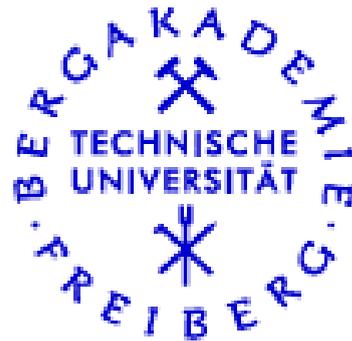


Joint SGA Student Chapter

Prague-Freiberg



**Regionally Metamorphosed Skarns of the
Bohemian Massif, and the Kutná Hora Ore
District**

Field Trip Guidebook

Kutná Hora, Czech Republic

April 2 to 3, 2004

Table of contents

Preface

Geological background – a brief geology of the Bohemian Massif

Introduction – Terminology, classification, and composition of skarn deposits

Problematic of regionally metamorphosed skarns in the Bohemian Massif

1st. day

Locality No. 1, Zliv near Kácov, Ca-Fe skarn

Locality No. 2, Vápenka near Kácov, reaction skarn

Locality No. 3, Holšice near Zruc nad Sázavou, Ca-Fe-Al skarn

Locality No. 4, Rendejov near Zruc nad Sázavou, beryl-columbite pegmatite

Locality No. 5, Vlastejovice near Ledec nad Sázavou, Ca-Fe skarn(-oid)+ pegmatites

2nd. day

Historical, geological and depositional background of Kutná Hora ore district

Locality No.6, quarry in front of the Vrba`s mill, alpine type veins minerals

Locality No.7, Vrba`s mill, slag dump+secondary mineralization

Locality No. 8, St. Anthony de Padua gallery, Sb-Ag mineralization

Locality No. 9, Kank - State Natural Preservation “Na Vrších”, Upper-cretaceous onshore reef facie

Locality No. 10, Staroceské zone, medieval ore dumps+secondary mineralization

References

Preface

This Field Trip Guidebook presents condensed description of ten localities of different skarn occurrences in Moldanubian zone of the Bohemian Massif and some interesting geologic places in the Kutná Hora ore district. The brief introduction to the geological development of the Bohemian Massif is focused on the northern part of the Moldanubian Zone and related regional-geological unit – Kutna Hora Unit. The general skarn chapters include general information on this type of the deposit in the entire world, and the special situation of the regionally metamorphosed skarn deposits of the Bohemian Massif (unclear genesis). The general chapter of Kutná Hora ore district contains history of mining in this town, geologic and depositional background of ore resources, and brief mineralogical description of the deposit.

First day we try to present individual skarn localities and related pegmatites with different geological, mineralogical and geochemistic conditions (and probably with different origin). We focus on some skarn localities at Moldanubian Zone, especially so-called “Posázavské” (near Sázava river) skarns.

Second day morning we visit southern part (silver rich) of the Kutná Hora ore district with localities of Ag-Sb mineralization, and interesting localities of slag dump and Alpine type veins mineralization. In the afternoon we shift to northern part of the Kutná Hora ore district (Kank deposit - silver poor, sulphide rich), where we visit the State Natural Preservation (paleontologic locality) and some reminders of the old (Middle Ages) and recent mining activity + mineralogic locality of As secondary minerals.

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Geologic background – a brief geology of the Bohemian Massif

(according to Novák et al. 2003)

The Bohemian Massif is the easternmost part of the Variscan orogenic belt spanning western and central Europe. The Moldanubian Zone is the most internal part of the orogenic belt (fig. 1). The northern and northwestern parts of the Bohemian Massif belong to the Saxothuringian Zone and Rhenohercynian Zone. The Cadomian crystalline basement, the Brunovistulicum, is exposed on the eastern margin as the Brno Batholith. The Bohemian Massif is comprised of Precambrian and Palaeozoic units and Triassic to Tertiary platform cover.

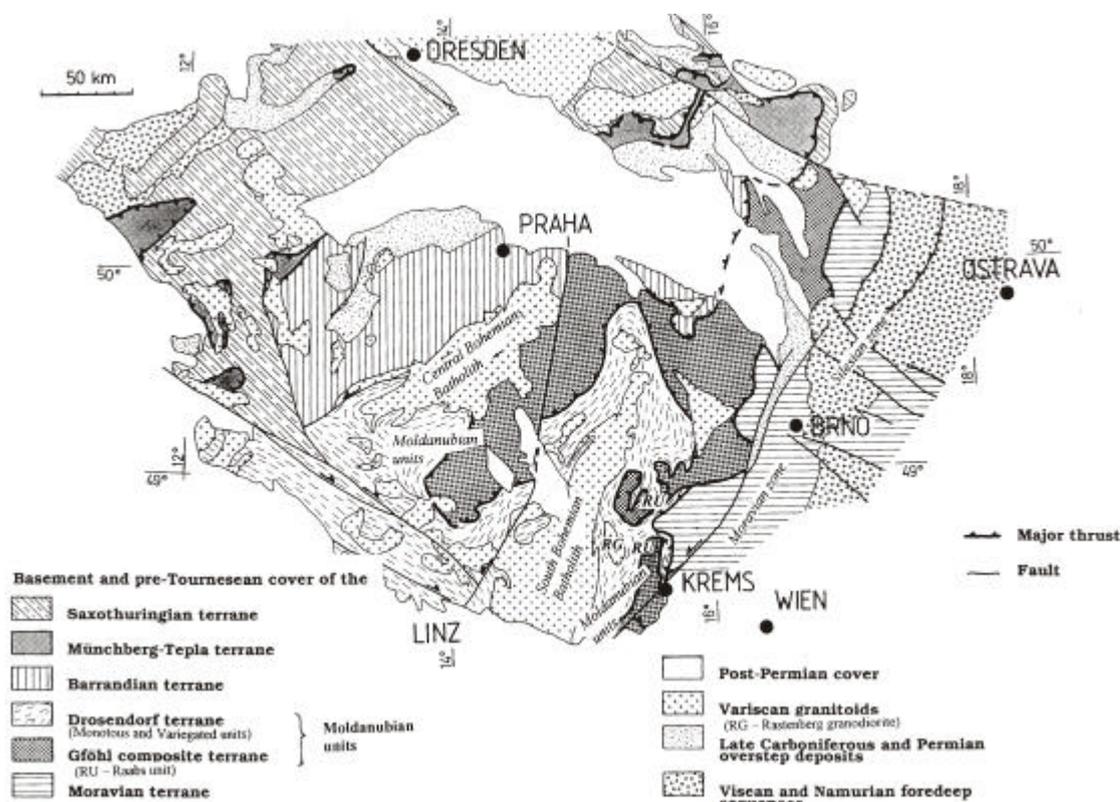


Fig. 1. Simplified tectonic map of the Bohemian Massif (from Neubauer & Handler 2000).

Moldanubian Zone

The Moldanubian Zone comprises first day field trip localities (Zliv, Vápenka, Holšice, Vlastejovice). The localities closed to the Kutná Hora ore deposit are located in the Kutná Hora Unit. Attempts at geological divisions of the Moldanubian Zone include lithostratigraphic (Zoubek 1988), tectonic (Fuchs & Matura 1976), and terrane (Matte et al. 1990) criteria. The following terranes were defined: (i) Gföhl terrane, named originally as the Gföhl nappe (Fuchs & Matura 1976), includes HP granulites associated with pyrope- and spinel-peridotites, pyroxenites, eclogites, leucocratic migmatites, orthogneisses, paragneisses, skarns, amphibolites and metagabbros. (ii) Drosendorf terrane (Drosendorf nappe in Austria, Tollman 1982) includes the Variegated Group and the Monotonous Group (Matte et al. 1990). It comprises meta-greywacke and meta-argilic gneisses with marble, calc-silicate gneiss, graphite gneiss, quartzite, amphibolite, and metagabbro layers.

An alternative approach for the division of the Moldanubian Zone is provided by geochronological data supported by geological, petrological, and geochemical information. They indicate the presence of ancient crustal segments, which are older than the majority of volcanosedimentary units. Examples include tonalitic to dioritic Svetlík orthogneiss in southern Bohemia, dated by zircon U-Pb age at 2100 Ma (Wendt et al. 1993) and the more extensive Dobra gneiss in Lower Austria with a zircon U-Pb age of 1380 Ma (Gebauer & Friedl 1994). Both orthogneiss units probably represent tectonically displaced segments of the old crust, on which the Variegated Group (Drosendorf terrane) was deposited.

Kutná Hora crystalline Unit (and also Svratka Unit) has many similarities with Moldanubian zone (e.g. evidence of subcrustal and mantle derived rocks, and Gföhl Unit,...), and therefore it is sometimes joined to Moldanubian Zone (e.g. Neubauer & Handler 2000), although of general lower metamorphic facies of the rocks of the Kutná Hora (and Svratka) Unit.

The Moldanubian Zone represents a crustal (and upper mantle) stack of allochthonous units assembled during the Variscan orogen and modified by several events of superimposed deformation and metamorphic recrystallizations. Three major metamorphic events were recognised: a HT-HP metamorphism developed particularly in granulitic, eclogitic and skarn rocks; a HT-MP regional metamorphism (kyanite, staurolite) widespread over many parts of the Moldanubian region; evidently later prograde major metamorphic events include HT-LP (periplutonic) regional metamorphism (cordierite, andalusite), which accompanying intrusions of late Variscan plutons. Extensional deformations, accompanying collapse of the overthickened crust, took place under amphibolite and locally greenschist facies conditions and may be related to the late HT-LP periplutonic events. These processes are responsible for the uniformity of large areas of gneisses and migmatites.

Ultramafic rocks of upper mantle derivation are inhomogeneous with respect to their age and structural relations. The majority of dated examples of peridotites, pyroxenites and eclogites belonging to the Gföhl Unit yield ages near 340, and in some parts 380 Ma (Medaris et al. 1995, Beard et al. 1991, 1992, Carswell & Jamtveit 1990).

Variscan and less abundant pre-Variscan granitic rocks, highly variable in composition, are widespread all over the region. Isolated bodies of pre-Variscan orthogneiss (tonalite, diorite to tourmaline leucogranite) belong likely to several distinct generations (cf. Wendt et al. 1993, Gebauer & Friedl 1994, Vrána & Kröner 1995). Five genetic groups of the Variscan granitoids were distinguished by Finger et al. (1997): Late Devonian to Early Carboniferous I-type granite (ca. 370-340 Ma); Early Carboniferous, deformed S-type granite/migmatite (ca. 340 Ma); Late Visean and Early Namurian S-type and high-K, I-type granitoids (ca. 340-310 Ma); Post-collisional epizonal I-type granodiorites and tonalites (ca. 320-290 Ma); Late Carboniferous to Permian A-type leucogranites (ca. 300-250 Ma).

Numerous barren granitic pegmatites of different origin are widespread throughout the Moldanubian Zone. Several populations of abundant LCT rare-element pegmatites (Rendejov) (beryl and complex (Li) type; monazite U-Pb age of 336 Ma; Novák et al. 1992), and rare NYF pegmatites were found (Novák et al. 1992). The present level of understanding the relationship between rare-element pegmatites and fertile granites is poor; however, the LCT pegmatites are not likely related to large batholites such as the Moldanubian Batholith, Central Bohemian Batholith, whereas large durbachite plutons seem to be fertile for NYF pegmatites.

Geochronological data of skarn rock are rare. Nd isotopic dating of garnet-pyroxene skarn from Slatina (Svratka Unit - Gföhl Nappe of the Moldanubian Zone) indicates a major metamorphic event at 415 ± 24 Ma (Pertold et al. 2000). As the closure temperature of the Nd diffusion in garnet is high, probably in excess of 650 °C, the obtained ages are interpreted as being close to the garnet growth in course of the high-grade metamorphism. However the age of protolith is unclear. The Pb-Pb age of some galenites of skarns and rocks related to skarn type of the Moldanubian Zone and the Lugicum (Pertold & Stehlík 1978) shows ages around 800 Ma.

Introduction – Terminology, classification, and composition of skarn deposits

Skarn deposits are one of the more abundant ore types in the earth's crust and have been the subject of numerous studies over the years (Burt 1982, provides a useful annotated historical bibliography). In addition to general academic interest, skarns also have been the subject of intense exploration activity throughout the world. One of the most exciting new discoveries is the Antamina skarn deposit, which at full production will be the world's third largest producer of concentrates, will rank third and seventh in the world, respectively, for Cu and Zn, and will be within the lowest quartile of global production (Redwood 1999).

Skarn is relatively simple rock type defined by its mineralogy that reflects the physical and chemical stability of the constituent minerals rather than implying any particular geological setting or protolith composition (e.g. Meinert 1992). Skarns occur on all continents and in rocks of almost all ages. Although the majority of skarns are found in lithologies containing at least some limestone, they can form in almost any rock type, including shale, sandstone, granite, iron formation, basalt, and komatiite. Skarns can form during regional or contact metamorphism and from variety of metasomatic processes involving fluids of magmatic, metamorphic, meteoric, and/or marine origin. Although most are found adjacent to plutons (fig. 4) (most known mineralised skarns formed by replacement of carbonate and/or mafic to intermediate igneous rocks), they also can occur along faults and major shear zones, in shallow geothermal systems, on the bottom of the sea floor, and at lower crustal depths in deeply buried metamorphic terranes. In addition to this geologic variability, skarns have been mined for a variety of metals, including Fe, W, Cu, Pb, Zn, Mo, Ag, Au, U, REE, F, B, and Sn.

Although there are earlier descriptions of deposits now known to contain skarn, the first known published use of the term "skarn" is by Törnebohm (1875). Among several excellent descriptions, translated by (Meinert et al. 2000), is the following: "As subordinate layers in the feldspar-poor felsic volcanic rocks, there appear peculiar dark rocks which also are the ore's host rock. These rocks are in the Persberg area denoted „skarn", a word which likely can be used as a collective term for all such odd rocks occurring alongside the ores". The word skarn was used for the first time by the old miners in Bergslagen area (medieval to contemporary Cu, Fe, and Ag mines in Sweden) and originally have a pejorative connotation in Swedish meaning crap and whore (IAGOD-excursion guide-book 1986).

The mineralogy of the skarn depends on factors including the composition of both the intrusive and carbonate rocks; the structural or relative permeable nature of the host rocks; and the level of intrusion. The new minerals are typically coarse-grained crystals that grow over or replace the fine-grained or massive host rock of intrusion (endoskarn) and carbonate-rich rock (exoskarn) (fig. 4). The calc-silicate minerals include garnet (calcium-rich grossularite and andradite to magnesium-rich pyrope), pyroxene (diopside to hedenbergite +/- johannsenite), epidote, olivine (forsterite to fayalite), wollastonite, amphibole (actinolite-tremolite to hornblende) and scapolite.

Skarns can be subdivided according to several criteria. Exoskarn and endoskarn are common terms used to indicate a sedimentary or igneous protolith, respectively. Magnesian and calcic skarn can be used to describe the dominant composition of the protolith and resulting skarn minerals. Such terms can be combined, as in the case of magnesian exoskarn, which contains forsterite-diopside skarn formed from dolostone.

Calc-silicate hornfels (fig. 2) is a descriptive term often used for the relatively fine-grained calc-silicate rocks that result from metamorphism of impure carbonate units such as silty limestone or calcareous shale. Reaction skarn (fig. 2) can form from isochemical metamorphism of thinly interlayered shale and carbonate units where metasomatic transfer of components between adjacent lithologies may occur on a small scale (perhaps centimetres) (e.g. Vidale 1969; Zarayskiy et al. 1987). Skarnoid (fig. 3) is a descriptive term for calc-silicate rocks which are relatively fine-grained, iron-poor, and which reflect, at least in part, the compositional control of the protolith (Zharikov 1970). Genetically, skarnoid is intermediate between a purely metamorphic hornfels and a purely metasomatic, coarse-grained skarn.

For all of the preceding terms, the composition and texture of the protolith tend to control the composition and texture of the resulting skarn. In contrast, most economically important skarn deposits result from large-scale metasomatic transfer, where fluid composition controls the resulting skarn and ore mineralogy. This is the mental image that most people share of a "classic" skarn deposit. Ironically, in the "classic" skarn locality described by Törnebohm at Persberg, skarn has developed during regional metamorphism of a mostly calcareous Proterozoic iron formation. This reinforces the importance of Einaudi et al.'s (1981) warning that the words "skarn" and "skarn deposits" be used strictly in a descriptive sense, based upon documented mineralogy, and free of genetic interpretations.

Not all skarns have economic mineralization; skarns, which contain ore, are called skarn deposits. In most large skarn deposits, skarn and ore minerals result from the same hydrothermal system even though there may be significant differences in the time/space distribution of these minerals on a local scale. Although rare, it is also possible to form skarn by metamorphism of pre-existing ore deposits as has been suggested for Aguilar,

Argentina (Gemmell et al. 1992), Franklin Furnace, USA (Johnson et al. 1990), and Broken Hill, Australia (Hodgson 1975).

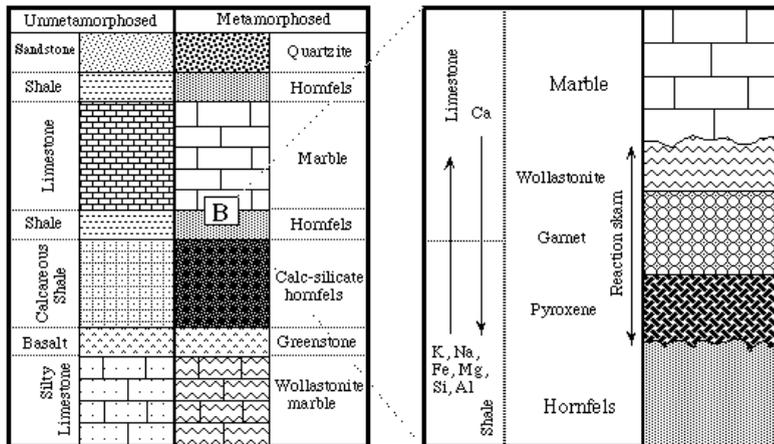


Fig. 2. Types of skarn formation: A) Isochemical metamorphism involves recrystallization and changes in mineral stability without significant mass transfer. B) Reaction skarn results from metamorphism of interlayered lithologies, such as shale and limestone, with mass transfer between layers on a small scale (bimetasomatism). (from <http://www.wsu.edu:8080/~meiner t/skarnHP.html>)

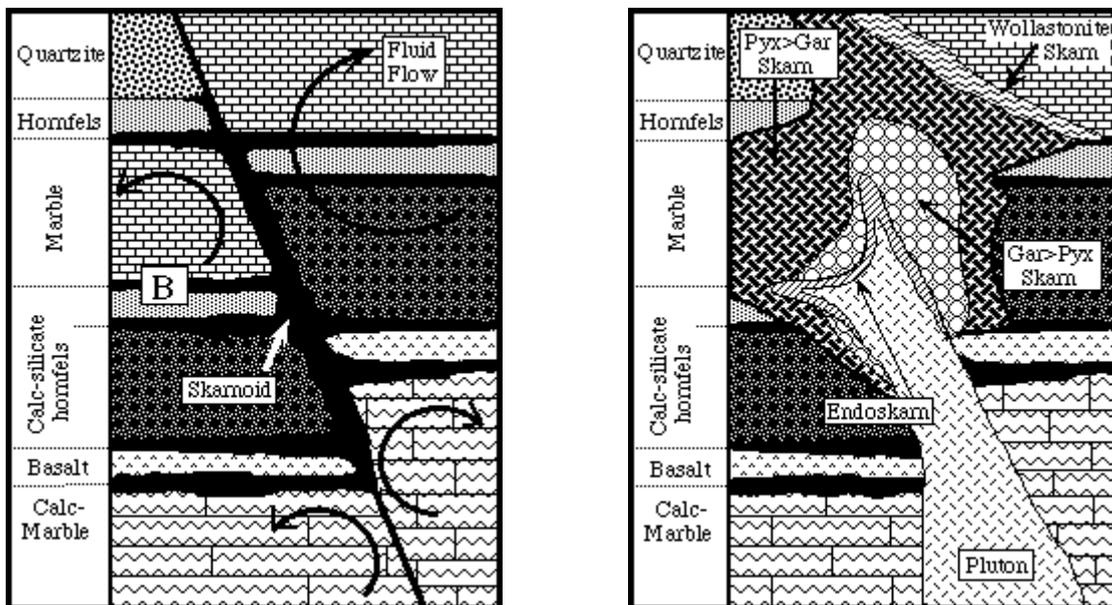


Fig. 3. Skarnoid results from metamorphism of impure lithologies with some mass transfer by small-scale fluid movement. The fluid-controlled metasomatic skarn typically is coarser grained and does not as closely reflect the composition or texture of the immediately surrounding rocks. (from <http://www.wsu.edu:8080/~meiner t/skarnHP.html>)

Fig. 4. Zonation of most skarns (classical) reflects the geometry of the pluton contact and fluid flow. Such skarns are zoned from proximal endoskarn to proximal exoskarn, dominated by garnet. More distal skarn usually is more pyroxene-rich and the skarn front, especially in contact with marble, may be dominated by pyroxenoids or vesuvianite. (from <http://www.wsu.edu:8080/~meiner t/skarnHP.html>)

GEOLOGY

Skarns usually appear in groups. The skarn bodies appear in areas covered by extensive complexes of orthogneisses and their migmatites (also of Gföhl type) or in close proximity to isolated orthogneiss bodies. There are also associated with zones of calc-silicate horizons, ultrabasic bodies, and granulites. In contrast they are absent in large areas formed exclusively by monotonous biotite-sillimanite paragneisses and their migmatites, as are the areas on both E and W sides of the central Massif.

The skarns form lenticular or tabular bodies inserted concordantly into paragneiss or mica schist series. They are tens or a few hundreds of meters along strike and several meters to some tens of meters thick.

In the skarn bodies, core consisting of feldspar-free assemblages (pyroxene and garnet skarns), and marginal zones of various thickness and composition are usually distinguishable. The latter consist of varied feldspar hornfelses and schists, less frequently of epidotes, feldspar-free almandine-biotite schist and other rocks. The skarn bodies also contain rare paragneiss and marble intercalations, and abundant pegmatite and feldspar dykes.

MAIN MINERALS

The skarn pyroxene belongs to the diopside-hedenbergite series. Its Mg content depends on mineral association and locality. Pyroxene of skarns is usually ferrosalite and hedenbergite. However, almost pure hedenbergite, known in some primary skarns, does not occur. Hence, pyroxene of the skarns under study did not most probably originate through the reduction of andradite. MnO (johannsenite component) of pyroxene shows mostly a relation to its FeO content, but it is always very low compared to different johannsenite content in primary skarns.

Garnet compositions vary among grossularite – almandine – andradite end members. The relative contents of Fe^{2+} , Fe^{3+} , and Ca differ in individual skarn localities skarn and layers. Usually, the andraditic-grossularite garnets occur in the cores of skarn bodies, and the almandine-grossularite rich garnet in the marginal rocks of skarn bodies. Mn and Mg content are generally very low. In some cases (Vlastejovice – Žáček 1997, Rešice – Houzar – personal communication 2000) skarns present F – enriched hydrous grossular – andradite.

Some minerals typical of primary skarns (especially vesuvianit and ilvaite) are absent in the skarns of Bohemian Massif.

Magnetite mineralization seems to be different types. In the main magnetite body at Vlastejovice, magnetite and quartz are younger than the silicates. Intergranular magnetite (titanium rich) and plagioclase at Slatina are also younger than gar and cpx. Magnetite in massive layers at some other localities (e.g. Rešice, Pernštejn) is equilibrated with silicates. It is aluminium rich at Rešice and silicium rich at Zliv. Some of the skarn bodies also carry masses of sulphides, mainly pyrrhotite, and also sphalerite, chalcopyrite, arsenopyrite, mainly in the Lügicum and Saxothuringicum. However, there is a group of skarns in the Moldanubian Zone, where the sulphides are frequently disseminated. Most frequent is pyrrhotite, followed by chalcopyrite, sphalerite, arsenopyrite, pyrite and by rare galena, bismutin, and bismuth. One of these localities, Svratouch, is characterized, besides the above-mentioned minerals, by the general presence of cobaltite, and rare molybdenite and gold. Gold is usually intergrown with Bi-minerals. Nemeč (1974) found a positive correlation of Bi and Au at this locality, with gold content up to 5 ppm.

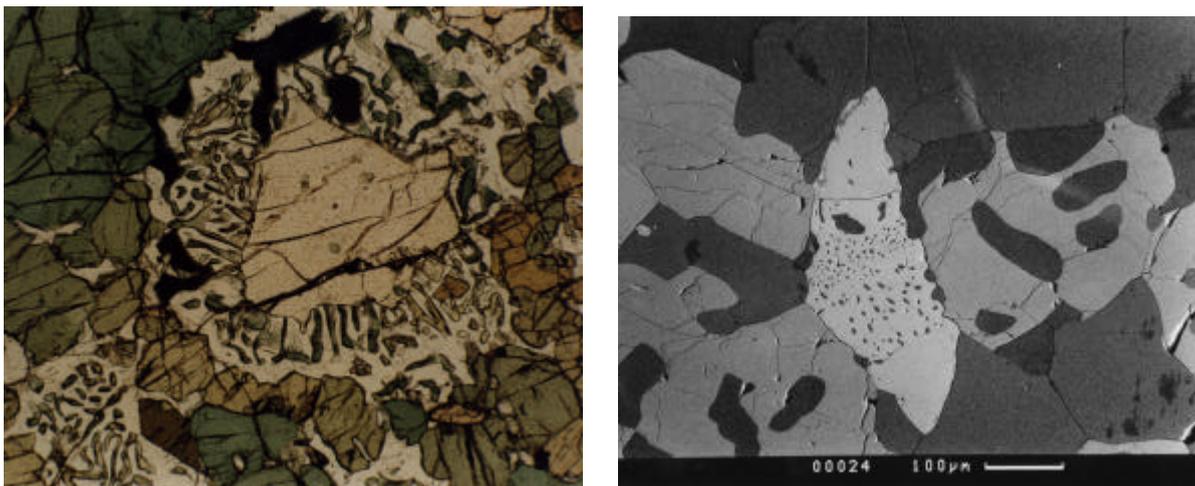


Fig. 6. Symplectite of plagioclase and clinopyroxene forms corona around garnet; titanite with younger titanite-plagioclase symplectite (both Rešice skarn locality, Gföhl nappe, Moldanubian Zone). From Pertold et al. 1997.

METAMORPHIC DEVELOPMENT

Geological structure and metamorphic equilibrium point clearly to polyphase development of skarn rocks. Tectonism is evidenced especially in wallrock gneisses and varied marginal skarn calc-silicate gneisses by their detailed plastic folding. In contrast to them, the skarn behaved as competent bodies and the paragneiss inclusions in them retained their monoschematical structure and straight foliation planes (e.g. Holšice). Ore exploration of some skarn has shown, that whole skarn bodies represent, in fact, large-scale boudins enclosed plastically by their mantle gneisses (Nemec 1991).

In the skarns, minerals stable under PT conditions of regional metamorphism are present. Thus, they contain abundantly hornblende, which is absent in the primary (metasomatic) skarns, except for very few occurrences. Similarly, almandine and grossularite-almandine do not occur in the primary skarns, but are abundant in regionally metamorphosed rocks. The type of minerals present in skarns agrees with the metamorphic grade of the area, but sometimes some of garnet-clinopyroxene assemblages conserve higher grade of metamorphic conditions compared with surrounding gneisses (Drahota et al. 2000). Thus, the skarns of Gföhl nappe, which has been metamorphosed in the granulite to eclogitic facies, contains abundantly symplectites of plagioclase and clinopyroxene around garnets and younger titanite-plagioclase (fig. 6) that are typical for high-grade conditions of genesis typical for eclogitic rocks.

Different phases of regional metamorphism can be recognised in the skarns (e.g. Drahota 2001). Temperature and pressure of the progressive metamorphism, deduced on the basis of minerals and minerals assemblages, has been estimated at different values for different localities (Drahota 2001, Potužák 1996, Pertoldová et al. 1998, Pertold et al. 1997). Usually one of the regionally metamorphic phases gets practically the identical conditions for gneiss migmatitization and skarn rock (equilibrium of garnet-amphibole assemblage). But sometimes we are able to find older mineral assemblages in the core of the skarn body (e.g. older garnet and clinopyroxene), which metamorphic equilibrium was estimated at higher PT conditions (e.g. Drahota et al. 2000).

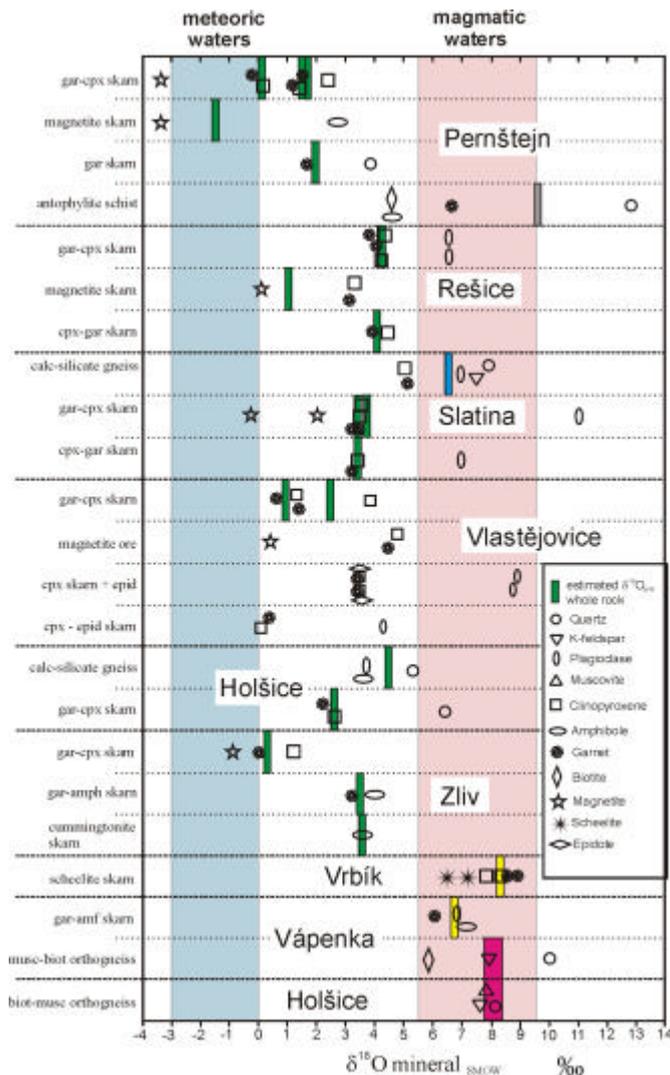


Fig. 7. Silicate mineral $\delta^{18}\text{O}$ values of regionally metamorphosed skarn rocks (Pernštejn, Rešice, Slatina, Vlastějovice, Holšice, Zliv) and some primary and/or reaction skarns (Vrbík, Vápenka), and related metagranites (Vápenka, Holšice).

OXYGEN ISOTOPES

Oxygen isotopes of carbonates from skarns were studied in numerous papers (e.g. Žák & Sztacho 1993, Drahota 2001). Commonly, skarn carbonates do not represent the residual carbonate from decarbonation reactions. The oxygen isotopic composition of skarn localities ranges from $\delta^{18}\text{O} = +3.7$ to $+13.1$ ‰ (SMOW). The lowest $\delta^{18}\text{O}$ fluid values cannot be of metamorphic or magmatic origin. Fluids depositing this calcite type are most probably of meteoric origin, and are only partially affected by oxygen isotope change with rock during the circulation. All skarn calcite $\delta^{13}\text{C}$ values are extremely low indicating dominance of organic matter-derived carbon during metasomatic processes. Metasomatic fluids circulated either during a late, low pressure stage of regional metamorphism and/or during granite intrusion.

Oxygen isotopes of silicates from skarns (fig. 7) show approximate equilibrium fractionation among garnets and pyroxene, and also sometimes (but not always) magnetite at some localities. There are usually differences in $\delta^{18}\text{O}$ between localities, and even between skarn types (layers). However, the $\delta^{18}\text{O}$ values of regionally metamorphosed skarn rock (Pernštejn, Rešice, Slatina, Vlastejovice, Holšice, Zliv) are very low (-1.5 to +3.5 ‰ $\delta^{18}\text{O}$) compared with metasomatic (magmatic derived) skarns from Bohemian Massif (Vrbík, Vápenka) and orthogneisses adjacent to skarn localities. Hence, the oxygen isotopic composition of skarn silicates is not compatible with the skarn origin associated with (meta) granitoid rocks (usual composition of +6 to +10 ‰ $\delta^{18}\text{O}$) and their high temperature metasomatic fluids.

REE

REE fractionate between garnet and clinopyroxene in individual samples (gar enriched in HREE, cpx depleted), most completely in granulite-eclogite facies (Gföhl gneisses of Moldanubian Zone) localities of Slatina and Rešice. Positive Eu anomalies are general in all localities, except Vlastejovice, suggest high temperature and/or reducing conditions during the formation of protolith. However, the contents of REE are different in individual samples within the locality, and also among the localities.

PREMETAMORPHIC ORIGIN

Original genesis of the skarns is obscured by their regional metamorphism. Varying major elements minor elements, REE, $\delta^{18}\text{O}$ values in individual parts of skarn bodies point to nearly closed rock system during peak of regional metamorphism. Some of skarn assemblages are older than migmatite and metagranite. Therefore, some authors (e.g. Pertold et al. 1997) assume that metasomatic origin of skarns during emplacement of granite bodies is highly improbable. On the other hand, some authors (e.g. Žáček 1997) assume, that the presence of F-enriched hydrous grossular-andradite indicates magmatic source of F in early garnet generations and this supports formation of the Fe-skarn from Vlastejovice and Rešice by contact metasomatism of carbonate rocks caused by granitic rocks.

Locality No. 1, Zliv near Kácov, Ca-Fe skarn

Skarn body Zliv was founded in 2000, during geologic mapping of Holšice surroundings (Drahota 2001). Skarn body appear in area covered by migmatites, orthogneisses and paragneisses. The adjacent rocks of the skarn body are not known exactly, because of thick soil cover, but the most probable geologic situation is given in the picture 8 (according to magnetometric and electrical methods modelling). The geophysical methods show that skarn/orthogneiss contact plain is tectonical. The skarn is associated with zone of regionally metamorphosed calc-silicates with intercalations of marbles (e.g. Vápenka locality) and small amphibolite pods.

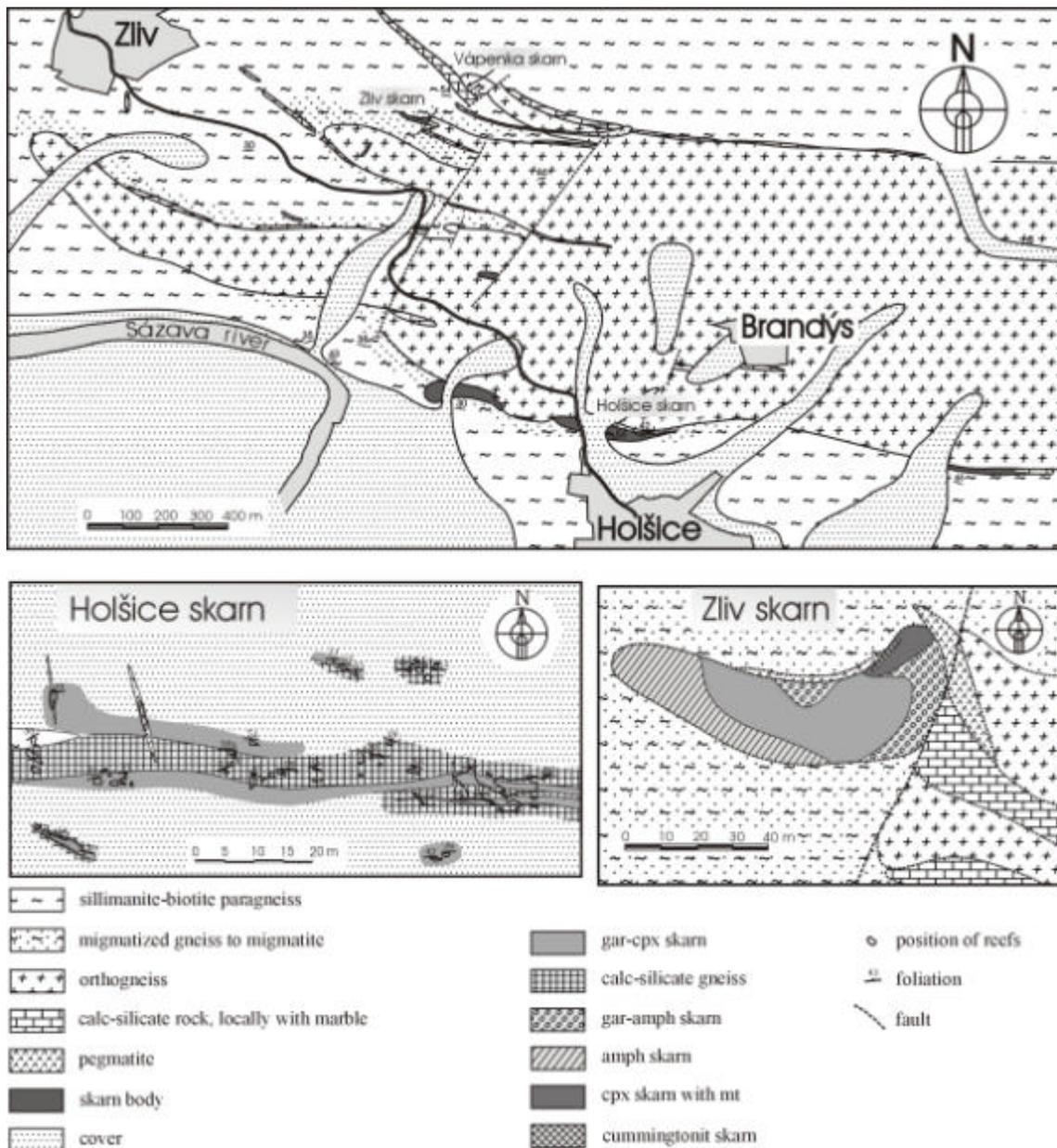


Fig. 8. Location and geologic setting of the Zliv, Holšice, and Vápenka skarns.

The Zliv skarn is quite interesting among the regionally metamorphosed skarns of the Bohemian Massif, because of very low content of Al (clinopyroxene without Al, pore andradite – such a pore andradite was described only from Kottaun skarn locality, Göttinger 1981), pore cummingtonite rock, and absence of generally abundant marginal hybrid rocks (calc-silicate gneisses probably developed by interactions of skarns and surrounding rocks during migmatization).

In central part of body, there are two skarn rock types: gar-cpx (andradite-hedenbergite) rock with magnetite, and cpx skarn with abundant magnetite (almost pure hedenbergite – fig. 14, and silician (!) magnetite – fig. 9a). In marginal parts of the skarn body, amphibole rock types prevail: amph skarn (ferropargasite to ferroaktinolitite >> ± gross-alm garnet > ± Mg hedenbergite > ± magnetite ± ilmenite > ± plagioclase), amph-gar skarn (ferropargasite ± gross-alm garnet >>> ± Mg hedenbergite > ± magnetite ± ilmenite > ± plagioclase), and cummingtonite skarn (cummingtonite>>>magnetite). The contacts between rock types containing cpx and amph are not sharp, because of different contribution of cpx and amph in the rock and secondary origin of amphiboles by uralitization of clinopyroxenes (fig. 9b).

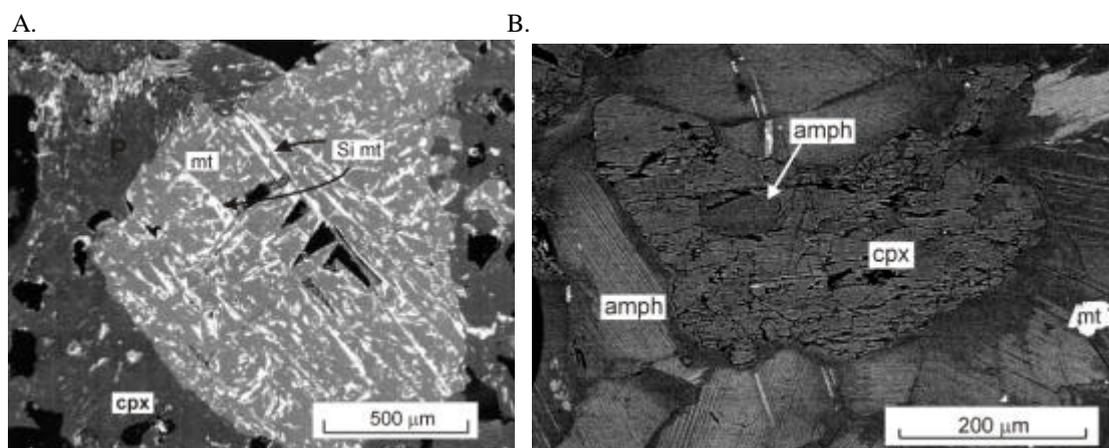


Fig. 9. Electron back-scattering images of: (A) SEM photograph of silician magnetite domains (Si mt) in the magnetite (mt) – if silicon is present in the magnetite structure as $?-Fe_2SiO_4$ molecule, 1) high pressure and/or 2) reducing conditions may be favourable for its formation (Shimazaki 1998); (B) replacement of cpx by lamellar and zoned amph

The garnet compositions vary according to the rock type and the location in the skarn body. The andraditic garnet occurs only in the central part, and almandine rich garnet prevails in marginal parts (fig. 10). The growth of andradites are connected with Al absent protolith and very high oxygen fugacity.

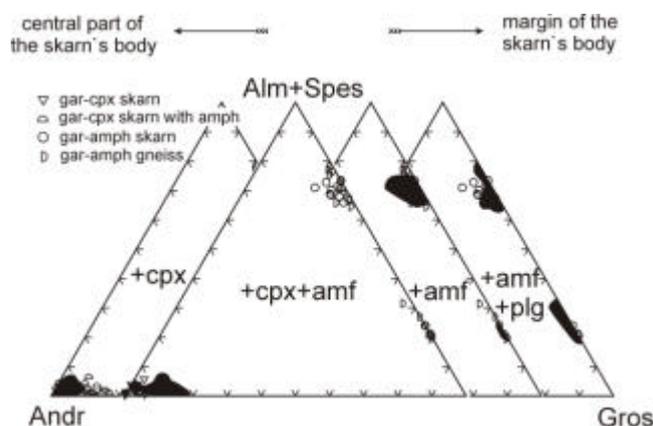


Fig. 10. The diagram showing mole composition of garnets from the Zliv locality with associated the main rock-forming minerals

Apparently, the andradite-hedenbergite (gar-cpx skarn) assemblage represents the oldest mineral paragenesis of Zliv skarn body. Almandine-amphibole assemblages (amph skarn, gar-amph skarn, cummingtonite skarn) represent younger mineral paragenesis, developed during prograde amphibole facie of regional metamorphoses, which affected and reworked all of the surrounding rocks (paragneisses, amphibolites). This regional metamorphose equilibrated at 670-690 °C, and 6-8 kbars (Drahota 2001). During retrograde regional metamorphism, and/or emplacement of granite body, the migmatization occurred. These K-rich fluids affected a lot the paragneisses closed to granite body, and also marginal planes of skarn body. The condition of the retrograde metamorphism was estimated at 520-560 °C and nearly 6 kbars. I have found a few samples of feldspar-rich gar-amph skarn, where feldspar replaces the garnet and amphibole (fig. 11a). The influence of incoming fluids into the skarn margins is also visible on dependency of amphiboles composition and their location in the skarn body (fig. 11b). At the same time, the cummingtonite amphibole was developed from

amphibole skarn, (the same temperature conditions were established from cummingtonite lamellas in ferroactinolites) and especially at the places where fluids were fluctuated a lot (cummingtonite skarn is closed to the main tectonic plane).

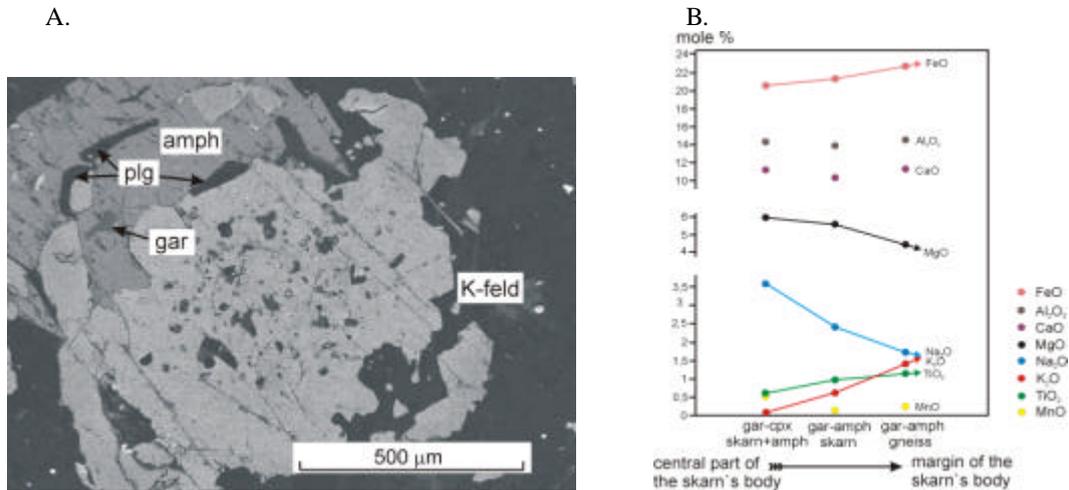


Fig. 11. (A) *Electron back-scattering image of almandine garnet replacement by the youngest amphibole, garnet, and feldspar; (B) averaged oxides content in amphiboles through the skarn body (from centre to margin).*

The oxygen isotope values of the skarn rocks (fig. 7) also indicate close system for gar-cpx skarn rocks and change (open system for margins) of pristine skarn isotope composition with migmatitic fluids composition. Hence, Drahota et al. 2000, Drahota 2001 assume non-metasomatic origin of the skarn rock.

Beside the skarn occurrence, in the field near the skarn body, the pieces of flints were found. We cannot assume the influence of fluvial terraces of river Sázava here, or another natural influences of their transport. Therefore, some kind of anthropogenic activity during paleolit period was here.

Locality No. 2, Vápenka near Kácov, reaction skarn

Vápenka locality represents old and abandoned open pit (10 m width, 50 m depth, 50 m length) mined for marble. The overlying rock represents metagranites with paragneisses intercalations and underlying rock are the paragneisses (fig. 8). Zoned skarn (4-8 cm width) layer was observed between marble and paragneiss and/or metagranite. Two distinct zones were distinguished from gneisses to marble: amphibole \pm amphibole-garnet skarn, and the calc-silicate (erlan) rock. Both of the layers contain amphibole, garnet, feldspar, quartz, titanite, chlorites, apatite, scheelite, and sulphides (pyrrhotite, pyrite, chalcocopyrite, and sphalerite). Reciprocal diffusion exchange of Si, Ca, Mg, Al, Fe, ... was obviously a dominant mechanism in the formation of zoned skarn during regional metamorphism. Moreover, it is visible (fig. 12), that the significant changes of carbon and oxygen isotopic a composition of marbles is restricted to the peripheral contact zones with skarn rocks, where local metamorphic exchange of components (bimetasomatic diffusion) between the two rock types occurred. Generally the C- and O-isotope systematics seem to be controlled by metamorphic devolatilization. The isotopic composition of the skarn layer is also well equilibrated with isotopic composition of metagranites (fig.7).

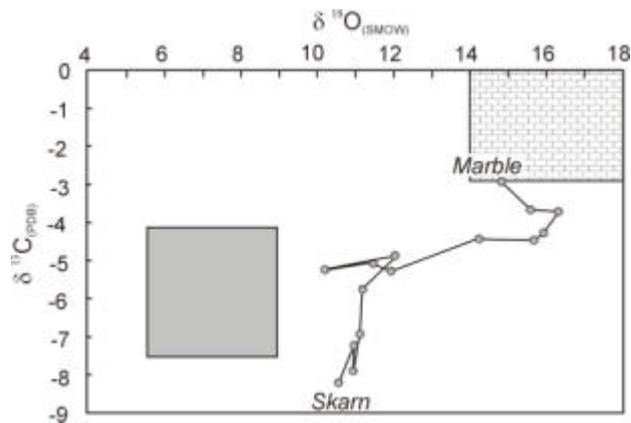


Fig. 12. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ change in the short profile (step 1 – 5 cm) across marble/metagranite bimetasomatic zone. Brick field covers the range shown by paleozoic limestones (Veizer & Hoefs 1976) and mid-grey field the typical range shown by magmatic fluids (Ohmoto & Rye 1979).

Another indirect evidence of magmatic adjacent fluids could be seen at geochemistry of the magmatic rocks and the mineralogy of related skarn bodies. The orthogneisses body closed to Vápenka, Holšice, and Zliv skarn rocks, originally belongs to granite to adamellite magmatic rock (fig. 13). These magmatic rocks are usually sources of the W, and Sn rich fluids (e.g. Meinert 1993), which is consistent with the evidence of scheelite in skarn layer of the Vápenka pit, and non-evidence of Sn- and W-ores in Holšice and Zliv skarn rocks.

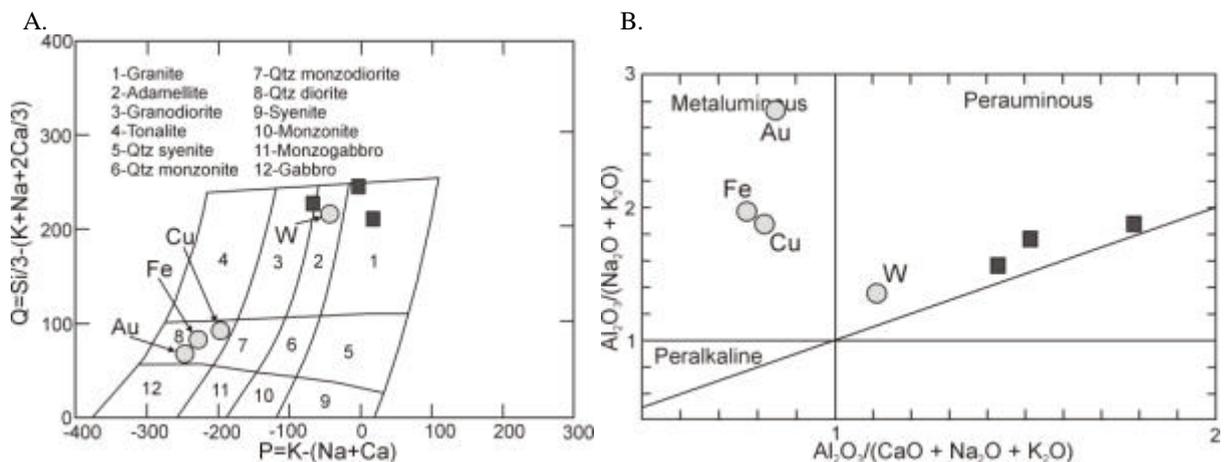


Fig. 13. Plots comparing the major element geochemistry of the studied orthogneiss (black squares) to intrusions related to Au, Fe, Cu and W skarns in British Columbia (data from Ray et al. 1996). A. Q-P plot (after Debon & Le Fort 1983). B. Aluminium saturation plot (after Maniar & Piccolli 1989).

Locality No. 3, Holšice near Zruc nad Sázavou, Ca-Fe-Al skarn

Holšice skarn body was founded by Koutek (1952) and described as metasomatic skarn body related to intrusion of overlying metagranite body. Holšice skarn body occurs in the long calc-silicate horizon of EW direction (fig. 8). The horizon can be observed for 800 metres, but moreover could be extrapolated to other skarn occurrences a few kilometres away. There are at least a three occurrences of skarn rocks in this calc-silicate horizon in studied area (fig. 8). Sometimes, the skarn bodies contain intercalations of biotitic-sillimanite paragneisses and always-abundant primitive pegmatites with allanites and/or epidotes (Drahota 2001). In contact planes The banding of the skarn is usually conformal with foliation of surrounding rocks, but sometimes it is able to find rare skarn-rock folds, which do not correspond with tectonics of the paragneisses and metagranites.

Holšice skarn body consist of two types of rocks: (1) banding gar-cpx skarn (garnet + clinopyroxene >> feldspar ± quartz >> epidote ± titanite). The rock forms cm thick bands of different proportion of cpx and gar and sometimes quartz bands. (2) banding calc-silicate gneisses (feldspar, quartz ± garnet ± amphibole ± clinopyroxene >> titanite, apatite, epidote, hisingerite). The banding rock form layers (0.X to X m thick) that change conformally with layers of banding skarn (gar-cpx skarn) (fig. 8).

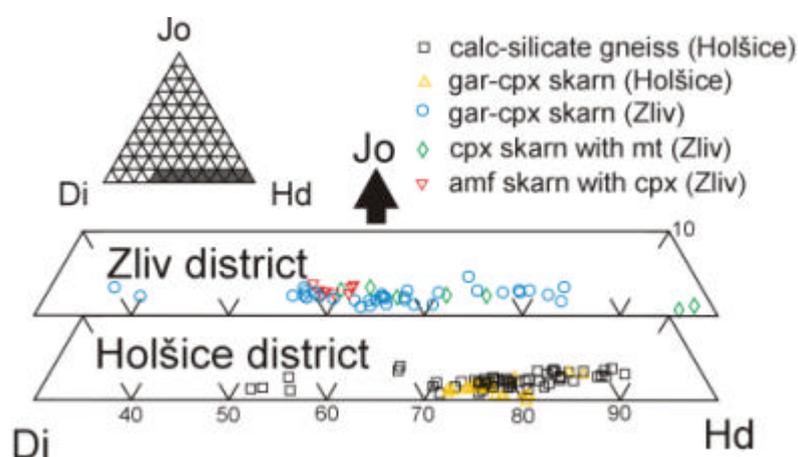
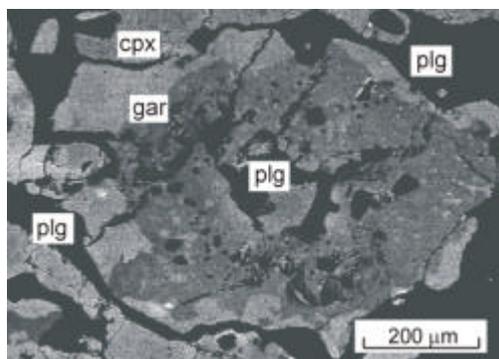


Fig. 14. Pyroxene composition from the Holšice and Zliv skarns. Di (diopside, Hd (hedenbergite), and Jo (Johannsenite).

Clinopyroxene of cpx-gar skarn belongs to the Mg-hedenbergite and hedenbergite. Pyroxenes associated with hornblende (calc-silicate gneiss) are always more magnesium-rich than pyroxenes of pure gar-cpx skarn. Evidently, in amphibole-pyroxene assemblages, iron prefers amphibole leaving more magnesium for pyroxene (fig. 14). Composition of gar-cpx skarn garnets belongs to the grossularite and almandine (fig. 15b). Amphibole (during MT-MP metamorphism) and hisingerite (LT-LP metamorphism) of calc-silicate gneisses replaces the clinopyroxene. The ore minerals are absent.

A.



B.

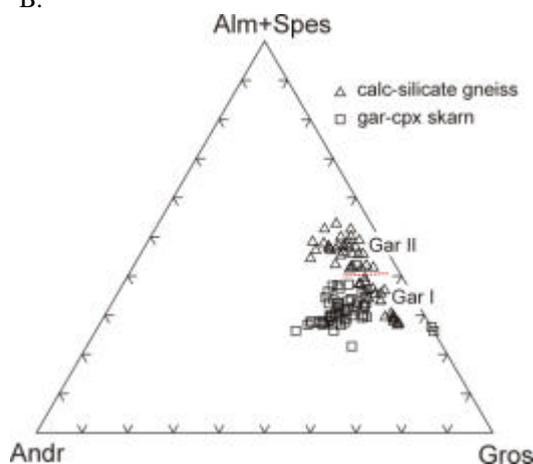


Fig. 15. A. Two stages of garnet (gar) from calc-silicate gneiss (Holšice) with plagioclase (plg) in the core, fissures, and the rim. B. Composition of garnet from Holšice skarn locality.

Garnets of calc-silicate gneisses are the same, but there are always zoned. It can be seen from the X-ray map (fig. 15a) that there is a distinct drop in Ca adjacent to margins of the garnet grain and to a large plagioclase inclusions and fissures. The loss of the high Ca core composition visible in fig. 15a is most probably a function of the plagioclase inclusion and adjacent garnet acting as a reaction domain during post-peak metamorphic decompression. The decompression-driven instability of the grossular component in garnet relative to the anorthite component in plagioclase is a common feature of high-pressure granulites (e.g. Cook et al. 2000). The narrow margins of the garnet grains contain elevated values of Mn (spessartine) component. This could be interpreted as a result of the youngest weak retrograde regional metamorphoses (e.g. Spears 1993).

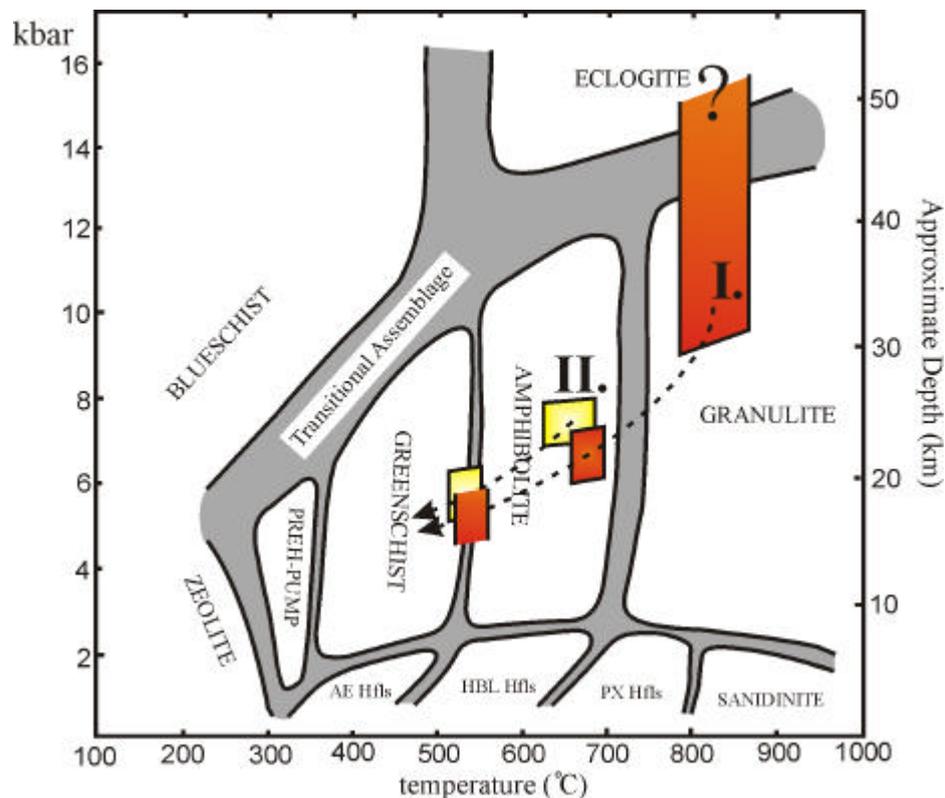


Fig. 16. P-T diagram illustrating the retrograde PT path of skarn bodies (I.) and neighbours gneisses (II.) from Holšice and Zliv localities together.

Drahota (2001) estimated that younger garnet of calc-silicate gneiss equilibrated at more than 800°C and pressure more than 12 kbars. Hence, garnet of gar-cpx skarn and older, grossular rich garnet of calc-silicate gneiss originated by another and older metamorphic event. If we compare the PT path of both skarn bodies (Holšice and Zliv) and surrounding rocks of paraserie (fig. 16), we can define distinctly two events of regional metamorphoses for all the rocks (skarns, paragneisse, partly metagranites), but the HT-HP metamorphose is restricted only at skarn mineral assemblages (but not the oldest !!!). It means, that skarns are very competitive bodies for preserving old tectono-metamorphic events such as ultrabasics and eclogites. Moreover, their metamorphic history disagrees with the theory of their metasomatic origin due to granite intrusion. Isotope composition of rocks (fig. 7) also corroborates improbability of that theory.

Locality No. 4, Rendejov near Zruc nad Sázavou, beryl-columbite pegmatite

New beryl-columbite pegmatite was founded in 2000 during geologic mapping of Holšice surroundings (Drahota 2001). This type of pegmatite occurs rarely in the Moldanubian Zone (Novák & Cerný 1999). The pegmatite occurs in mica orthogneiss (fig. 8). The pegmatite was found as boulders in the stream alluvial sediments and there is unfortunately unknown exact location of pegmatite dyke in the ground. However, it is possible to distinguish different types of pegmatite. Metasomatic replacements are also frequent (mainly the white-green cleavelandite replaces others feldspars). We can distinguish quite fine-grained (granitic) pegmatite with very high content of spessartite garnet (usually 1-6 mm), and black tourmaline; coarse-grained pegmatite with crystals of feldspar, tourmaline, beryl, and apatite, and blocky pegmatite with big crystals of microcline and quartz (also contain small cavities with crystallized feldspar and quartz). The parts of pegmatite seem to be metamorphosed a bit and show foliation like structures. These mineral assemblages are characterized by the presence of abundant cassiterite, rarely andalusite. Pegmatite also contains a lot of accessories, which has been investigated by XRD and optical microscope for the present.

Accessories:

Ferrocolumbite and/or manganocolumbite form small idiomorphic tables (up to 7 mm length and 0.7 mm width) and occur abundantly in coarse-grained pegmatite. The columbite evidence is often related to Be-mineral presence.

Ixiolite is very rare and associated only with ferro- mangan- columbites.

Rutile and anatase form small crystals associated with columbite and/or ixiolite. They are very rare.

Cassiterite forms small idiomorphic crystals (up to 3 cm). Its presence is restricted to coarse-grained pegmatite.

Garnet forms small crystals (up to 2 mm) in the fine-grained (granitic) pegmatite of marginal parts of the dyke, and bigger rare crystals (up to 5 mm) in the coarse-grained pegmatite. The idiomorphic crystals made combinations of 110 and 211 of the crystal shapes.

Apatite forms two different crystals. Abundant crystals form quite big (up to 2.5 x 1.5 cm) blue-green frosted crystals. The second type form small transparent blue crystals, but it is rare.

Beryl is very abundant mineral. It occurs abundantly in coarse-grained pegmatite and rarely in fine-grained one. It forms up to 5 cm high and 2 cm width columns. It often decomposes into plagioclase, muscovite, and bertrandite.

Bertrandite forms small lozenge tabulates in cavities (after the decomposition of beryls). The tabulates are bright, transparent, and up to 1 mm big. The biggest sample infill the cavity of 2 cm length and 0.7 cm width.

Sulphides and arsenides: Both arsenopyrite and löllingite are present as small bright silver grains to idiomorphic crystals (up to 1 cm long and 0.5 cm width).

Arsenates: arseniosiderite, pharmacosiderite, scorodite, and arsenolite were found. All of the arsenates are quite abundantly (except arsenolite) associated with both sulphides, and replaces them. They form yellowish brown to rusty brown crusts in small pockets in feldspar. These arsenates were found always with the arsenopyrite and/or löllingite, and therefore we can assume their origin by direct oxidation of arsenopyrite and löllingite. Arsenolite is very rare. In the sample, it forms the crusts on the arseniosiderite. The mineral succession of the secondary arsenates was not studied yet, but we can expect the most usual succession arseniosiderite – pharmacosiderite – scorodite - arsenolite.

Locality No. 5, Vlastejovice near Ledec nad Sázavou, Ca-Fe skarn(-oid)

Vlastejovice skarn locality represents one of the most complex and complicated skarn bodies among skarns of the Bohemian Massif, because of different skarn types of different genesis. A skarn in Vlastejovice is represented by several, up to several hundred meter large bodies, and a wallrock with mainly a two-mica tourmaline bearing orthogneiss and a two-mica paragneiss, both metamorphosed under amphibolite grade (sillimanite zone) conditions (Žáček 1997). There are also associated minor and much smaller bodies of amphibolite, quartzite and rare eclogite (Potužák 1996). The Fe skarn bodies were periodically exploited for iron-ore (magnetite) from the beginning of 16th century till 1965. Large stone open-pit situated at the “Holý vrch” (fig. 17b), about 0.5 km northeast from Vlastejovice, provides recently an excellent section of the southernmost and largest skarn body and associated rocks.

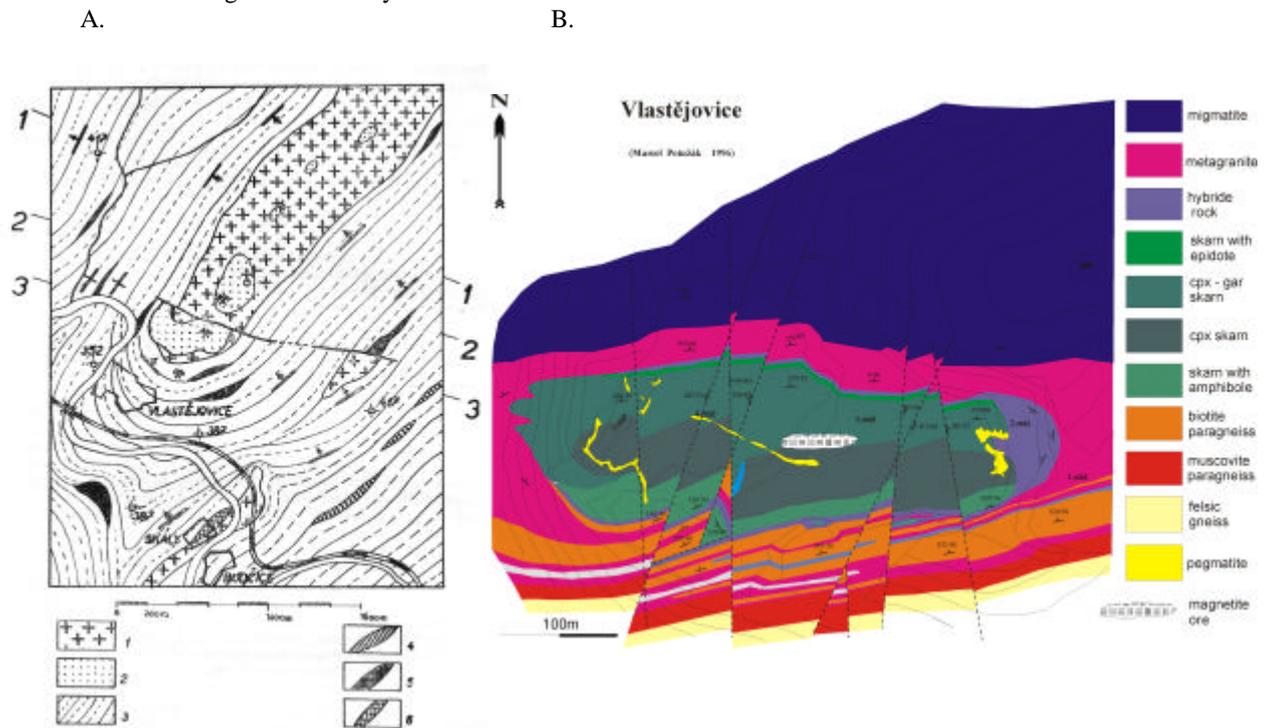


Fig. 17. (A) Structural and geologic map of the Vlastejovice vicinity. 1. orthogneiss, 2. skarn, 3. paragneiss, 4. quartzite, 5. amphibolite, 6. eclogite (Koutek 1952); (B) Structural and geologic map of the main skarn body “Na holém vrchu” (Potužák 1996).

The skarn bodies are highly heterogenous consisting of massive garnetites, gar-cpx, gar-cpx-epidote and magnetite rocks. The texture of the skarn rocks is also highly heterogenous. The massive texture prevails over banding. Some parts of the skarn rocks are contaminated by calcite, plagioclase and/or magnetite. The marginal parts of the skarn bodies are represented by hybrid of skarn and orthogneiss, “pseudodiorites” by Koutek (1959), which contains also quartz and feldspar beside typical skarn minerals (in particular OH bearing minerals). The hybrid rocks most probably represent regionally metamorphosed marginal part of skarn contaminated by orthogneiss derived fluids during migmatization processes. Skarn contains a variety of epigenic veins filling open fractures and mylonite zones. They originated in late stages of the geological development, when the skarn behaved as a brittle unit. (1.) Clinopyroxene-epidote veins with the succession clinopyroxene-epidote-grandite-fluorapatite-alcite-quartz. (2.) Different pegmatites with reaction aureoles (see next chapter). (3.) Monomineral calcite (frequently with crystals in the cavities) and quartz veins. (4.) Alpine veins composed of quartz, prehnite and apophyllite. Prehnite also occurs sometimes as the latest phase in pegmatite veins. (5.) Antimony mineralization in mylonite zones with prevailing berthierite, accompanied by gudmundite, pyrite, pyrrhotite, antimone, chalcopyrite, native antimony, Fe-rich sphalerite, secondary chapmanite, etc. (Brabec 2002) in quartz and calcite gangue.

Žáček (1997) found five generations (types) of chemically, and structurally different garnets (fig. 18) in skarn rocks (garnets I-III. represent grossular-andradite composition and contain up to 1.2 wt. % fluorine, 1 wt. % H₂O, and elevated concentrations of Sn, Sc, Y). The first three successive generations occurring in the centre of

the skarn body. Garnets IV.-V. occur in the assemblage with epidote (garnet IV) and in the margin of the skarn (garnet V) and they replaced minerals of the skarn *sensu stricto*. They correspond to grossular-almundine and almandine respectively, and display the continuous zoning characteristic of amphibolite-grade progressive regional metamorphism. Based on thermobarometry, P-T conditions for the main regional event (on the basis of the garnet IV. and garnet V. mineral associations) have been calculated to about 700°C and 6.5 kbars (Potužák 1996). The conditions of retrograde metamorphism were estimated at about 550°C and 4.5 kbars (Potužák 1996, Žáček 1997).

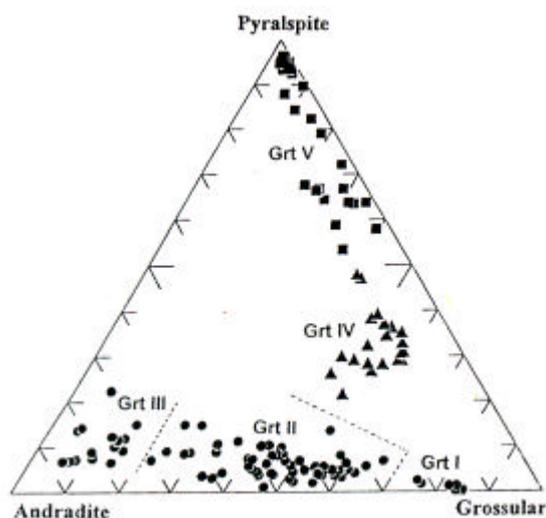


Fig. 18. Compositions of garnet of the Vlastejovice skarn expressed in mole proportions. (circles – garnet garnetites and gar-cpx skarn (garnet I.-III.), triangles – garnet of garnet-epidote-clinopyroxene skarn (garnet IV.), squares – garnet of hybrid rocks rimming the skarn body (garnet V.).

GENETIC SCENARIOS:

- a) Based on the fluorine content in garnets I.-III., on the different zoning pattern and on the two different compositional trends of garnets Žáček (1997) considered first three garnets to be a result of contact metasomatism, and garnets IV.-V. the result of superimposed amphibolite-grade regional metamorphism. In this case, the development steps of the skarn formation could be the followings:
 - ?? Intrusion of fluorine rich granite body into the variegated group of volcano-sedimentary rocks with intercalations of marbles.
 - ?? Early metasomatic stage (replacement of marble by fluorine rich garnet I.) at the middle depths of the Earth crust
 - ?? Middle and late metasomatic stage (origin of garnet II. and III. with lower content of fluorine; of course during the uplift of the skarn body, the oxygen fugacity increases and hence, andradite component increase too)
 - ?? Prograde period of regional metamorphism (a lot of pristine mineral assemblages are changed into the OH bearing assemblages; the hybrid rocks margins („reaction skarn“) originated; free fluorine from old garnet generations originate the fluorite rich pegmatites; magnetite originated from the: andradite + hedenbergite + 4CO₂ ? magnetite + quartz, where CO₂ is delivered by fluids on the rock fractures
 - ?? Retrograde period of regional metamorphism overprint some mineral assemblages and form zoning characteristics of the marginal garnets

- b) Based on oxygen isotopes of carbonates (Žák & Sztacho 1993), silicates (fig. 7), geochemistry of metagranites and skarn rocks, tectono-metamorphic development of skarn rocks Potužák (1996) assume non-metasomatic origin of skarn body of the Vlastejovice. In this case, the early development steps of the skarn formation could be the following:
 - ?? There is a distinct and strong anomaly of sedimentary-exhalative rocks (skarn protolithe) with higher content of fluorine (such as Sudbury deposit) in the volcano-sedimentary complex.
 - ?? Next high grade regional metamorphisms overprint pristine mineral assemblage into the current state. It is possible to suppose high grade conditions of metamorphism of the rock and preservation of the volatile components in the mineral structure (e.g. Su et al. 2002)

Pegmatites from Vlastejovice, Czech Republic

ACKERMAN, L.

The Moldanubian Unit of the Bohemian Massif contains abundant iron-bearing skarn bodies, the origin of which (contact skarns vs. regionally metamorphosed Fe-bearing sedimentary/sedimentary-exhalative layers) has been a matter of many disputes (see Pertold et al. 1997, and references therein). Numerous small-sized pegmatite dykes intrude Skarns, at many localities. This paper presents the preliminary results of fluid inclusion studies of the magmatically grown fluorite from a pegmatite intruding the magnetite-bearing skarn at Vlastejovice (ca. 80 km SE from Prague).

We can recognize three basic types of pegmatites, with respect to their mineral assemblages and internal structure. The most frequent type are basic pegmatites which consists of oligoclase + K-feldspar + quartz + fluorite + hornblende ± garnet. Accessory phases are allanite, sphene, and apatite. The other pegmatite types are elbaite subtype pegmatite with variable presence of tourmaline (schorl and elbaite) and pegmatites with zircon and U-Th bearing-minerals.

The fluorite, of variable violet color to colorless, is either intimately intergrown with feldspars, garnet and quartz (hieroglyphic-like texture), or more frequently fills in irregular pockets, in the mm. to cm. size range, in the coarsely grained quartz-feldspar matrix. No growth zones were distinguished in fluorite on a microscopic scale. In cold-stage cathodoluminescence it shows a homogeneous low dark-blue luminescence, with a few irregular light-blue centers/patches. In polarized light, numerous tiny fractures (usually only up to 0.1mm thick) filled in by calcite can be observed in fluorite, but not in the associated quartz and feldspars. Fluorite fracture-surfaces show etch features (partial dissolution of fluorite possibly associated with calcite precipitation).

Basic pegmatites have frequently simple composition (plagioclase/K-feldspar + quartz) without any zonality, but we can find very rare pegmatites with very simple zonation. Pegmatites form veins up to 2 m thick, but commonly only to 50 cm. Most of the pegmatites have contact zone with skarn, which is composed from hornblende, garnet, fluorite, biotite and allanite. Allanite is the only mineral, which carries rare elements (LREE, Th, U etc.). We can find small veins of epidote and very common veins of Sb-mineralization, which crosscut pegmatites. Pegmatites originated from H₂O-CO₂ rich fluids at the temperatures 430-470°C and pressures around 4 kb (based on data from fluid inclusions, feldspar thermometry and stable isotope thermometry).

Li-pegmatite of elbaite subtype are very rare, only one body was found at the early 80s. Pegmatite formed 2 metres thick vein with zonal structure. We can distinguish three zones: 1) coarse-grained plagioclase-quartz pegmatites with tourmaline (schorl), which is dominant, 2) medium-grained plagioclase-quartz pegmatite which forms only small pockets in the coarse-grained type, 3) blocky K-feldspar which creates core of the pegmatite, with very common pockets full of zonal crystals of elbaite-schorl (up to five centimetres), danburite, datolite and bavenite. Also columbite was found, but it's very rare. The other accessories of the pegmatite are titanite, biotite, magnetite and fluorite. Pegmatites originated from H₂O-CO₂ rich fluids at the temperatures 420-450°C and pressures around 3,5 kb (based on data from fluid inclusions, feldspar thermometry and stable isotope thermometry). They are many solid phases in the fluid inclusion, some of them are trapped but some form daughter crystals (nahcolite etc.)

Pegmatites with U-Th (Ti-Zr-Nb-Ta) are quite rare. It consist of plagioclase, K-feldspar, quartz, hornblende and fluorite, which is inflection of metamictization of radioactive minerals – uraninite and thorite, which form grains up to 2 mm. They accompanied by sulfides (pyrite and pyrrhotite), metamict zircon and very rare anatase and pyrochlore. Temperatures and pressures of origin of these pegmatites are unknown.

Historical, geological and depositional background of Kutná Hora ore district

BRIEF HISTORY OF MINING IN KUTNÁ HORA

(according Korán 1950, and Pauliš & Mikuš 1998)

Beginning of mining in Kutná Hora are according to some speculations laid already into the 10th century when in a village Malín a famous Slavníkovecian mint was run. The real expansion of exploitation started in the second half of the 13th century, probably thanks to contributions of Cistercians from the monastery in Sedlec. In the beginning of the 14th century Kutná Hora (called Mons or Chuttis) represented one of the largest mining towns of Europe with advanced organization and technology. This situation reflected in a significant improvement of an economic and power position of the Czech state and also in declaration of an important legal document Mining Law – *Ius regale montanorum* (around 1300) and establishment of the royal mint where famous Prague groschens were minted.

The exploitation started at first on natural exposures of “silver” zones, it means on Kuklík Hill (where probably eluvium was mined at first), on the NW slopes of Kank Hill, on Rejsy lode and in Vrchlice River valley on Osel and Rovina zones. Ore coming from these deposits was relatively easily processable. The rest of major ore deposits was successively revealed by intensive mining by the end of the 13th century.

In the first period exploitation was carried out by shallow inclined shafts, which were destined only from 20 to 30 m. After reaching more depth, it means during the 14th and 15th century, shafts for exploitation of water (“žentour” shafts) were built. These shafts were usually also inclined, their distance was longer (50 to 80 m), depth reached 75 to 100 and sporadically even 180 m, and many gates connected them.

In the 14th century some mines in Kutná Hora (especially on Osel and Grejf lodes) represented difficult systems of inclined pits, gates, blind shafts and workings. In pre-Hussite period some pits already reached the depth 450 m, which was at that time far the most all over the world. On every lode tens of mines were operated, their names are often known, but their more specific localization is very difficult nowadays. In the first half of the 14th century, when annual production of silver was 5-6 t, 1000-2000 people worked in local mines and 90 % of the Czech silver came from mining in Kutná Hora. At the end of 14th century the number of employees increased (by estimation to 3000 people). Apart from 6-7 t of silver also 50-100 t of cooper was obtained.

Broken ores were processed in smelters, which were situated in contemporary Karlov, near the village Grunta, and in the river valleys (Vrchlice, Bylanka). Operation of smelters required using of pyretic sulphides (from northern zones) and lead, which served for segregation of silver from roasted ores or from raw “black” copper, which contained 12 % of Ag. Copper represented a permanent-accompanied product of smelters, but its production never overreached the local importance, because takings for it ranged from 1 to 12 % of raw takings. Lead was imported from the second half of the 15th century from Poland, Hartz and Korutany area.

After stagnation of mining in the 15th century, which was probably caused by increasing expenses on reaching greater depths, exhausting of silver lodes and also devastation and inundation of mines during Hussites wars, the new boom started before the end of the 15th century.

The second half of the 16th century represented the second zenith of Ag production. From this time in the deep of the Staroček lode, huge workings were preserved. There are parts of an old timber support here, gates with s.c. smoke stope drifts, which served for air supply and fume exhaustion during s.c. “setting by fire”. Heat of fire caused fracturing and easier workability of rocks. Ores on these northern lodes were poorer (200-300 g/t Ag) but veins were more massive. An average annual production of silver ranged from 2 to 4 t of silver. In the half of the 16th century mines of Osel zone were abandoned forever and on the turn of century also exploitation in bottom parts of Grejf, Kuklík, Hlouška and Rejsy zones was ended for emptying of tongues. For reducing of expenses on water drawing, in the second half of the 16th century an advanced water-hoisting engine was built on Turkank zone above Hlízov village. This machine was driven by water wheel when water was supplied by canal from the Vrchlice River.

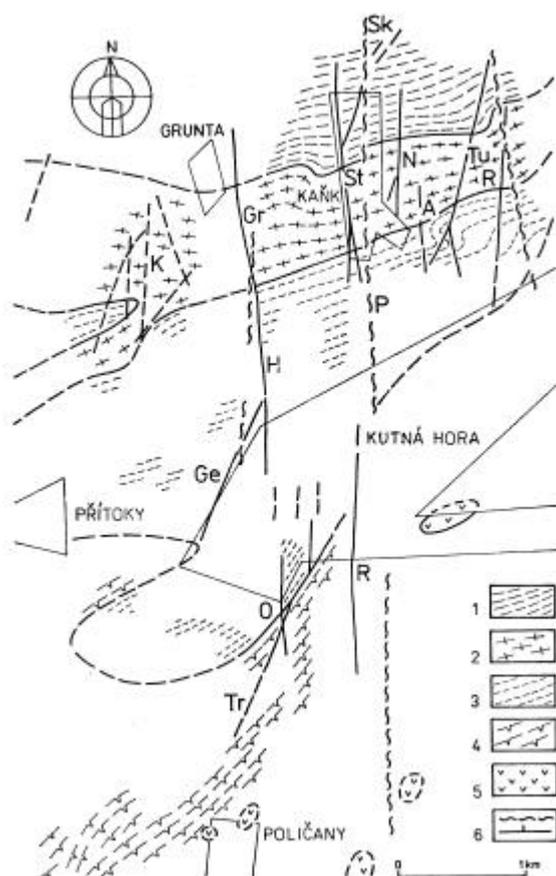
Operating costs increasing continually, following reduction of rentability and at the same time also a competition of cheaper silver from American, Krušné Hory's and other German deposits caused a decline of all mines in Kutná Hora district at the turn of the 16th and 17th century. After 1620 mining had only small extent and was restricted especially on trial mining. In 1722 even the royal mint was liquidated and Kutná Hora became the town of provincial character. Neither reviving of mining on Turkank, Rejsy and Hlouška lodes at the end of the 17th and the beginning of the 18th century, discovery of Skalecké zone in 1733 nor experiments with exploitation of new hollowed out shafts Skalecká, Grejf, Rovina and Turkank in the 1880's and 1890's did not have great extent and were not very successful.

The last development of exploitation in the local mining district started at instigation of German administration in 1939. Exploitation of polymetallic ores, especially Zn and Pb, started on Turkank mine. This reviving, other search and building of flotation dressing plant was followed by extent mining of Rejsy and Turkank lodes (Rudné doly, n.p. Příbram). Utilized ores were sphalerites with Ag admixture (ore contained 1.5-2 % Zn and 20

g/t Ag). Simultaneously intensive mineral exploration, field investigation and test boring of the whole mining area were carried out (especially the northern part). In 1992 Turkank mine was definitely liquidated for unrentability.

Since 1290 till 1800, Kutná Hora yielded 2,500 tons of silver (in terms of loss during medieval smelt technology and average 400-500 h/t Ag in ore it means 10 millions of ore in process), Freiberg 5,290 tons and the Havlíckuv Brod area 180 tons of silver.

GEOLOGICAL AND DEPOSITIONAL BACKGROUND



Sketch of geologic structure of the Kutná Hora ore district (according to Holub et al. 1982)

Malín Unit: 1 – upper gneisses, 2 – central migmatites, 3 – lower gneisses, 4 – upper part of the Variegated Group, 5 – amphibolites and serpentinites; 6 – dislocation zones and mineralized zones: K – Kuklická Zone, Sk – Skalecká Zone, Gr – Gruntecká Zone, St – Staroceská Zone, N – Nifelská Zone, A – Alžbetina Zone, T – Turkanská Zone, R – Rejzská Zone, P – dislocation of Panská pit, H – Hloušecká Zone, Ge – Grejfská Zone, O – Oselská Zone, R – Rovinská Zone, Tr – Trojická Zone

By its genetic position, age (Lower Permian), and mineral composition this mineralization belongs quite clearly to the postmagmatic katathermal mineralization of the middle Variscan granite plutonism, to the Central Moldanubian Pluton (Bernard 1967). The Freiberg (*kb+eb* mineralization) and the Kutná Hora mineralizations (*k-pol* association) are identical (Bernard 1961). In comparison with its famous history, the present significance of this mineralization is minimal. Certain possibilities exist in the wider northern surroundings of Kutná Hora and in some deep portions of this district, in which explorations were carried out recently.

During the final phase of the intrusion of the Moldanubian Pluton its axial part was uplifted. At this time, a system of fissures formed in the Kutná Hora ore district that was typical of the transition from anticlines to synclines (Holub et al. 1982). Lamprophyres and isolated granodiorite porphyries penetrated along the tension structures of this system. In the same field of stress, tourmalite veins and veinlets (in places with cassiterite) and quartz were formed (Losert 1968). After release of stress in the axial part of the dome it subsided and the older system of fissures was used in a new function. The original tension structures was assumed by the fissures dipping W. The original tension structures probably served as supply channels of hydrothermal fluids. Mineralization, however, occurred mainly in the fissures dipping W. Best suited for mineralization were the section with brecciated structures near the boundaries between the gneiss and the migmatite complexes.

The ascending fluids were obviously acid and caused strong silicification (Holub et al. 1982). Arsenic was important among the elements supplied during this early developmental phase of the veins. On the other hand, studies of primary halos have shown that Si and possibly all Fe, Sn, and S came from the country rock. In the deepest parts of the known geochemical cross section, arsenopyrite formed in the veins. Its amount decrease upward and it crystallized in the surroundings of altered rocks. During the same phase of development, also hydrothermal alteration occurred (silicification and sericitization in the immediate vicinity of the supply channel,

chloritization rather than from the supply channel) and primary halos characterized by the removal of chemical elements were formed. There is a striking correlation between the amount of quartz and Fe in the veins and the composition of the rocks pierced by these veins. During the crystallization of quartz I., the tectonic movements were renewed and the minerals of the second mineralization period began to be precipitated from the hydrothermal solutions. The minerals did not precipitate over the whole surface of the vein, but ore shoots of sphalerite, pyrite and pyrrhotite were formed that were accompanied in the deeper portions by stannite and chalcocopyrite and in the upper portions enriched with Ag. The bulk of the sulphides crystallized and this period may be considered as the major ore-producing period of the district. Towards the end of the first development stage, the first carbonates (dolomite, kutnahorite, etc.) crystallized in the upper part of the cross section. They are missing in the deepest parts (in the Hlavní vein) After revival of the tectonic movements, quartz II. began to crystallize. This revival was intensive only in the major structures of the upper part of the section, where galena is separated from the older minerals by tectonic surfaces. Similarly as chalcocopyrite II., it replaces older minerals in the feathered veinlets. Chalcocopyrite II. crystallized somewhat later than galena and this occurred preferably in the deeper parts of the veins. Tetrahedrite formed two distinct maxima. The first, more prominent one is associated with galena in the upper parts of the section. The second, less prominent maximum is associated with chalcocopyrite II. The minerals of this period occupy a considerably smaller part of the surface of the vein than those of the first period. They tend to concentrate near the more complicated structural parts of the zones. At the end of the stage, carbonates were formed anew, which were siderite and calcite now. It is interesting to note, that both stages observe the same scheme of zoning. Simultaneously with the two stages also prominent primary halos were formed. The distribution of introduced chemical elements follows the same scheme of zoning as in the major mineralised structures.

After the change of the field of tensile stress the horizontal movements on the fissures gradually predominated, whereby the western blocks moved to the S. The minerals of the third development stage that originated in the field occur as separate younger veinlets mostly developed near the margins of older veins and there are separated by conspicuous structural surfaces or may form separate diagonal veinlets. The minerals of the third development stage observe the zoning of the previous stages but they occur even inside the deeper zones of the previous stages in places with complicated structural conditions. The important role of Sb and the declining role of Ag is typical for this stage.

Their dominant direction is N-S with subordinate Ne-SW direction and a steep dip both to the E and W; the structures of the western dip are mainly hydrothermally altered. Their length attains several hundred meters up to 3 km, max. 6 km, the depth extent of the veins is 500 to 600 m. The thickness of the vein zones is commonly several metres and the lateral alteration zone is as much as 27 m (Koutek 1964). The ores proper contain several % of Zn, about 1 % of Pb. The ore zone Staroceské contains in the depth of 550 m still 0.5 to 0.7 % Cu, 2 to 4 % As and over 50 g/t Ag. The vein zones are located within an area of only 10x4 km. The mineralization here, which is classified as the sulphide polymetallic association *k-pol* (Bernard et al. 1967), has a similar composition as the Freiberg mineralization.

The mineralization stages are:

- | | | |
|------|-------------------|---|
| I. | development stage | 1. arsenopyrite period
2. sphalerite-pyrrhotite period
3. first period of carbonates (dolomite) |
| II. | development stage | 1. galenite – tetrahedrite – chalcocopyrite period
2. second period of carbonates (siderite) |
| III. | development stage | 1. period of noble Ag ores
2. berthierite-antimonite period |
| IV. | development stage | of quartz – pyrite – calcite |

DEVELOPMENT STAGE	I.			II.		III.		IV.
	1	2	3	1	2	1	2	1
JAKOBSIT	--							
KASITERIT	-							
ARZENOPYRIT	--			---				
PYRIT	---		---					---
KREMEN	---			---				---
SFALERIT		---						
STANIN		---						
CHALKOPYRIT		---			-			
PYRHOTIN		---						
MARKAZIT			---					---
KUTNOHORIT			---					
DOLOMIT			---					
RODOCHROZIT			---					
MANGANSIDERIT			---					
GALENIT				---				
RYZÍ VIZMUT (BIFAZE)				-				
Pb-Sb-SULFOSOL				---				
DIAFORIT				---				
FREISSLÉBENIT				---				
OWYHEEIT				---				
CANFIELDIT				---				
BOURNONIT				---				
FREIBERGIT (TETRAEDRIT)				---				
RYZÍ ZLATO				---				
SIDERIT					-			
KALCIT					-			---
PYRRARGYRIT - PROUSTIT						---		
MIARGYRIT						---		
ELEKTRUM						---		
RYZÍ STRÍBRO - ALARGENTUM						---		
STEFANIT - POLYBAZIT (?)						---		
AKANTIT						---		
BERTHIERIT							-	
ANTIMONIT								---
GUOMUNDIT								---

Mineral succession of ore veins (according to Holub et al. 1982).

Locality No.6, Quarry in front of the Vrba`s mill, alpine type veins minerals

The deserted quarry is situated in front of the Vrba`s mill in the Vrchlice river valley, 2.5 km south of the town centre, 500 m north of Policany village, near a red marked tourist path from Kutná Hora to Velký rybník (Big Lake).

Kutná Hora has been also famous mineralogical locality of the minerals of alpine type veins. The occurrence of this mineralization belongs according to Bernard (in Bernard et al. 1981) to the Ca poor mineral association of A type, characterized mainly by berg crystal, chlorites, adularia, muscovite and calcite. However, there are interesting especially accessories: anatas, brookite and fluorite. Unfortunately, all of the old and classical mineralogical localities are destroyed and unavailable. The last perspective locality of this mineral paragenesis is just the quarry in front of the Vrba`s mill. It was quarried from 30`s to 80`s of 20th century. The first anatas was found in 1936 (Veprek 1937), when the quarry just started to be open. Petrographic frame of the quarry`s rocks is given at Hoffman & Trdlicka (1967). There are different types of gneiss in the quarry (two –mica gneisses, biotitic gneisses, and hybrid gneisses). Minor part of the rocks represents mica schists, garnet schist and amphibolite lenses. In the NE part of the quarry has occurred garnet-cyanite rock. Amphibolites often contain coarse-grained parts represented by amphibole, plagioclase, and apatite. Younger association of alpine type usually penetrate them. In the quarry, there are also feldspar rich pegmatite dikes with biotite, chlorite, apatite, schorl, zirkone, and rutile, penetrated by the small veins of pyrite and chalcopyrite. In the SW mylonitic part of the quarry, the quartz-berthierite veins with pyrite, arsenopyrite, kutnahorite, sphalerite, galenite, chalcopyrite, etc. were found.

The most common mineral filling of the fissures is made by quartz crystal and berg crystals, dark-green fans of chlorite (pennin), and minor adularia. Anatas made black and dark-grey dipyrnidal crystals up to 3 mm long. The new discovery comprises small (0.X mm) red-orange crystals of anatase. Brookite is rare and usually forms yellow-brown, green-yellow to yellow tabular crystals of max. length 2 mm. Next minerals comprise sagenite, fluorite, schorl, pyrite, muscovite, etc.

List of the minerals from quarry in front of Vrba`s mill

adularia	fluorite	quartz	pyrhotite	rutile (sagenite)
anatas	chlorite	markasite	pyrite	schorl
brookite	calcite	muscovite		

Locality No.7, Vrba`s mill, slag dump+secondary mineralization

Slag dumps are situated in the Vrchlice River valley, 2.5 km south of the town centre, 500 m north of Policany village, near a red marked tourist path from Kutná Hora to Velký rybník (Big Lake), near the quarry in front of the Vrba`s mill.

The dumps, up to 10 m high, are the memories on royal smelters activity, which already originated at 15th century. The royal smelters were located in the river valleys (especially in the Vrchlice valley), because of water energy. During the decrease of the mining activities, all of the pristine smelters in the Vrchlice valley were rebuilt into the mills that could be seen at the present. For example, the Upper Smelter was in the half of 18th century rebuilt into the Vrba`s mill. The dams in front of the Vrba`s mill were partially redistributed, but there is about 400 000 t of slag forever.

In the 50th of the last century, the slag was investigated in conjunctions of content of the residual metals. It was discovered, that the composition of the slag correspond to ferro-silicate mass, which on the average contains 42.6 % SiO₂, 28.9 % Fe, 2.3 % Al, 4.1 % Ca, 1.3 % sulfidic S, 0.2 % Ag, 0.3 % Cu, 0.3 % Pb, 0.07 % Sn, and 2.3 % Zn. The metals are especially bonded on silicates, or oxides. The minor amount of metals in the slag is in native form and alloy or bonded on residual sulphides.

The locality represents the most interesting slag dump in the term of mineralogic point of view. The main mineralogic component of the slag represents silicate glass-like matrix, skeletal haematite and recrystallized quartz. During metallurgical processes, the new minerals of olivine group (fayalite), and melilite group (gehlenite, ackermanite, hardystonite) crystallized in the matrix mass. There are also present a minor amounts of willemite, troilite, wurtzite, magnetite, spinel minerals, wüstite, and relicts of sphalerite, and pyrrhotite. In the slags with higher content of copper, (Trdlicka 1964) discovered rare native copper, cuprite, and tenorite. The weathering of the slag results the origin of secondary phases containing copper, zinc, calcium, etc. The most common secondary mineral is blue-green chryzokole and crystallised gypsum. The scarce minerals comprise blue coatings of azurite, green malachite, white to grey smithsonite and hemimorphite (Trdlicka 1963). Pauliš et al. (1998) found dark red coatings of alacranite, max. 0.5 mm long needles of dark green brochantite, grains of willemite and zinkite, chalkozin, djurleite, troilite and native plumbum.

List of the minerals from slag dumps in the Vrchlice River valley

ackermanite	haematite	"limonite"	plumboferrite	spinel
alacranite	hemimorfite	magnetite	pyrhotite	tenorite
azurite	hydrozinkite	malachite	"röpperite"	troilite
brochantite	chalkozin	native copper	gypsum	willemite
djurleite	chryzokole	melilite	"serpierite"	wurtzite
fayalite	jarosite	olivine	sphalerite	wüstite
gehlenite	quartz	plumbum	smithsonite	zinkite
hardystonite	cuprite	pitticite		

Locality No. 8, St. Antonín Paduánský (St. Anthony de Padua) gallery, Sb-Ag mineralization

The gallery of St. Antonín Paduánský is situated in the Vrchlice River valley, 500 m north of Policany village, near a red marked tourist path from Kutná Hora to Velký rybník (Big Lake). Today the locality is one of the most promising minerals deposits in the Kutná Hora mining district.

In the path along Vrchlice River valley between Velký rybník (Big Lake) and the Kutná Hora, there are preserved a few exploration and mining galleries (e.g. galleries in front of the Wagenknecht's mill; near the Vrba's and Spálený's mills). The oldest preserved mining map of the Kutná Hora ore district (1534) describes one of these galleries – Policany gallery. It is the second oldest mining map of the Middle Europe; the oldest one is Freiberg mining map from 1529 (author Köhler) (Malec 1997). However, the most important and interesting is the gallery of St Antonín de Padua. It was termed after the name of the miners group, which started the mining activity at 1752 in that gallery. The mining works following the Sb and Ag rich vein 0.7 m thick were successful and promising at the beginning,. However the veins were Ag poor soon and the mining activity stopped here after the three years. Next and unsuccessful mining began at the years of 1769-1770. The last mining operations were carried out at 1943-1944. The gallery close to the Vrchlice River, and mined at NS direction, strike to the crossing of the mineralised structures after the 60 metres. In this place, the Ag rich ores occur. The gallery is 326 m long.

In the gallery and in the dump, it is always possible to find typical veins minerals, but we can also find with a bit luck some noble Ag ores. Ca-Mn carbonate is an interesting mineral of the veins. It was termed after the first locality of discovery – kutnahorite. Berthierite is the main ore of the veins. It forms steal grey granular, and columnar aggregates in the quartz gangue. Small grains and crystals of usual sulphides are abundant (pyrite, arsenopyrite, galena, and sphalerite). The Ag minerals are scarcer. The famous mineral of the locality is miargyrite, which forms grey-black grains and crystals up to 10 mm (short columns) in the quartz gangue. One of the scarcer minerals from the locality are diaforite, which forms up to 3 mm big, steely grey milled crystals, which sometimes growth together pyrargyrite in the quartz cavities, freieslebenite (short columns – up to 2 mm, grey crystals), and pyrostilpnite (red to orange coatings and max. 4 mm big, very sheeny tabular crystals). There is also possibility to find boulangerite, native silver, small dipyramides of anatas, etc. Secondary minerals originating from weathering of Sb ores comprise valentinite, and senarmontite.

List of the minerals from the gallery of St. Antonín Paduánský

akantite	boulangerite	freieslebenite	miargyrite	gypsum
almandine	calcite	galena	muskovite (Cr)	senarmontite
anatase	cervantite	chalcopyrite	proustite	sphalerite
antimonite	diaforite	jamesonite	pyrargyrite	siderite
argentite	dolomite	KUTNAHORITE	pyrhotite	stefanite
arsenopyrite	electrum	quartz	pyrite	silver
berthierite	freibergite	markazite	pyrostilpnite	valentinite

Locality No. 9, Kank - State Natural Preservation “Na Vrších”, Upper-cretaceous onshore reef facie

State Natural Preservation “Na vrších” is located in the 2 km NE of the Kutná Hora centre, in the SE slope of the Kank hill. This preservation was declared in 1933 for protection of vestiges of onshore reef of Upper-Cretaceous Sea. In the depressions of the originally onshore cliffs, the surge facies rocks were deposited. Coarse-grained limestone conglomerates, and organodetrritic limestones represent this facie. Overlying rocks are represented by marlites with a lot of remnants of *spongies*. Initially, the sediments were considered to be of Cenomanian age, next investigation reveals their lower Turonian age (e.g. Nemeč 1976). The thickness of sediments southwest of the preservation reaches 15 m at the average (max. 25 m). The bedrock consists of gneisses to migmatites with quartz intercalations. In the quarry of the reservation, there are also aplite dikes with garnet, cyanite, and filamentous, violet dumorthierite (Losert 1956).

The rocks with abundant fossils were discovered in the 19th century, when the quarry started to be mined for stone. The limestones and conglomerates contain mainly remnants of the bivalves – genera *Ostrea*, *Exogyra*, *Lima*, *Pecten*, *Cordia*, *Area*, and *Spondylus* (e.g. *Exogyra sigmoidea*, *Exogyra reticulata*, both REUSS), and the bryozoans – genera *Stromatopora*, *Heteropora*, *Membranibora*, *Diastopora*, *Kankopora* (e.g. new species *Kankopora kankensis*). The other usual fossils of the locality represent corals of the genus *Synhelia*, *Stichobothrion* (e.g. new species *Synhelia squarrosa*), and the biggest coral of the secondary era sea – *Isis miranda*. Gasteropods (snails) are represented by the genera *Pleurotomaria*, and *Leptomaria* (the most common is *Pleurotomaria geinitzi* d'ORBIGNY), foraminifera by the genera *Discorbina*, *Flabellina*, *Fronicularia*, *Globigerina*, *Nodosaria*, etc. (e.g. *Globigerina cretaceae* d'ORBIGNY). Abundant fossils are also brachiopod *Cyclothyris zahalkai* NEKVASILOVÁ, spines of echinoids of genus *Cidaris*, shark teeth, sponges of genera *Craticularia*, *Corynella*, *Guertardia*, parasite fungi, and the worms of the family *Serpulidae*.

Locality No. 10, Staroceské zone, Medieval ore dumps+secondary mineralization

Medieval dumps of Šafary and Kuntery mines on the Staroceské lode (in the village Kank), 3 km north of Kutná Hora) are meaningful mineralogical deposits of the Kutná Hora region. Some of the primary minerals can be found here. For example arsenopyrite, sphalerite, stannite, etc. First of all, arsenic minerals bukovskyite, kankite, zýkaite, and newly paraskorodite are famous of secondary minerals.

The mining activity in the Staroceské zone began later than in the others zones (till 14 century), because of lower content of silver in the ores (the Staroceské lode belong to the “sulphidic” or “polymetalic” zones of the Kutná Hora district). However, in the 15th century the smelting processes were improved, and the smelters required pyritic sulphides and lead. Therefore, in that time the mining on the Starocech lode activity increased a lot. Moreover, rapid development was also subjected to stagnation of southern silver rich zones such as Osel and Grejfy zones. At the end of the 15th century there were about 15 active mines on the Starocech zone. From the south to the north, there are visible dumps of the mines Tolpy, Šváby, Nyklasy, Šmitna, Fráty, Hoppy, Rabštejn, Kuntery, Šafary, and Trmandl forever. Most of the mines were named after some Kutná Hora miners. In the beginning of the 16th century, the mining in the Starocech lode was really huge. Ores of these northern mines were poorer (about 200-300 g/t Ag), however an annual production of Starocech lode was about 5 thousand of the ore containing 1.0-1.5 t of silver. The boom activity in the Starocech lode in the first half of the 16th century returned a Kutná Hora district to the second zenith of its mining. The largest mining activity was connected with the Hlavní vein.

The NS Hlavní vein is dipping west at 75°. The productive stage of the Hlavní vein is about 1.4 to 1.7 km long, the thickness of the vein ranged from 1.5 to 5.0 metres, and the thickness of the zone ranged from 10 to 100 metres. The main primary minerals of the Hlavní vein are represented by quartz, pyrite, pyrrhotite, arsenopyrite, and sphalerite, the minors are calcite, chalcopyrite, siderite, stannite, and galena, and the accessory is cassiterite.

The meaningful mineralogical deposits are represented by the dumps of medieval mines Kuntera and Šafary, which are located NW of gothic church St. Vavrinec, near the road from Kank to Libenice villages. The primary minerals of the dump are represented by massive to granular aggregates of pyrite, pyrrhotite, black sphalerite (sphalerite contains 3-21 % Fe, up to 4 % Mn, up to 0.8 % Cd, and up to 0.2 % In – Hak et al. 1983), galena, and arsenopyrite. Arsenopyrite quite abundantly forms up to 1 cm big crystals in the quartz gangue. The macroscopic crystals of stannite are rare.

The locality is famous, because of the first discovery of some secondary minerals. The bukovskyite forms up to 1 m big cauliflower-like bulbs of yellow-green to grey-green colour, which is composed of columnar microcrystals up to 0.01 mm long. In the past, this mineral was known as so called Kutná Hora's toxic clay. The mineral was studied by Bukovský (1915) and Novák et al. (1967) and classified as independent mineral of the strunzite – beraunite group. Next new mineral, kankite, was named after the discovering locality (Cech et al. 1976). It usually forms yellow-green coatings and crusts (up to 7 mm thick) on the stones of the dump. Scarce zýkaite forms soft, grey-white and yellowish films of small cavities and small (max. 3 cm big) round aggregates (Cech et al. 1978). The latest discovery of new inclusions paraskorodite, which forms white to light yellow-brown aggregates of max. 2 cm size (Pauliš 1998).

The other secondary minerals include the crystals of gypsum, the coatings and the crusts of scorodite, jarosite, limonite, melanterite, anulogen, rozenite, etc. (Pauliš 1998).

List of the minerals from the ore dumps in the Kank deposit (Starocech zone - mines Kuntery, and Šafary)

alacranite	galena	cassiterite	pitticite	siderite
allargentum	chalcantite	quartz	pyrrhotite	scorodite
aluminite	chalcopyrite	"limonite"	pyrite	stannite
anulogen	jarosite	markasite	rozenite	ZÝKAITE
arsenopyrite	calcite	melanterite	gypsum	
BUKOVSKYITE	KANKITE	PARASKORODITE	sphalerite	

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