amphibole grains from light layer.

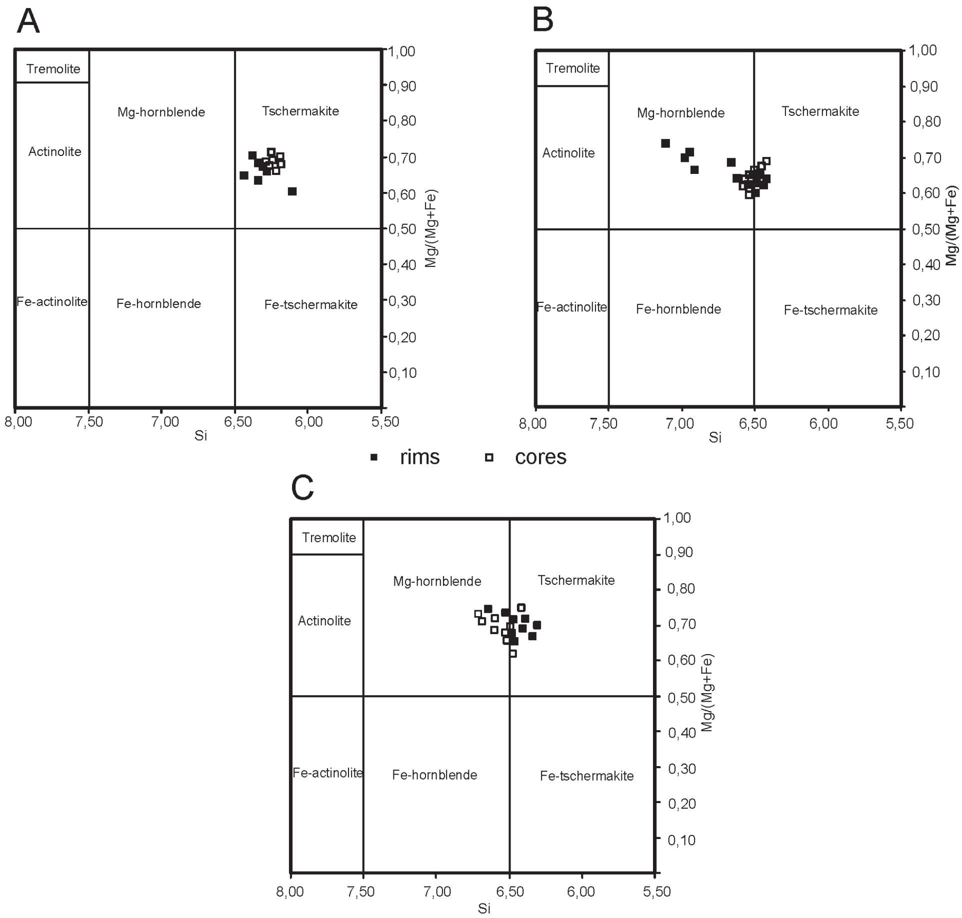

Fig. 4. The position of amphiboles from amphibolites of the Polish part of the Stare Město Zone on diagram of Leake et al. (1997).
A — zoned tschermakite grains; B, C — zoned tschermakite / Mg-hornblende grains

enriched in Si relative to the rims (Fig. 4C, Table 2). Very sparse large grains, displaying initial silica content decrease followed by its increase towards rims are present as well (Table 2). Zoned amphiboles are unevenly distributed within the banded amphibolites, however all kinds occur within the single hand-specimen.

Plagioclase has the composition of oligoclase and andesine. It is normally zoned (from cores to rims, respectively: 42% ⇒38% An, 40 ⇒34% An; Table 3, Fig. 5), reversely zoned (from cores to rims, respectively: 35⇒41% An, 17⇒23%, 28⇒32 An; Table 3, Fig. 5) or is homogenous. Homogenous albite (7–8% of An, Table 3, Fig. 5) grains occur in the amphibolites situated in the nearest neighbourhood of granitoids. Andesine grains exhibiting reverse zoning in the inner part, followed by normal zoning in the outer parts are very scarce (Table 3). All kinds of plagioclase grains occur together with no evidence for preferred distribution.

TABLE 3

Representative chemical analyses of feldspars ($O^{2-} = 8$) from banded amphibolites of the Polish part of the Stare Město Zone

Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			core	rim	core	rim	core	rim	core	rim	core	rim	core	→	rim
SiO_2	64.54	68.47	60.33	58.23	63.17	62.34	61.73	61.35	58.37	60.23	57.36	58.56	60.23	56.60	59.52
Al_2O_3	20.80	20.23	25.78	26.87	22.79	23.42	24.50	24.83	26.68	25.18	26.69	26.52	25.18	27.53	25.88
Fe_2O_3	0.16	0.00	0.10	0.18	0.10	0.22	0.14	0.27	0.14	0.29	0.13	0.31	0.29	0.11	0.29
CaO	1.91	0.75	7.39	8.75	3.53	4.87	6.02	6.51	8.33	7.15	8.87	8.17	7.15	9.57	7.64
Na_2O	7.39	11.25	7.59	6.92	9.29	8.73	8.42	8.06	6.71	7.62	6.61	7.27	7.62	6.4	7.46
K_2O	4.22	0.09	0.04	0.04	0.32	0.09	0.09	0.10	0.10	0.07	0.12	0.08	0.07	0.10	0.07
Total	99.02	100.80	101.23	100.99	99.20	99.67	100.09	101.12	100.33	100.55	99.79	100.91	100.55	100.31	100.85
Si^{4+}	2.90	2.97	2.66	2.58	2.81	2.77	2.72	2.70	2.60	2.67	2.58	2.60	2.67	2.54	2.64
Al^{3+}	1.10	1.03	1.34	1.41	1.20	1.23	1.27	1.29	1.40	1.32	1.41	1.39	1.32	1.45	1.35
Fe^{3+}	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.01
Ca^{2+}	0.09	0.03	0.35	0.42	0.17	0.23	0.28	0.31	0.40	0.34	0.43	0.39	0.34	0.46	0.36
Na^+	0.64	0.95	0.65	0.60	0.80	0.75	0.72	0.69	0.58	0.66	0.58	0.63	0.66	0.56	0.64
K^+	0.24	0.01	0.00	0.00	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00
Total	4.99	4.99	5.00	5.01	5.00	4.99	5.00	5.00	4.99	5.00	5.00	5.02	5.00	5.02	5.01
Or	25	1	0	0	2	1	0	1	1	0	1	0	0	1	0
Ab	66	96	65	59	81	76	71	68	59	66	57	62	66	54	64
An	9	4	35	41	17	23	28	32	40	34	42	38	34	45	36

Total Fe as Fe_2O_3.
Analysis 1 — center of K-feldspar grain from light layer,
analysis 2 — center of albite grain from dark layer,
analyses 3–4 and 7–8 — central and marginal part of two plagioclase grains from light layer,
analyses 5–6; 9–10 and 11–12 — central and marginal part of three plagioclase grains from dark layer,
analyses 13–15–15 — from central to marginal part of large plagioclase grain from dark layer.

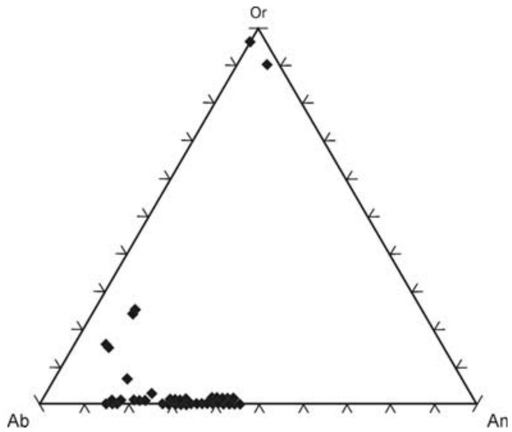

Fig. 5. Chemical composition of feldspars from amphibolites from the Polish part of the Stare Město Zone on the Ab-An-Or diagram

TABLE 4

Representative chemical compositions of opaques from amphibolites from the Polish part of the Stare Město Zone

Component	1	2	3	4	5	6	7	8	9
SiO_2	—	—	—	—	—	—	3.39	2.92	0.05
TiO_2	49.28	48.39	45.40	50.86	50.30	51.16	0.02	0.02	0.00
Al_2O_3	—	—	—	—	—	—	0.03	0.21	0.19
FeO	42.87	46.61	46.42	47.54	47.75	44.35	81.01	82.05	81.26
MnO	4.14	1.73	1.39	3.07	0.58	2.96	0.07	0.14	0.00
MgO	0.01	0.03	0.11	0.04	0.12	0.02	0.47	0.44	0.06
CaO	—	—	—	—	—	—	0.20	0.23	0.04
Na_2O	—	—	—	—	—	—	0.08	0.02	0.05
K_2O	—	—	—	—	—	—	0.03	0.02	0.01
Total	96.30	96.72	93.21	101.47	98.63	98.48	85.29	86.06	81.65
Ti^{4+}	0.97	0.95	0.92	0.95	0.96	0.99	—	—	—
Fe^{2+}	0.88	0.91	0.88	0.88	0.95	0.92	—	—	—
Fe^{3+}	0.06	0.11	0.16	0.10	0.07	0.03	—	—	—
Mn^{2+}	0.09	0.04	0.03	0.06	0.01	0.06	—	—	—
Mg^{2+}	0.00	0.00	0.00	0.00	0.00	0.00	—	—	—
Total	2.00	2.00	2.00	2.00	2.00	2.00	—	—	—

Total Fe as FeO, Fe^{3+} were calculated according to Stormer (1983).
Analyses 1, 2 — euhedral ilmenite from amphibole-rich layer,
analysis 3 — subhedral ilmenite from amphibole-rich layer,
analyses 4, 5, 6 — anhedral ilmenite from ilmenite-iron hydroxide layer,
analyses 7, 8 — anhedral iron hydroxide from amphibole-rich layer,
analysis 9 — anhedral iron hydroxide from ilmenite-iron hydroxide layer.

The light layers of thickness 0.4–1.0 mm are composed mainly of subhedral plagioclase and anhedral quartz grains. K-feldspars and amphibole are sparse. Chemical composition of these minerals is the same as in the dark layers.

Euhedral or subhedral ilmenite and anhedral iron hydroxides (Table 4) form individual accumulations. Ilmenite contains 88–95 mol.% of $FeTiO_3$ and up to 9 mol.% of pyrophanite ($MnTiO_3$). The content of hematite varies from 2 to 9 mol.%. Iron hydroxides contain 62–63 wt.% of Fe. Both ilmenite and iron hydroxides concentrate within the amphibole rich layers and are located in interstices among other rock-forming minerals. Occasionally anhedral ilmenite and iron hydroxides accumulate, forming thin (up to 0.05 mm), discontinuous layers parallel to the layering (Table 4). Locally ilmenite occurs as small intergrowths in amphiboles.

Apatite, titanite and zircon occur as individual subhedral or euhedral short prisms (up to 0.05 mm long) in both the dark and light layers. Locally, accessories form elongated monomineral aggregates, parallel to the layering. Garnet was found in two exposures only (Pasieczna mountain and Bielice village). It is weakly zoned from $Alm_{67}Spe_{7}Py_{17}Gr_{9}$ in cores to $Alm_{66}Spe_{5}Py_{20}Gr_{9}$ in rims (Bielice vicinity) or from $Alm_{61}Spe_{4}Py_{16}Gr_{19}$ to $Alm_{63}Spe_{4}Py_{17}Gr_{16}$ (Pasieczna, Fig. 6, Table 5). Smaller grains (0.2–2.0 mm) occur within the light layers, greater ones (1.0–0.5 mm) occur within the dark layers. Greater garnet grains contain numerous inclusions of amphibole, feldspar, quartz, opaques, biotite.

Biotite occurs only in paragenesis with garnet, as intergrowth or asymmetric pressure shadows. It contains elongated accumulations of opaque oriented parallel to its cleavage and displays pale-brown pleochroism suggesting its decomposition. Low

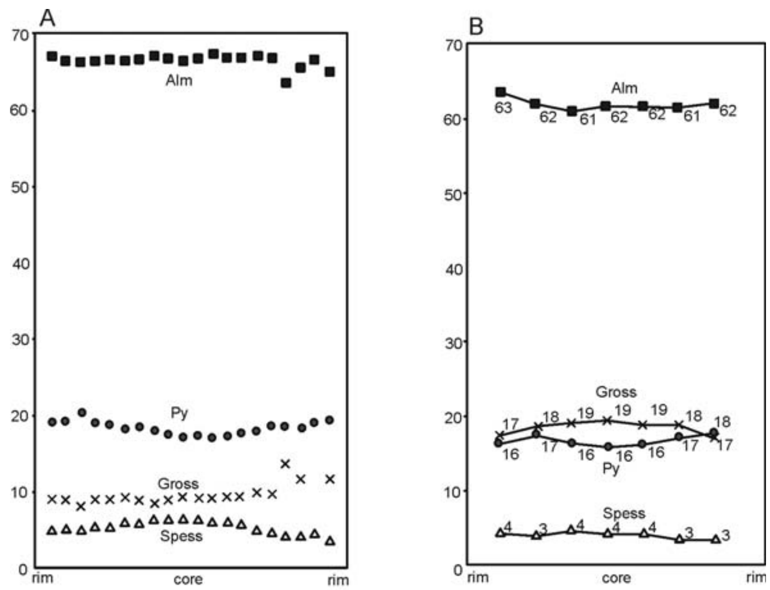

Fig. 6. Zonation of garnet from the amphibolites cropping out in the Bielice vicinity (A) and Pasieczna (B)

TABLE 5

Representative chemical analyses and structural formulae (O^{2-} = 12) of garnets from amphibolites of the Polish part of the Stare Město Zone

Component	1	2	3	4	5	6	7	8	9
	rim	→	→	core	rim	→	→	→	core
SiO_2	37.27	37.46	37.43	37.52	38.20	38.21	38.85	38.09	38.62
TiO_2	0.08	0.04	0.06	0.08	0.17	0.09	0.21	0.05	0.00
Al_2O_3	21.46	21.49	21.68	21.17	21.74	21.74	21.78	21.56	21.78
FeO	30.50	30.83	30.88	30.96	29.32	29.03	28.91	28.15	28.24
MnO	2.38	2.54	2.96	3.07	1.70	1.55	1.74	1.80	1.44
MgO	4.95	4.99	4.66	4.60	4.16	4.56	4.12	4.10	4.36
CaO	3.27	3.24	3.08	3.26	6.08	6.56	6.99	6.61	6.63
Total	99.91	100.59	100.76	100.65	101.37	101.75	102.58	100.36	101.07
Si^{+4}	2.96	2.96	2.96	2.97	2.98	2.97	2.99	2.99	3.01
Ti^{+4}	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00
Al^{+3}	2.01	2.00	2.02	1.98	2.00	1.99	1.98	2.00	2.00
Fe^{+2}	2.03	2.04	2.04	2.05	1.91	1.89	1.86	1.85	1.84
Mn^{+2}	0.16	0.17	0.20	0.21	0.11	0.10	0.11	0.12	0.10
Mg^{+2}	0.59	0.59	0.55	0.54	0.48	0.53	0.47	0.48	0.51
Ca^{+2}	0.28	0.27	0.26	0.28	0.51	0.55	0.58	0.56	0.55
Total	8.03	8.04	8.03	8.03	8.01	8.03	8.01	8.00	8.00
Py	20	19	18	17	16	17	16	16	16
Alm	66	66	67	67	63	62	62	62	61
Spess	5	6	6	7	4	3	4	4	4
Gross	9	9	9	9	17	18	19	19	19

Total Fe as FeO.
Analyses 1, 2, 3, 4 — large garnet from dark layer (amphibolite from Bielice vicinity),
analyses 5, 6, 7, 8, 9 — large garnet from dark layer (amphibolite from Pasieczna).

content of potassium and low totals suggest that it consists of chlorite/biotite intergrowth (Table 6).

Pale-green or pale-brown chlorite contains 55–66 mol.% of clinochlore (Bailey 1980, Table 6). It replaces amphibole crystals or its radial aggregates fill the fissures in the amphibolites.

Prehnite commonly fills fissures, or replaces feldspars within zones of several millimetres in thickness. These zones contact sharply with the surrounding rock, where prehnite is missing.

TABLE 6

Representative chemical analysis and structural formulae (O^{2-} = 28) of chlorite and decomposed biotite from banded amphibolites of the Polish part of the Stare Město Zone

Component	1	2	3	4	5
SiO_2	27.31	25.20	25.91	32.83	28.08
TiO_2	0.02	0.03	0.04	1.53	0.65
Al_2O_3	20.34	18.62	19.34	16.58	17.17
FeO	17.33	24.72	23.29	26.04	29.66
MnO	0.52	0.65	1.20	0.16	0.19
MgO	19.68	17.38	18.16	9.19	11.44
CaO	—	—	—	0.18	0.09
Na_2O	—	—	—	0.20	0.03
K_2O	—	—	—	6.22	1.23
Total	85.20	86.60	87.94	92.93	88.54
Si^{+4}	5.67	5.41	5.43	—	—
Ti^{+4}	0.00	0.00	0.01	—	—
Al^{+3}	4.98	4.71	4.78	—	—
Fe^{+2}	3.01	4.44	4.08	—	—
Mn^{+2}	0.09	0.12	0.21	—	—
Mg^{+2}	6.09	5.56	5.67	—	—
Total	19.84	20.23	20.18	—	—
Clinochlore mol. %	66	55	57	—	—

Total Fe as FeO.
Analyses 1, 2 — chlorite plates replacing amphibole,
analysis 3 — chlorite plate from fissure,
analyses 4, 5 — strongly decomposed biotite plates.

GEOTHERMOBAROMETRY AND PETROLOGICAL SIGNIFICANCE OF MINERAL'S CHEMICAL COMPOSITION

The plagioclase grains occurring in amphibolites are (1) reversely, (2) normally and (3) complexly — reversely/normally zoned. Those reversely zoned as well as the reversely zoned central parts of the complex grains record the progression of metamorphism. The normally zoned ones as well as the normally zoned outer parts of the complex grains record regression of metamorphism.

Amphibole exhibits (1) silica content decrease, (2) silica content increase or (3) initial silica content decrease followed by its increase towards rims. The latter record progression of metamorphism followed by it's regression, whereas amphibole displaying silica content decrease or increase crystallized during progression or regression of metamorphism, respectively.

These observations indicate that the amphibolites were subjected first to the progressive metamorphism, which was followed by retrogression. Only small part of grains record both progression and retrogression, whereas most of them record only one of these processes.

Occurrence of oligoclase suggests that the progressive metamorphism changed conditions from those characteristic of epidote-amphibolite facies to those characteristic of amphibolite facies. Oligoclase is formed under epidote-amphibolite facies conditions before epidote breaks down. In consequence, significant amounts of calcium are bounded in epidote during plagioclase crystallization, leading to low-calcic plagioclase compositions. This effect does not occur during the progression from greenschist to amphibolite facies, leading to formation of more calcic plagioclase (Spear 1993). Since the assemblage of epidote-amphibolite facies requires minimum 4 kbar pressure to be formed (*op. cit.*), this is the lower pressure limit of progressive path of the P-T metamorphic path. The presence of numerous ilmenite grains and lack of rutile indicates that pressure did not exceed 12 kbar (Ernst, Liou 1998).

Almandine dominated garnets from amphibolites suggest their crystallization during medium PT conditions (Spear 1993). The increase of pyrope and almandine content towards rims implies the garnet crystallized during the increase of metamorphic grade. The garnet-amphibole thermometer (Graham, Powell 1984) yields temperatures ranging between 615–670°C

Points representing amphiboles from the Polish part of the Stare Město Zone cluster within the area of Dalradian terrane on the diagram of Laird and Albee (1981, Fig. 7), therefore suggesting that amphibolites were subjected to medium pressure metamorphism.

Since the studied amphibolites are of tholeiitic composition the semi-quantitative geothermobarometer of Ernst and Liou (1998) can be used. It suggests that the amphibole's cores crystallized under temperatures of 750–800°C and pressures 7–11 kbar (Fig. 8), whereas their rims under slightly lower temperatures ranging from 800 to 600°C.

The peak metamorphic temperature was calculated using amphibole-plagioclase geothermometer of Blundy and Holland (1990), Holland and Blundy (1994), with corrections presented by Dale et. al. (2000), and is between 650–720°C. The pressure was estimated at 8.0–9.5 kbar using Grt-Hbl-Qtz-Pl geobarometer of Kohn and Spear (1990). The garnet-biotite geothermometer was not applicable due to strong decomposition of biotite.

According to Parry et al. (1997) banded amphibolites underwent a granulite low-pressure metamorphism, related to Cambro-Ordovician rifting during D_1 deformation. Their temperature estimates for this event are within the range of 750–850°C, proved by occurrence of amphibole-clinopyroxene-plagioclase assemblage (*op. cit.*) marking the transitions from amphibolite to granulite facies. My observation do not indicate such the elevated temperature. Moreover, pyroxene has not been found within amphibolites from the Polish part of the Stare Město Zone.

The peak metamorphism was followed by its regression. Amphibole rims, containing 0.60–1.80 wt.% TiO_2, and 8.2–12.5 wt.% Al_2O_3 suggest temperatures and pressures of their crystallization to be within the range of 600–780°C and 7–10 kbar (Fig. 8). During the regression, normally zoned andesine was formed, as well as outer parts of complexely zoned plagioclase grains. Decrease of metamorphic grade formed

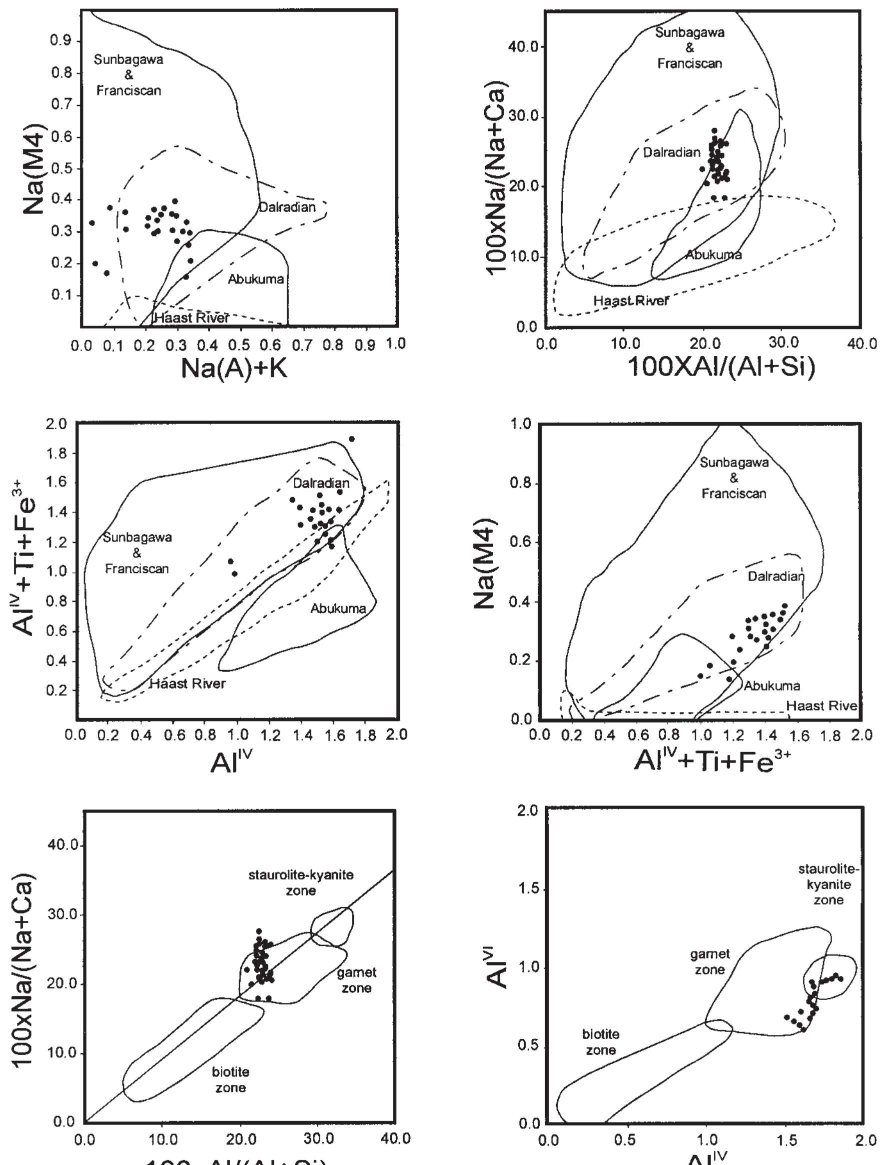

Fig. 7. Chemical composition of amphiboles from banded amphibolites on diagrams of Laird and Albee (1981)

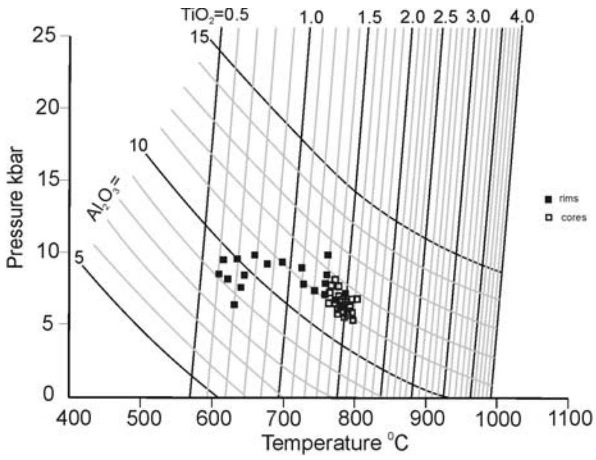

Fig. 8. Content of Al_2O_3 and TiO_2 in amphiboles from banded amphibolites on diagram of Ernst and Liou (1998)

Mg-hornblende rims over tschermakite and zoned, Mg-hornblende/tschermakite grains. Advancing regression resulted in greenschist and subgreenschist metamorphism producing abundant chlorite, prehnite and sparse albite.

SUMMARY

The amphibolites cropping out in the Polish part of the Stare Město Zone underwent a multi-phase metamorphism, with a clockwise PT path. The first M_1 metamorphic event was marked by an increase of metamorphic grade from epidote-amphibolite to

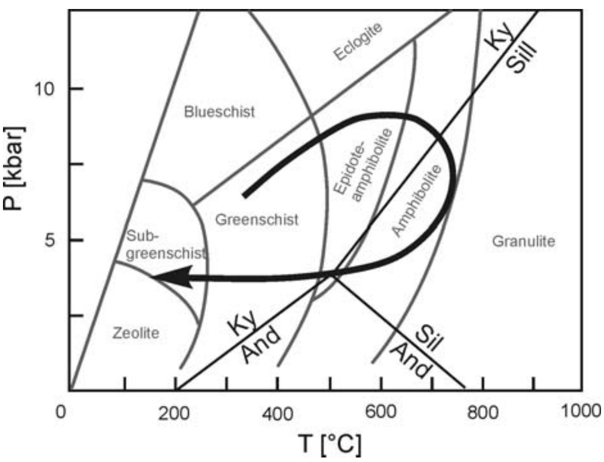

Fig. 9. P-T path for the banded amphibolites from the Polish part of the Stare Město Zone. P-T diagram derived from Spear (1993)

amphibolite facies (Fig. 9). The progression of metamorphism led to a peak of metamorphic temperature, calculated at 650–720°C using amphibole-plagioclase geothermometry. The M_1 metamorphic event was followed by retrograde M_2 one (Fig. 9). The presence of sparse albite, common chlorite and prehnite replacing amphibole and plagioclase, prehnite and chlorite filling fissures or forming asymmetric pressure shadows documents the LT metamorphism M_3 under the conditions of greenschist and sub-greenschist facies (Fig. 9). This metamorphic phase was supposedly due rapid uplift and related to regional low-grade mylonityzation.

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Wojciech BARTZ

EWOLUCJA METAMORFICZNA AMFIBOLITÓW POLSKIEJ CZĘŚCI STREFY STAREGO MĚSTA (SUDETY, SW POLSKA)

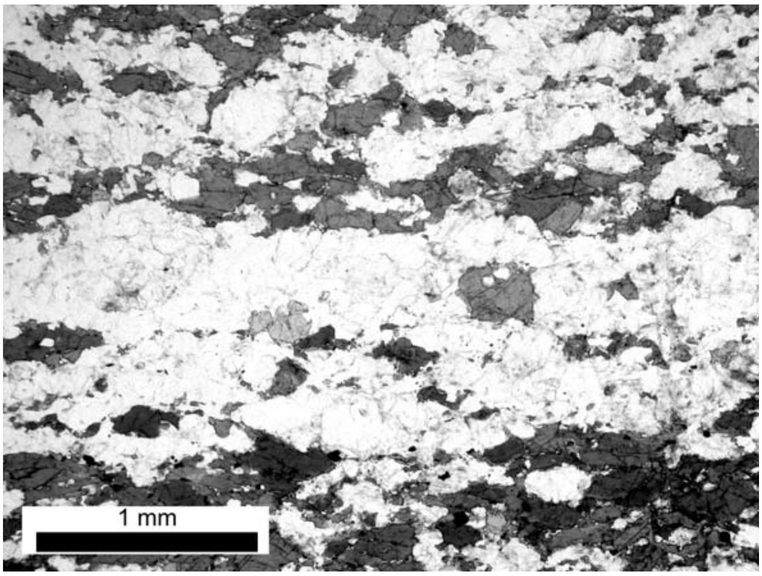
Streszczenie

We wschodniej części kopuły Orlicko-Śnieżnickiej znajduje się strefa Starego Města, usytuowana bezpośrednio na zachód od nasunięcia ramzowskiego, które oddziela Sudety zachodnie od Sudetów wschodnich. Niewielka część skał strefy Starego Města odsłania się na obszarze Polski, w okolicach Bielic. Obszar ten zbudowany jest głównie z warstwowanych amfibolitów.

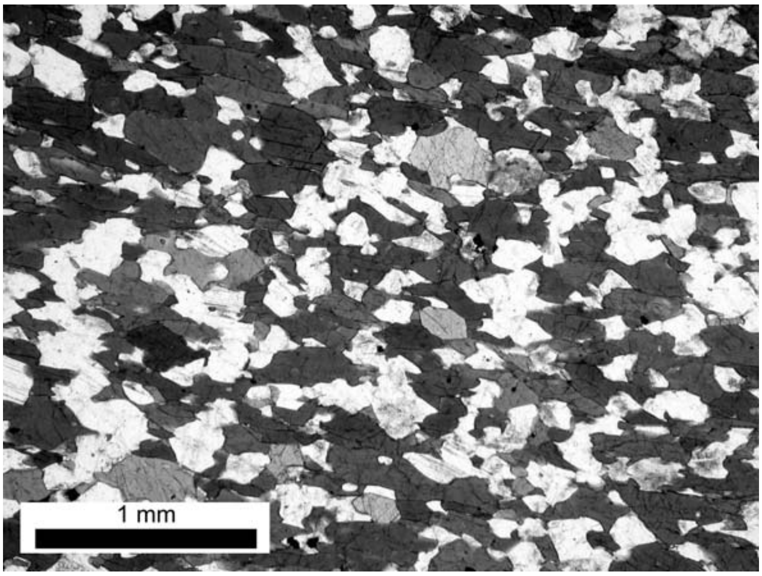
Amfibolity warstwowane, odsłaniające się na terenie polskiej części Strefy Starego Města są skałami średnio- lub rzadziej gruboziarnistymi. Odmiana gruboziarnista nie tworzy samodzielnych wystąpień, a jedynie niewielkiej miąższości wkładki w obrębie

amfibolitów średnioziarnistych. Amfibolity warstwowane zbudowane są głównie z amfiboli i plagioklazów, tworzących naprzemianlegle ułożone warstewki ciemne zdominowane przez amfibole oraz warstewki jasne zdominowane przez plagioklazy. Podrzędnie w amfibolitach warstwowanych występuje kwarc oraz lokalnie niewielkie ilości skalenia potasowego. Z minerałów akcesorycznych w amfibolitach występują: cyrkon, apatyt, tytanit, lokalnie granat i biotyt, minerałami wtórnymi są chloryt oraz prehnit.

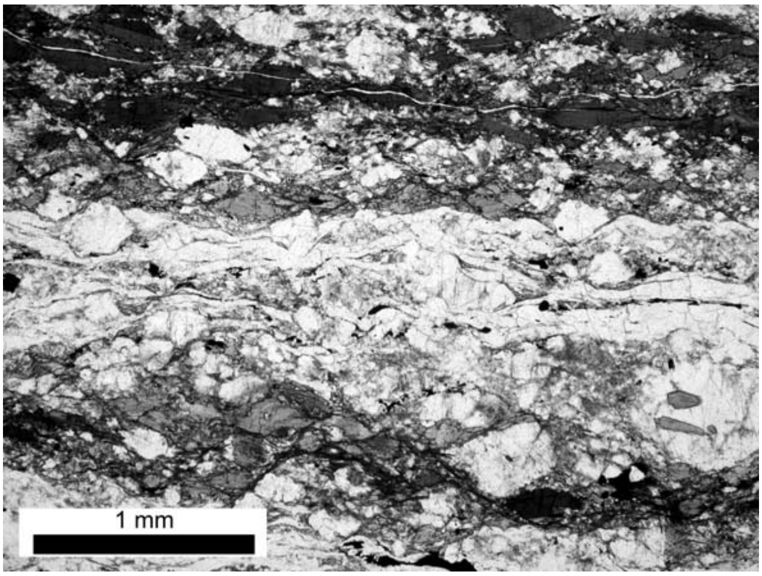
Amfibolity warstwowane zarejestrowały trzy etapy metamorfizmu. Pierwszy z nich M_1 miał charakter progresywny z maksimum temperatury i ciśnienia rzędu 650–720°C i 8,0–9,5 kbar. Po etapie progresywnym M_1 nastąpił izotermalny spadek ciśnienia, odpowiadający etapowi M_2. Ostatni etap M_3, izobaryczny, wiązał się z gwałtownym schładzaniem kompleksów skalnych, powiązanym z regionalną mylonityzacją i metamorfizmem niskiego stopnia w warunkach facji zieleńcowej i prehnitowo-pumpelyitowej.



Phot. 1. Banded amphibolite with alternating light — leucocratic layers and dark — amphibole rich layers



Phot. 2. Homogeneous amphibolite



Phot. 3. Strongly mylonitized amphibolite