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The hornblende-plagioclase hornfels from the contact aureole of the Tanvald granite, northern Bohemia – the raw material for Neolithic tools

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Abstract. A hornblende-plagioclase hornfels is described from a new exposure near the village of Jeřmanice, where it is present as a 30–35 cm thick layer within spotted phyllites at the exocontact of the Krkonoše-Jizera granite massif in northern Bohemia. The hornfels layer seems to be part of the Poniklá Group of Ordovician -Upper Silurian age. It corresponds to the metabasites used in the production of Neolithic artifacts (e.g., the Jistebsko archeological site near Jablobec nad Nisou), which were hitherto known only as loose fragments from localities on the lower slopes to the south of the granite ridge between Liberec and Tanvald. New data show that this rock is situated inside the contact aureole of the Tanvald alkali-feldspar granite, its remarkable mechanical strength being due to the effects of contact metamorphism. The hornfels corresponds compositionally to tholeiitic basalt. Its major minerals are amphiboles ranging in composition from the predominate magnesiohornblende to subordinate actinolite, calcic plagioclase, and ilmenite. This rock represents neither a dike nor a lava sheet, but rather a sill or a tuff layer modified by regional and thermal metamorphic reconstruction and tectonic deformation.

Key words: metabasites, “nephrite”, contact metamorphism, mineral whiskers, amphiboles, opaque minerals, Neolithic artifacts

Introduction

Hornblende-plagioclase hornfels occurrences within the southern contact aureole of the Krkonoše-Jizera granite massif, between Liberec and Tanvald in northern Bohemia, have been known since the early description by Milch (1902). Huyer (1914, 1928) recorded seven additional localities along the southern slopes of the ridge. In the literature, this amphibole-rich rock is variously designated as nephrite, actinolite schist, actinolite rock, actinolite hornfels, and greenschist. This rock was used by Neolithic populations for the production of tools because of its remarkable mechanical properties. Among the modern local population this very strong, fine-grained rock of dark green-grey colour was known as “ironstone” (*Eisenstein*). The rock makes a ringing sound when struck with a hammer. Gränzer (1933) published a detail description of this rock and emphasized his recognition that the hornfels was used for the production of Neolithic tools, although this information received little attention. During the following decades, brief notes concerning this rock in the literature dealt mainly with its classification (Watznauer 1934, 1935, Hejtman 1962). Chaloupský et al. (1989) does not mention this rock type and its occurrences are not shown in the accompanying geologic map. Several localities of the amphibole hornfels were recorded at Vinice near the Zadní Zbytky settlement during the course of recent geologic mapping (Klomínský et al. 2000)*. Further field observations indicate the presence of four hornfels horizons, partially exposed in two imperfect outcrops (V. Kachlík, pers. com.).

Tool artifacts produced from this type of hornfels have been found by archeologists at many Neolithic sites in Europe, particularly in the Czech Republic, Germany, and Poland (Štelcl and Malina 1972, Vencl 1975), though the source of the raw material remained uncertain. Gradually, the contention developed that the material originated in northern Bohemia (Přichystal 1991). Bukovanská (1992) pointed out the similarity of the “nephrite” described by Gränzer (1933) from the Maršovický Hill, southeast of Jablonec nad Nisou, and some of the Neolithic implements from various Czech localities. This interpretation was gradually strengthened by comparative studies of the petrography, mineralogy, geochemistry, and petrophysical properties of these stone artifacts and natural fragments presumed to represent the raw material (Šreinová et al. 1997, Šrein et al. 1999, 2000, Přichystal 2000). As a result of increasing interdisciplinary research, a site of large-scale production of stone implements from loose fragments was located near Jistebsko, at the foot of the Černá Studnice mountain between Železný Brod and Jablonec nad Nisou (Šrein et al. in print). Another recently found tool production site near Velké Hamry, 10 km east of Jistebsko, was reported by Přichystal (2002); though a detailed petrographic and mineralogic analysis was beyond the scope of that article.

The above mentioned information shows that this amphibole hornfels attained international importance as a raw material used by Neolithic humans. However, neither archeological excavations nor previous geological research (except for the recent information by V. Kachlík on the Zadní Zbytky locality) have revealed an in situ occur-

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* During the writing of this article a new “nephrite” layer, with a thickness of two metres, was discovered in the well of a house in Velké Hamry, SW of Tanvald.

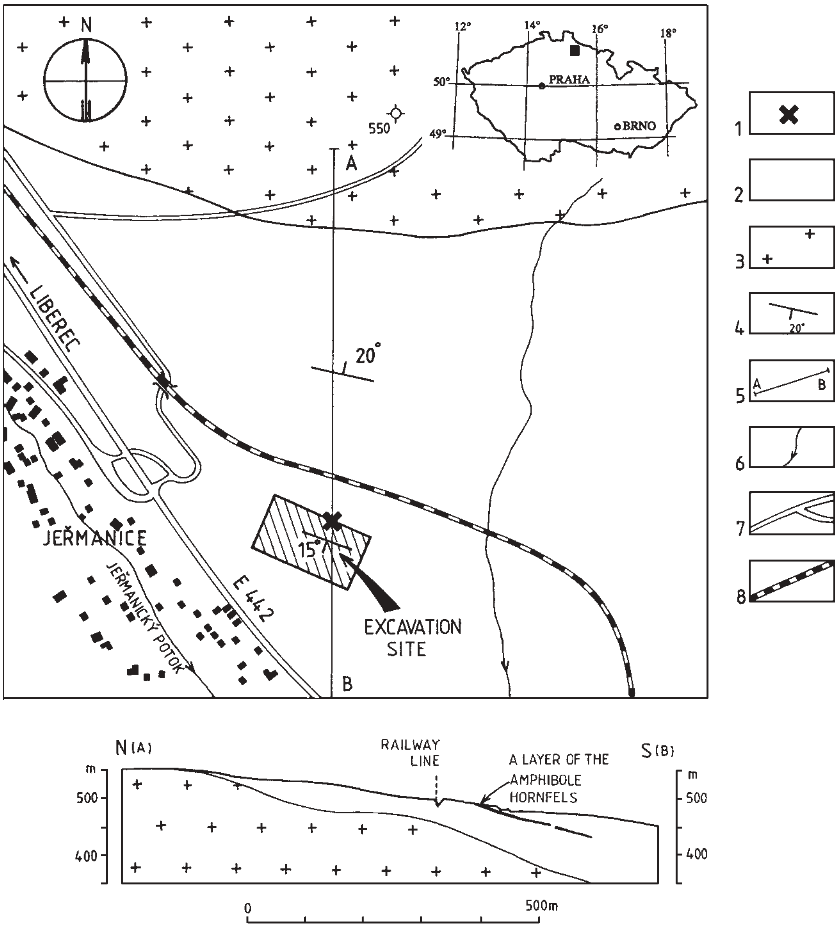

Figure 1. Sketch map of the Jeřmanice – Rádlo locality and geological cross section.
1 – location of hornblende-plagioclase hornfels at the excavation, 2 – contact metamorphosed phyllite to mica schist, 3 – Tanvald type two-mica alkali-feldspar granite, 4 – strike and dip of schistosity, 5 – line of the cross section, 6 – right-hand tributaries of the Mohelka river, 7 – road, 8 – railway line.

Figure 2. Hornblende-plagioclase hornfels layer, 30 cm thick (hammer for scale), at the construction site east of Jeřmanice near Liberec (see Fig. 1). The footwall rock is a spotted sericite-biotite phyllite, also containing andalusite and cordierite.

rence of the amphibole hornfels and its relations to the country rocks.

An in-situ occurrence of the amphibole hornfels was found during the study of a construction site excavation in 2002. This discovery allows the observation of the hornfels in its geological context. The rock is very similar to the material from Jistebsko described by Šrein et al. (2002).

Location and geologic setting

The above mentioned construction site, approximately two hectares in size, is located on a meadow sloping towards the southwest, between road E 442 and the railway line from Liberec, 3 km south of Hodkovice nad Mohelkou (Fig. 1). In autumn 2002 the exposure consisted of three steps exposing the bedrock that had originally been covered by 1 to 3 metres of slope soil and loose rock debris. The predominant type of bedrock ranges from sericite-biotite phyllite to mica schist. Chaloupský et al. (1989) classified these rocks with the Velká Úpa Group, assumed to be of Proterozoic age. Kachlík (in Klomínský et al. 2000) correlated similar schists further to the east with the Poniklá Group of Ordovician-Silurian to Lower Devonian age. These schists exhibit multiphase high-pressure and high-temperature metamorphism with a shallow dipping of schistosity from 15° to 30° to the SSW. All of the rocks exposed by the excavation are affected by contact metamorphism, expressed by 5 mm long elliptical porphyroblasts of cordierite and some andalusite, both of which have been strongly altered into secondary minerals. The porphyroblasts intersect a pre-existing lineation, corresponding to phyllitic crenulation. There are sets of conformable flat veins of milky white quartz, 10 to 25 cm thick and relatively rich in ore minerals (wolframite with subordinate cassiterite), which are the object of a separate study (Klomínský and Táborský 2003). The country rock adjacent to quartz veins is strongly tourmalinized.

The exposure of the hornblende-plagioclase hornfels occurs in the middle of the uppermost level of the excavation. It forms a layer 30 to 35 cm thick, is exposed for 2 metres along its strike, and is perfectly conformable with the country rock phyllite (Fig. 2). Its immediate contacts with footwall and hanging wall phyllite are exposed. No visible alteration effects were observed on either side of the hornfels contact. Loose blocks of the hornfels on both sides of the exposure for a total distance of 200 m indicate the continuation of the layer along strike. Loose blocks of similar, though not always identical, metabasite were observed within lower levels of the construction site. The edge of the alkali-feldspar Tanvald granite is 500 m to the north, where it extends in the E-W direction across the top of Hraničník hill (elevation 603 m), and is approximately parallel to the foliation of the phyllite. The Tanvald granite is considered to be of the oldest Variscan age granite generation of the late-tectonic Krkonoše-Jizera massif (Klomínský et al. 2000). Its muscovite $^{40}Ar/^{39}Ar$ age of 312 ± 2 Ma (Marheine et al. 2002) was reset by the younger Liberec granite, which gives a Pb evaporation age of 304 ±14 Ma (Kröner et al. 1994). The intrusive contact of the Tanvald granite with the phyllites probably slopes gently toward the south. Therefore, the true distance from the layer of hornblende-plagioclase hornfels to the granite body is probably significantly shorter (less than 100 metres) than suggested by the geologic map (see Fig. 1). No traces of Neolithic exploitation of the hornfels have been found in the surroundings of the excavation site; thus, this occurrence probably remained unknown.

Petrography and whole-rock composition

The rock is dark greenish-grey in colour, and too fine-grained to allow its mineral constituents to be identified by the naked eye. The texture is usually massive. Occasionally, a fine and weakly defined compositional layering is seen, particularly in thin sections (Fig. 3). Some pieces carry thin quartz veinlets and lenses parallel with foliation (Fig. 4), which sometimes contain minor scheelite, tourmaline, or veinlets of somewhat coarser amphibole (actinolite, Fig. 5), all of which indicate local hydrothermal alteration related to wolframite-cassiterite mineralization (Klomínský and Táborský 2003). Amphibole is the most abundant component of the hornfels. It forms acicular crystals in radial and felted aggregates. These textural features led earlier petrographers (Gränzer 1933) to conclude that the mineral is actinolite, or *strahlstein* in the German terminology of that time. Besides the dominant amphibole and plagioclase, opaque minerals are relatively abundant and contribute to the bluish, dark-grey colour of the rock. A modal estimate of the mineral assemblage gives 55 % amphibole, 30 % plagioclase, 10–15 % ilmenite, magnetite, pyrrhotite, chromite, and minor quartz. Magnetic susceptibility analyses show considerable variation from 0.4 to 54.5 . 10^{-3} SI units. Ilmenite and minor magnetite are accompanied by pyrrhotite and rare additional sulfides. The ilmenite content contributes to the somewhat elevated density of the rock; Milch (1902) reported a density of 3.05 g/cm^3.

A typical sample of the hornblende-plagioclase hornfels from the excavation site was subjected to wet analysis pro-

Figure 3. Thin-section of the hornblende-plagioclase hornfels showing planar-parallel fabric. Black grains and aggregates correspond to ilmenite, magnetite, and possibly chromite; magnesiohornblende and actinolite form light green aggregates; plagioclase and minor quartz are grey-white. Plane polarized light. Figure width is 10 mm.

Figure 4. A younger lenticular aggregate of quartz with acicular actinolite in the matrix of the hornblende-plagioclase hornfels. Plane polarized light. Figure width is 5 mm.

Figure 5. Detail of the younger veinlets of radial actinolite (transversal and parallel to foliation) and fine chlorite aggregate. Plane polarized light. Figure width is 5 mm.

Table 1. Chemical analyses of hornblende-plagioclase hornfels

	1	2
SiO_2	49.38	49.4
TiO_2	2.51	Trace
Al_2O_3	12.67	17.2
Fe_2O_3	2.22	n.d.
FeO	9.81	15.02
MnO	0.74	n.d.
MgO	8.01	6.06
CaO	11.13	10.60
SrO	0.03	n.d.
Na_2O	0.87	1.62
K_2O	0.30	0.38
P_2O_5	0.27	n.d.
F	0.37	n.d.
H_2O^+	1.85	0.28
H_2O^-	0.10	n.d.
CO_2	0.05	n.d.
total	100.31	100.56

1 – Jeřmanice – Rádlo; analyzed by V. Janovská in 2002, CGS laboratories, Prague.
2 – exact locality unknown, Watznauer (1934).

Table 2. Representative microprobe analyses of ilmenite and magnetite from the hornblende-plagioclase hornfels

	1	2	3	4
SiO_2	0.41	0.35	0.82	0.26
TiO_2	50.30	51.13	51.63	0.49
Al_2O_3	0.00	0.11	0.21	0.20
Cr_2O_3	0.15	0.00	0.00	0.31
Fe_2O_3	3.04	3.34	0.38	67.39
FeO	40.68	39.55	39.85	30.99
MnO	4.65	5.96	6.90	0.11
MgO	0.09	0.24	0.27	0.14
CaO	0.13	0.30	0.07	0.59
total	99.45	100.98	100.13	100.48
Si	0.021	0.017	0.041	0.079
Ti	1.918	1.917	1.946	0.112
Al	0.000	0.006	0.012	0.072
Fe^{+3}	0.116	0.125	0.014	15.470
Fe^{+2}	1.725	1.649	1.670	7.907
Mn	0.200	0.252	0.293	0.028
Mg	0.007	0.018	0.020	0.064
Ca	0.007	0.016	0.04	0.193

Cation numbers are based on 6 (O) for ilmenite, 32 (O) for magnetite. Ferrous/ferric iron is calculated from stoichiometry.

cedures in the laboratory of the Czech Geological Survey, Prague. The analysis is presented in Table 1 and plotted in a TAS diagram together with an older, incomplete, but very similar analysis by Watznauer (1934) of a hornfels sample collected in the vicinity of the southern exocontact of the Tanvald granite (Fig. 6). Two features of the hornfels composition are notable: 1. the rock plots in the field of sub-alkali tholeiitic basalt of island arcs, in which the alkali content is exceptionally low, 2. the rock plots away of the field of the Železný Brod metabasite complex, represented by 35 whole-rock analyses of bimodal volcanics (Chaloupský et al. 1989).

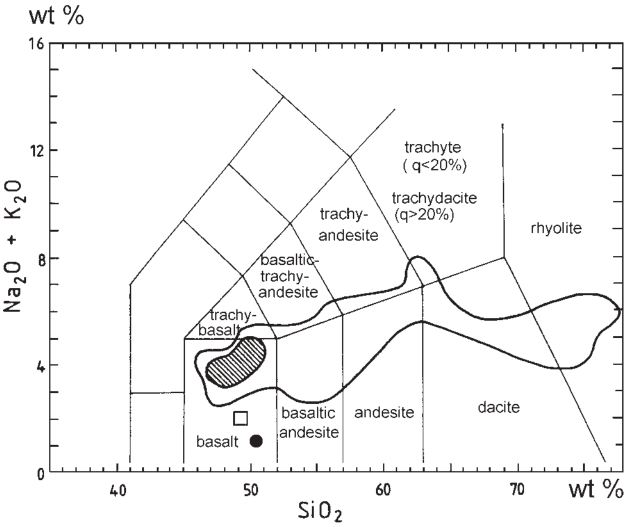

Figure 6. TAS diagram of hornblende-plagioclase hornfels from the Jeřmanice – Rádlo locality (full circles) and of analogous rocks analyzed by Watznauer (1934) from unknown locality (open squares). Diagram after LeMaitre 2002. The contour shows the field of volcanic rocks of the Železný Brod volcanosedimentary complex, based on 35 analyses from Chaloupský et al. (1989); oblique ruling shows maximum frequency of data.

Composition of the major minerals

Electron microprobe analyses of ilmenite, plagioclase, and amphiboles were performed in the laboratory of the Czech Geological Survey, Prague, with Cam Scan 4 equipment and a Link Isis energy dispersion analyzer using 15 kV, 3 nA, and an 80s counting time. For recalculations of minerals the program Minpet was used (Richard 1988).

The ilmenite contains a significant pyrophanite component (10 to 15 mol.%), while the geikielite component is insignificant (analyses 1–3, Table 2). MnO contents of 4.7 to 6.9 wt.% in the ilmenite point to the preferential distribution of Mn into this phase: the associated magnetite contains only 0 to 0.18 wt.% MnO, while the amphiboles also contain significantly lower MnO than the ilmenite. Magnetite shows a very low magnesioferrite content, but somewhat elevated concentrations of ulvöspinel and chromite molecules (analyses 4, Table 2).

The plagioclase in these samples, which is accompanied by minor quartz, is relatively calcium-rich. Its composition varies widely from labradorite to calcic bytownite (An 57 to An 88, Table 3). For comparison, Gränzer (1933) assumed that plagioclase in this rock type to be albite.

The microprobe analyses show that the major amphibole variety in the rock is magnesiohornblende, with a

Table 3. Microprobe analyses of plagioclase from the amphibole-plagioclase hornfels

	1	2	3
SiO_2	52.39	51.46	44.33
TiO_2	0.03	0.00	0.00
Al_2O_3	29.95	29.12	32.88
FeO	0.88	1.27	0.26
MnO	0.23	0.00	0.20
MgO	0.07	0.63	0.17
CaO	11.08	13.12	20.57
Na_2O	3.90	3.65	1.50
K_2O	1.10	0.00	0.14
total	99.63	99.25	100.05
Si	9.571	9.464	8.303
Ti	0.004	0.000	0.000
Al	6.449	6.312	7.258
Fe^{+2}	0.134	0.195	0.041
Mn	0.036	0.000	0.003
Mg	0.019	0.173	0.047
Ca	2.169	2.585	4.128
Na	1.381	1.302	0.545
K	0.256	0.000	0.033
% An	56.97	66.51	87.71
% Ab	36.29	33.49	11.58
% Or	6.74	0.00	0.71

Cation numbers are based on 32 (O).

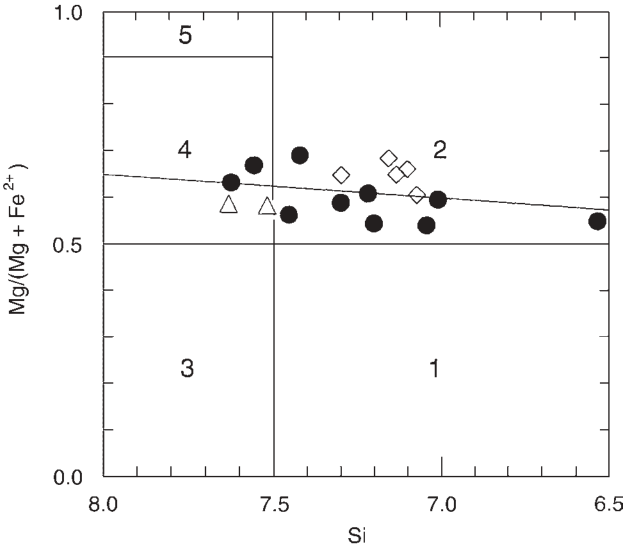

Figure 7. Plot of the composition of calcic amphiboles (Leake et al. 1997) from the hornblende-plagioclase hornfels from the Jeřmanice – Rádlo locality. Full circles = amphiboles of Table 4a, open diamonds = typical "whisker" of Table 4b (1–5), open triangles = actinolites from the secondary transversal veins of Table 4b (6 and 7). Composition fields: 1 – ferrohornblende, 2 – magnesiohornblende, 3 – ferroactinolite, 4 – actinolite, 5 – tremolite. The trend line is constructed for the whole sample set.

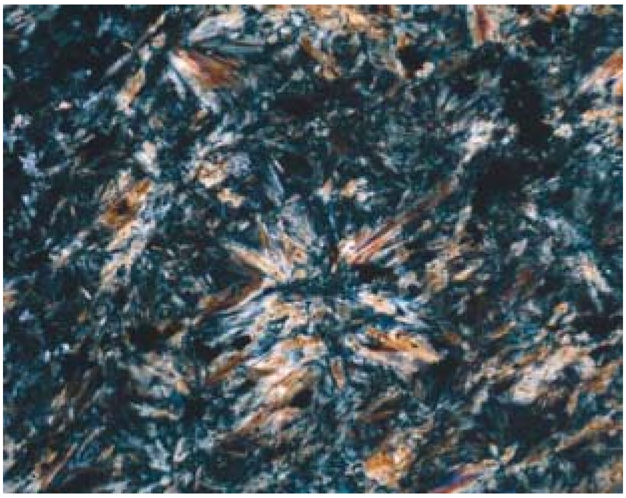

Figure 8. Radial arrangement of the hornblende crystals showing the "whisker" texture that is typical for this hornblende-plagioclase hornfels. Crossed nicols. Figure width is 0.9 mm.

Mg/Fe ratio close to the boundary with ferrohornblende (Table 4a, Fig. 7). Regardless of chemical composition, all amphiboles show radial, divergent, and felted textures (Fig. 8). It is this particular texture of the acicular amphiboles that is responsible for the exceptional tensile strength of the hornfels. The fabric of divergent and interwoven\ felted elongate crystals acts almost like the fiber crystals applied in whisker technology for deformation-resistant plastic materials and metal alloys. This kind of amphibole structure in the hornfels could be thus classified as "mineral whiskers". The microprote analyses of typical specimens of these extremely long and thin amphiboles has shown them to be of magnesiohornblende composition (Table 4b, Fig. 7). Conversely, the amphiboles in secondary transversal veinlets, often of plume-form, are typical actinolites (see also Table 4b, Fig. 7).

Using the geothermometer of Blundy and Holland (1990), compositional data for the plagioclases and amphiboles in immediate contact (i.e. analysis 3, Table 3, and analysis 4, Table 4) gave an equilibration temperature of 701°C, assuming a pressure of 3 kbar.

Discussion

The data described above indicate that this hornfels is analogous to the metabasite occurrences reported from the contact aureole of the alkali-feldspar Tanvald granite by Milch (1902). Gränzer (1933) and Bukovanská (1992) recognized the archaeological importance of these hornfels occurrences. The discovery of Neolithic tool-production sites by Šrein et al. (2002) and Přichystal (2002) was decisive in this respect.

The hornfels studied in this paper and the metabasite from the Jistebsko locality on the slope of the Maršovický hill (described by Šrein et al. 2002) are analogous in terms of macroscopic appearance, exceptional hardness, and the correspondence between their mineralogical composition and texture. However, there are also some notable differences between them, which are apparently due to regional variations in composition. For example, the samples from

Table 4a. Microprobe analyses of amphiboles from the amphibole-plagioclase hornfels

	1	2	3	4	5	6	7	8	9	10
	MgHbl	MgHbl	MgHbl	MgHbl	MgHbl	MgHbl	MgHbl	MgHbl	Act	Act
SiO_2	43.86	47.50	46.93	48.41	49.15	49.83	51.65	50.94	52.64	52.50
TiO_2	0.17	0.41	0.26	0.17	0.13	0.20	0.11	0.30	0.31	0.18
Al_2O_3	11.39	7.07	6.76	5.82	6.25	5.33	4.66	4.02	3.84	2.96
Cr_2O_3	0.10	0.12	0.19	0.00	0.03	0.00	0.20	0.00	0.00	0.07
FeO	18.58	17.67	19.26	18.99	16.55	17.37	13.58	18.34	14.32	15.72
MnO	1.00	0.84	1.18	1.20	0.84	1.32	0.74	1.26	0.16	0.40
MgO	9.42	11.41	10.02	10.43	11.91	11.69	14.51	11.43	14.42	13.55
CaO	11.26	11.46	11.19	11.73	11.96	11.64	12.03	11.79	12.18	12.28
Na_2O	1.56	1.25	1.23	0.95	0.78	0.91	0.87	0.72	0.52	0.35
K_2O	0.33	0.17	0.01	0.00	0.11	0.19	0.00	0.00	0.08	0.10
total	97.67	97.90	97.03	97.70	97.71	97.48	98.35	98.80	98.47	98.11
TSi	6.533	7.007	7.041	7.198	7.215	7.297	7.419	7.452	7.554	7.620
TAl	1.467	0.993	0.959	0.802	0.785	0.703	0.581	0.548	0.446	0.381
CAl	0.531	0.235	0.235	0.218	0.295	0.216	0.207	0.145	0.203	0.126
CCr	0.000	0.014	0.023	0.000	0.003	0.000	0.023	0.000	0.000	0.008
CFe^{3+}	0.588	0.465	0.498	0.412	0.342	0.334	0.227	0.294	0.180	0.187
CTi	0.019	0.045	0.029	0.019	0.014	0.022	0.011	0.033	0.033	0.020
CMg	2.092	2.509	2.241	2.312	2.606	2.552	3.107	2.493	3.085	2.932
CFe^{2+}	1.695	1.680	1.900	1.949	1.686	1.793	1.380	1.950	1.448	1.703
CMn	0.063	0.052	0.074	0.090	0.052	0.083	0.045	0.085	0.010	0.025
BFe^{2+}	0.031	0.035	0.019	0.000	0.003	0.000	0.024	0.000	0.050	0.017
BMn	0.064	0.053	0.076	0.061	0.052	0.081	0.045	0.071	0.010	0.025
BCa	1.797	1.811	1.799	1.869	1.881	1.826	1.851	1.848	1.873	1.910
BNa	0.108	0.101	0.107	0.070	0.063	0.093	0.079	0.081	0.068	0.048
ANa	0.344	0.257	0.251	0.204	0.159	0.166	0.163	0.123	0.077	0.050
AK	0.063	0.032	0.002	0,000	0.021	0.035	0.033	0.000	0.015	0.019

Cation numbers are calculated on the basis of 23 (O), the relation (15-NK + 13-CNK)/2 and Fe^{2+}/Fe^{3+} ratio were calculated following Richard (1988). MgHbl = magnesiohornblende, Act = actinolite.

Jistebsko contain predominantly magnesiohornblende along with barroisite and cummingtonite, none of which have been found in the hornfels from the locality described in this paper. Amphiboles from our locality contain significantly lower contents of $K_2O + Na_2O$ and higher MnO. The Mn contents in the ilmenite of our hornfels samples is an order of magnitude higher than in the rock from Jistebsko, and the plagioclase from Jeřmanice shows a wider compositional range. At present, we are unable to compare whole-rock compositions from the two localities, as Šrein et al. (2002) have not yet published their analyses, while the report by Přichystal (2002) does not provide the data necessary for petrologic correlation.

However, the data reported by the present authors puts an end to the prolonged variation in terminology of the hornblende-plagioclase hornfels metabasites from localities between Liberec and Tanvald. The designation of these rocks as nephrite, introduced by Gränzer (1933; modified to nephritoid by Bukovanská 1992), was refuted by Watznauer (1934, 1935), who instead recommended the name "actinolite rock" (Actinolithfels). Hejtman (1962) suggested that the latter term be used for the massive rocks, and "actinolite schist" for the foliated varieties. However, actinolite is neither the sole nor the dominant amphibole in these rocks. Moreover, these rocks are not monomineralic actinolite (or tremolite) rocks, as should be the case if they were to be classed as nephrite. Přichystal (2002) considered them to be greenschists, probably because greenschists are common in the Železný Brod volcanosedimentary complex outside the contact aureole, but also because the hornfels shows the effects of contact metamorphism more weakly at his locality near Velké Hamry. The hornblende-plagioclase hornfels from the new locality exhibits apparent recrystallization textures under amphibole hornfels facies conditions, and is short on typical greenschist minerals (albite, chlorite, and dominant actinolite). However, this statement should not be taken to mean that small layers of greenschists, or rather albite-epidote amphibolites, do not occur in places outside the granite contact aureole within the vicinity of our locality.

Šrein et al. (2002) used the name "amphibole hornfels" for the particular rock type used for the Neolithic artifacts. In naming this rock a hornblende-plagioclase hornfels, we supplement the latter term by acknowledging the rock's

Table 4b. Microprobe analyses of whisker-like amphiboles (1–5) and of actinolites (6 and 7) in secondary transversal veins

	1	2	3	4	5	6	7
	MgHbl	MgHbl	MgHbl	MgHbl	MgHbl	Act	Act
SiO_2	46.86	47.85	48.15	48.29	49.57	50.19	51.45
TiO_2	0.33	0.21	0.26	0.36	0.13	0.25	0.16
Al_2O_3	7.36	7.94	6.94	6.48	5.93	4.07	3.38
Cr_2O_3	0.14	b.d.	b.d	0.02	0.12	0.15	b.d
FeO	15.94	14.33	15.00	16.34	15.06	16.44	16.51
MnO	0.32	0.73	0.59	0.79	0.57	0.43	0.56
MgO	11.58	12.44	12.67	13.06	12.89	11.95	12.25
CaO	11.21.	10.84	11.23	9.98	11.26	11.62	11.77
Na_2O	1.20	1.39	1.26	1.20	1.05	0.78	0.76
K_2O	0.08	b.d.	0.07	0.12	0.13	0.12	b.d.
total	95.02	94.74	96.17	97.64	96.70	95.98	96.83
TSi	7.070	7.099	7.132	7.155	7.296	7.517	7.628
TAl	0.930	0.901	0.868	0.845	0.704	0.483	0.372
CAl	0.397	0.486	0.343	0.263	0.324	0.235	0.218
CCr	0.017	0.000	0.000	0.002	0.014	0.018	0.000
CFe^{3+}	0.301	0.358	0.339	0.670	0.310	0.145	0.126
CTi	0.037	0.023	0.029	0.039	0.014	0.028	0.018
CMg	2.604	2.751	2.798	2.826	2.828	2.668	2.708
CFe^{2+}	1.643	1.336	1.454	1.151	1.475	1.878	1.895
CMn	0.020	0.0045	0.037	0.048	0.035	0.027	0.035
BFe^{2+}	0.067	0.084	0.065	0.162	0.069	0.036	0.025
BMn	0.021	0.046	0.037	0.049	0.036	0.027	0.035
BCa	1.812	1.723	1.782	1.552	1.776	1.865	1.870
BNa	0.100	0.147	0.116	0.166	0.119	0.072	0.070
ANa	0.251	0.253	0.246	0.172	0.180	0.154	0.149
AK	0.015	0.000	0.013	0.022	0.024	0.023	0.000

Recalculations and abbreviations of analyses as in Table 4a.

plagioclase content and by specifying the prevailing amphibole as hornblende, which rightly corresponds to the mineralogical composition of these rocks (or more precisely as magnesiohornblende – calcic plagioclase hornfels) and to the effects of contact metamorphism.

Conclusions

The present discovery of hornblende-plagioclase hornfels in a construction-site excavation provides reliable information on the geological setting of this archaeologically important rock. As the previous literature exclusively concerned material found as loose blocks and fragments, there had been a wide range of interpretations relating to this amphibole hornfels. However, the exposure described here clearly shows the position of the hornfels as a layer in the local phyllite-mica schist unit.

The present data invalidates Huyer's (1928) and Watznauer's (1935) opinion that the mineralogical composition and texture of this rock are not related to contact effects of a Tanvald type granite. Furthermore, Watznauer's assumption of a high-pressure origin for the hornfels is not supported by the new data. An opposing view published by Milch (1902) and Gränzer (1933) on the role of contact metamorphism in the recrystallization of this hornfels is supported by our observations, which include the proximity of the granite to the hornfels, the presence of spotted phyllites in the hanging wall and footwall of the hornfels layer, and the microstructural reconstruction of the hornfels metamorphic protolith. Considering the relatively gentle dip of the granite contact below the phyllite unit, it is probable that the distance of the hornfels exposure to the granite is less than 100 m.

The hornblende-plagioclase hornfels forms a < 0.5 m layer, conformable to the schistosity of the enclosing phyllite. As indicated in the 1 : 50,000 geologic map (Watznauer 1935), the hornfels can be followed, using loose blocks and fragments, as a line of discontinuous segments extending along strike for a distance of 15 km: from the new exposure near Rádlo, through Jistebsko, and up to Velké Hamry. The horizon recurs at several levels in some places. No occurrences have been recorded further east in the contact zone of the Krkonoše-Jizera massif, where Tanvald type alkali-feldspar granite is absent.

The dimensions of the blocks and fragments found at the presently known localities do not exceed the width of the layer observed at the newly exposed site. The metabasite layer probably represents either an original lava sill or a tuff layer, subsequently modified by deformation. This would suggest that the rock is either synchronous with the Upper Silurian to Lower Devonian sediments of the Poniklá Group, or somewhat younger.

The small width of the metabasite layer and the fact that exploitation of this material was limited to a depth of two or three metres could suggest that the material was mostly of local significance. However, considering the regional extension of this hornfels layer, the quantity of material available amounts to around 10^4 tons. This quantity was apparently sufficient for providing raw material for Neolithic communities throughout Central Europe. The maximum frequency of the occurrence of artifacts made from the hornblende-plagioclase hornfels from the lower slopes of the Černá Studnice ridge, as indicated by Šrein et al. (2002) and Přichystal (2002), has been recorded at sites of the stroke-ornamented ware culture (for example at Mšeno, in Přichystal 2002). These relations show that the industrial use of this hornfels for tool production took place approximately 7000 years ago.

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