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SPINEL-HORNBLENDE-ANTHOPHYLLITE (NEPHRITOID) NEOLITHIC AXES FROM WESTERN SLOVAKIA

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Abstract: Among artifacts from several localities/sites in western Slovakia (the Malé Karpaty Mts. and the Danube Upland (Podunajská pahorkatina)) those composed of green Al-rich spinel, hornblende and anthophyllite are characteristic. Other minerals (olivine, clinozoisite, muscovite, ilmenite, magnetite and sphene) are present in accessory amounts. The stones bear several characteristics of nephrites. In paper we use the common term nephritoids for various varieties of the discussed rocks. Primary occurrences of these Al-rich spinel-hornblende-anthophyllite rocks are yet known. On the basis of the predominance of hornblende and anthophyllite, the rocks under consideration are thought to be products of medium-temperature metamorphism of spinel bearing orthopyroxene-clinopyroxene rocks (ferroultramafics) under static conditions and high P/H_2O.

Key words: Neolithic, axes, (Al-rich) spinel-hornblende-anthophyllite (nephritoid) rocks.

Introduction

During the last decade a wealth of new information on formerly uncommon rock-type occurrences within the Western Carpathian territory have been published, but rock of Al-spinel-hornblende-anthophyllite composition are still unknown. Occurrences of tools made from this rock type are shown in the Fig. 1. In an attempt to find the original rock-bodies we have looked at the published information on adjacent geological units as well.

Although Central Europe, (the Bohemian Massif, Eastern Alps and Western Carpathians), has several geological units containing greenschists (actinolite, tremolite, hornblende and chlorite schists); the presence of chlorite sheets, together with pronounced preferred orientation (= foliation), limits the use of such rock-types as a raw material for polished tools. On the other hand rocks with radial orientation of amphibole needles or felt-like fabric of given rocks have appropriate technical features to be used as raw material for polished industries.

On the basis of generally accepted principles of metamorphic petrology, regional metamorphic recrystallization of ultramafics could be favorable for the origin of radial or felt-like fabrics of rocks commonly used as raw materials for Neolithic polished industries.

Petrology of rocks

The spinel-hornblende-anthophyllite, anthophyllite-hornblende and hornblende schists (felses), used as the raw material of Neolithic axes/adzes from several localities in western Slovakia, have some common features which could be summed up as follows:

i) all discussed petrographic varieties are, observing them by naked eyes, aphanitic to very fine-grained tough rocks of generally dark (dark grey, dark greyish-green, dark green) colour,

ii) they are mostly massive (Fig. 2), or in some thin sections slightly foliated (Fig. 3),

iii) they lack sheet silicates (accessory amounts of chlorites are exceptions). This is one of the supposed aspects of the good quality of this raw material for production of polished industries,

vi) the very fine-grained character of the rock studied (less than 0.1 mm) does not allow the determination of their quantitative mineral composition. On the basis of estimation in several thin sections, the volume of hornblende and anthophyllite varies in the range 60–95 per cent. Total absence of quartz, and feldspars is characteristic.

vii) The presence of colourless magnesian hornblende, together with other Al-containing phases (green Al-spinel, clinozoisite) allow us to suppose that Al-silicates were constituents of the protolith. The high XFe in the minerals present is a genetically important value. It is not typical for ordinary ultramafics and favours a ferroultramafic protolith for the rocks studied. The mineral association of the rocks under discussion indicates P-T conditions of metamorphic recrystallization (there is no doubt that the rocks under consideration are metamorphites) corresponding to those of the low temperature area of the amphibolite facies. A contact-thermic origin may be assumed comparable with those of the central parts of contact aureoles of granitic massifs.

viii) The dominant phases are hornblende and anthophyllite indicating recrystallization under high P/H_2O conditions.

Mineral association

The leading minerals of the rock types studied are hornblende and anthophyllite. They form longcolumnar till fibrous, often felty matrix, in which grass-green spinels are ir-

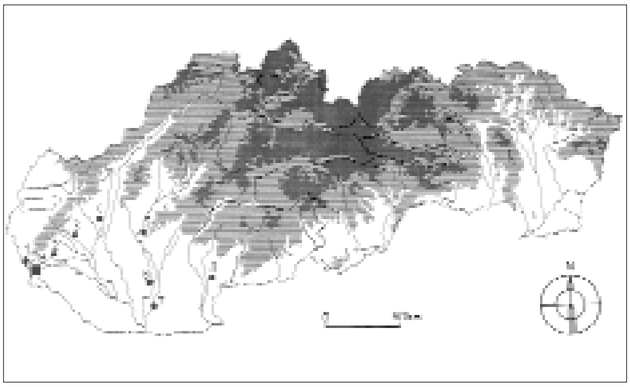

Fig. 1. Localities with spinel-hornblende-anthophyllite axes: **1** — Bratislava-Dúbravka, **2** — Blatné, **3** — Ružindol, **4** — Žlkovce, **5** — Lefantovce, **6** — Nitriansky Hrádok, **7** — Bajč, **8** — Santovka, **B** — Bratislava.

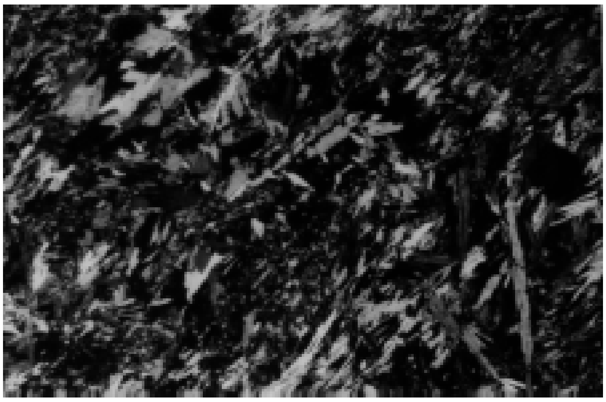

Fig. 2. Random orientation of anthophyllite + hornblende longcolumnar crystals of variable size. Ružindol, magn. 30×, X polars.

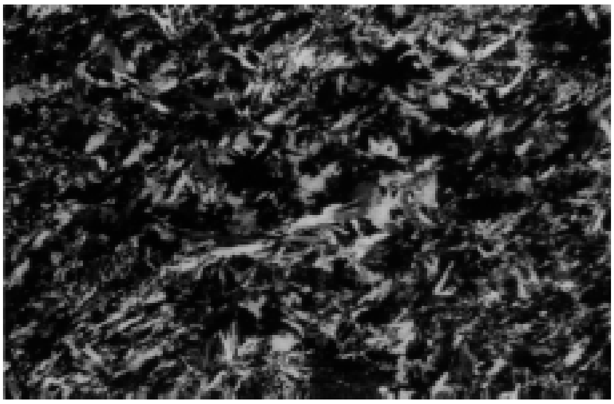

Fig. 3. Slightly expressed preferred orientation of longcolumnar anthophyllite + hornblende. Nitriansky Hrádok, magn. 30×, X polars.

regularly distributed (up to 20 per cent). In accessory amount crystals of clinozoisites, olivines, ilmenites, magnetites, sphenes and muscovites are present. Hornblende is colorless and, based on analytical results (Tab. l), it is represented (XFe 0.24–0.27) by low Na-calcic hornblende of the edenite-hornblende series (Leake l978).

The anthophyllite has low contents of Al_2O_3 (l.3–l.6 per cent) and an appropriate amount of iron (XFe 0.30–0.3l).

Al-spinels (Tab. 2) contain solution of Cr_2O_3 (0.l–l.8 wt. per cent) and they have medium Fe content (XFe 0.54–0.6l). The above mentioned 3 phases represent 93–96 per cent of the bulk composition of the rocks under consideration.

Rare Fe-rich olivine crystals (XFe 0.4l) are in full equilibrium with amphiboles and spinels and are of metamorphic origin. Clinozoisites are characterized by a low content of Fe_2O_3 (0.5–4.3 per cent). The very rare flakes of muscovite (Tab. l) are characteristic by a low natrium content. The very fine-grained sphenes are practically without Al. Ore minerals are represented by homogeneous magnetite and ilmenite crystals in intergrowth with rutile and sphene. So their origin by breakdown of titanomagnetite is probable.

Pre-metamorphic protolith

The feldspars- and quartz-free association and stability of the spinel-hornblende-anthophyllite assemblage allow us to suppose that the protolith (orthopyroxene-clinopyroxene-spinel rocks) recrystallized under epidote-amphibolite to lowgrade amphibolite facies conditions. The spinel-rutile-sphene intergrowths, products of breakdown of original titanomagnetite, are evidence in favour of this.

However the determined mineral composition of the rock studied is not in agreement with the supposed ultrabasic protolith. The main objectives are as follows:

a — the present minerals are characterized by elevated XFe in comparison to minerals of common ultramafite rocks,

b — two of the three rock-forming minerals: hornblende and spinel, have a high Al content. Two of the accessories present (muscovite and clinozoisite) are also Al-rich. On the basis of the facts the protolith should have contain a substantial amount of alumina, significantly higher than the Al-content in ultramafites.

In conclusion we suppose that the spinel-hornblende-anthophyllite rocks originated by metamorphic recrystallization of ultramafic two-pyroxene cumulate of the gabbro-noritic clan. Only a such type of the protolith could explain the elevated content of Al and Fe simultaneously and the lower content of Cr_2O_3 in metamorphic (and in such way also in original magmatic) spinels.

The phase equilibria of the spinel-hornblende-anthophyllite rocks are presented in diagrams of Ca-Al-Mg, Fe and Fe-Si-Al (Fig. 4). They do not exclude the possibility that the metamorphic association originated by metamorphic recrystallization of two-pyroxene-spinel cumulate. The identified variety of metamorphic olivine indicates that in the pre-metamorphic protolith this mineral was also rare, so the original rock was relatively SiO_2 saturated.

In connection with the problem of the raw material provenance it ought to be taken into consideration that even spinel-hornblende-anthophyllite axes/adzes have been found on several western Slovak sites, no rock debris deposits were reported during archaeological surveys of these sites. So it should be expected that finished tools have been transported. Taking into account the identical mineral composition of the finds studied, we suppose that one rock-body or rock-bodies of identical origin are the source of raw material for spinel-anthophyllite axes/adzes.

Table 1: Microprobe analyses of hornblendes (**Hbl**), anthophyllites (**Ath**), olivine (**Ol**) and secondary muscovites (**Ms**).

	Hbl				Ath			Ol	Ms	
Sample	L-5	D-PA-1	R-r		L-5	D-PA-1	R-r	R-r	D-PA-1	R-r
	1	2	3	4	5	6	7	8	9	10
SiO_2	49.81	47.68	48.41	49.66	55.21	55.18	55.20	35.21	45.62	45.42
TiO_2	0.51	0.62	0.59	0.67	0.15	0.14	0.01	-	-	0.08
Al_2O_3	9.23	11.23	10.22	9.72	1.37	1.58	1.62	0.11	37.99	38.65
FeO	9.54	9.24	10.10	9.59	17.34	16.98	17.02	35.08	0.48	0.54
MnO	-	0.01	0.05	0.07	0.37	0.17	0.40	0.34	-	0.06
MgO	16.63	16.07	15.67	16.08	22.02	22.37	22.04	27.87	0.01	0.29
CaO	11.43	11.63	11.51	11.39	1.02	1.21	1.76	0.01	-	0.58
Na_2O	0.72	1.15	1.23	0.47	0.05	0.11	-	-	0.35	0.59
K_2O	0.25	0.22	0.17	0.05	0.04	-	0.04	-	10.93	9.84
Total	98.12	97.85	97.95	97.70	97.57	97.74	98.09	98.61	95.38	96.05
Si	7.02	6.79	6.88	7.01	7.82	7.79	7.80	0.99	3.01	2.96
Al^{IV}	0.98	1.21	1.12	0.99	0.18	0.21	0.20	-	0.99	1.04
Al^{VI}	0.55	0.67	0.59	0.63	0.05	0.05	0.07	-	198	1.93
Ti	0.05	0.07	0.06	0.07	0.02	0.02	-	-	-	-
Fe	1.12	1.10	1.20	1.13	2.05	2.00	2.01	0.83	0.02	0.03
Mn	-	-	0.01	0.01	0.04	0.02	0.05	0.01	-	-
Mg	3.50	3.41	3.32	3.38	4.66	4.71	4.64	1.17	-	0.03
Ca	1.73	1.77	1.75	1.72	0.15	0.18	0.27	-	-	0.04
Na	0.20	0.32	0.34	0.13	0.02	0.03	-	-	0.04	0.05
K	0.04	0.04	0.03	0.01	0.01	-	0.01	-	0.93	0.82
X_{Fe}	0.24	0.24	0.27	0.25	0.31	0.30	0.30	0.41		

Table 2: Microprobe analyses of spinels (**Spl**), clinozoisites (**Czo**), ilmenites (**Ilm**), magnetites (**Mag**) and titanite (**Ttn**).

	Spl				Czo			Ilm			Mag	Ttn
Sample	L5	D-PA-1	R-r		L-5	D-PA-1	R-r	D-PA-1[1]	R-r[2]		R-r[1]	R-r[2]
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	0.01	0.08	0.07	0.10	39.36	38.93	38.73	0.11	0.09	0.09	0.55	30.40
TiO_2	-	0.17	0.07	0.09	-	0.03	0.10	50.92	51.03	50.55	0.01	39.71
Al_2O_3	59.74	62.87	61.58	60.69	33.51	31.49	32.30	-	0.19	0.09	-	0.39
FeO	6.69	24.44	26.93	27.95	0.53*	4.30*	3.49*	47.65	46.83	47.88	99.05**	0.39
MnO	0.04	0.01	0.14	0.13	0.12	0.08	0.07	0.37	0.95	0.70	0.01	-
MgO	10.47	11.58	10.21	9.84	-	0.28	0.34	0.54	0.17	0.12	0.06	0.11
CaO	-	0.07	0.03	-	24.12	22.62	22.82	0.04	0.08	0.19	0.21	28.16
Cr_2O_3	1.81	0.25	0.23	0.10	-	-	-	0.05	-	-	0.01	0.03
ZnO	0.66	0.17	0.59	0.82	-	-	-	-	-	-	-	0.37
Total	9.41	99.54	99.85	99.72	97.64	97.73	97.86	99.68	99.34	99.62	99.90	99.56
X_{Fe}	0.59	0.54	0.60	0.61								

* — all Fe as Fe_2O_3; ** — all Fe as FeO; [1] — from separate grains; [2] — from the ilmenite-titanite-rutile intergrowths

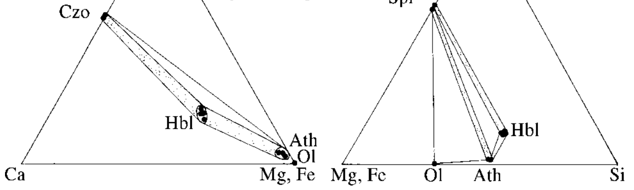

Fig. 4. Associations of rocks studied on Ca-Al-Mg,Fe, and Si-Al-Mg,Fe diagrams.

Supposed provenience of the raw material

In the Western Carpathians no comparable rocks have been described up to now. An up to date survey of the main rock types used as raw material for Neolithic-Eneolithic axes/adzes is given in a paper by Illášová & Hovorka(1995). The only occurrence of anthophyllite bearing rock, forming the reaction rim around the ultramafic body in the Veporic Unit (central Slovakia: Hovorka 1967) due to its extremely small extent cannot be counted among the possible sources of raw material of the discussed axes.

The Bohemian Massif is the adjacent geological unit situated west of the described localities. The Moldanubian Varied

Group in particular bears occurrences of anthophyllite gneisses. Migmatized types of anthophyllite gneisses and biotite-cordierite-anthophyllite gneisses have been reported from the vicinity of Žárovná in southern Bohemia (Vrána 1963). Anthophyllite gneisses (composition: anthophyllite — 54–56 %, biotite — 24–28 %, plagioclase, quartz, actinolite and accessories) have been described from the gallery south of Český Šternberk by Zikmund (1971). Amphibolites with anthophyllite have also been reported from this geological unit in the past (Ginějko-Savicka 1928; Orlov 1931).

Another genetic group of anthophyllite monomineral and anthophyllite bearing rocks is that of reaction rims round basic and especially ultrabasic rock-bodies located within gneisses and migmatites of the above mentioned geological unit (Kudělásková et al. 1961).

Comparing the spinel-hornblende-anthophyllite rock studied with those described from the Moldanubian Varied Group (citation see above) and with those from northern Bohemia described by Granzer (1933), Hejtman (1962) and especially by Bukovanská (1992) there exist substantial differences:

a — although from the northern Bohemian metamorphics several types have been described (tremolite, actinolite, hornblende bearing rocks) no rhombic amphiboles have been reported in the past,

b — among minerals of rock under consideration no author described the presence of green, Al-rich spinel. It should be pointed out that in some of the thin sections green spinel is one of the substantially present mineral phases.

The distribution of polished Neolithic/Eneolithic artifacts is more-or-less regular in the whole territory of western Slovakia. Among the most hopeful areas, that of northern Bohemia seems to be an area of primary occurrences of stony raw material for the Neolithic/Eneolithic polished goods. From that area Bukovanská (1992) described actinolite and actinolite-hornblende schists with characteristic radial structures of amphiboles and general massive to foliated cleavage. In northern Bohemia Precambrian-Early Paleozoic basic to ultrabasic volcanics and especially volcaniclastics have been thermally recrystallized within the contact aureole of the Variscan Krkonoše-Jizerské hory Mts. granitic massif. Thus contact-thermic recrystallization under static conditions and high PH_2O, represents a second metamorphic episode (following the greenschist facies metamorphism of regional extent).

Discussion

From the genetic point of view the association Al-spinel + hornblende + anthophyllite is the most important. For the solution of the protolith problem we use the following thin section observations:

— we studied the above mentioned mineral association in several thin sections, but we found relics of rhombic pyroxene of estimated hypersthene chemistry in only one,

— mentioned relic is surrounded by a felty matrix composed of hornblende + anthophyllite and green Al-rich spinel,

— the irregular distribution of green spinels, but simultaneously its observed occurrences in spatially limited "fields" indicates their origin from the breakdown of original orthopyroxene following the equation:

orthopyroxene + H_2O = anthophyllite + Al-rich spinel.

The shape (longcolumnar to needle-like) of the prevailing anthophyllite, structure (felty, often radial), submicroscopic dimensions of phases allow us to use denomination "nephritoids" for the whole group of, by naked-eyes aphanitic, dark, massive to slightly schistose rock types free of quartz, feldspars and chlorite.

Conclusions

In this paper we offer information on an unusual rock-type which was used in Neolithic time period as a relatively frequent type of raw material. No bodies of Al-rich spinel-hornblende-anthophyllite rocks are known outcropping in Central Europe. The relatively uniform character of the studied artifacts suggests that one rock-body, or several rock-bodies of identical origin ought to be considered as the source of raw material for these artifacts.

Distribution of spinel-anthophyllite Neolithic/Eneolithic axes within western Slovakia, and lack (any such artifacts have been found yet) of artifacts made from discussed rock type within the central as well as in the eastern Slovakia, indicate that the primary occurrence/occurrences were located west of the archaeological sites with axes/adzes made of spinel-anthophyllite rocks.

The submicroscopic grain-size, mineral composition as well as felty, mostly massive and often radial fabrics allow us to denominate the rocks under discussion as "nephritoids".

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