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Rock-forming minerals in contact-metamorphosed greenschists of the polished stone artefacts (Neolithic, Slovakia, site Bajč-Medzi kanálmi)

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Abstract: On the Bajč-Medzi kanálmi site during the Middle Neolithic among stone raw materials used are repredsented namely by amphibole schists, amphibole schists with anthophyllite, phlogopite-anthophyllite schists and anthophyllite schists with Al-rich green spinel and corundum. Mineral assemblages of the greenschists and namely discriminant minerals (cordierite, Al-rich green spinel, corundum, anorthite, anthophyllite and orthopyroxene) are characteristic for rocks originated in contact-thermic aureoles developed in metabasites. Presence of grinders and saws made from the hardest occurring rocks (anthophyllite schists with Al-rich spinel and corundum) is in favour of idea that stone implements were made on the given site. Appropriate raw material has been transported, the most probably, from the crystalline complex of the Malé Karpaty Mts. Neolithic men based on, by naked eyes evaluated raw materials, choosed the most convenient (hard but simultaneously elastic) rock varieties characterized below.

Key words: Neolithic, Slovakia, site Bajč-Medzi kanálmi, polished stone artefacts, raw material, greenschists, rock-forming minerals

Introduction

The beginning of inhabitation on the site Bajč-Medzi kanálmi (Fig. 1) corresponds to 3rd stage of the Želiezovce group ranked to the the final period of the Middle Neolithic (around 4000 years B.C.). During the systematic survey in the past numerous fragments of chipped as well as polished industries together with artefacts made from clays, bones and antlers were uncovered.

Together around 300 pieces of stone artefacts were documented from the site. Based on their typology the most abundant are flat axes and shoe-last wedges, in lesser amount also grinders, globular maces, axe hammers, crushers, chisels and various semiproducts were described (Hovorka and Cheben 1997, Méres et al. 2001). Polished stone artefacts known from the discussed site were made from eruptive, sedimentary as well as metamorphic rock types.

The most commonly used were metamorphic rocks, among which greenschists were dominant (94 % of the stone artefacts documented).

In presented paper we dealt with the characteristic features of greenschist, which should offers information on the raw material source area and in such way to precise communication paths of communities living in the given area during the Middle Neolithic. We studied metamorphic mineral assemblages in detail and based on the chemical composition (electron microprobe determination) we present classification of amphiboles present.

Characterization of the raw material types

Based on mineral composition among the studied set of stone artefacts we distinguished the following varieties of the used greenschists: amphibole schists, amphibole schists with anthophyllite, phlogopite-anthophyllite schists and anthophyllite schists with Al-rich green spinel and corundum.

Fig. 1. Location of the site Bajč-Medzi kanálmi

Amphibole schists have mostly augen appearance, very fine-grained granularity and dark greyish-green color. Chracteristic is their volcaniclastic texture. In the rock matrix very fine-grained (less than 50 μm) needle-like amphiboles prevails. By naked eyes observable light spots are composed of plagioclase, more sporadically also by quartz (Fig. 2/A, /B, /C). In accessory amount Mg-chlorite, clinozoisite, quartz, carbonates and ore minerals were identified.

Plagioclases in the amphibole schists, based on their composition, are zonal (Tab. 3). Their anorthite molecule contents is increased from the cores (An38) to the rims (An56). Also Ca-amphiboles present have zonal composition. Their cores are represented by actinolite and rims by Mg-hornblende and tschermakite (Fig. 2/C, 9, Tab. 1). In core of zonal amphiboles often clinozoisites occur. magnesiohornblendes and tschermakites do

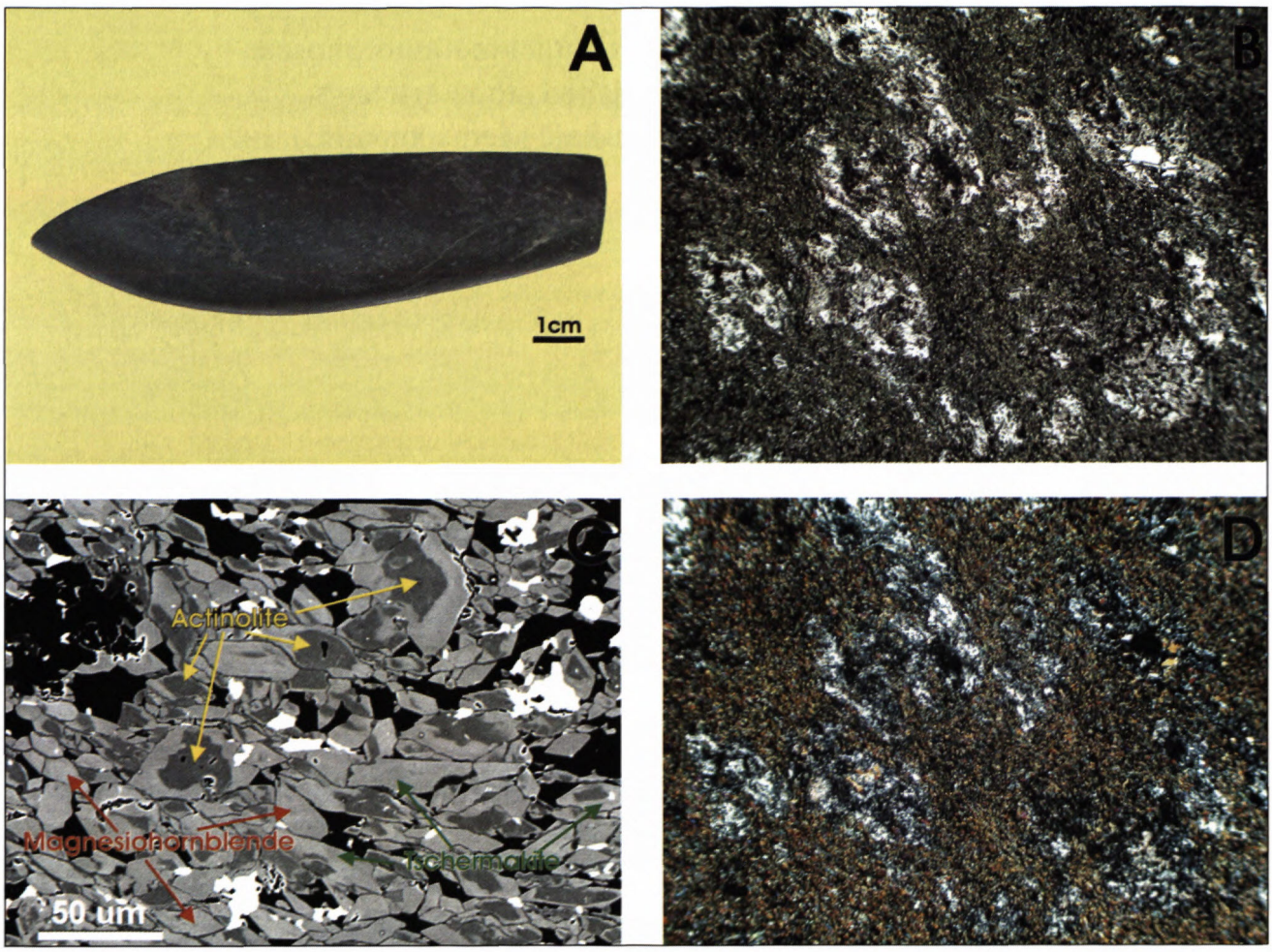

Fig. 2. A - Shoe-last wedge made from the amphibole schist. Samle B-18. Site: Bajč-Medzi kanálmi. B - Fine-flaky matrix of the amphibole schist is composed of amphiboles and light plagioclase plates/augens (sporadically also quartz). Parallel polars, C - Composition of zonal amphiboles (in cores actinolite, in rims magnesiohornblende and tschermakite) in scattered electrons, D - Identical with B: crossed polars.

occur also in the form of individual needles in the rock matrix.

Amphibole schists with anthophyllite represent very fine-grained light greyish-green up to dark-grey rocks. In some of them dark spots formed by the quartz aggregates (Fig. 4) are present. In the rock matrix dominant are tiny amphibole needles (Fig. 3/b, /c, /d, 4/b, /c). In this rock variety in accessory amont also Mg-chlorite, clinozoisite, quartz, phlogopite and ore minerals are present. In some artefacts high amount of ore minerals cause their dark color.

Also in this rock variety amphiboles are compositionally zonal. Following their chemical composition group of Ca-amhiboles (actinolite and magnesiohornblende) and Mg-Fe-Mn-Li amphibole group is represented by anthophyllite (following the Leake´ et al. classification, 1997, Fig. 9, Tab. 1). Cores of zonal amphiboles are formed by actinolites and the rims by magnesiohornblende and anthophyllite (Fig. 3/C). Actinolite and magnesiohornblende are the most abundant, anthophyllite is present in lesser amount. The last one we identified also in the form of individual very fine needles (below 5 μm) in the rock matrix. The anorthite molecule in plagioclases varies in wide range (An2 - An98, Tab. 3).

Phlogopite-anthophyllite schists are represented by fine-grained greyish-green rocks. Characteristic is spotty appearance observable namely in foliation planes. Spots are formed by aggregates of phlogopites (Fig. 5/A). In mineral composition dominant is fine-grained amphibole of needle-like morphology. In accessory amount clinozoiste, Mg-chlorite, ilmenite, plagioclase, quartz and muscovite are present. In this rock variety also cordierite was identified. (Tab. 2). In contrast to previously characterized rock varieties in this one only anthophyllite from the group of Mg-Fe-Mn-Li amphiboles (Leake et al. 1997) was identified. Plagioclase is represented by anorthite (Tab. 3).

Anthophyllite schists with spinel and corundum also represent very fine-grained dark-green rock variety. In their mineral composition amphibole prevails. Presence of green, Al-rich spinel and corundum located often in the space of probably orthopyroxene ancestors was documented. In described variety, except of mentioned phases, also orthopyroxene, clinozoisite, phlogopite,

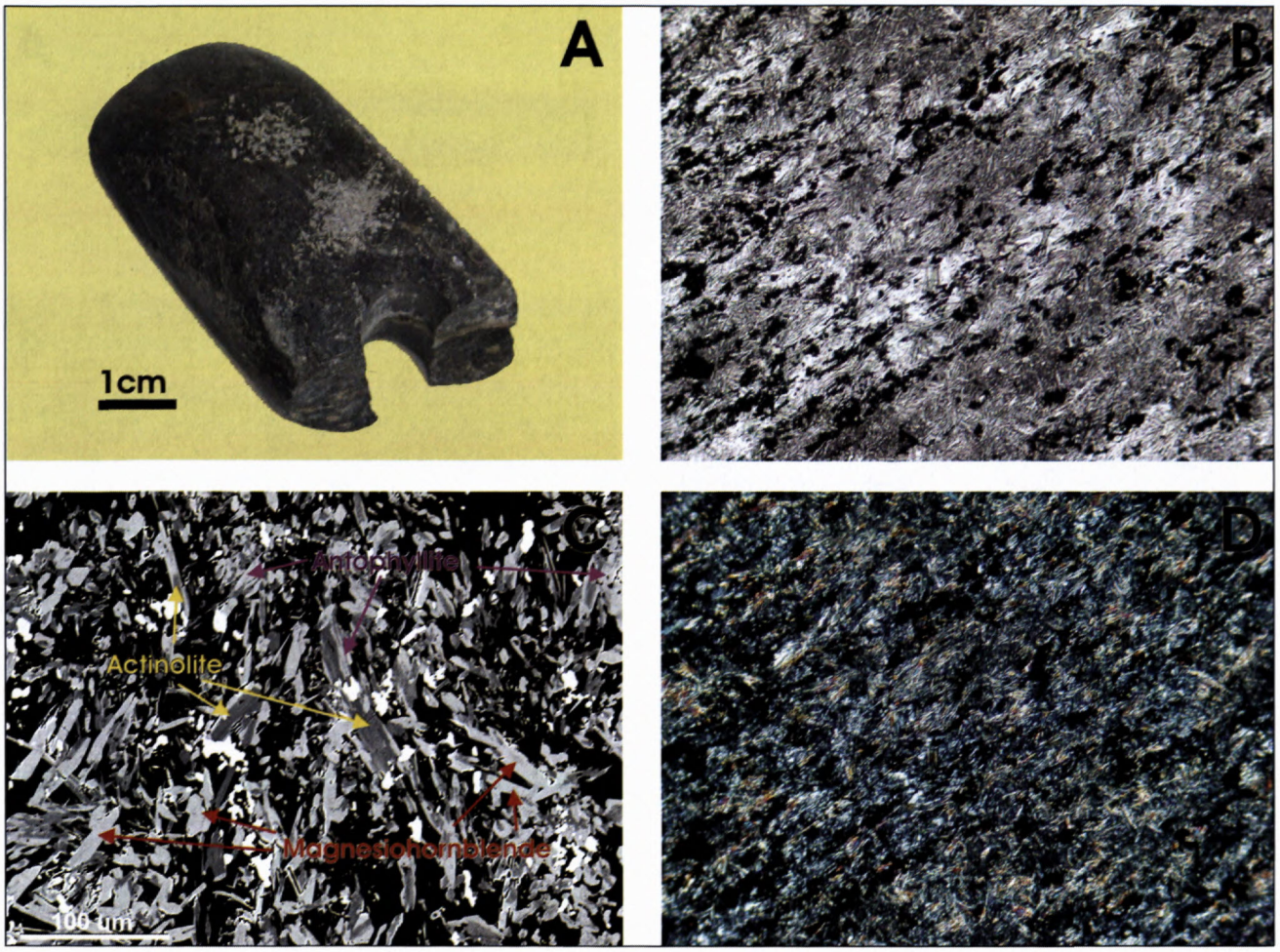

Fig. 3. A - Double-armed axe hammer made from amphibole schist with anthophyllite. Sample B-229. Site: Bajč-Medzi kanálmi. B - Fine-platy matrix composed of amphiboles and ore minerals (black). Parallel polars. C - Composition of zonal amphiboles (in cores actinolite, on rims Mg-hornblende or anthophyllite (in scattered electrons). D - Identical with B: crossed polars.

Mg-chlorite, plagioclase, muscovite, quartz and ore minerals are present (Tab. 2).

In several thin sections also magnesiohornblende and anthophyllite were identified (Fig. 9, Tab. 1). Plagioclase (Tab. 3) is represented by practically pure anorthite (An99).

Discussion

Our laboratory study was concentrated on the composition of rock-forming minerals of the most abundant raw material type - various varieties of greenschists. Special attention was paid to amphiboles.

Following the classification of amphiboles by Leake et al. (1997, Tab. 1, Fig. 9) in studied stone artefacts we identified two main groups of amphiboles: 1) Ca- amphiboles (actinolite, magnesiohornblende and tschermakite) and 2) Mg-Fe-Mn-Li amphiboles represented by anthophyllite. In studied artefacts also the following minerals were identified: phlogopite, anorthite, cordierite, spinel and corundum. Mentioned asemblage is present mostly in contact-thermic aureoles developed in metabasites. Preliminary identification of greenschists varieties, as it was presented above, was consequently proved on the base of their mineral composition and the intensity of their metamorphic recrystallization, as well.

In amphibole schists characteristic is presence of zonal amphiboles. In their cores actinolite do occur, while in the rims magnesiohornblende and tschermakite were identified. This rock variety corresponds the most probably to the regionally metamorphosed greenschists occuring in the source area. Amphibole schists with anthophyllite differ from the amphibole schists by the presence of anthophyllite located on the rims of zonal amphibole crystals, but occurring also in the rock matrix. Increase of anthophyllite content documents the increased grade of metamorphic recrystallization. Anthophyllite schists respresent rock variety originated in the outermost part of contact-thermic aureole. Phlogopite-anthophyllite schists on the other side represent totally thermally recrystalized original amphibole schists. Anthophyllite schists with corundum and Al-rich green spinel represent the most intensively thermally recrystallized original amphibole schists which originated just on, or near the contact between the greenschists and granite magma. Identification of different mineral

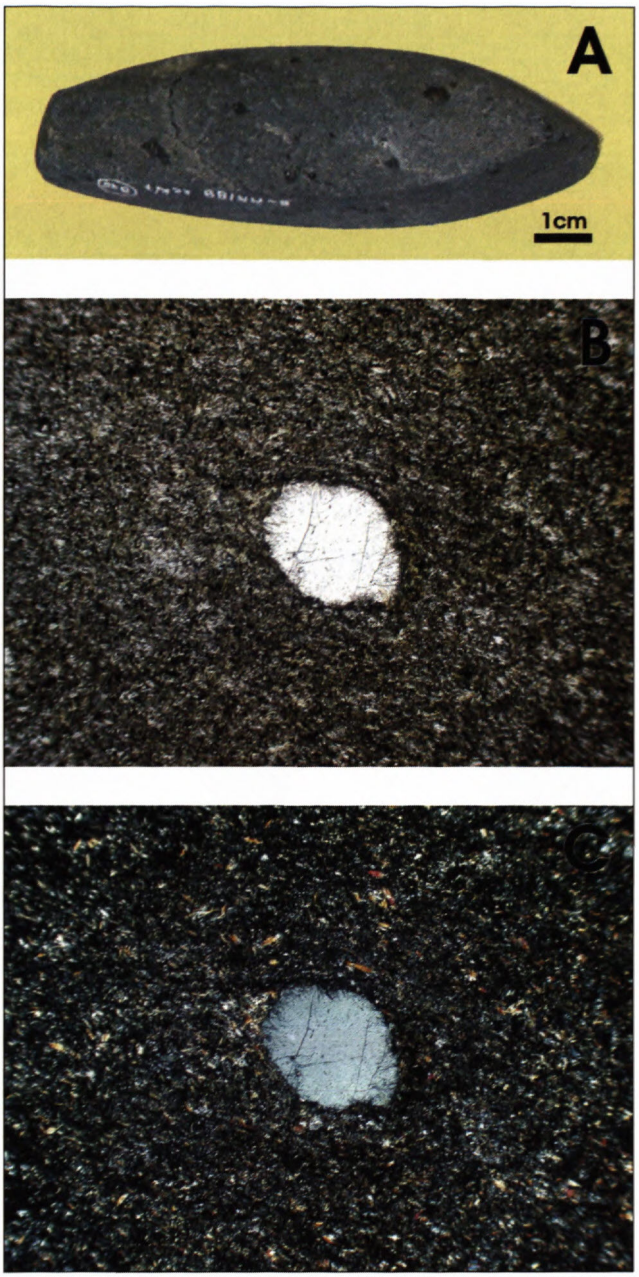

Fig. 4. A - Shoe-last wedge made from amphibole schist with anthophyllite. Sample B-95a. Site: Bajč-Medzi kanálmi. B - In fine grained matrix composed mostly of amphiboles sporadically present are also guartz grains. Parallel polars. C - Identical B: crossed polars.

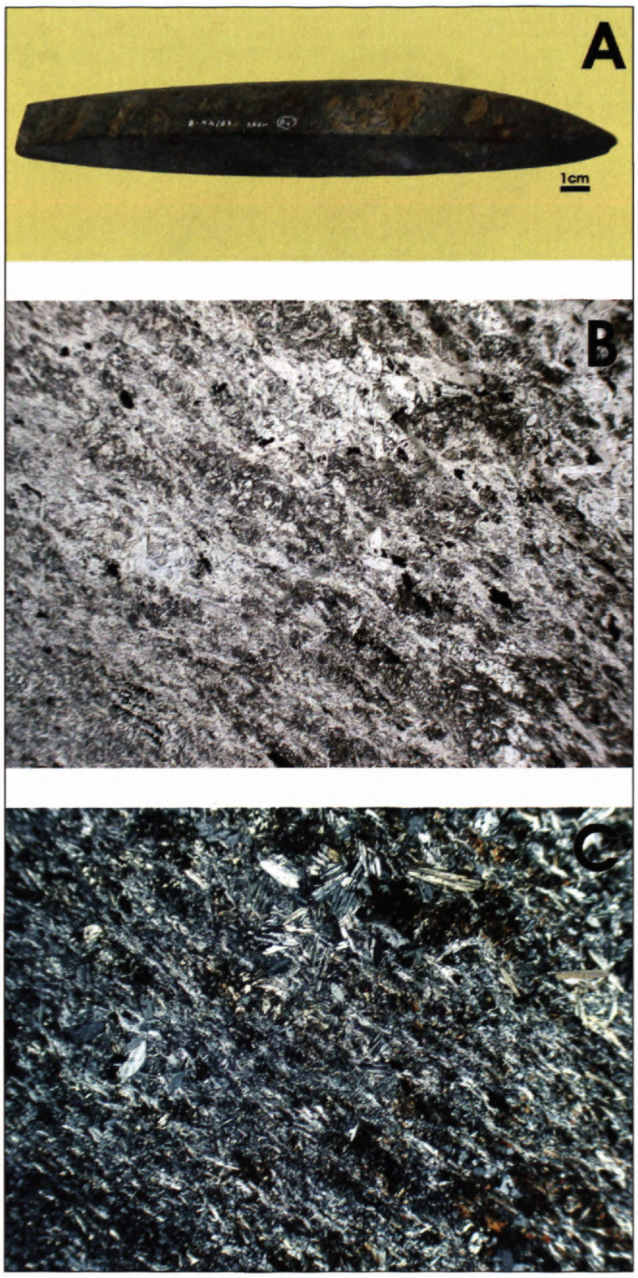

Fig. 5. A - Shoe-last wedge made from spotty phlogopite-anthophyllite schist. Sample B-1. Site: Bajč-Medzi kanálmi. B - Fine-platy matrix is composed of anthophyllite, spots of phlogopite and ore minerals (black). Paralel polars. C - Identical with B: crossed polars.

assemblages in various varieties of greenschist leads us to suppose their formation within one contact-thermic aureaole.

During the Neolithic/Aeneolithic time spane greenschists in the frame of the Bohemian Massif (Přichystal 2000) and Carpathian Basin together with the southern slopes of the Carpathian mountain chain (Hovorka and Illášová 2000, Szakmány and Kasztowszky 2001, Biró and Szakmány 2000) were the most frequently used raw material type for the stone implements construction. Based on the greenschists technical properties (hardnes, but simultaneously appropriate elasticity and chemical stability) were also frequently used in the praehistoric site Bajč-Medzi kanálmi (Hovorka and Cheben 1997, Méres et al. 2001). The favorable technical properties of greenschists used for the stone implements construction have increasing trend in accordance with gradually increasing amount of anthophyllite (increasing durability) and simultaneously with increasing amount of green spinel and corundum (elevated hardnes of the raw material). The fact that among various greenschists varieties just those of the most favourable technical properties have been chosen by the Neolithic/Aeneolithic populations for the following treatment, prove their high skillful-

Tab. 1 Representative amphibole analyses of greenschist of the Neolithic polished stone artefacts. Site: Bajč-Medzi kanálmi.

Sample	amphibole schists									amphibole schists with anthophyllite						Phl-Ath schists	
	B18/2	B18/5	B18/7	B18/8	B18/9	B117/3	B117/4	B117/5	B117/6	B229/1	B229/2	B229/4	B95/1	B95/2	B31A/1	B1/2	B1/5
	Ts	*Mho*	*Act*	*Mho*	*Mho*	*Act*	*Mho*	*Act*	*Ts*	*Ath*	*Act*	*Mho*	*Ath*	*Act*	*Ath*	*Ath*	*Ath*
SiO_2	41,72	44,19	53,94	52,90	52,45	55,34	45,11	55,17	41,75	53,61	52,18	51,14	56,55	53,90	56,57	55,11	55,96
TiO_2	0,41	0,51	0,14	0,25	0,34	0,08	0,46	0,06	0,45	0,03	0,13	0,31	0,05	0,05	0,10	0,07	0,03
Al_2O_3	14,90	12,04	2,72.	4,25	5,35	1,04	11,41	0,89	14,22	0,39	3,96	5,66	0,90	2,79	0,67	0,81	0,49
FeO	16,62	16,27	12,34	8,95	9,47	12,76	16,34	12,54	17,28	25,27	14,73	17,19	15,74	9,27	17,85	18,85	19,12
MnO	0,24	0,20	0,17	0,13	0,16	0,27	0,20	0,23	0,25	1,18	0,30	0,52	0,34	0,10	0,27	0,30	0,35
MgO	8,90	10,30	15,59	18,67	17,82	16,11	10,28	16,24	8,67	15,54	14,40	13,67	22,37	18,13	21,82	21,45	21,49
CaO	12,17	12,31	12,75	11,76	12,00	12,83	12,26	12,83	12,06	0,96	11,82	9,10	1,82	11,81	1,31	0,87	0,64
Na_2O	1,89	1,57	0,36	0,58	0,66	0,09	1,48	0,11	1,81	0,04	0,28	0,36	0,12	0,36	0,04	0,03	0,00
K_2O	0,36	0,25	0,06	0,06	0,08	0,03	0,16	0,02	0,38	0,00	0,06	0,11	0,01	0,04	0,01	0,00	0,02
Total	97,21	97,64	98,07	97,55	98,33	98,56	97,70	98,08	96,88	97,01	97,87	98,07	97,89	96,46	98,63	97,48	98,09

Tab. 1 continuation

Sample	phlogopite anthophyllite schists								anthophyllite schists with Spl and Crn									
	B1/7	B24/1	B24/2	B177/2	B177/4	B177/5	B177/6	B177/9	B61/1	B61/3	B61/4	B61/7	B61/8	B61/12	B61/13	B70A/3	B70A/8	B70A/9
	Ath	*Ath*	*Ath*	*Ath*	*Ath*	*Ath*	*Ath*	*Ath*	*Ath*	*Ath*	*Mho*	*Mho*	*Ath*	*Mho*	*Ath*	*Ath*	*Ath*	*Ath*
SiO_2	56,09	55,77	55,79	54,41	55,51	56,41	56,42	56,27	56,13	55,76	48,98	51,03	55,75	50,68	55,80	54,36	55,56	56,46
TiO_2	0,02	0,07	0,02	0,17	0,13	0,05	0,13	0,05	0,53	0,03	0,55	0,33	0,02	0,48	0,53	0,10	0,04	0,05
Al_2O_3	0,42	1,48	1,49	3,97	2,15	1,17	1,01	1,57	1,16	1,18	9,93	7,67	0,78	8,56	1,13	4,53	2,52	1,24
FeO	18,41	16,80	17,11	15,25	17,26	17,49	17,53	15,74	17,53	17,43	9,91	8,99	17,63	9,45	17,90	16,24	16,85	16,70
MnO	0,34	0,22	0,22	0,17	0,18	0,19	0,17	0,31	0,29	0,27	0,05	0,10	0,30	0,09	0,30	0,17	0,17	0,19
MgO	21,57	23,06	22,83	22,95	22,47	22,73	22,76	23,28	21,97	22,05	16,02	17,12	22,20	16,86	21,73	22,57	23,00	23,16
CaO	0,66	0,33	0,36	0,50	0,36	0,35	0,33	0,54	1,00	1,05	11,76	12,07	0,81	11,62	1,66	0,57	0,69	0,64
Na_2O	0,03	0,06	0,06	0,40	0,11	0,05	0,07	0,10	0,05	0,04	0,35	0,24	0,04	0,27	0,04	0,31	0,14	0,06
K_2O	0,01	0,01	0,00	0,02	0,00	0,00	0,01	0,01	0,01	0,01	0,28	0,17	0,00	0,24	0,00	0,00	0,01	0,00
Total	97,55	97,81	97,88	97,84	98,16	98,43	98,43	97,86	98,66	97,81	97,84	97,73	97,54	98,25	99,10	98,85	98,97	98,50

All analyses presented in this paper were realised in electron microprobe under standard condition in geological Survey of Slovak Republic. Explanation: Mho = magnesiohornblende, Ath = anthophyllite, Act = actinolite, Ts = tschermakite,

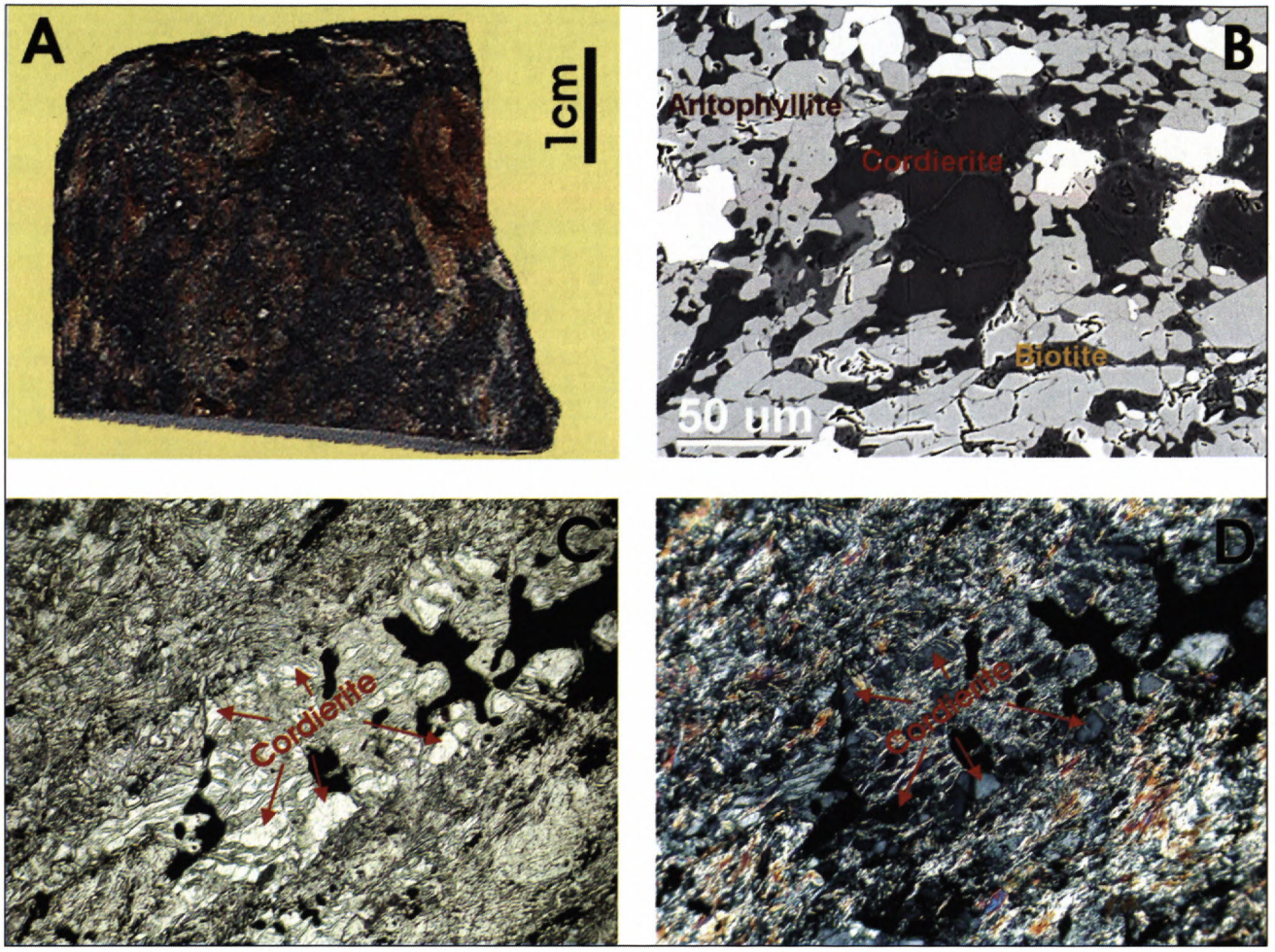

Fig. 6. A - Flat axe made from spotty phlogopite-anthophyllite schist with cordierite. Sample B-177. Site: Bajč-Medzi kanálmi. B - Anthophyllite, phlogopite, cordierite and ilmenite composition in scattered electrons. C - Fine-grained matrix is composed namely of anthophyllite, spots of cordierite and ore minerals (black). Paralel polars. D - Identical with C: crossed polars.

Tab. 2 Representative analyses of selected minerals from greenschists of polished stone artefacts from the site Bajč-Medzi kanálmi.

	phlogopite anthophyllite schists					anthophyllite schists with Spl and Crn				
Sample	B177/1	B177/7	B177/3	B177/8	B1/3	B61/5	B61/6	B61/10	B61/11	B70A/2
Mineral	*Phl*	*Ms*	*Crd*	*Crd*	*Ms*	*Opx*	*Opx*	*Spl*	*Spl*	*Spl*
SiO_2	39,92	47,67	50,28	49,93	47,69	53,47	52,86	0,02	0,03	0,00
TiO_2	1,68	0,00	0,00	0,00	0,00	0,19	0,08	0,04	0,12	0,04
Al_2O_3	16,75	36,22	32,96	33,12	39,30	1,77	1,64	58,10	58,43	62,86
Cr_2O_3	0,41	0,00	0,04	0,00	0,01	0,02	0,00	1,85	1,52	0,15
MgO	20,11	0,90	11,35	10,80	0,00	23,33	23,59	9,11	9,50	11,78
CaO	0,00	0,15	0,00	0,03	0,18	0,36	0,32	0,03	0,03	0,02
MnO	0,02	0,00	0,01	0,02	0,00	0,29	0,33	0,14	0,12	0,03
FeO	8,21	0,76	3,68	3,56	0,14	21,34	21,44	26,49	25,71	23,60
Fe_2O_3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,34	1,99	0,60
Na_2O	0,67	0,80	0,40	0,92	0,05	0,00	0,00	0,00	0,00	0,00
K_2O	7,79	9,59	0,00	0,00	10,15	0,00	0,00	0,00	0,00	0,00
Total	95,56	96,09	98,72	98,38	97,52	100,77	100,26	98,12	97,45	99,08

Explanation:
Crd – cordierite, Crn – corundum, Opx – orhopyroxene, Phl – phlogopite, Ms – muscovite, Spl – spinel

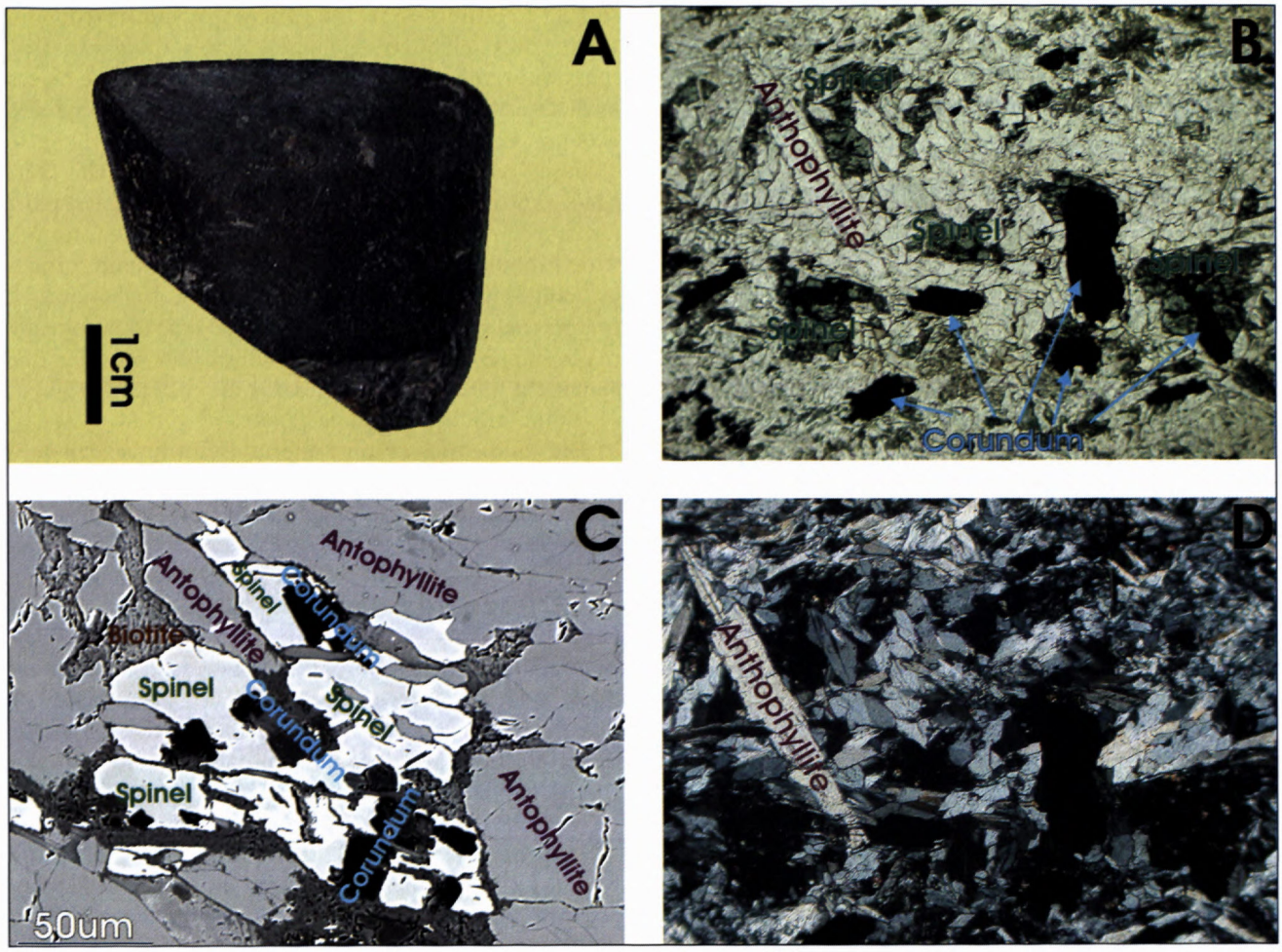

Fig. 7. A - Flat shoe-last axe made from anthophyllite schist with spinel and corundum. Sample B-70A. Site: Bajč-Medzi kanálmi. B - In fine-grained matrix green Al-rich spinels are present. Parallel polars. C - Composition of antophyllite, spinel, corundum and phlogopite in scattered electrons. D - identical with B: crossed polars.

Tab. 3 Representative analyses of plagioclase from greenschists of polished stone artefacts from the site Bajč-Medzi kanálmi.

Sample	amphibole schists			phlogopite anthophyllite schists			phlogopite anthophyllite schists			
	B18/4	B117/1	B117/2	B31/2	B95/3	B229/3	B61/14	B61/9	B70/11	B70/6
	Plg	*Plg*	*Plg*	*Plg*	*Plg*	*Plg*	*Plg*	*Plg*	*Plg*	*Plg*
SiO_2	54,13	59,09	54,05	69,14	47,83	45,73	43,50	43,06	43,31	43,40
Al_2O_3	29,11	26,45	29,19	19,39	33,42	34,72	36,52	36,19	35,38	35,64
CaO	11,53	7,99	11,78	0,36	16,87	18,26	20,29	20,16	20,10	20,08
Na_2O	5,11	7,24	5,12	11,44	2,07	1,26	0,07	0,05	0,06	0,08
K_2O	0,04	0,03	0,02	0,07	0,01	0,00	0,00	0,01	0,05	0,01
Total	99,92	100,80	100,16	100,4	100,2	99,97	100,38	99,47	98,90	99,21
Ab	44,38	62,01	43,97	97,93	18,16	11,10	0,63	0,48	0,57	0,70
Or	0,25	0,15	0,15	0,38	0,07	0,02	0,01	0,03	0,30	0,08
An	55,37	37,84	55,88	1,70	81,77	88,88	99,36	99,49	99,13	99,21

Explanation: Pl – plagioclase, An – anorthite, Or – orthoclase, Ab – albite.

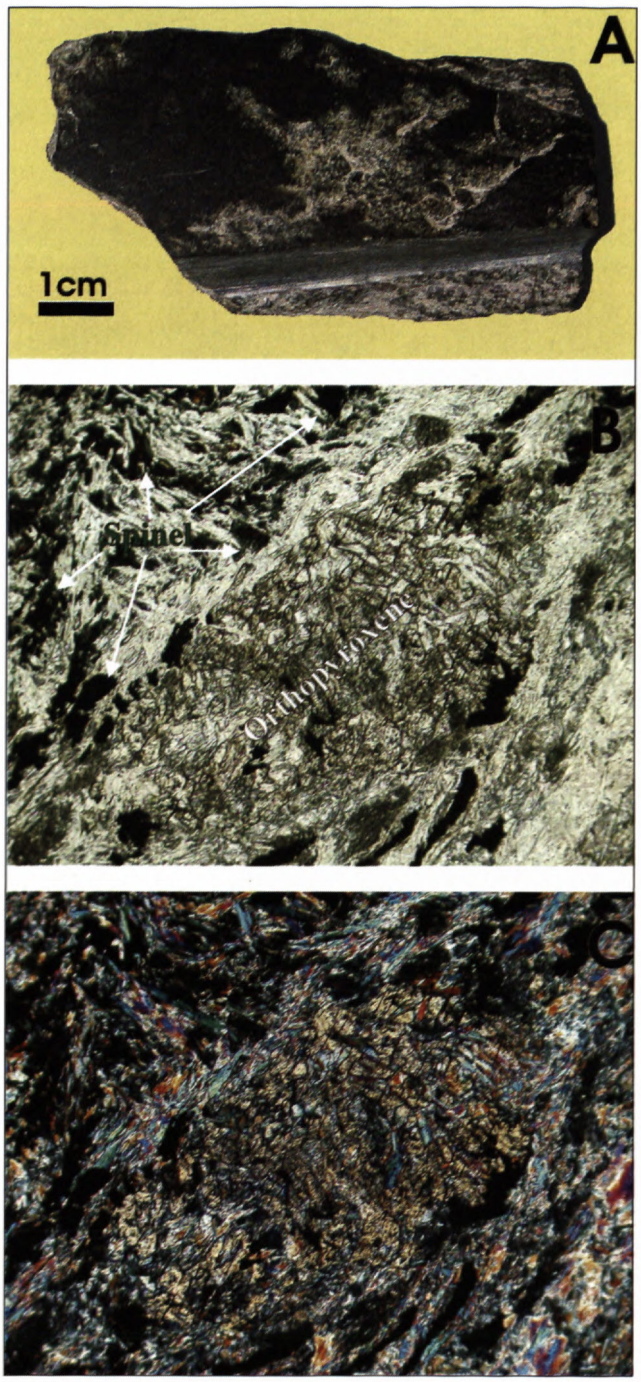

Fig. 8. Grinder made from anthophyllite schist with spinel and corundum. Sample B-61. Site: Bajč-Medzi kanálmi. B - In fine-grained matrix green Al-rich spinels and porphyritic orthopyroxene are present. Parallel polars. C - Identical with B: crossed polars.

ness in chosing the best inorganic raw material types. Neolithic men based on practical knowledge distinguished that some of the raw material types can be used as grinders or saws, meanwhile other are polisheable. This fact is just on the discussed site documented by the find of saws, which have been used for the other stone implement production (Fig. 8). Mentioned saws and grinders are made from the hardest raw material types - from the anthophyllite schists with corundum and Al-rich green spinel. Neolithic stone implements producers choosed for the next elaboration namely fine-grained varieties, meanwhile spots of phlogopite consequently were places of the most intensive destruction (weathering) processes, acted on the ready made implements.

Based on the fact that in the vicinity of the site Bajč-Medzi kanálmi neither do occur rock of the greenschist facies provenience nor their contact-thermic varieties which should be compared with the raw material varieties being raw material of stone Neolithic implements, it follows that raw materials of discussed type (but no ready made implements) were imported on the site. For this statement the leading argument is the occurrence just of saws and grinders on the given site.

The source area of raw material is not yet solved definitelly. Origin of the raw material identified varieties described above as a part of alluvial deposits is of low probability. Among raw matrial type evidently prevail various varieties of the greenschists, among which namely those, consequently influenced by the contact-thermic recrystallization, are characteristic. So we suppose that "specialists" chosed appropriate raw materials just on their in situ occurrences. The nearest occurrences of rock from the contact-thermic aureoles is known to occur in the Malé Karpaty Mts., namely in the zone between Bratislava and Modra (Cambel 1962, Korikovskij et al. 1994, 1995). Mentioned support occurrences of implements made from identical rock-types in the Neolithic/Aeneolithic sites located aroud the Malé Karpaty Mts. (Hovorka et al. 1997). Taking into account high skillfulnes of the Neolithic/Aeneolithic men, even identical roc-types are not known on nowadays surface in the mentioned mountain range, as realistic seems supposition, that mentioned extremely hard rocks (with corundum and Al-rich spinels) were selectively exploited. Changes of morphology (urbanization of the area) should "cover" given rock varieties. So our repeatedly realised field survey in the mentioned area was unsuccesfull til now.

Conclusions

By the use of electron microprobe we studied composition of rock-forming minerals of the most frequrently used raw material varieties of stone implements on the Neolithic site Bajč-Medzi kanálmi. From identified set of minerals present it follows:

a) mineral associations and discriminant minerals (cordierite, Al-rich green spinel, corundum, anorthite, anthophyllite, orthopyroxene) do occurs in rocks, which originated in contact-thermic aureoles in metabasites/greenschists,
b) members of the Middle Neolithic human community occupying site Bajč-Medzi kanálmi based on, by naked eyes observed properties, were abble selectively choose and consequently elaborate rock (raw material) types, which were the most suitable,
c) described raw material (rocks) varieties have the

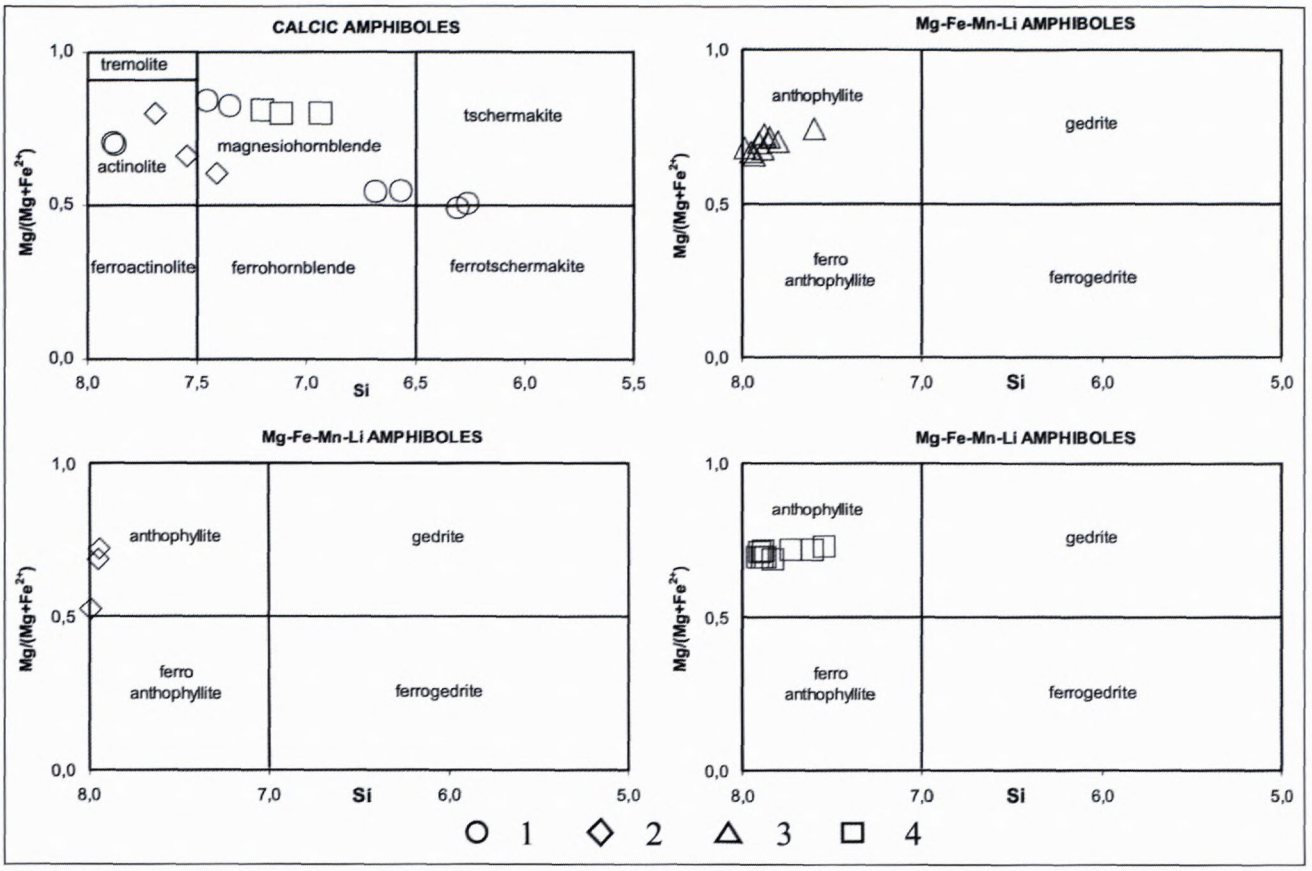

Fig. 9. Amphiboles from the greenschist raw material varieties classification (site: Bajč-Medzi kanálmi) in the Leakes´ et al. (1997) scheme. Analyses are presented in Table 1. Calculation used according to Schumacher (in Leake et al. 1997). Explanation: 1 - amphibole schists, 2 - amphibole schists with anthophyllite, 3 - phlogopite-anthophyllite schists, 4 - anthophyllite schists with spinel and corundum.

most probably their in situ occurrences in the Malé Karpaty Mts, which moumtain chain is of approximately 80-100 kms distance from the site,

d) based on the observed presence of the Neolithic implements made just from identical rock varieties which do occur in the area of the Malé Karpaty Mts. (Hovorka et al. 1997) it shoud be expected that given rock varieties were totally exploited in the past.

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