Chapter 3
Czech Republic

Uranium is a widespread commodity throughout the crystalline Bohemian Massif and the basins of its platform cover in the Czech Republic. Most uranium mined occurred in vein- and sandstone-type deposits that cluster in a number of districts within eight uranium regions. Small deposits and occurrences also occur isolated elsewhere in the country. ➲ Figure 3.1 shows the uranium regions with districts and deposits and ➲ Table 3.1 lists reported data of districts and deposits.

Since uranium mining was resumed after World War II, 74 deposits were mined in 6 districts and at several localities scattered throughout the country. The principal uranium districts include *Horní Slavkov (Schlaggenwald)*, *Jáchymov (St. Joachimsthal)*, *Příbram*, *West Bohemia*, and *West Moravia* with vein uranium deposits, and the *Stráž Block* in the northern Bohemian Cretaceous Basin with sandstone uranium deposits. Additionally, small structure-controlled uranium deposits occur at *Okrouhlá Radouň* in the southern Bohemian Massif, and in the *Krkonoše Mountains* (Riesengebirge), *Rychlebské hory* (Reichensteiner Gebirge), and the *Orlické hory Mountains* (Adlergebirge) in the Saxo-Thuringian Zone of the Sudetes. Strata-bound uranium deposits associated with lignite or coal deposits are reported from the Upper Paleozoic basins of *Kladno-Rakovník* and the *Intra-Sudetic Depressions*, and from the Tertiary *Sokolov (Falkenau) Basin*.

All deposits are depleted or shut down except for the *Rožná* and *Stráž* deposits. OECD-NEA/IAEA (2012) reports remaining resources (status 2011) of 374 t U in the <$130 per kg U RAR category for the Rožná deposit, and 116 000 t U in the >$260 per kg U RAR + Inferred categories in the Stráž Block. Additional speculative resources of 179 000 t U are assumed to exist in the North-Bohemian Cretaceous Basin.

Uranium production from 1946 through 2010 totaled 110 939 t U (OECD-NEA/IAEA 2012); some 85% of which was recovered from conventional mining and processing plants and ca. 15% by ISL techniques (see ➲ Table 3.1 for site-specific production figures of uranium contained in mined ore).

The bulk of conventional mined ore was recovered by underground methods except for 350 t U, which derived from open pit mining. Present-day exploitation (2012) is confined to the Rožná underground mine in West Moravia and the ISL facility at *Stráž pod Ralskem* in northern Bohemia. The latter now produces uranium only as a product of well field rehabilitation.

Eight beneficiation *facilities* were formerly in operation including four hydrometallurgical plants: *Nejdek*, *Mydlovary*, *Stráž pod Ralskem*, and *Dolní Rožínka* (see Subsect. *Historical Review*). Only the latter was still active in 2012.

ČSUP (Československý uranový průmysl/Czechoslovakian Uranium Industry), a state-owned enterprise, was the operator for all uranium operations after the USSR had handed over responsibilities for the uranium sector to the ČSSR in the 1950s. The enterprise was renamed DIAMO in 1993 and is now in charge of uranium production and rehabilitation of former uranium mine and mill sites.

Sources of information. DIAMO webside (2012), Hrádek (1995), OECD-NEA/IAEA (1994, 1996, 1998, 2000, 2008, 2010, 2012), Šuráň and Veselý (2001).

Historical Review

Uranium has been known from a number of localities in the Czech Republic, most notably from the Jáchymov veins in northwestern Bohemia for at least two centuries as documented by Kirchheimer (1963) in a comprehensive inventory of uranium sites discovered prior to 1898, when nowadays Czech Republic was a part of the Austrian Empire.

Although some prospecting for uranium dates back to the late 1800s, it was only after World War II that systematic countrywide uranium exploration began, initiated by the USSR in 1945/1946. Numerous uranium deposits were discovered with all significant deposits in the Czech part of the then ČSSR, and only a few small deposits in the Slovakian part (see Chap. 14 *Slovak Republic*). Milestones in the discovery of major uranium deposits and districts are: 1946 *Horní Slavkov (Schlaggenwald)*, 1947 *Příbram*, 1952 *Zadní Chodov (Hinterkotten)*, 1956 *Rožná-Olší*, 1962 *Okrouhlá Radouň*, 1964 *Dyleň*, and, between 1963 and 1968 *Hamr* and other uranium deposits in the North Bohemian Cretaceous Basin.

Early mining of uranium commenced at the Ag-Co-Ni-Bi-U veins of Jáchymov (St. Joachimsthal) in the southwestern Krušné hory (Erzgebirge), where pitchblende was recovered intermittently since 1833. Uranium was first used for paints and pharmaceutical purposes, and later on, in the first decades of the 20th century, for extraction of radium. Production of preconcentrated ore with 20–50% U amounted to at least 620 t between 1833 and 1898 (Kirchheimer 1963), the year, in which Madame Curie discovered radium. Two railroad freight cars of concentrate from paint production residues were shipped from St. Joachimsthal to Madame Curie in Paris, from which she extracted the first radium in 1898. Mining in the Jáchymov district dates back to the 16th century, however.

Silver-bearing veins were discovered in 1546 at Jáchymov (St. Joachimsthal) and, in its early days, Jáchymov (St. Joachimsthal) was one of the leading silver producers in central Europe. Later on, in the 18th and 19th century, cobalt, nickel, and bismuth were recovered. Admixed uranium, largely pitchblende, was dumped together with waste rock. Pitchblende was mentioned here for the first time in 1727.

Another historical aspect is the denomination of currency. The medieval silver mint at St. Joachimsthal produced coins called Thaler or Taler, which, in later centuries, provided the root word for dollar in the USA.

During the second half of the 20th century, 194 uranium deposits and occurrences were explored in detail, 74 of which were mined in six districts and at several localities elsewhere in the country. Mining at Jáchymov (St. Joachimsthal) restarted in 1946, followed by the vein districts of Horní Slavkov (Schlaggenwald) in 1948, Příbram, one of the largest and richest vein uranium districts in the world, in 1950, West Bohemia (Zadní Chodov (Hinterkotten)) in 1952, and West Moravia

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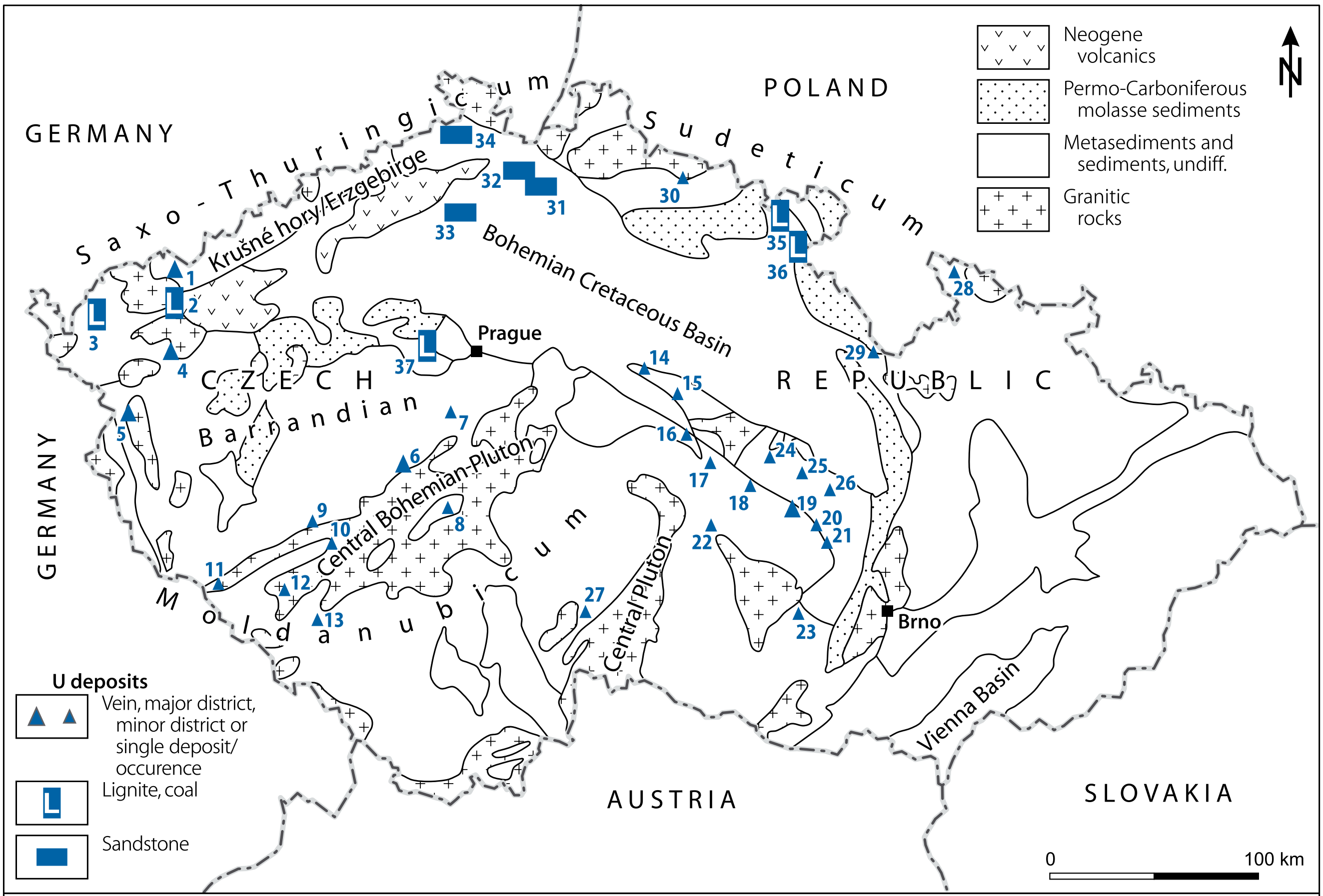
Fig. 3.1.

Czech Republic, uranium regions, districts, deposits mined, and principal occurrences in the Bohemian Massif, Saxo-Thuringian and Sudetic Silurian metallotectonic zones, and intermontane basins. (Geology simplified after Kodym et al. 1967)



U deposits and occurrences

Northwest Bohemian U Region

1 Jáchymov (St. Joachimsthal) District
Potůčky, Princ Evžen, Seify-Rýžovna, Zlatý Kopec, Abertamy, Barbora, Eliáš, Eduard, Eva, Rovnost, Svornost, Adam, Bratrství, Popov, Panorama, Plavno
Other U deposits/occurrences in the NW Bohemian U Region
Přebuz, Nový Fojtov, Dolní Rotava, Bouči-Oloví, Horní Rozmyšl, Klement, Horní Blatná, Krásný les, Přisěnice, Boži Dar, Měděnec

Tertiary Basins in Northwest Bohemia

2 Sokolov Tertiary Basin/Hroznětín and Ostrov Subbasins
Hroznětín Subbasin: Odeř, Ruprechtov I, II, III, Hroznětín I, II, III, Hájek North and South
Ostrov (Otovice) Subbasin: Mezirolí, Kocourek, Sedlec, Bor, Nivy, Ztracený Rybník
3 Cheb Basin
Velký Luh, Křižovatka
4 Horní Slavkov (Schlaggenwald) District
Nadlesí, Bošířany, Pichtova hora, Zdař Bůh, Barbora, Svatopluk, Ležnice, Krásná, Čistá, Krásno

West Bohemian U Region

5 West Bohemian District
Dyleň, Svatá Anna, Vítkov II, Zadní Chodov, Pandský Vrch, Horní Ves, Cech s. Víta, Chodovský Újezd, Štokov, Březi, Vítkov I, Oldřichov, Pernolec, Bezděkov, Tachova, Borek
Other U deposits/occurrences in West Bohemian U Region
Dolní Žandov, Smrkovec, Kladská, Kynžvart, Stará Voda, Lîštany (Plzen Basin)

Central Bohemian U Region

6 Příbram District
Třebsko, Kamenná, Lešetice, Brod, Jeruzalém, Háje, Bytíz 4, Bytíz 22–40, Skalka, Obořiště, Vojna
7 Other deposits/occurrences off Central Bohemian U Region
Nová Ves pod Pleší, Mníšek
8 Other deposits/occurrences within Central Bohemian U Region
Vrančice, Předbořice, Heřmaničky, Kojetín Petrovice, Zbislav, Kovářov, Pechová-Lhota, Sobědraž, Petrovice Velká

Southwest Bohemian U Region

9 Novotníky
10 Újezd u Kosejovic
11 Dlažov
12 Ustaleč, Lipová Lhota
13 Damětice, Železnov, Nahošín, Mečichov
Other deposits/occurr. in SW Bohemian U Region
Čeřnic, Březové Hory, Bohutín, Chanovice, Jílové, Kasejovice, Klatovy, Radětice, Prádlo

Southeast Bohemian Region (Železné Hory and adjacent areas)

14 Bernardov, Zdechovice, Litošice
15 Licoměřice, Březinka
16 Budov, Běstvina, Kraborovice, Pukšice-Přísečno, Klocočov
17 Chotěboř, Vestec

West Moravian Region

18 Škrdlovice
19 Slavkovice, Petrovice, Veselíčko
20 Rožná
21 Olší
22 Polná Brzkov
23 Jasenice-Pucov
24 Svratka
25 Daňcovice, Kuklík, Jimramovské Pavlovice
26 Vír
Other Occurrences in West Moravian Region
Nová Ves, Přísečnice, Zlatkov, Strhaře

South Bohemian Region

27 Okrouhlá Radouň

Westsudetic-Silesian Region, East Bohemia

28 Rychlebské hory
Zálesí-Javorník, Bílá Voda, Jelení vrh, Velká Morava
29 Orlické hory
Kamenec, Klášterec, Mladkov, Nebeská Rybná, Říčky, Klodsko
30 Krkonoše Mountains
Medvědin, Labská/Přehrada, Harrachov, Přichovice, Rádlo, Mísečky, Černý Důl, Svatý Petr, Kozí Hřbety

North-Bohemian Cretaceous Basin

31 Stráž Block
Křižany, Břevniště, Osečná-Kotel, Hamr North and South, Holičky, Stráž, Srní Potok, Pavlín, Mimoň, Vranov, Hvězdov
32 Tlustec Block
33 Heřmanky Block
34 Jetřichovice Block

Permo-Carboniferous Basins in Eastern and Central Bohemia

35 Intra-Sudetic Žacléř-Svatoňovice Basin
Rybníček, Stachanov, Zdeněk, Chvaleč, Kolektiv, Pětiletka, Lambertice, Radvanice, Vernéřovice, Jívka, Bohdašín, Hronov
36 Krkonoše/Riesengebirge Foreland Basin
Valteřice, Štěpanice
37 Kladno-Rakovník Basin
Rynholec, Jiří II, Jedomělice, Nečtiny, Radnice, Soseň

Table 3.1.

Czech Republic, uranium production of mining regions, districts, and selected deposits. *Deposit type: Coal* lignite/coal, *Nt-diss* network-dissemination, *Ss* sandstone, *Ve* vein, *-endo* endogranitic, *-exo* perigranitic. *Host rock*: *Grt* granite, *metam* metamorphite, *sed* sediments, *ss* sandstone, *xenol* xenolith (schist/gneiss in granite). *Stratigraphic age*: *C* Carboniferous, *€* Cambrian, *K* Cretaceous, *Herc* Hercynian/Variscan, *P* Permian, *P-C* Permo-Carboniferous, *Pt* Proterozoic, *TT* Tertiary. *Method*: *ISL* in-situ-leaching, *OP* open pit, *UG* underground. *Period*: partly discontinuous operation during the shown period. *Production figures*: rounded, may partly require verification; in addition to the given figures, an estimated amount of several hundred t U was recovered by exploration work. *Grade*: approximate average grade of extracted ore. *Depth*: maximum depth of shaft, incline, open pit. *Note*: Compared with a total of 126 726 t U as given in this table, OECD-NEA/IAEA, 2010, reports a total production of 110 427 t U to 2008 inclusive, which indicates that most production amounts given below correspond most likely to uranium contained in mined ore. (*Resource references*: *(1)* Anonymous (web side 2012), *(2)* Diamo (web side 2012), *(3)* OECD-NEA/IAEA 1995 to 2012; *(4)* additional data from Komínek J, pers. commun. 1997, and other DIAMO staff as mentioned in text)

Region/district	Deposit type	Host rock/age	Mining					Remarks/references
			Method	Period	Prod (t U)	Grade (% U)	Depth (m)	
Central and Southwest Bohemia				**1950–1991**	**Σ 49 224**			
Příbram district	Ve, exo-grt	Metam, Pt, sed, €	UG	1950–1991	48 432	0.18	1 400	(2), (4)
Others	Ve, exo + endo-grt	Metam, Pt; grt, Herc	UG	??	792	<0.15	??	
North Bohemian Basin				**1967–1996**	**Σ 31 836**			
Hamr I	Ss	Ss, K	UG	1972–1993	13 206	0.11	106	(2)
Křižany	Ss	Ss, K	UG	1982–1990	1 108	0.09	190	(2)
Stráž	Ss	Ss, K	ISL	1967–1995	15 562	0.1 –0.15	220	(2)
Stráž				1996–2010	1 960			U from well fields rehabilitation (3)
Northwest Bohemia				**(1853–)1946–1971**	**Σ 10 511**			
Horní Slavkov district	Ve, exo-grt	Metam, Pt	UG	1948–1962	2 668	0.15	800	(2)
Jáchymov district	Ve, exo-grt	Metam, P-C	UG	1853–1966	7 540*	0.1 –1	1 000	* Mining losses deducted (1)
Other	Ve, exo + endo-grt	Metam, Pt; grt, Herc	??	??	<100	0.1		
Sokolov Basin	Coal-Ss	Lig-ss, TT	OP	1965–1971	203	0.15	85	(2)
South Bohemia				**1972–1990**	**Σ 1 340**			
Okrouhlá Radouň	Ve	Metam, Pt	UG	1972–1990	1 340	0.1 –0.2	600	(2)
West Bohemia				**1953–1993**	**Σ 9 349**			
Dyleň	Ve, exo-grt	Metam, Pt	OP + UG	1965–1991	1 100	0.1 –0.2	1 200	(2)
Svatá Anna	Ve, exo-grt	Metam, Pt	UG	??	125	0.1 –0.3	??	(2)
Vítkov II	Ve, endo-grt	Grt, Herc	OP + UG	1961–1991	3 973	0.15–0.3	1 050	(2)
Zadní Chodov	Ve, exo-grt	Metam, Pt	UG	1953–1993	4 151	0.19	1 200	(2)

Table 3.1. *Continued*

Region/district	Deposit type	Host rock/age	Mining					Remarks/references
			Method	Period	Prod (t U)	Grade (% U)	Depth (m)	
West Moravia				**1958–**	**Σ 23 273**			
Rožná	Ve, Nt-diss	Metam, Pt	UG	1958–active	ca. 19 800*	0.08–0.15	1 100	* To end 2011 (2) + (3)
Olší	Ve, Nt-diss	Metam, Pt	UG	1959–1989	2 922	0.08–0.15	900	(2)
Slavkovice-Petrovice	Ve	Metam, Pt	UG	??	175	0.2	??	
Jasenice-Pucov	Ve	Metam, Pt	OP + UG	1963–1991	311	0.12	400	(2)
Polná Brzkov	Ve	Metam, Pt	UG	1988–1990	65	0.15–0.25	300	(2)
Westsudetes-Silesia, E Bohemia				**<1970**	**Σ <605**			
Intrasudetic Basin	Coal-Ss	Coal, ss, P-C	??	<1970	ca. 100	0.05–0.2		
Krkonoše Mtns	Ve, exo-grt		??	1950s	<100	??	??	
Rychlebské-Orlické hory Zálesí-Javornik	Ve	Metam, Pt	??	<1970	405	0.1 –0.2	??	
Železné hory, SE Bohemia				**1968–1990**	**Σ 588**			
Bernadov	Ve	Metam, Pt	UG	??	56	0.1 –0.25	??	
Licoměřice-Březinka	Ve	Metam, Pt	UG	1968–1982	383	0.2	400	(2)
Chotěboř	Ve	Metam, Pt	UG	??	149	0.15	100	
Total				**(1853–)1946–2011**	**ca. 126 726***			*** Incl 17522 t U recovered from ISL well fields**

(Rožná-Olší) in 1957, and the sandstone uranium deposits of North Bohemia (Hamr) in 1967. Mining, in most cases, was by underground techniques except for 16 small open pit mines. ISL extraction has been applied since 1967 at Stráž pod Ralskem, a sandstone-type deposit in North Bohemia adjacent to Hamr. Some uranium was also recovered by small scale ISL in addition to open pit exploitation of the sand-lignite deposit Hroznětín in the Sokolov (Falkenau) Basin.

Eight beneficiation facilities served the uranium mines. Beneficiation of ore to a preconcentrate grading in excess of 0.5% U was by hand sorting and gravity presorting in the Jáchymov, Horní Slavkov, and Příbram districts from the mid-late 1940s into the 1950s. Three gravity facilities were active: Eliáš (1946–1966) in the Jáchymov (St. Joachimsthal), Horní Slavkov-Vlčí (1948–1958) in the Horní Slavkov, and the Příbram plant (1959–1991) in the Příbram district. An additional facility for ore blending existed at Horní Ždár in the Jáchymov district. Four hydrometallurgical plants produced yellow cake: Nejdek (1955–1966), Mydlovary (1962–1991), Dolní Rožínka (1968 to date), and Stráž pod Ralskem (1979–1993).

Annual production reached a peak of some 3 000 t U in about 1960 and stayed between 2 500 and 3 000 t U from 1960 to 1989 when it began to decline to 541 t U in 1994. Due to the depletion of deposits, uranium mining ceased in the districts of Horní Slavkov (Schlaggenwald) in 1962, Jáchymov (St. Joachimsthal) 1966, Příbram 1991, and West Bohemia in 1993. Economic reasons forced the closure of the underground mine of Hamr in 1993. By 1994, all mines where closed except for Rožná and the ISL fields of Stráž, but the latter produces uranium only in course of the clean up efforts.

All uranium products have been exported to the USSR and only the amount required for Czechoslovakia's nuclear power stations has been returned (as fabricated fuel). The manually and gravity preconcentrated material was shipped as lump ore until the 1960s. The shipment of this material was subsequently replaced by yellow cake with the start up of the hydrometallurgical plants.

3.1 Northwest Bohemian Uranium Region

This uranium region covers part of the western Krušné hory (Erzgebirge) and the southerly adjacent Karlovy Vary Massif in northwestern Bohemia (➲ Fig. 3.1). Besides numerous scattered uranium occurrences, significant uranium deposits occur in two districts, *Jáchymov* (St. Joachimsthal) and *Horní Slavkov* (Schlaggenwald). Most deposits are polymetallic and perigranitic, while a few small ones are intragranitic vein-type uranium deposits associated with the granitic Karlovy Vary-Eibenstock Massif.

Tertiary intermontane basins such as *Sokolov* (Falkenau) and *Cheb* (Eger) contain lignite-sandstone-type uranium deposits. The basins are downfaulted into granites of the Karlovy Vary Massif and adjacent metamorphic complexes. ➲ Figure 3.2 provides a generalized geological map of the region with the location of uranium deposits and major uranium occurrences.

3.1.1 Jáchymov (St. Joachimsthal) District, Northwest Bohemia

Jáchymov (Czech) or St. Joachimsthal (German) is located 20 km north of Karlovy Vary (Karlsbad) in northwestern Bohemia. Mineralization is polymetallic composed of Ag, Co, Ni, Bi, and U. In excess of 200 mineralized veins are known from the district, which covers about 45 km^2. Total original uranium resources are thought to have been on the order of 9 000 t U. Average ore grades ranged from 0.1 to 1% U.

Veins of the district, discovered in 1546, were first exploited for silver and later on for cobalt, nickel, and bismuth. Uranium mining began in 1853, initially for use in paints and pharmaceuticals, and, in the early 20th century, for the extraction of radium (see Subsect. *Historical Review*, p. 57, for more details). After 1946, when mining resumed, seven major vein systems were exploited for uranium through shafts between 300 and 1 000 m deep.

Between 1853 and 1966, the mines produced 7 539 t U (mining losses deducted), 469 t U of which were extracted from 1853 through 1944, and 7 070 t U between 1946 and the closure of the last mine in 1966 (Anonymous, web side 2012).

The *Abertamy* mine was the largest and lowest cost producer of the district. It delivered about 700 t U at a high grade. Veins at *Potůčky*, adjacent to *Johanngeorgenstadt* in Germany, were accessed from the German side and delivered 185 t U (Wismut 1999).

Sources of information. Kolektiv (1984), Komínek and Veselý (1986), and Ruzicka (1971) published concise reviews on the Jáchymov deposits that provided the base for the following compilation amended by data from Anonymous (web side 2012), Bernard et al. (1968), Dymkov (1961), Komínek et al. (1994), Kraus (1916), Leutwein (1957), Mrňa (1963a,b, 1967), Mrňa and Pavlů (1967), Oelsner (1958), Ondruš et al. (1997a,b), Pluskal (1998), Schumacher (1933), Veselovský et al. (1997a,b), Veselý (1985, 1986), Vogl (1856), Zückert (1926), pers. commun. by Komínek J, Pluskal O, Kirchheimer F (1963) has given a synoptical description of uranium veins, mineralogy, and production data of the Joachimsthal district as they were known in the 19th century. For more recent data on Erzgebirge geology and mineralization the reader is referred to Breiter et al. (1997, 2005, 2006), Dymkov (1996), Štemprok (1986, 1992, 1993), Štemprok et al. (2003), Velichkin et al. (2004).

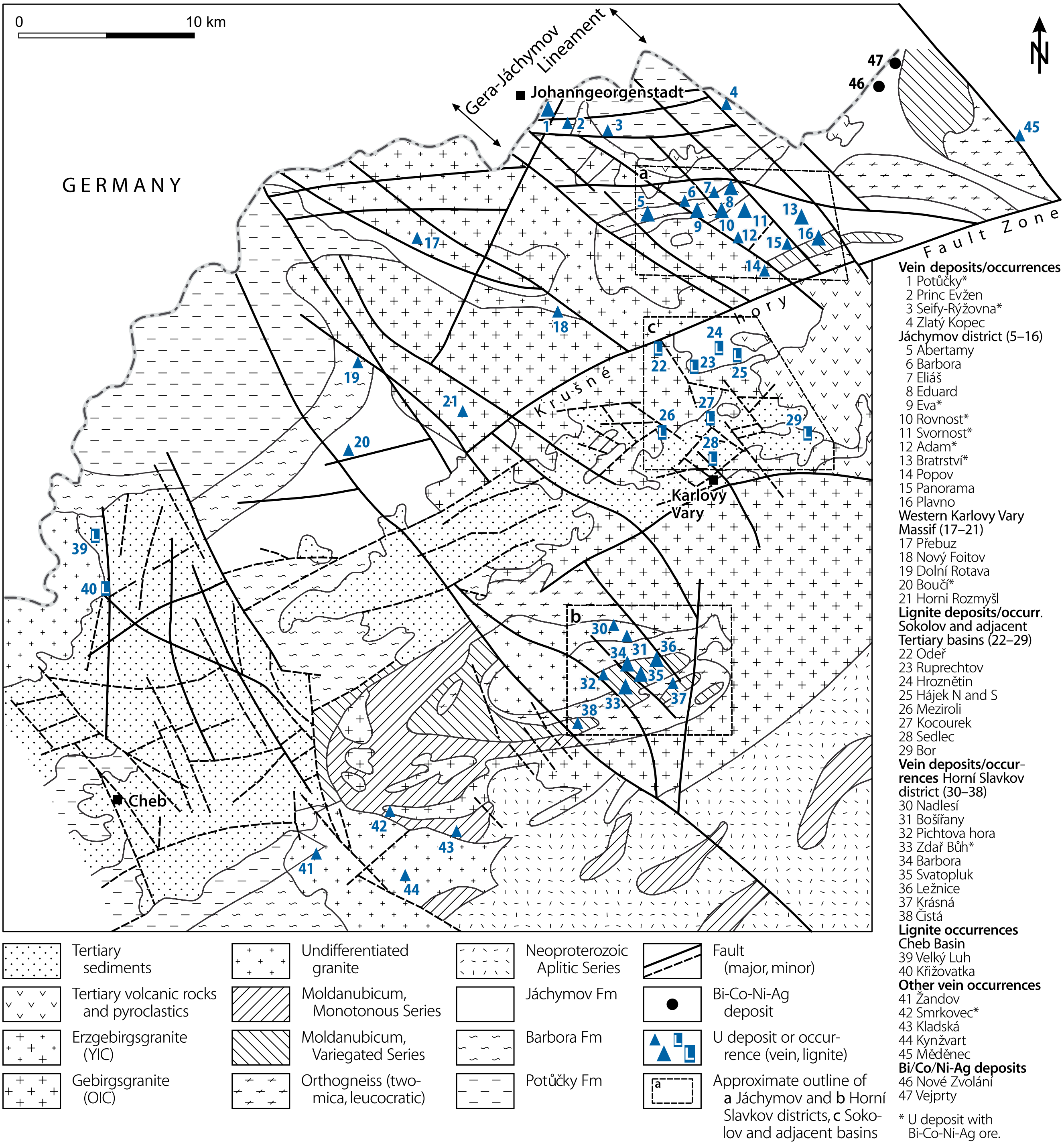
Regional Geologic Setting of Mineralization

The Jáchymov district is located at the eastern margin of the Eibenstock-Karlovy Vary granitic massif in the western Erzgebirge. The massif is a segment of the Saxo-Thuringian metallotectonic zone of the Hercynian orogenic belt. The massif is mantled by Cambro-Ordovician metasediments of the *Mica Schist Formation*, which includes the following lithostratigraphic series (Kolektiv 1984) (➲ Fig. 3.3):

Potůčky Series. 1 000–1 500 m thick, sericitic and chloritic-sericitic phyllite with amphibolite intercalations; uranium veins in upper section at Potůčky vein cluster.

Fig. 3.2.

Northwest Bohemia, southwestern Krušné hory (Erzgebirge)-Karlovy Vary Massif region, generalized geological map with location of uranium districts and individual deposits and occurrences. (After Kolektiv 1984)



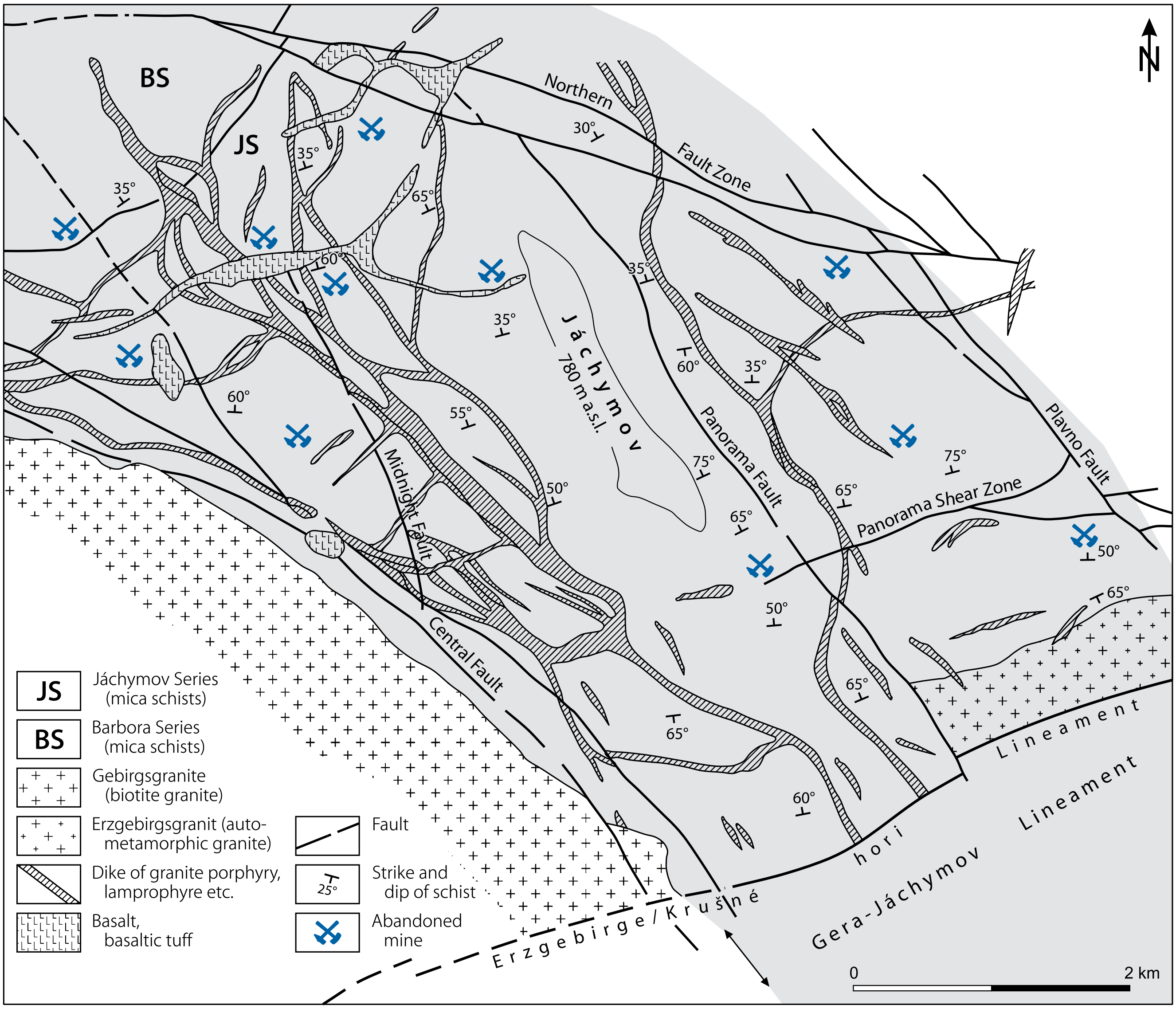
Barbora Series. 700–1 000 m thick

- upper unit: garnet-muscovite schist with intercalated amphibolite and skarn,
- lower unit: two-mica schist.

Jáchymov Series. 1 000–1 200 m thick

- upper unit: monotonous two-mica schist, rare uranium veins,
- middle unit: albitized muscovite and muscovite-biotite schists, partly pyritic and/or graphitic; calc-silicate, banded microskarn; important uranium host at *Plavno* (Pl), *Panorama* (Pa), *Bratrství* (Br), *Svornost* (Sv), *Rovnost-Eliáš-Eduard* (Ro-El), *Eva-Barbora* (Ev-Ba), *Abertamy* (Ab) (letters refer to Fig. 3.4),
- lower unit: garnet-muscovite-biotite schist with quartzite and orthogneiss layers (corresponds to Klínovec schist/stage).

Fig. 3.3.
Jáchymov district, simplified geological map with distribution of principal country rocks, dikes, and major faults. (After Kolektiv 1984)



Komínek and Veselý (1986) and Kolektiv (1984) subdivide the metasediments of the *Barbora* and *Jáchymov Series* into six horizons with a cumulative thickness of 900–1 000 m (top to bottom):

6. garnet-muscovite-biotite schist with quartzite and orthogneiss layers
5. biotite and garnet-biotite schists with amphibolite and quartzite intercalations
4. muscovite, muscovite-biotite, garnet-muscovite, and garnet-muscovite-biotite schists
3. biotite and phlogopite-biotite-albite schists
2. fine-grained biotite and sericite-biotite schists, and schistose phyllite
1. medium-grained, albitized biotite-phlogopite schist

All these horizons include pyrite and calc-silicate (erlan) layers and contain finely disseminated graphite.

The metasedimentary complex was intruded by Early Hercynian diorite and gabbro-diorite stocks, as well as Late Hercynian granitic plutons, which were followed by a variety of dikes. Tertiary volcanics of alkaline chemistry (nephelinite, leucitite, tephrite) are the youngest igneous rocks (Ruzicka 1971) (Fig. 3.3).

The large Eibenstock-Nejdek-Karlovy Vary Massif (ca. 600 km^2 in outcrop) is composed of Late Hercynian granites. They outcrop on the southwestern side of the Jáchymov district and in cupolas, which are connected underground, on its NW and SE margins. These granites underlie metasediments with an undulating surface at depths between 300 and 1 000 m. They generated an inner contact-metamorphic aureole, 10–60 m wide, of biotite-hornfels, skarn, and mildly greisenized metasomatites with increased B (tourmaline), W, and Mo values, and a wider contact-metamorphosed outer halo similar to that at the nearby Tellerhäuser deposits in Saxony.

Two principal types of Late Hercynian granites are recognized (Kolektiv 1984; Komínek and Veselý 1986) (see Sect. 7.1 *Erzgebirge, State of Saxony*, for more recent studies on granite compositions and new classification of granite types). The older "*Gebirgsgranite*" also referred to as "normal granite" (340–320 Ma, references see Subsect. *Geochronology*, p. 71) includes porphyritic biotite or muscovite-biotite adamellite, medium-grained, indistinctly porphyritic biotite granite, and a marginal facies of porphyritic biotite adamellite to porphyritic biotite granite. The main facies contain elevated values of radioactive elements with a Th / U ratio greater than 1.

The younger "*Erzgebirgsgranite*" (310–300 Ma), also referred to as "autometamorphic granite", consists of leucocratic, autometamorphosed porphyritic tourmaline-biotite or biotite-muscovite granite, with autometamorphosed aplitic granite and tourmaline granite dikes. The Erzgebirgsgranite typically contains higher amounts of accessory minerals and elevated Clarke uranium values (Gebirgsgranite/biotite granodiorite 6.8 ppm U, 17–24 ppm Th, Erzgebirgsgranite/autometamorphic biotite granite 10.4–11.6 ppm U, 12.2–12.5 ppm Th (Škubal and Vachuška 1973 and Absolonová and Matoulek 1975 cited in Kolektiv 1984)). Uranium occurs in the form, among others, of minute uraninite crystals (Kohl 1954). U and Th associate with Be, Nb, REE, and Sn.

Erzgebirgsgranite exhibits strong autometamorphic modifications comparable to a large degree with the late magmatic phenomena described by Poty, Cuney and co-workers for granite-related uranium districts in the Massif Central and Armorican Massif, France (see Sect. 6.1.1 *La Crouzille District, Limousin Region* and Sect. 6.3.1 *Vendée District, Mortagne Massif*). Modifications include albitization, muscovitization, and greisenization. Granitic facies with elevated uranium tenors are commonly strongly greisenized with high contents of Sn (cassiterite), Li (Li micas), F (fluorite), and topaz.

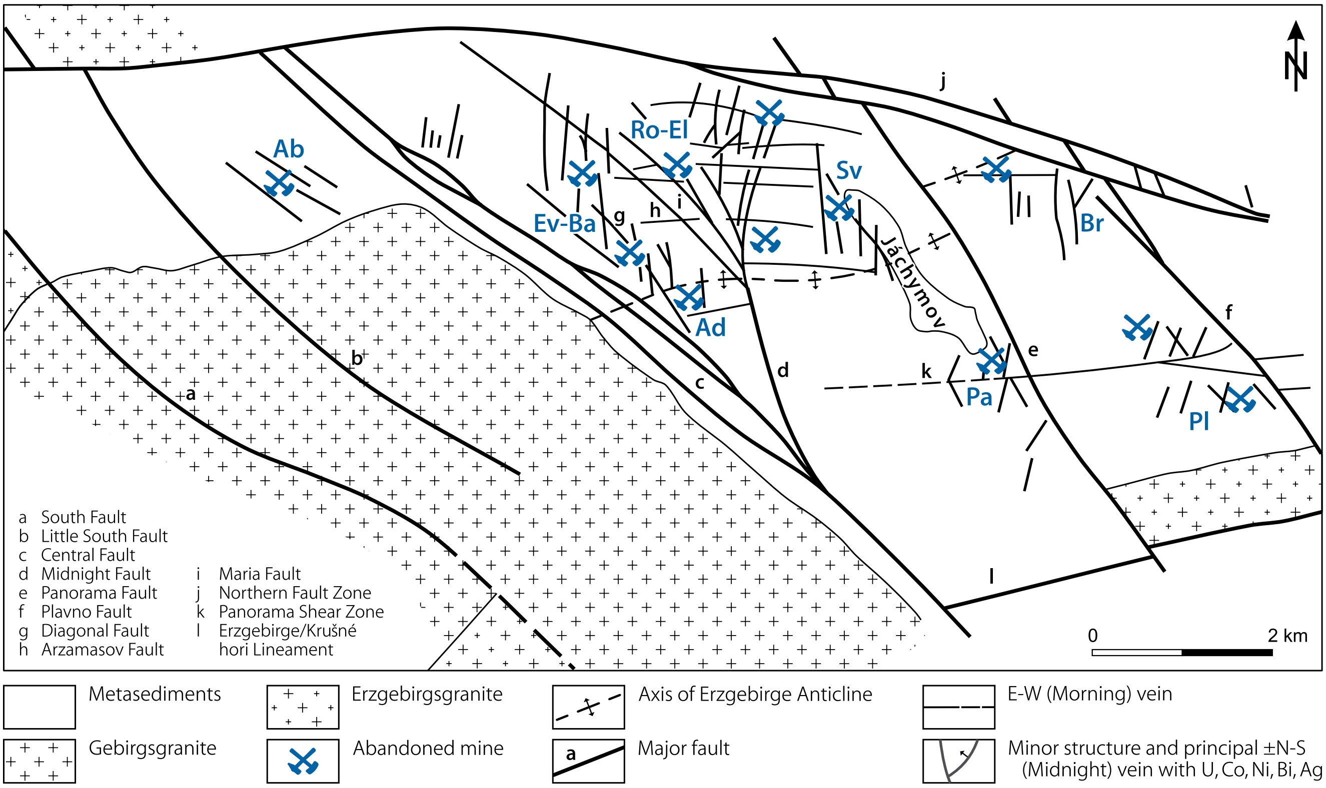
Boundaries between Gebirgs- and Erzgebirgsgranite display both gradational transitions and sharp contacts. The former may suggest an evolution by differentiation of the Eibenstock-Nejdek-Karlovy Vary Massif similar to that as demonstrated for the Saint-Sylvestre Massif/Limousin, France (Friedrich et al. 1987).

Post-granite intrusions include granite porphyry, quartz porphyry, pegmatite, lamprophyre, and aplite dikes dated at 290–280 Ma.

Metasediments of the Jáchymov district occur within the southwestern part of the NE–SW-oriented Erzgebirge Anticlinorium. Subsidiary folding overprinted the regional structural grain and generated the approximately E–W-trending Keilberg (Klínovec) Anticline in the northern and the Holzbach Anticline in the southern segment of the district. The anticlines are asymmetric. Their wings dip 20–35° N and 60–70° S. Smaller folds overprint the southern wings of both anticlines.

Fig. 3.4.

Jáchymov district, generalized structural map projected into the Daniel horizon level (630–640 m a.s.l.). The map shows major faults/lineaments, the clusters of the NE to NW oriented U-Co-Ni-Bi-Ag "Midnight veins" and E–W trending "Morning veins", and the position of the district with respect to the autometamorphic "Erzgebirgsgranite". ***Vein clusters*: *Ab* Abertamy, *Br* Bratrství, *Ev-Ba* Eva-Barbora, *Pa* Panorama, *Pl* Plavno, *Ro-El* Rovnost-Eliáš, *Sv* Svornost. (After Komínek and Veselý 1986; Kolektiv 1984; Bernard et al. 1968)**



Brittle deformation produced four fault systems oriented ENE–WSW, NW–SE, N–S, and E–W (Fig. 3.4). The first two systems are of regional magnitude. Most prominent of the ENE–WSW system is the Krušné hory (Erzgebirge) Lineament that extends for more than 100 km and separates the northerly located Erzgebirge Block from the southerly Central Bohemian Block and, as such, the Saxo-Thuringian from the Moldanubian metallotectonic zone of the Hercynian belt. This lineament dips 70–80° S and consists of a sheared and brecciated zone up to 300 m wide. The southern block has been downfaulted for several hundred meters, most recently in Tertiary time. The Erzgebirge Lineament forms the southern boundary of the Jáchymov district.

NW–SE-oriented faults belong to the ancient and repeatedly reactivated Gera-Jáchymov (also referred to as Gera-České Budějovice) Lineament. The South Fault (*a* in Fig. 3.4) limits the Jáchymov district to the west and is the largest structure of this system. It dips 70–80° NE, is 60–300 m wide, and caused a vertical displacement of the granite contact of 500–700 m. Other faults of the NW–SE system located east of the South Fault include, from west to east, the Little South (b), Central (c), Midnight (d), Panorama (e), and Plavno (f) Faults. These faults consist of 20–80 m, locally 200 m, wide zones composed of gouge, sheared country rocks, and authigenic quartz and dolomite. They range in length from 4 to 30 km, dip 70–85° NE in the western and steeply SW in the central and east parts of the district, and caused displacements of 80–200 m vertically and 100–1 000 m laterally.

N–S-oriented faults often derived by branching of the NW–SE structures. E–W faults are abundant and include the North Fault that forms the northern boundary of the district. The NW–SE and associated N–S structures (called Midnight veins) and the E–W (Morning veins) are the principal hosts for mineralization.

Principal Host Rock Alterations

Dymkov (1961) and Ruzicka (1971) describe general alteration features in rocks surrounding uranium deposits in the Erzgebirge, which can be summarized as follows:

Alteration in metasediments

- Pre-uranium alteration: skarn development and biotitization in an initial stage; scapolitization of gneiss; pyritization, chloritization of amphibolite, tuff, gneiss, etc.; graphitization along shear zones,
- Syn? to post-uranium alterations: silicification, carbonatization, hematitization,
- Post-uranium alteration: sericitization, silicification, kaolinitization

Alterations in granitic facies

- Pre-uranium alteration: greisenization, albitization, muscovitization, silicification,
- Syn-uranium alteration: sericitization,
- Post-uranium alteration: sericitization, kaolinitization

Kolektiv (1984) recognizes two stages of wall rock alteration, a pre- and a syn-uranium stage:

- The *pre-uranium alteration stage* affected wall rocks in a zone 0.5 to 3 m outward from veins with a wider zone on the footwall side. An early alteration phase begins with disintegration of mafic minerals such as biotite, amphibole, and pyroxene associated with removal of Ca, Fe, and Mn and recrystallization of chlorite, phlogopite, rutile, and, in immediate proximity to veins, pyrite and larger quantities of calcite. In a final phase, intense silicification replaced many minerals including calcite and produced a wide zone of quartzification. Older calcite stringers and veins formed particularly in silicified marly schists, graphite-biotite schists, and phlogopite-biotite schists that contain intercalations of silicified marble. Pyrite is concentrated in few but large lenses along the contact of calcite veins.
- The *syn-uranium alteration stage* overprinted the vein-adjacent part of the older alteration zone and extends only centimeters to several tens of centimeters away from the vein contact. The principal recrystallization products are albite and adularia that formed in several generations within the wall rock or on comb quartz. Pyrite was replaced by hematite and calcite by dolomite.

Principal Characteristics of Mineralization

Kolektiv (1984) and Komínek and Veselý (1986) separate the Jáchymov (St. Joachimsthal) mineralization into seven mineral associations/stages (Fig. 3.5):

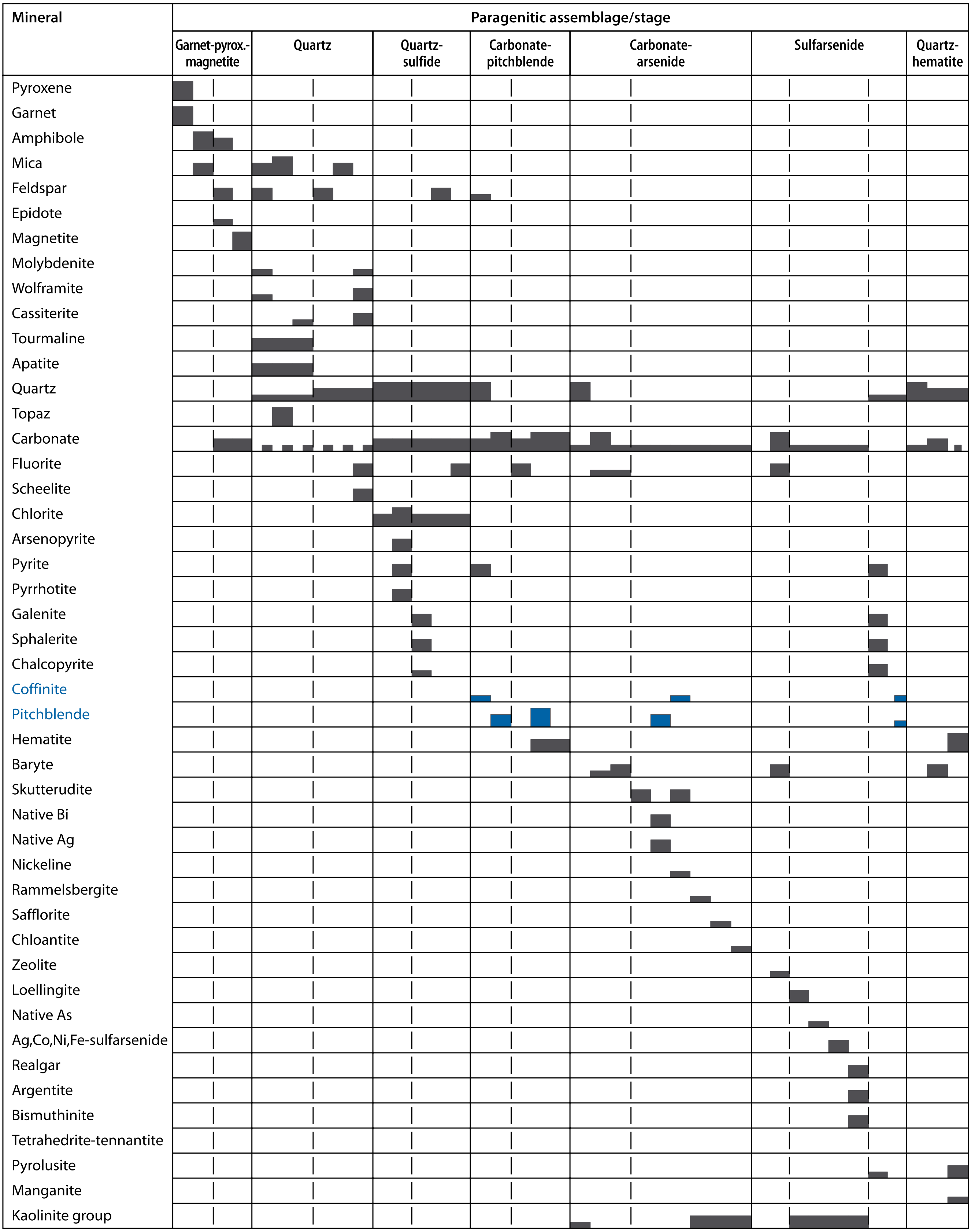
1. garnet-pyroxene-magnetite,
2. quartz-wolframite-cassiterite,
3. quartz-sulfide,
4. carbonate-pitchblende,
5. carbonate-arsenides,
6. sulfoarsenides, and
7. quartz-hematite-manganite.

The first two associations are of more regional distribution and the last five constitute actual vein fillings of the district.

Mrňa (1967) distinguishes six stages of mineralization which correspond, partly by overlapping, to stages 3 to 6 of Kolektiv (1984):

1. *older sulfide stage*: quartz and locally sulfides in insignificant amounts (bornite, chalcopyrite, galena, pyrite, sphalerite, a.o.);
2. *quartz stage*: chalcedony-like and hematite-rich quartz prevailing in lower levels, and comb- or palisade-quartz in upper levels; quartz is often smoky; some ankerite and fluorite; strong alteration;
3. *pitchblende stage*: mostly colloform pitchblende associated with reddish dolomite and small amounts of pyrite and fluorite. Distribution is predominantly in deeper parts of the deposit. Fluorite is typically a dark purple “Stinkspat”, releasing a fetid, stinky odor (fluorine) when crushed;

Fig. 3.5.
Jáchymov district, paragenetic scheme of Ag, Bi, Co, Ni, U vein mineralization. *Note*: The "quartz" stage is termed "quartz-wolframite-cassiterite" stage, and this stage together with the "quartz-sulfide" and "carbonate-pitchblende" stages are attributed to Hercynian events, whereas the last three stages are attributed to Young Kimmerian events by Komínek et al. 1994. (After Kolektiv 1984)



4. *arsenide stage*: semitransparent quartz and subordinate carbonate associated with two metallic substages:
   - Substage 4a: native silver and arsenides with a generally higher Ni content including nickeline, rammelsbergite, skutterudite, and locally safflorite, loellingite;
   - Substage 4b: native bismuth and arsenides with a generally higher Co content including loellingite, rammelsbergite, safflorite, and skutterudite.

   Substage 4a is characteristic for upper and middle levels and substage 4b for middle and lower levels;
5. *sulfoarsenide stage*: native arsenic, argentite, proustite, locally stephanite, rare loellingite, pyrargyrite, realgar, sternbergite, stibnite, associated with dolomite. Sb-containing Ag minerals occur below the level of Ag-As minerals;
6. *younger sulfide stage*: bornite, chalcopyrite, galena, marcasite, pyrite, sphalerite, stannite, and minor amounts of antimonite, arsenopyrite, tetrahedrite, associated with calcite. In addition to the listed minerals, adularia, anhydrite, gypsum, and marcasite are present. Stage 6 is only rarely represented at Jáchymov (St. Joachimsthal) in contrast to other districts of the Erzgebirge, where it is the main component of veins.

Ruzicka (1971) provides the following elemental suite and ranges of percentages in lodes of the Jáchymov veins: >1% Fe, U; 1–0.1% As, Cu, Pb, Sb, Se, V, Y, Zn; 1–0.01% Bi, Mn; 0.1–0.01% Ag, P, Sc, Th, Ti, W, Y; <0.01% Ba, Be, Ce, Co, Li, Mo, Ni, Sn, Sr, Tl.

Primary pitchblende is predominantly of colloform habit. It is essentially restricted to the carbonate-pitchblende stage. Redistributed uranium occurs mostly in the form of sooty pitchblende and coffinite which, are the main uranium minerals in the arsenide and sulfoarsenide stages.

Minerals of the different stages overlap spatially in veins with the exception of arsenides, native silver, and native bismuth, which show a pronounced antagonism (see next chapter).

Younger ore mineral transformations include leaching of native silver, transformation of part of the native bismuth into bismuthinite, mobilization and redistribution of primary pitchblende and native bismuth, and leaching of less resistant skutterudite constituents associated with a localized degradation to a lower arsenide stage. Part of these mobilizations and redepositions occurred after the extrusion of the Tertiary volcanics.

Two varieties of veins containing uranium, simple and complex, are recognized by Kolektiv (1984) and Komínek and Veselý (1986).

Veins of simple composition contain the carbonate-pitchblende assemblage emplaced within gouge and brecciated wall rock material. Fractures hosting simple mineralization are mostly those of fifth and sixth order (see later). Veins are 150 to 400 m long and 3 to 25, rarely 50 cm wide. In a schematic section, simple veins exhibit a symmetric mineral distribution. Quartz-adularia-albite-fluorite forms discontinuous comb-textured vein skirts along the wall rock, whereas coarse-crystalline, pink dolomite with relics of calcite inclusions fills the axial space. Pitchblende commonly occurs between the comb-textured skirts and dolomite. Pitchblende forms elongated bands and spherulitic chainlike selvages either in cleavages of or between individual carbonate grains.

Two substages are present. Pitchblende 1 and coffinite 1 are the principal minerals of the older substage; they associate with comb-textured aggregates of quartz, albite or adularia, and fluorite. Minerals of the younger substage include pitchblende 2, dolomite, and hematite. Dolomite 1 pseudomorphously replaces older calcite. Hematite derived by alteration of pyrite commonly forms aggregates with dolomite and imprints a pink hue on dolomite. Pitchblende partly replaces calcite crystals pseudomorphously. At the end of the carbonate-pitchblende stage, minor amounts of sulfides (galena, sphalerite) were introduced. They partly replace pitchblende and fill fractures.

Veins containing primary pitchblende are only preserved in structures of a higher order that had been sealed early, and which were not reactivated.

Veins of complex composition contain, in addition to minerals of the carbonate-pitchblende assemblage, those of the younger carbonate-arsenide and quartz-sulfide stages. Fractures hosting complex veins predominantly follow the schistosity of metasediments or are fourth order structures that had been reactivated and are now characterized by breccias and deformed gouge. Veins are more than 1 000 m long and 10–60 cm wide. At sites of complex structures, e.g., at lacing veins, minerals of variously aged assemblages may occur concurrently.

Complex veins comprise several generations of carbonate and quartz combined with ore minerals. Coarse-crystalline, pink dolomite closely associates with pitchblende, whereas fine-grained, grey dolomite 2, ankerite and para-ankerite enclose arsenides, baryte, and fluorite. In addition to pitchblende 1 and 2 of the carbonate-pitchblende stage, minor amounts of pitchblende 3 and coffinite 2 occur. They formed with the younger carbonate-arsenide and quartz-sulfide stages. Characteristic mineral components of complex veins are tri- and diarsenides of Co and Ni together with native Ag, As, and Bi. Complex veins are commonly of breccia texture in which pitchblende coats vein walls or rock fragments. On the other hand, pitchblende fragments are cemented by ankerite, dolomite 2, quartz, and/or Ni- and Co arsenides (Fig. 3.6).

Veins of complex composition display a *vertical zoning*. Upper levels, more than 600 to 800 m above the granite basement or from surface to 400 m deep, respectively, are dominated by native silver, arsenides, and redistributed pitchblende. Lower levels extending 200 to 300 m upwards from the granite basement are dominated by native bismuth, arsenides, and by primary pitchblende.

In the weathering zone that persists as much as 300 m deep along major shear zones, pitchblende is decomposed with uranium partly removed and partly transformed into U^{6+} minerals. U hydroxides and U silicates crystallized under alkaline conditions and U phosphates and U arsenates in an acid environment.

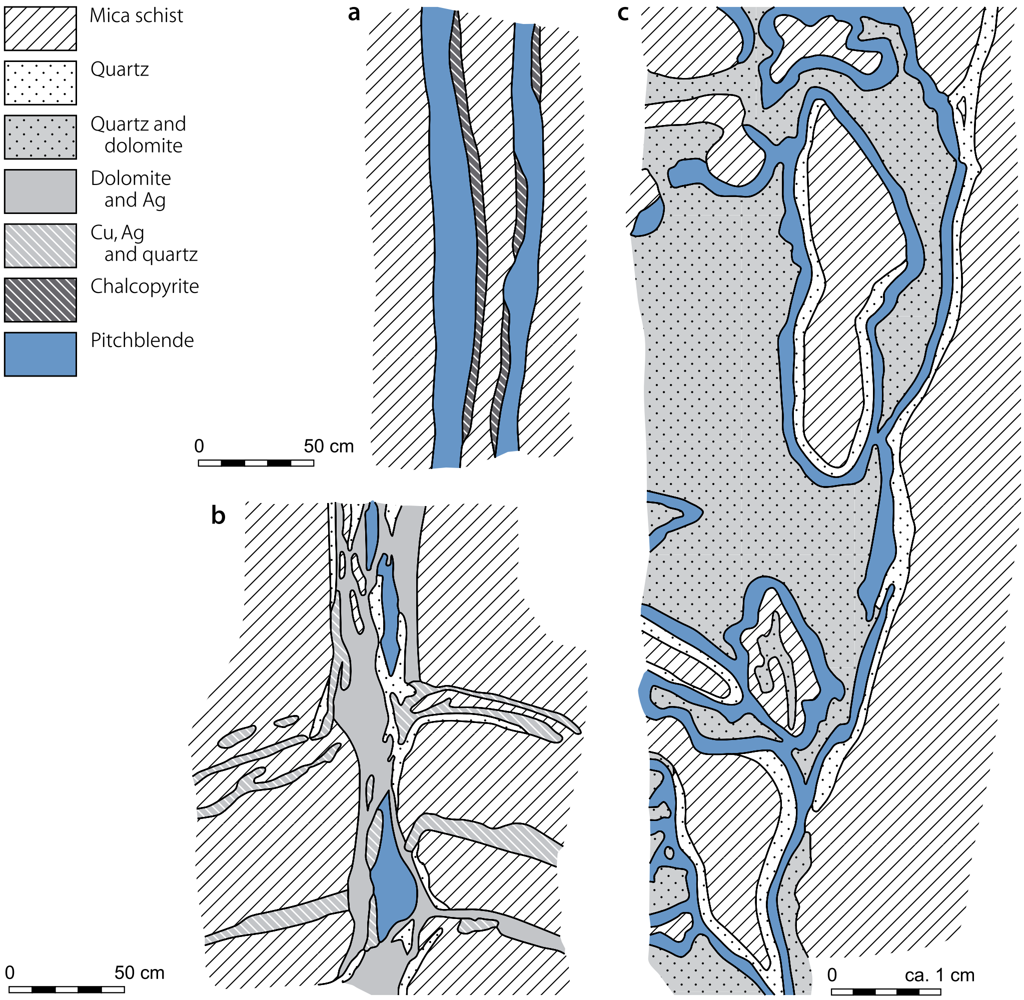
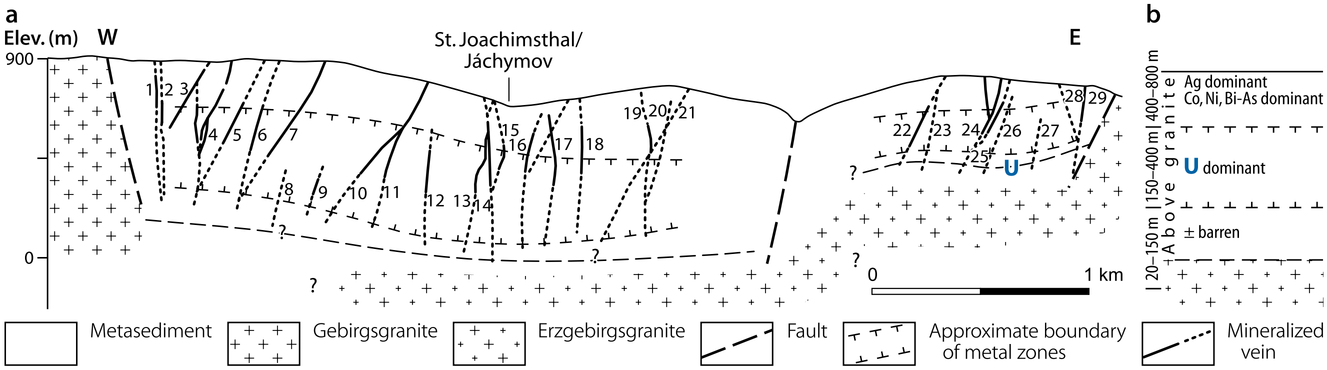


Fig. 3.6. Jáchymov district, **a** Geister vein, 326 m below surface; **b** and **c** Hildebrand vein (**b** is 214 m below surface). Schemes of composition of mineralized veins within mica schist wall rock. **a** Association of massive pitchblende and chalcopyrite. **b** Main vein composed of pitchblende associated with silver, gangue of dominant dolomite and quartz and mica schist fragments; lateral veins consist of quartz, chalcopyrite and silver. **c** Detail of a vein showing mica schist fragments encrusted with quartz and pitchblende embedded in a gangue matrix of quartz and dolomite. (After **a**, **b** de Launay in Roubault 1958; **c** Step and Becke 1904)

Fig. 3.7. Jáchymov district, **a** generalized W–E section showing the principal vein systems/clusters and vertical zones of metal distribution; **b** schematic diagram of metal zoning. An upper zone persists from approximately 400 to 800 m above the granite contact; Ag prevails on the uppermost levels followed downwards by Co, Ni, Bi and As dominance with minor (redistributed) uranium. A medium zone, ca. 150–400 m above the granite, is typified by uranium dominance with more or less Co, Ni, and rare Ag. Veins of the lowest zone are almost barren of metals except for very wide veins. (After Kraus 1916; Petrascheck and Petrascheck 1950)



General Shape and Dimension of Deposits

Mineralized veins of the Jáchymov district occur in an area of about 45 km^2. The veins group in clusters. Most of the uranium mined was contained in seven clusters, from SE to NW (letters refer to Fig. 3.4). *Plavno* (Pl), *Panorama* (Pa), *Bratrství* (Br), *Svornost* (Sv), *Rovnost-Eliáš-Eduard* (Ro-El), *Eva-Barbora* (Ev-Ba), and *Abertamy* (Ab). Another cluster, *Potůčky*, is located about 12 km northwest of Jáchymov (St. Joachimsthal).

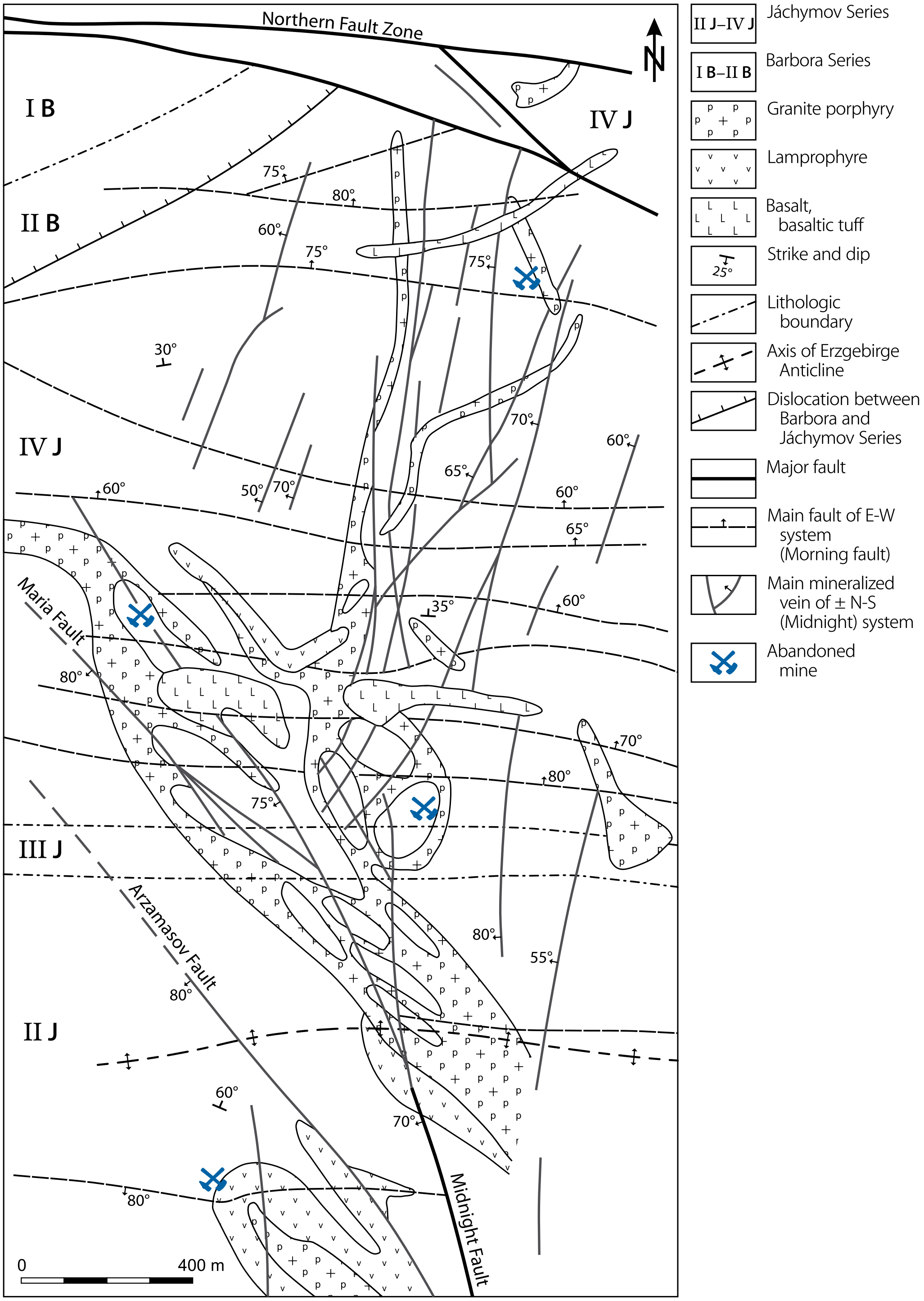
Pay streaks of uranium exhibit a pronounced spatial relationship to the intrusive surface of granite in depth. They occur in a zone between 150 and 400 m above and paralleling the granite contact, which is 300 to 1 000 m deep (Fig. 3.7).

Mineralized veins follow three main directions, about NW–SE, N–S, and E–W. The first two were named "*Midnight veins*" and the E–W system "*Morning veins*" some 400 years ago. Most mineralized structures are complex in nature and form clusters by lateral and vertical lacing, bifurcation, and/or ramification of veins of different orders (main and subsidiary structures) (Figs. 3.4 and 3.8).

Vein clusters often consist of tree-like asymmetric geometry in which the variably trending branches or fault systems contain different mineral associations:

- *Trunks* are represented by major NW–SE structures up to many kilometers long and several meters wide. They are filled with gouge and authigenic quartz, dolomite, hematite, and manganite of the youngest mineralization stage.
- *Branches* of about NW–SE to N–S orientation are 200–1 000 m, rarely 2 500 m long, 10–30 cm, rarely 50 cm wide, and caused displacements of up to 50 cm. These structures are irregular

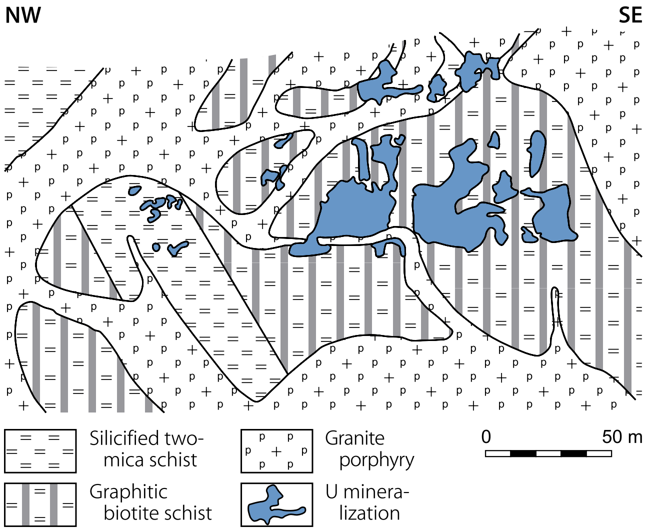
Fig. 3.8.
Jáchymov district, Rovnost vein cluster, generalized lithologic-structural map projected into the Daniel horizon level (630–640 m a.s.l.). Uranium mineralization markedly concentrates at sites near the splaying of a major NNW–SSE structure into NW to NE oriented "Midnight" veins. For lithologies of the Barbora (*I B–II B*) and Jáchymov (*II J–IV J*) Series see text. (After Komínek and Veselý 1986; Kolektiv 1984)



open fissures with commonly westerly dip. A spatial and genetic relationship to the major NW–SE faults is apparent. Oldest infill consists of quartz-feldspar locally associated with fluorite and sulfides, but these structures also host the economically important carbonate-pitchblende stage. Uranium lodes are irregularly distributed in these veins but concentrate at intersections or interjunctions of different fracture systems and where regional faults thin out and branch (Fig. 3.8). Uranium is absent in these veins for about 30 to 50 m away from the splay off site at the major fault.

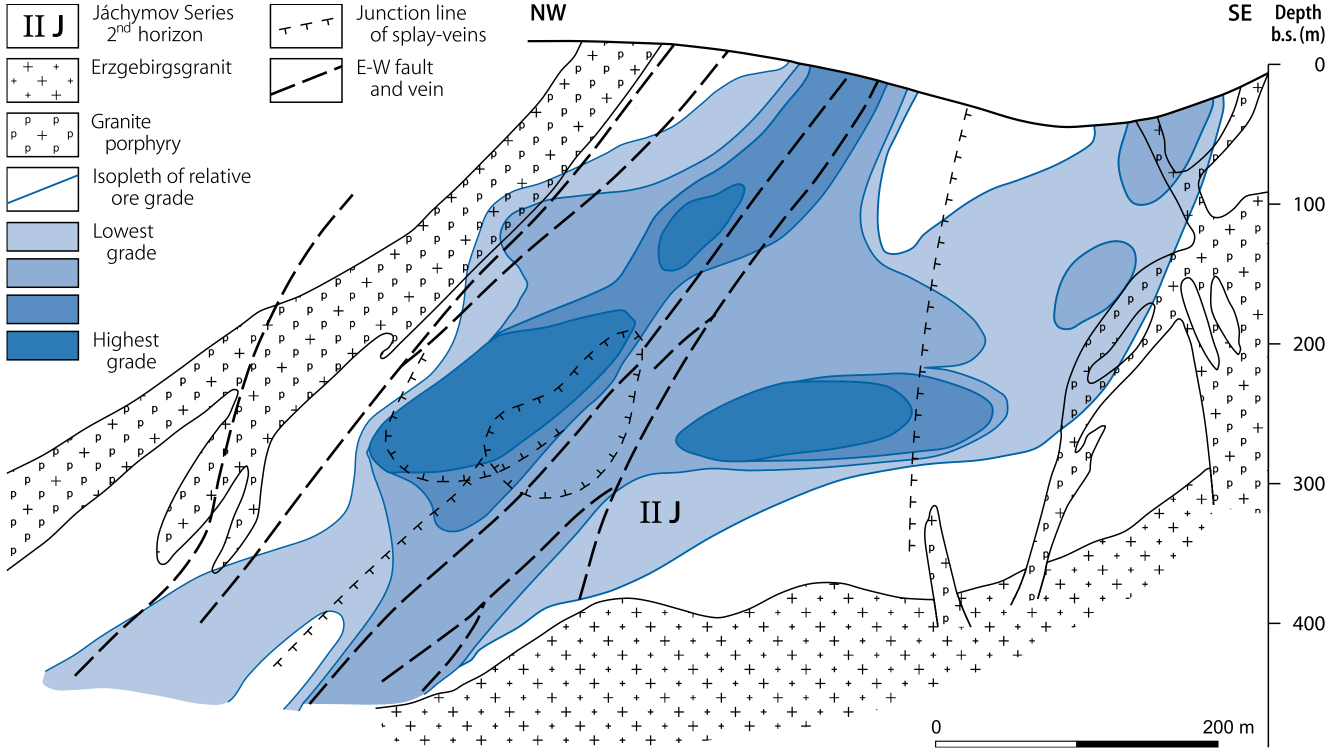
- *Feather joints* trending between NW–SE, N–S, and NE–SW ("Midnight veins") are a few tens to some hundred meters long and a few to 30 cm wide, rarely more. They contain quartz-carbonate-arsenide and younger sulfide-sulfoarsenide mineralization associated with redistributed uranium constituting the so-called Ag-Co-Ni-Bi-U association. N–S-oriented veins with arsenide stage minerals dissect the NW–SE carbonate-pitchblende veins.
- *E–W veins* ("Morning veins") are 500–1 500 m long and 10–50 cm wide. The inclination of these veins is preconditioned by the attitude of schistosity. Veins dip 60–80° N in the northern part and 60–80° S in the southern part of the district. Veins are commonly of simple configuration and consist mainly of gouge and the older quartz-sulfide assemblage. Locally, veins contain pockets with Ag mineralization but are practically devoid of uranium except at a few intersections with NW–SE veins, where rich ore shoots may have developed.

Fig. 3.9.
Jáchymov district, east part of the Rovnost vein cluster, longitudinal section of the Bergkittler 1 vein demonstrating uranium concentration preferentially in vein sections that cut through granite porphyry dikes. Dikes are thought to have acted as barriers to mineralizing solutions. (After Kolektiv 1984)



Uranium of the carbonate-pitchblende stage occurs in variably shaped and intensive concentrations, mostly in the central part of a vein, in the form of thin stringers, streaks, and patches. The richest lodes occur mainly in thick veins, but in

Fig. 3.10.
Jáchymov district, Abertamy vein cluster, vertical projection along the A2 vein with isopleth of relative ore grades. Ore is contained in a lode between and controlled by granite porphyry dikes. (After Komínek and Veselý 1986)



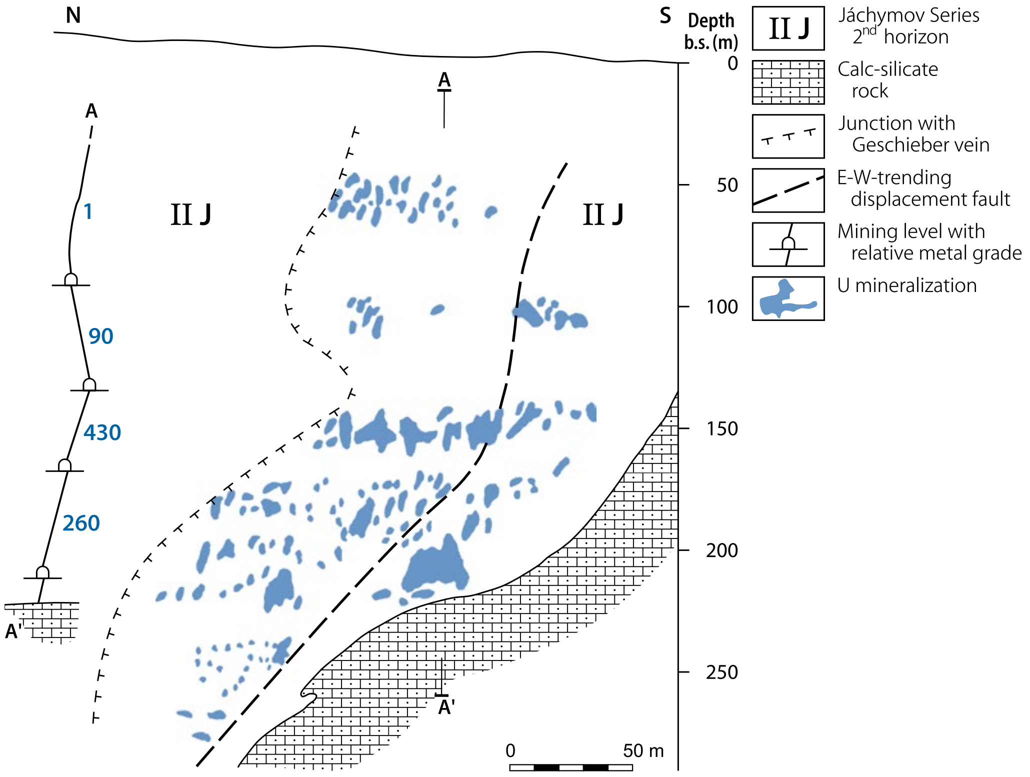


Fig. 3.11. Jáchymov district, 4th splay vein of the Geschieber vein, Svornost vein cluster. The longitudinal section shows relatively small ore shoots, which cumulatively form minable lodes. Section *A–A'* shows the attitude of the 4th splay vein and relative metal grades of the various mining levels. (After Komínek and Veselý 1986)

these veins uranium is not necessarily concentrated in the center but also occurs as individual veinlets closer to vein margins. Uranium accumulations are grouped in larger but narrow and irregularly shaped lenses (Figs. 3.9–3.11), irregularly distributed throughout the vein system and separated by barren ground. Such lodes are several square meters to some hundred, rarely more than a thousand square meters in tabular size and are composed of sections of different grade as demonstrated in Fig. 3.10. The richest lodes attain dimensions of 100 by 300 m. The widths range from few millimeters to several tens of centimeters. The thickest ore lens was found at the intersection of the Barbora and Eva II veins. Lodes most frequently occur in moderately dipping and only occasionally in flat or vertically dipping sections of the host structure.

Uranium pinches out within 20–90 m, rarely in a distance of 120–140 m as in the Rovnost vein cluster, above the granite, i.e., more or less within the hornfels zone of contact metamorphism. The barren interval averages 60–90 m thick where the granite contact is almost horizontal, and 20–25 m thick where the contact forms depressions. Only a few uranium veins persist to the granite. Uranium is also absent for the first 30–50 m away from major faults as mentioned earlier.

Uranium mineralization in veins of complex composition does not display the same geometry as in simple veins. Although often concentrated near its margins or as cross-cutting veinlets, it is distributed irregularly across the vein and not limited by sharp boundaries. Locally, pitchblende fills microcracks in or impregnates the schistose wall rocks (e.g., scapolitic wall rock contained 0.26% U in the Edelleut Mine).

Planar distribution of uranium in a vein is highly irregular and restricted; it occupies only 4–6% of the total vein plane mined, i.e., the coefficient of mineralization or productivity (*Kr* = mineralized plane to total vein plane mined) is only on the order of 0.05 (Fig. 3.11). In spite of this limited uranium distribution, the mostly very high grade of ore pockets yielded an average mining grade between 0.1 and 1% U.

Geochronology

Kolektiv (1984 based on Smeykal) reports the following isotope ages and time related events unless otherwise stated (more recent data are given in Sect. 7.1 *Erzgebirge, State of Saxony*):

- *Tertiary*: reactivation of major faults and lineaments (Erzgebirge Lineament), extrusion of alkaline volcanics; 30–5 Ma: mobilization and redeposition of 3rd generation pitchblende (Ruzicka 1971) supposedly associated with the young generation of Co-Ni minerals during Tertiary tectonism as deduced from paleomagnetic data by Baumann and Krs (1967).
- *Cretaceous*, 150–100 Ma (U/Pb): mobilization and redeposition of 2nd generation pitchblende associated with quartz, dolomite, and Co-Ni-Bi-As stage minerals (Kolektiv 1984).
- *Permian and younger*, 220–150 Ma: galena (from Erzgebirge); 270–230 Ma (247 ±7 Ma) (U/Pb): 1st generation pitchblende (pitchblende datings by Legierski 1966: 230–220 Ma, Leutwein 1957: 260–220 Ma, Vinogradov et al. 1959: 180 Ma).[2]

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[2] It is not clear whether only the above mentioned three generations of uranium/pitchblende as shown for the Jáchymov district exist in the Erzgebirge. Legierski and Sattran (1967), for example, established isotope ages of 290–230 Ma, 220–190 Ma, and 180–170 Ma for pitchblende from marginal zones of the Bohemian Massif.

- *Late Carboniferous to Early Permian*, 280 Ma: Sn-W greisens; 290–280 Ma (K/Ar): granite porphyry dikes; 310–300 Ma (K/Ar): Erzgebirgs-(autometamorphic)-granite.
- *Namurian*, 340–320 Ma (K/Ar): emplacement of Gebirgs-(normal)-granite.
- *Pre- to Early Hercynian*: activation of lineaments.

Principal Ore Controls and Recognition Criteria

Uranium mineralization of the Jáchymov district is of polymetallic, perigranitic vein type associated with highly differentiated leucocratic granite. The original uranium phase is of monometallic nature but became polymetallic by a younger, uranium-unrelated, introduction of other metals.

Uranium ore control is multifold by structure, lithology, underlying granite, and mineral composition of veins.

Geological Environment

- Paleozoic heterogeneous metasediments intruded by various Hercynian granites; the latter underlie, and locally outcrop at the periphery of the district
- Metasediments range in composition from mafic sulfidic schists to amphibolite, gneiss, and quartzite
- Two main generations of granite occur, including a differentiated/autometamorphic leucocratic granite (Erzgebirgsgranite) that is considered the critical metallogenetic source rock facies
- Numerous consanguineous, granite-related dikes of variable composition cut metasediments
- Metasediments are contact metamorphosed in an inner, hornfels aureole, as much as 90 m wide, and a wider outer halo around granite
- Intersection of two regional lineaments (Gera-Jáchymov and Krušné hory (Erzgebirge)) (Fig. 3.2)
- Intense tectonic overprint of all host lithologies

Alteration in metasediments

- Pre-uranium skarn development, biotitization, chloritization, graphitization, pyritization, scapolitization
- Syn-? to post-uranium carbonatization, hematitization, silicification
- Post-uranium kaolinitization, sericitization, silicification

Alteration in granitic facies

- Pre-uranium albitization, greisenization, muscovitization, silicification
- Syn-uranium sericitization
- Post-uranium kaolinitization, sericitization

Mineralization

- Association of primary pitchblende with pink and brown carbonates, mainly pink dolomite, and quartz (Fig. 3.6)
- Redistributed pitchblende associated with younger, light-colored, fine-grained carbonates, and Co-, Ni-, Bi-, Ag minerals
- Emplacement of the carbonate-pitchblende association in structures of a distinct system trending about NW–SE to N–S (Figs. 3.4 and 3.8)
- Richest ore concentrations at sites of structural complication of veins such as
  - marked changes in strike and dip direction
  - interjunction, branching, or ramification of veins
  - splaying or horse-tailing (short veins of up to 30 m long are well mineralized, whereas long splays are commonly not mineralized except at its margins)
  - cross-cutting faults or dikes acting as structural barriers (particularly E–W faults and granite porphyry dikes) (Figs. 3.9 and 3.10)
- Thickening of veins
- Moderately inclined sections

All intervals with the above-listed structural features typically show intense cataclasis of wall rocks, development of a series of microjoints, and relatively wide aureoles of host rock alteration.

Lithologic Relationship of Mineralization

- Emplacement within contact-metamorphosed metasediments with rare exceptions of uraniferous veins approaching or entering granite (Fig. 3.7);
- Restriction of uraniferous intervals to vein transections with mafic or semimafic schists containing sulfides, Fe-, Ca- and Mg minerals;
- Best grades and the bulk of the ore occur at intersections with strongly pyritic biotite and biotite-phlogopite schists of the Jáchymov Series (often 2nd and 3rd horizons) (Figs. 3.10 and 3.11). Similarly well-mineralized are sections cutting lithologic boundaries between chlorite-sericite phyllite and pyritic amphibolite and biotite schists;
- Sections of lower grade are within weakly pyritic schists;
- Other favorable sites are proximal to dikes and zones of abundant dikes (Figs. 3.8–3.10); at intersections of veins with red granite porphyry dikes, ore often accumulated below the dikes;
- Barren intervals are within quartzose muscovite and sericite schists, quartzite, calc-silicate rocks, granite, albitite, and dikes of granite porphyry and lamprophyre; simple veins cutting these rocks consist commonly of quartz and lack carbonate and pitchblende;
- Uranium disappears within the inner contact-metamorphic aureole leaving a barren interval, 10–60 m wide, above the granite;
- Depletion of uranium proximal to basaltic dikes (of Tertiary age);
- Position of mineralized veins is related to morphology of underlying granite.

Metallogenetic Concepts

The various mineral associations of Jáchymov veins are thought to have formed by discontinuous multistage hydrothermal processes spanning a time interval from Permian to Cretaceous–Tertiary with each new phase of mineralization occurring in association with tectonic activity (Mrňa 1967).

Most Jáchymov veins, as well as most dikes are restricted to a structurally unstable area at the intersection of two regional lineaments. The Hercynian granite pluton mass must have already been well cooled at the time of intrusion of the oldest granite porphyry dikes as indicated by felsitic contacts of dikes in both mica schists and granite. Therefore, later emplacement of ore veins must also have occurred well after consolidation of the granite pluton.

Classical views (Vogl 1856; Kraus 1916; and others) regard the (autometamorphic) granite and late magmatic hydrotherms, respectively, as the source of uranium and its transporting solutions. The time gap between Erzgebirgsgranite crystallization, 310–300 Ma ago and pitchblende deposition, 270–230 Ma ago puts restrictions, however, on such magmatic hydrothermal models.

Ruzicka (1971) favors the idea that lateral secretion was instrumental in formation of Jáchymov veins and suggests that both, metasediments and autometamorphic granite played significant roles. Both have anomalous contents of uranium. That in the autometamorphic granite is partly in the form of minute uraninite crystals, which would indicate the presence of leachable uranium. As such, both lithologies may be considered potential source rocks.

Since the Erzgebirgsgranite resembles, as far as is known, the Saint-Sylvestre Granite in Limousin, France (see Sect. 6.1.1 *La Crouzille District, Limousin Region*) in both composition and evolution, it would be of much interest to determine, whether the processes suggested for the formation of the French vein uranium deposits are also applicable to Jáchymov and other pitchblende veins of the Erzgebirge.

Geochemically different fluids introduced various metals to form five or six mineral associations of monometallic and polymetallic composition. Two principal periods of ore formation have been deciphered for the Erzgebirge in general by Baumann (1967). The first includes the carbonate-pitchblende stage and occurred during Late Hercynian time; the second formed Co-N arsenides/sulfoarsenides assemblages some time between the Late Triassic and Tertiary and was probably generated by the Saxonian/Alpidic tectonic event.

Older mineral associations precipitated in ancient, reactivated structure systems and closest to the Erzgebirgsgranite. The carbonate-pitchblende association is the oldest ore generation. It is thought to be of hypogene hydrothermal origin introduced by mesothermal fluids. Decrepitation tests by Mrňa and Pavlů (1967) indicate temperatures of 370–470 °C.

Uranium-bearing solutions supposedly carried larger amounts of U, Ca, Fe, Mg, and CO_2, minor amounts of SiO_2 and F, and traces of V and REE (Ruzicka 1971). Dymkov (1961) proposes that most of the pitchblende precipitated together with carbonates within a geochemical environment of pH 8. Precipitation was caused by reducing agents such as Fe^{2+}, S, or C contained in earlier deposited vein minerals or in constituents of the host rocks. Kolektiv (1984) remarks that rocks with high Fe and Ca contents influenced precipitation of pyrite and calcite and therefore served as favored host rocks for ore minerals. Pyrite acted as a reductant and calcite maintained the alkalinity required for redox reactions between Fe^{2+} of pyrite and U^{6+} to deposit pitchblende. Mrňa and Pavlů (1967) suggest the following chemical reactions for carbonate-pitchblende formation and for the pink hue of dolomite due to hematite enclosures:

$$90Mg + 45(UO_2)(CO_3)_3 + 2FeS_2 + 94CaCO_3 \rightarrow$$
$$15U_3O_8 + Fe_2O_3 + 4CaSO_4 + 49CO_2 + 90CaMg(CO_3)_2$$

Ruzicka (1971) recognizes two episodes of remobilization and recrystallization of pitchblende, 160 to 60 Ma ago that roughly correspond to Kolektiv's (1984) 150 to 100 Ma old generation, and 30 to 5 Ma ago (more recent data are given in Sect. 7.1 *Erzgebirge, State of Saxony*).

Various processes and results of redistribution are addressed by Kolektiv (1984). Carbonate-pitchblende of the early stage survived only in subsidiary structures of the fifth and sixth order. These structures were only activated initially and for only a short time and then remained sealed against attack by younger solutions. Mineralized fourth order structures were reactivated and opened to circulation of younger solutions, which decomposed pitchblende and carbonate and replaced these phases by quartz associated with an impoverishment of the ore and changes in the shape of lodes. This dissolution and subsequent redeposition of pitchblende 2 and coffinite occurred coeval with precipitation of arsenides and locally baryte.

Third order structures experienced relative long periods of activation and, consequently, uranium mineralization in these structures was more heavily attacked and down graded. The structures were reopened simultaneously with those of the second order and prior to introduction of sulfoarsenides and sulfides. This provided time for infiltration of oxygenated fluids that leached uranium and reacted contemporaneously with arsenides to form sulfoarsenides.

First order structures were, after emplacement of early pitchblende, repeatedly and reactivated for long periods, which permitted solutions to decompose pitchblende, baryte, carbonate, fluorite, and other minerals and replace them with minerals of the young quartz-hematite stage, and to form magnetite-hematite-bearing veins.

See also Sect. 7.1 *Erzgebirge, State of Saxony*, for views on the metallogenesis of uranium veins associated with the granitic Eibenstock-Karlovy Vary Massif and other granitic massifs in the western Erzgebirge.

3.1.2 Horní Slavkov District, Northwest Bohemia

The Horní Slavkov (Schlaggenwald) district is located some 10 km southwest of Karlovy Vary (Karlsbad) in northwestern Bohemia. Perigranitic vein-type uranium deposits include *Barbora*, *Ležnice*, and *Zdař Bůh*. Their location is shown in ➲ Fig. 3.2 together with other uranium occurrences. The district produced 2 670 t U, between 80 and 90% of which came from veins hosted in paragneiss. Mining grades averaged 0.15% U. Mining was by underground methods.

Sources of information. Kolektiv (1984), Komínek et al. (1994), pers. commun. by Komínek J and Pluskal O.

Regional Geological Setting of Mineralization

The *Horní Slavkov (Schlaggenwald)* uranium deposits occur in an isolated, commonly 400–600 m and locally up to 1 500 m thick inlier of Proterozoic metamorphics within Hercynian granites of the southern extension of the Eibenstock-Karlovy Vary Massif (Figs. 3.2 and 3.12). Coarse-grained biotite orthogneiss and a sequence of paragneiss intercalated with amphibolite, quartzite, and calc-silicate rocks constitute the inlier. The metasediments are migmatized for up to several hundreds of meters from the orthogneiss contact.

Granites of the Karlovy Vary Massif include two main facies, an older biotite granite termed "Gebirgsgranite" and a younger autometamorphically differentiated felsic facies termed "Erzgebirgsgranite" (for composition see Sect. 3.1.1 *Jáchymov (St. Joachimsthal) District, Northwest Bohemia*). The biotite granite prevails to the east and south, and the autometamorphic granite to the west and northwest of the district. Aplite, aplite granite, and diorite apophyses and dikes related to the Hercynian granite pluton transect the metamorphic suite. Granite porphyry, pegmatite, and lamprophyre dikes occur in subordinate amounts.

Metamorphic rocks are asymmetrically folded in a complex manner. The main fold axis trends E–W. Flanks dip 60–80° N and S. Secondary folds are superimposed on this system. Two principal fault systems are discerned. The first oscillates between NE and ENE, and dips mostly 60–80° NW and rarely SE. The second trends between WNW and NNW and has a 60–85° SW inclination. Several subparallel NW–SE-oriented regional faults separate the district into a number of dislocated blocks.

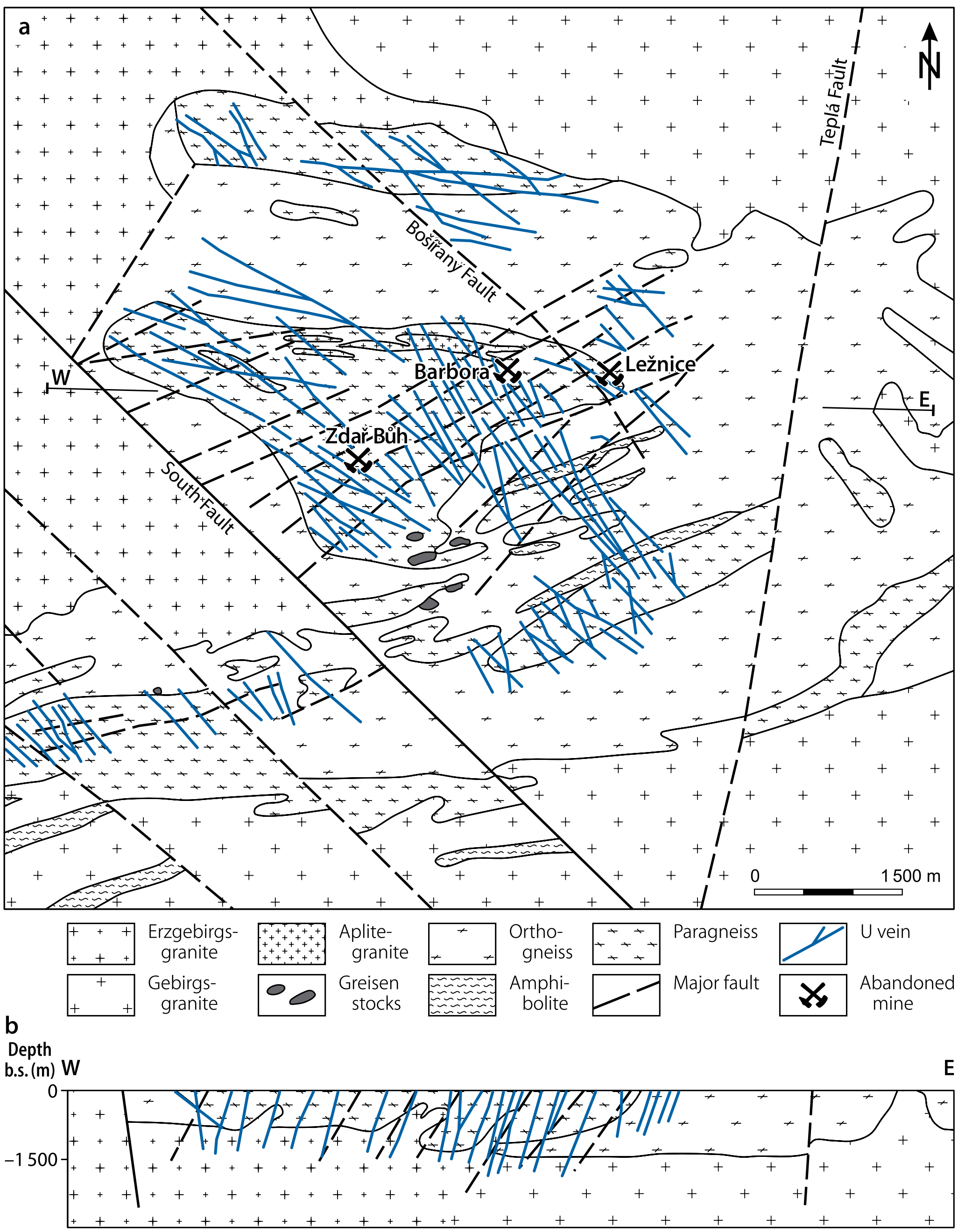


Fig. 3.12. **Horní Slavkov (Schlaggenwald) district, generalized geology with location of vein-type uranium deposits in an inlier of metamorphic rocks within Hercynian granites. (After Kolektiv 1984)**

Principal Host Rock Alteration

Country rocks exhibit chloritization, greisenization, and sericitization. Greisenization affected also felsic granite. Hematitization tends to be the only essential ore-related wall rock alteration.

Principal Characteristics of Mineralization

Pitchblende, coffinite, and black U oxides are the principal uranium minerals. U^{6+} minerals, mainly U silicates and hydrated U oxides are common in weathered intervals. Associated metallic minerals include arsenopyrite, chalcopyrite, galena, pyrite, sphalerite, and hematite. The Zdař Bůh deposit contains, in addition, Ni- and Co diarsenides, nickeline, native Ag, As, and Bi. Gangue minerals are predominantly quartz and minor ankerite, calcite, dolomite, and rare siderite. Quartz is present in several, and dolomite in two generations. Veinlets of dark fluorite and, sporadically, baryte occur locally.

Two main phases of mineralization are noted:

a an older quartz-coffinite association composed of coffinite, pitchblende 1, calcite, dolomite 1, and hematite; and
b a younger carbonate-U(-arsenide) association composed of pitchblende 2, dolomite 2, ankerite, and, at some occurrences, Ni- and Co arsenides, and native Ag, As, and Bi. The younger phase corresponds to the arsenide association in the Jáchymov district.

NW–SE-trending veins host vertically zoned uranium mineralization. Quartz, carbonates, and coffinite prevail on upper levels, dolomite and pitchblende on medium levels, and carbonates, particularly ankerite, at depth. Uranium ore is predominantly concentrated in the medium depth interval.

NE to ENE-oriented structures contain mainly gouge and are barren of uranium except for sporadic, thin quartz-carbonate-pitchblende veinlets, but they may contain quartz-wolframite-cassiterite mineralization in vicinity of greisens.

General Shape and Dimensions of Deposits

The Horní Slavkov (Schlaggenwald) district covers an area of 4 by 5 km in which the three main deposits are clustered within a NE–SW-elongated, ca. 3 000 m long and 800 m wide zone.

Uranium-mineralized veins trend between WNW and NNW and dip 60–85° SW. Major veins are often accompanied by abundant subsidiary veins. At some intersections of these structures with NE–SW faults, curvilinear apophyses, several tens of meters long, branch off the main vein and often contain high-grade ore. Multiple veins group together to form structurally complex vein bundles, which occur preferentially at sites where abundant NE–SW faults intersect NW–SE structures. A prominent domain of this setting is in the 1 500 m thick central part of the metamorphic inlier; and the three mines mentioned earlier are located in this segment.

Due to the structural complexity and related system of lacing veins, the configuration of uranium deposits is irregular. The main structure of a deposit may reach a length in excess of 2 000 m while associated mineralized veins range from 300 to 500 m in length. Vertical vein distribution persists to the granite contact, i.e., over a depth interval of commonly 400–800 m and locally 1 500 m. The average vein thickness varies between 5 and 20 cm but may expand up to 2 m at bulging intervals of the host structure. Most veins have a straight attitude with vertical and lateral diversions of less than 10°. Vein contacts are normally sharp.

The distribution, shape, and dimension of uranium ore shoots within a vein vary strongly. Ore shoots are erratically distributed and rarely occupy more than 10% of a vein (equal to a mineralization coefficient of 0.07–0.10). They are mostly tabular to lens shaped and dip 60–80° NW and rarely NE. These bodies range from a few tens to several hundred square meters in plane area and from a few millimeters to some tens of centimeters in thickness. Ore shoots in approaching/converging veins group together and form stockwork ore bodies.

Two categories of ore bodies are distinguished, large and narrow. Large ore bodies extend from 200 to 400 m downdip. They are elongated along the inclination at a lateral to downdip extension ratio of 1:1.5 to 1:3. All rich ore bodies in major veins belong to this category. Narrow ore bodies occur parallel to the junction line of cross-cutting structures. Their lateral to downdip extension ratio ranges from 1:5 to 1:8.

Principal Ore Controls and Recognition Criteria

Uranium deposits of the Horní Slavkov (Schlaggenwald) district can be classified as granite-related vein-type deposits. Some are monometallic (Barbora and Ležnice) and others polymetallic (Zdař Bůh). The geological positions of the deposits and country rock facies resemble those of the Jáchymov district.

Principal ore controls and/or recognition criteria include structural and lithological parameters such as:

Geological Environment

- Proterozoic metamorphic rocks occurring as inlier within intrusive Hercynian granites
- A potential uranium source is provided by the autometamorphic Hercynian "Erzgebirgsgranite"
- Ore-related wall rock alteration is restricted to hematitization while more widespread chloritization and sericitization etc. are apparently not related to the uranium deposition

Mineralization

- U-hosting veins trend about NW–SE, i.e., they follow the same structural direction as most granite-related uraniferous veins within the Hercynian chain in Europe
- U-bearing veins are restricted to metamorphic rocks adjacent to intrusive granite
- Biotite paragneiss constitutes the preferential and amphibolite a subordinate host rock

- Veins lose uranium mineralization when entering granite
- Ore consists essentially of pitchblende, coffinite, and black U oxides, sulfides, and quartz with minor carbonates and locally arsenides
- Uranium is concentrated in downdip elongated ore shoots
- Ore shoots occur in erratic distribution within veins
- Veins have a low coefficient of mineralization (U ore occupies rarely more than 10% of a vein)
- Structural features that control the position of uranium ore shoots within veins include
    - change in attitude of veins
    - intersections of veins with cross-cutting faults
    - forking of veins
    - apophyses splaying from main veins

Metallogenetic Concepts

The regional geological setting, host rock facies, potential source rocks, and partly comparable mineral paragenesis of uranium-mineralized veins in the Horní Slavkov (Schlaggenwald) district are similar to those in the Jáchymov district; therefore metallogenesis in both districts is considered more or less identical.

3.1.3 Other Uranium Deposits in Crystalline Rocks of the Southwestern Krušné Hory/ Karlovy Vary Massif

Minor, structurally-controlled uranium deposits within and adjacent to the granitic Karlovy Vary Massif (Fig. 3.2) include *Bouči-Oloví*, *Dolní Rotava*, *Horní Rozmyšl*, *Nový Fojtov*, and *Přebuz*, which are situated in the central and northwestern part of the massif. Original resources of these deposits were up to some tens of tonnes uranium at grades ranging from 0.05 to 0.15% U.

3.1.3.1 Nový Fojtov, Northwest Bohemia

This deposit is located in the central part of the Karlovy Vary Massif, about 15 km northwest of the town of Karlovy Vary (Karlsbad). It is a structurally-controlled surficial-type uranium deposit. Mining was by underground methods and produced 39 t U at a mining grade of 0.1% U.

Source of information. Kolektiv (1984), amended by pers. commun. by Pluskal O, and Komínek J.

Geology and Mineralization

Host rock is weathered “Erzgebirgsgranite” close to the contact with “Gebirgsgranite”. NE–SW-oriented fractures, up to several meters long and a few centimeters to exceptionally 1 m wide, that are mainly filled with granite fragments, gouge, hematite, and rare quartz contain uranium mineralization. Mineralization consists of various phases of meta-autunite. Most common is dark green meta-autunite. It is present as up to 4 × 4 × 1 cm large aggregates of platy crystals. Other phases are earthy yellow aggregates and locally up to 1.5 cm large brown crystals.

Ore bodies consist of irregularly shaped lenses predominantly composed of uranium minerals coating fracture planes. Lenses are up to 10 cm thick, have a plane extent of up to a few square meters, and persist to a depth of about 30 m. The intensity of mineralization decreases rapidly below this level.

Isotope analyses show a lack of radiogenic lead, which suggests a recent origin of the uranium minerals presumably by supergene processes. Surficial waters are thought to have leached uranium from the weathered uraniferous host granite. Redeposition of uranium associated with wall rock chloritization and hematitization occurred in dilational fractures.

3.1.4 Tertiary Basins in Northwest Bohemia

Several Tertiary basins occur along the Erzgebirge Lineament that separates the Erzgebirge from the Bohemian Massif. The basins contain strata-bound uranium mineralization. Most significant deposits occur in the Sokolov (Falkenau) Basin. Minor occurrences such as *Velký Luh* are found in the Cheb (Eger) and other basins (Fig. 3.2).

3.1.4.1 Sokolov (Falkenau) Tertiary Basin/ Hroznětín and Ostrov Subbasins

The Sokolov (Falkenau) Basin is located immediately north of Karlovy Vary (Karlsbad) and encompasses two subbasins with lignite-sandstone-type uranium mineralization. The *Hroznětín Subbasin* contains the deposits/occurrences *Hájek North* and *South*, *Hroznětín I*, *II*, *III*, *Odeř*, and *Ruprechtov I*, *II*, *III*, and the *Ostrov (Otovice) Subbasin* contains *Bor*, *Kocourek*, *Mezirolí*, *Nivy*, and *Ztracený Rybník* (Fig. 3.13).

Original resources were about 1 000 t U. The grade averages 0.05% U but localized pockets have increased uranium tenors with maxima in excess of 1% U. 203 t U have been extracted from the 85 m deep Hájek open pit operation. The mining grade was reportedly 0.15% U. In addition, 243 615 m^3 kaolin, 5 325 m^3, and 846 458 m^3 basalt have been recovered from this open pit mine (DIAMO, web side 2012).

Source of information. Kolektiv (1984), pers. commun. by CSUP/DIAMO staff.

Regional Geological Setting of Mineralization

The Sokolov (Falkenau) Basin is situated at the intersection of the Krušné hory (Erzgebirge) and Jáchymov Lineaments. Paleogene and Miocene clastic and pyroclastic sediments fill the basin and rest upon deeply weathered, kaolinized granite of the Karlovy Vary Massif. Upper Tertiary volcanics, mainly basalt, extruded through the sedimentary sequence. A generalized lithostratigraphic profile through the basin exhibits the following features:

- *Neogene*: extrusive volcanics (mainly basalt)
- *Miocene*:
  - Cypris Formation (Upper Miocene): pelite
  - Volcanogenic Formation: tuff, tuffite, fluvial and lacustrine sediments with interbedded lignite seams in the lower part of the formation
  - Eluvium
- *Paleogene*: Staré Sedlo Formation: sand and sandstone deposited in shallow depressions
- *Hercynian* basement: granites of the Karlovy Vary Massif

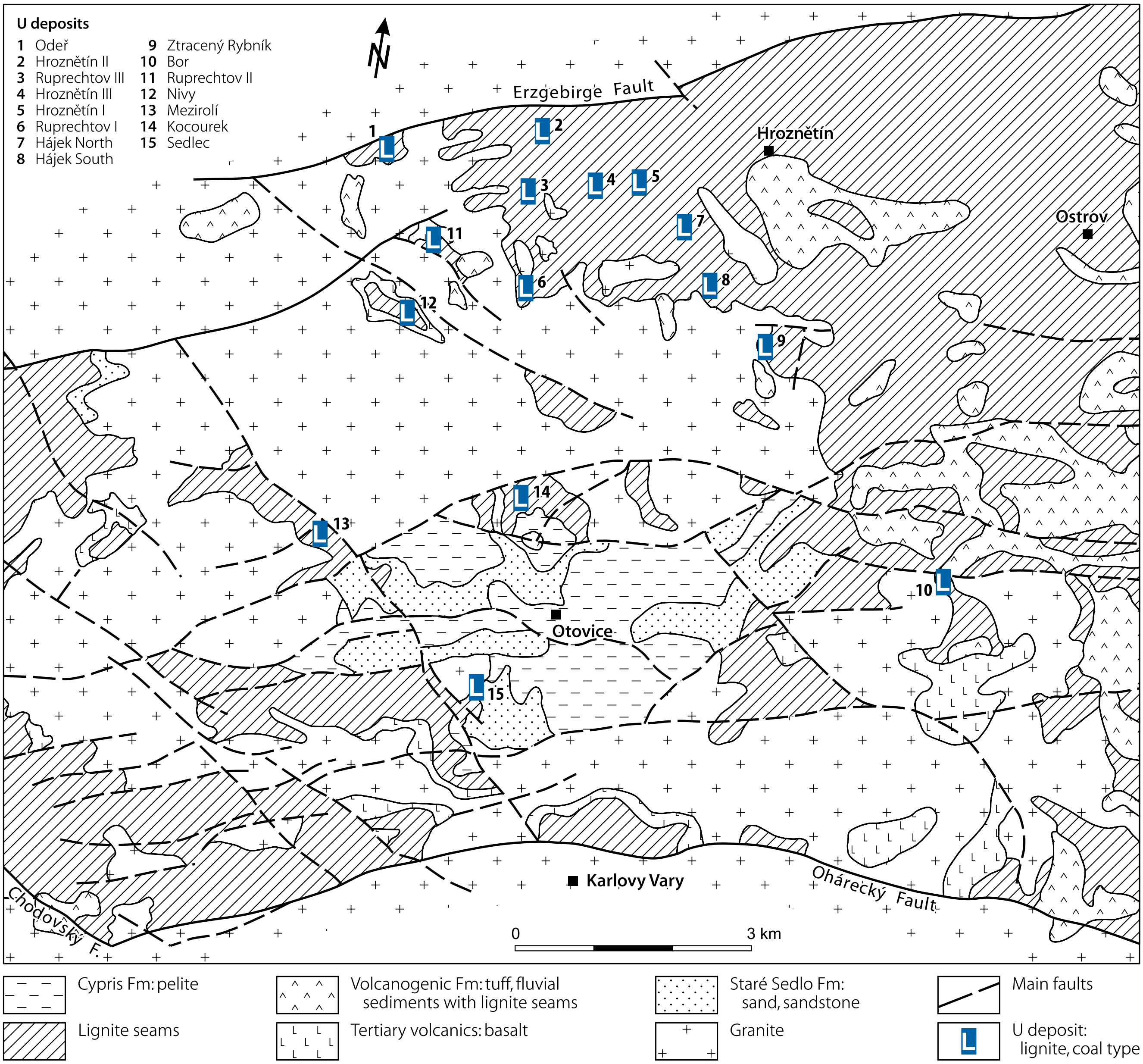
The thickness of the Volcanogenic Formation increases gradually from the south and southwestern transgressive boundary to more than 150 m at the northern contact, which is fault bound by the Erzgebirge Lineament. Volcanic constituents of this unit augment markedly in the eastern part of the Sokolov (Falkenau) Basin.

The whole sequence and overlying recent peat have elevated uranium tenors; sediments and tuff average 2–7 ppm U, and lignitic beds some 10s to several 100 ppm U.

Lithology and thickness parameters of the Volcanogenic Formation are applied as criteria for a subdivision of the eastern part of the Sokolov (Falkenau) Basin into the northeasterly situated Hroznětín and the southwesterly adjacent Ostrov Subbasin. All uranium deposits and major uranium occurrences are located in these two subbasins and east of the Chodov Fault.

Fig. 3.13.

Sokolov (Falkenau) Tertiary Basin, generalized structural-geological map with locations of uranium occurrences. (After Kolektiv 1984)



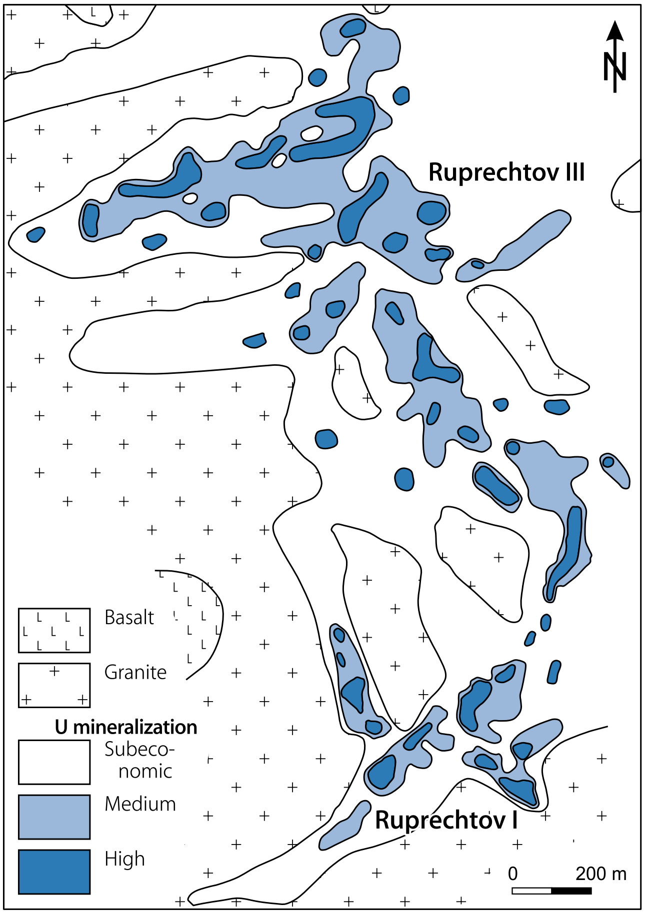
Principal Characteristics of Mineralization

Although pitchblende, coffinite, nenadkevite, ningyoite, uraniferous leucoxene and metacolloidal TiO_2-phases have been determined, most uranium occurs as cryptocrystalline uranium oxides and adsorbed on organic material. *Associated minerals* include arsenopyrite, galena, marcasite, melnicovite, pyrite, sphalerite, ilmenite, and psilomelane. The thorium content of uranium mineralization is low as reflected by a Th/U ratio between 0.02 and 0.004.

Uranium mineralization is stratigraphically confined to the Volcanogenic and Staré Sedlo Formations in which it occurs in various facies below major lignite seams. Uranium is often concentrated as a matrix constituent in sandstone that contains coalified plant remains, kaolinite-rich eluvial material, lignite, and lignitic clays. Less favorable hosts include sapropelite, tuff, tuffite, clay, and claystone. Uranium is generally associated with organic material with the best uranium concentrations in pyrite-rich carbonaceous sediments. Argillaceous carbonatic (siderite) concretions also contain elevated uranium tenors.

The spatial distribution of mineralization is controlled by two structural-morphological configurations of the granitic basement paleosurface as reflected by restriction of uraniferous beds to *(a)* graben-like depressions bordered by major faults and filled with strongly distorted and locally overturned sediments, and *(b)* paleovalleys incised into strongly weathered granite and filled with subhorizontally bedded strata. Figure 3.14 documents the correlation between uranium distribution and paleorelief. Ore bodies are preferentially grouped along depression axes and pinch out on valley flanks.

Fig. 3.14.
Sokolov (Falkenau) Tertiary Basin, Ruprechtov I and III deposits, simplified map with distribution of uranium mineralization in lignite-sandstone beds. (After Kolektiv 1984)



Uranium deposits in the two subbasins exhibit the following peculiarities.

Hroznětín Subbasin. The principal uraniferous horizons occur in the basal part of the sedimentary accumulation, which consists of tuffitic sediments with interbedded lignite seams, organic-rich clays, and local sapropelite of the Volcanogenic Formation, and sandstone of the Staré Sedlo Formation. This sequence contains several stacked uranium lenses in the southern and southwestern section of the subbasin, and a single uraniferous bed in its northern part. The Hájek North and Ruprechtov III deposits are hosted in sandstone of the basal Staré Sedlo Formation, and Hájek South, Hroznětín I, II, III, and Ruprechtov I are contained in erosional depressions incised into granite.

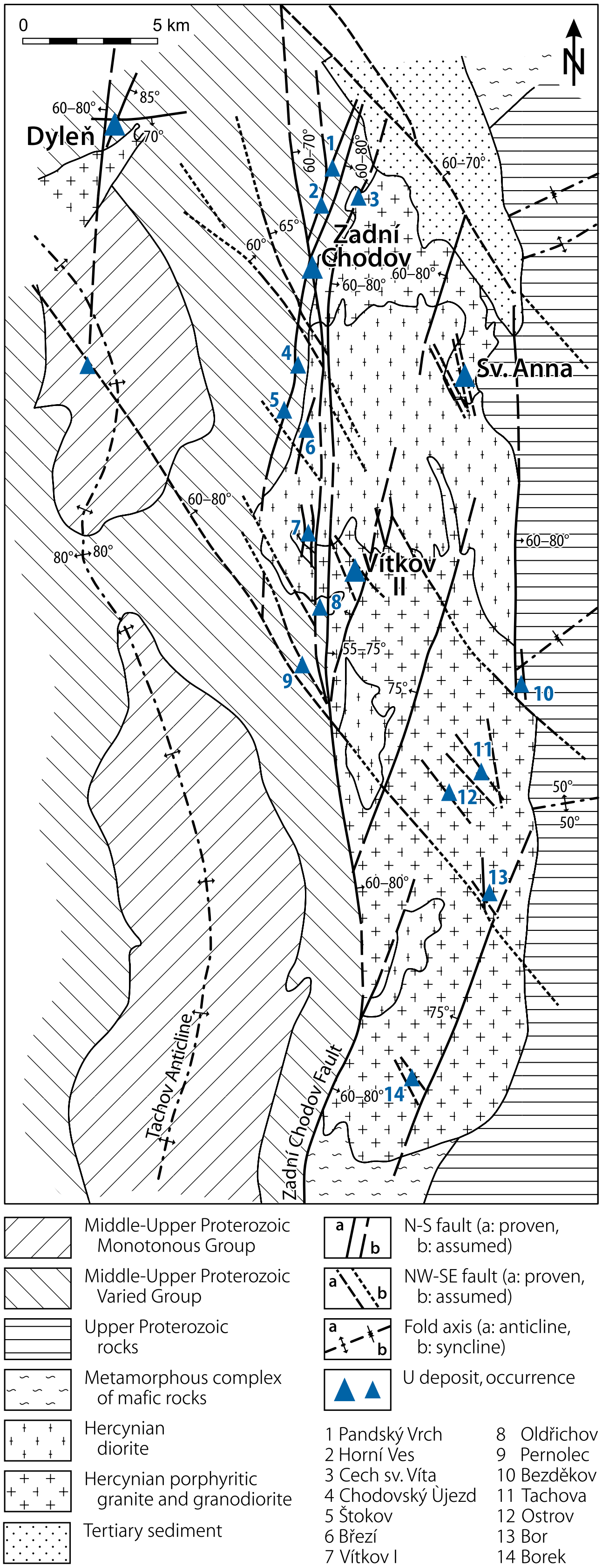
The *Odeř* deposit is located in an isolated asymmetric tectonic outlier depression in which sediments were accumulated to a thickness of 290 m. Here, sedimentation was strongly influenced by periodic movements along the depression bounding the Erzgebirge Lineament. Basal members in this depression consist of 60°-inclined eluvial sediments. They include a 50 m thick lignite unit in its upper part. Pyroclastics rest on the eluvium. Ore bodies occur in lignite, sapropelite, and proluvial-eluvial sediments. Also of interest here is a uranium occurrence in Quaternary peat, which reflects uranium mobilization until recent times.

Ostrov Subbasin. Two deposits, Meziroli and Kocourek, and several occurrences were delineated. *Meziroli* is located in an asymmetric graben, which is bounded to the northeast by a fault. Ore body morphology reflects the block structure. A lignitic sequence, which encloses the Josef Seam or an equivalent organic-rich horizon, is the uranium host. Uranium mineralization also occurs locally in other lignite beds within the Volcanogenic Formation and sandy beds of the basal Staré Sedlo Formation. *Kocourek*, located in the north part of the subbasin, is bounded to the south by a fault, adjacent to which the Volcanogenic Formation achieves a thickness of 260 m. Synsedimentary tectonic activity provided clastic material for several eluvial beds near the base of and within the Volcanogenic Formation. Uranium mineralization is confined to the basal beds.

General Shape and Dimensions of Deposits

Uranium deposits consist of elongated tabular to lenticular bodies. Mineralization is hosted by horizontal to slightly inclined sediments in erosional depressions incised into the granitic basement. These depressions commonly contain mineralized lenses in several horizons. Lenses are often interconnected and range in length from several tens to more than 1 000 m. Length is often a multiple of width. Figure 3.14 illustrates the size of ore bodies, grade distribution, and paleorelief control on mineral localization. Deposits that were mined occurred at a depth of about 70 m.

Fig. 3.15.
West Bohemian district, geological map with location of uranium deposits and occurrences and their relationship to prominent structures. (After Kolektiv 1984)



Metallogenetic Concepts

Multiple epigenetic and diagenetic processes are thought to have formed uranium mineralization in the Tertiary Sokolov (Falkenau) Basin. This uranium was very likely derived from deeply weathered and kaolinized granite that underlies the basin and has elevated uranium tenors. This assumption is supported by cleavage water in this granite containing 5 ppm U. Tertiary volcanism produced thermal waters that leached uranium and transported it into carbonaceous host beds. Both permeable beds and fracture zones provided pathways for solutions.

3.2 West Bohemian Uranium Region

The West Bohemian uranium region is located in northwestern Bohemia close to the border with Germany. It extends for some 35 km in a N–S and 8 km in an E–W direction. Major deposits are *Dyleň*, *Svatá Anna*, *Vítkov II*, and *Zadní Chodov (Hinterkotten)*. They are grouped in the West Bohemian district. Additional small deposits/occurrences are shown in Fig. 3.15. The deposits fulfill to some extent the criteria for a monometallic, granite-related type, but it remains an open question whether this is valid or not. Original resources of the region amounted to 11 500 t U, 9 750 t U of which were extracted; mining grades averaged 0.15–0.3% U.

Sources of information. Kolektiv (1984), Pluskal (1992a), amended by pers. commun. by Hrubý J, Komínek J, Pluskal O, and Zuckermann.

Regional Geological Setting of Mineralization

The West Bohemian uranium region is within the Moldanubian Zone of the Hercynian Orogen and is dominated by two geological units:

a a basement of katazonally metamorphosed Neoproterozoic granite-gneiss and orthogneiss within Neo- and Mesoproterozoic (Moldanubicum) metasediments, and
b the N–S-elongated granitic Bor Massif of Hercynian age.

Neoproterozoic rocks prevail on the eastern side and older Moldanubicum rocks on the western side of the Bor Massif. The Moldanubicum includes the Monotonous and Varied Groups; the first is represented by sillimanite and sillimanite-biotite gneisses and the second by biotite and sillimanite-biotite gneisses with numerous intercalations of amphibolite, quartzite, and calc-silicate rocks. Cordierite replaces sillimanite in a halo up to several kilometers wide around the pluton contact.

Moldanubian metasediments are folded into the N–S-oriented Tachov Anticline. Metasediments of the Monotonous Group form the core of the anticline and rocks of the Varied Group form the flanks, which dip 60–80° E and W, respectively. Magmatites of the Bor Massif were intruded into the eastern flank of this anticline. Two principal igneous suites are discerned: older diorite prevails in the northern and western part of the massif, while younger porphyritic, coarse-grained biotite granite and granodiorite form the bulk of the massif. Two-mica granite occurs locally.

Dikes occur along N–S-trending structures. The oldest dikes include porphyritic, medium-grained and aplitic granites, pegmatite, and aplite. These dikes are 2–15 m thick and up to several kilometers long. They commonly dip at less than 45° E. A second generation of dikes consists of lamprophyre, and diorite and granodiorite porphyrites. These dikes are 1–6 m thick, up to several kilometers long, and dip 60–80° W. The youngest are quartz veins up to 3 km long and locally up to 100 m thick.

Brittle deformation occurred during several episodes and resulted in major N–S and NW–SE fault zones with marked displacements. Structures of these systems provided space for the dikes mentioned above. Minor faults, a few centimeters to 1 m wide, trend NW–SE, NNE–SSW, and E–W. They are filled with gouge, rubble, veinlets of quartz and carbonate with disseminated sulfides and, locally, uranium.

Regional Characteristics of Alteration and Mineralization

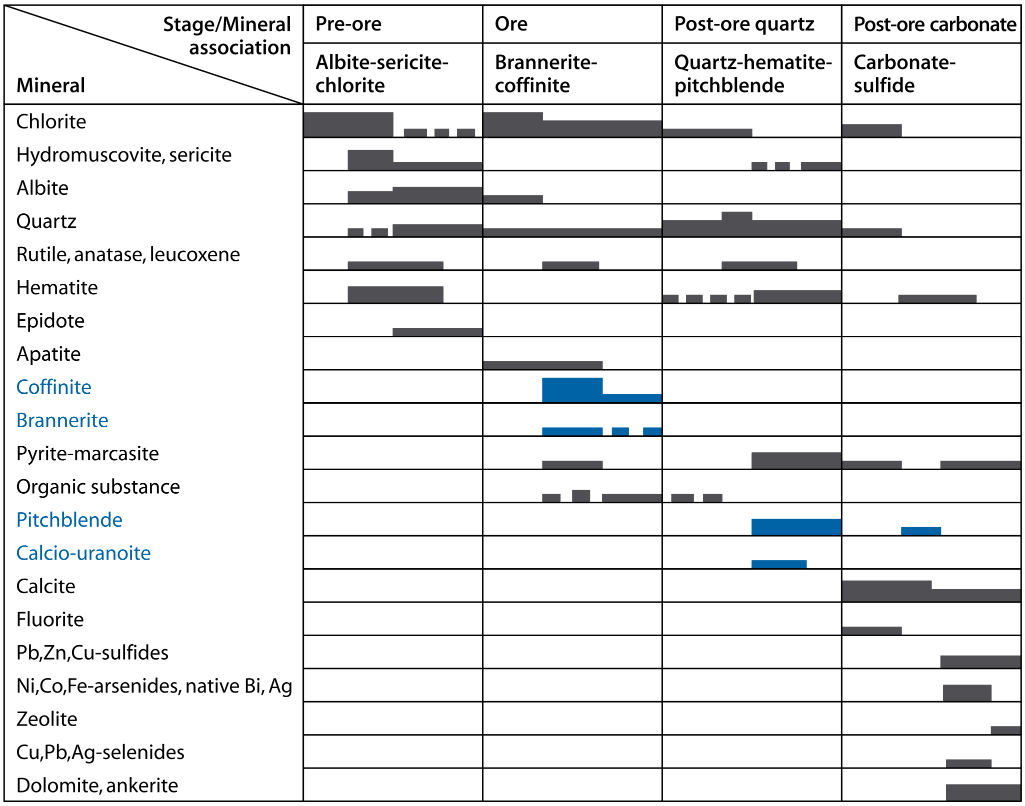
Four stages of alteration-mineralization are recognized by Kolektiv (1984) and documented in Fig. 3.16:

- *Pre-ore stage* phases consist of albite-sericite-chlorite, which form aureoles around uranium-mineralized structures;
- *Ore stage* minerals include coffinite, brannerite, chlorite, quartz, and minor albite, apatite, pyrite-marcasite, Ti oxides, and organic substances;
- *Late to post-ore quartz stage* phases are represented by quartz-hematite-pitchblende associated with pyrite-marcasite, minor chlorite, hydromuscovite-sericite, and Ti oxides;
- *Post-ore carbonate-sulfide stage* includes ankerite, calcite, dolomite, some pyrite-marcasite, and Pb-, Zn-, Cu sulfides, and minor pitchblende, chlorite, fluorite, hematite, quartz, zeolite, and locally arsenide and selenide minerals.

All four mineral stages are developed in all deposits but in variable quality and quantity. Pre-ore and post-ore stage assemblages are most frequent.

N–S structures control uranium mineralization. Some deposits occur in metasediments at the exocontact of Hercynian granite-granodiorite, others are within granitic rocks. Two varieties of host rock-related uranium distribution are noticed. Disseminations, stringers, and veinlets occur predominantly in coarse-grained paragneiss and granite, while veins prevail in fine-grained gneiss and amphibolite. Shapes and dimensions of deposits are listed in the subsequent description of individual deposits.

Fig. 3.16. West Bohemian district, principal paragenesis of uranium mineralization. (After Kolektiv 1984)



Geochronology

U/Pb dates are highly variable. Pitchblende in calcite veins at Svatá Anna yields an apparent age of ca. 265 Ma, and at Vítkov II 160 to 140 Ma. The albite-chlorite-coffinite assemblage is dated at 185 ±15 Ma. These ages are consistent with those of uranium ore-forming processes elsewhere in the Bohemian Massif except that in West Bohemia early Kimmerian remobilization is more pronounced. Granites of the Bor Massif give ages between 501 and 280 Ma (Kolektiv 1984) and the granite near Dyleň 320 Ma (Zuckermann, pers. commun.).

Regional Ore Controls and Recognition Criteria

West Bohemian uranium deposits are primarily controlled by structure and secondarily by altered lithologies. They exhibit the following ore controls and/or recognition criteria:

Host Environment

- Country rocks include Proterozoic metamorphic rocks intruded by Hercynian granite-granodiorite
- Host rocks are biotite and amphibole-rich gneisses of the Moldanubian Varied Group and Hercynian granitic rocks
- Pegmatite, aplite, granite-granodiorite porphyry and lamprophyre dikes cut country rocks
- Tectonic activity occurred repeatedly

Alteration

- Alteration (and mineralization) is present in four stages
- Alteration minerals are arranged in a zonal pattern around deposits
- Original chloritization, sericitization, silicification, and local albitization is overprinted by carbonatization, hematitization, silicification, and sulfidization
- Weathering persists to depths of several hundred meters

Mineralization

- Ore is monometallic and occurs in four stages
- Principal *uranium minerals* are coffinite and brannerite; pitchblende is commonly a redistribution product
- Quartz and carbonates are the predominant gangue or associated minerals
- Organic/graphitic substances often associate with ore
- Ore bodies consist predominantly of disseminated uranium minerals forming irregularly shaped lenses within fracture zones
- Mineralization extends to great depth (>1 100 m)
- Mineralization is relatively continuous in host structures (structure occupation >50%)
- Major N–S faults exerted the principal structural control
- Subsidiary faults, horsetail fractures, and structurally complex sections (flexures, bifurcations, widening of structures) associated with the main faults provide prime sites for ore concentrations
- Granite-hosted deposits occur close to the contact with Moldanubian metasediments
- Deposits are positioned in some vicinity to the unconformity separating the Moldanubicum from Upper Proterozoic rocks
- Locally, uranium concentrations occur at the contact with and below aplite or pegmatite dikes, quartzitic layers or metasedimentary xenoliths; these rocks are considered to have acted as barriers for mineralizing solutions

Metallogenetic Aspects

Metallogenesis of West Bohemian uranium deposits is still an open question. Although the endogranitic or perigranitic setting of various uranium deposits suggest an attribution to the granite-related vein type, a number of criteria are more symptomatic for a non-granite-related, monometallic vein-type or perhaps a modified subunconformity-type mineralization. A granite-related origin is contradicted by

a in particular, the large time gap of >15 Ma between uranium mineralization and granite emplacement,
b the type of granite, which is not identical with that of a U-fertile granite,
c the kind of distribution and continuity of mineralization in host structures, and
d the depth extension and composition of mineralization.

West Bohemian uranium deposits exhibit a number of features, which also characterize uranium deposits in the Moravian uranium region. The reader is therefore referred to Subsect. *Principal Ore Controls, Recognition Criteria, and Metallogenetic Aspects of West Moravian-Type Uranium Deposits*, p. 113, for the discussion on metallogenesis.

3.2.0.1 Dyleň, West Bohemia

Dyleň is located 20 km south-southeast of Cheb (Eger) in the western part of the West Bohemian uranium region. It is ca. 1 km north of, and on the same major structure as, the Wäldel/Mähring deposit, Germany (see Chap. 7 *Germany*).

The disposition of this veinlike-type deposit is perigranitic, but a precise classification as granite-related or non-granite-related vein type, or even as a modified unconformity-related type remains open to debate (see discussion in Sect. 3.5 *West Moravian Region*).

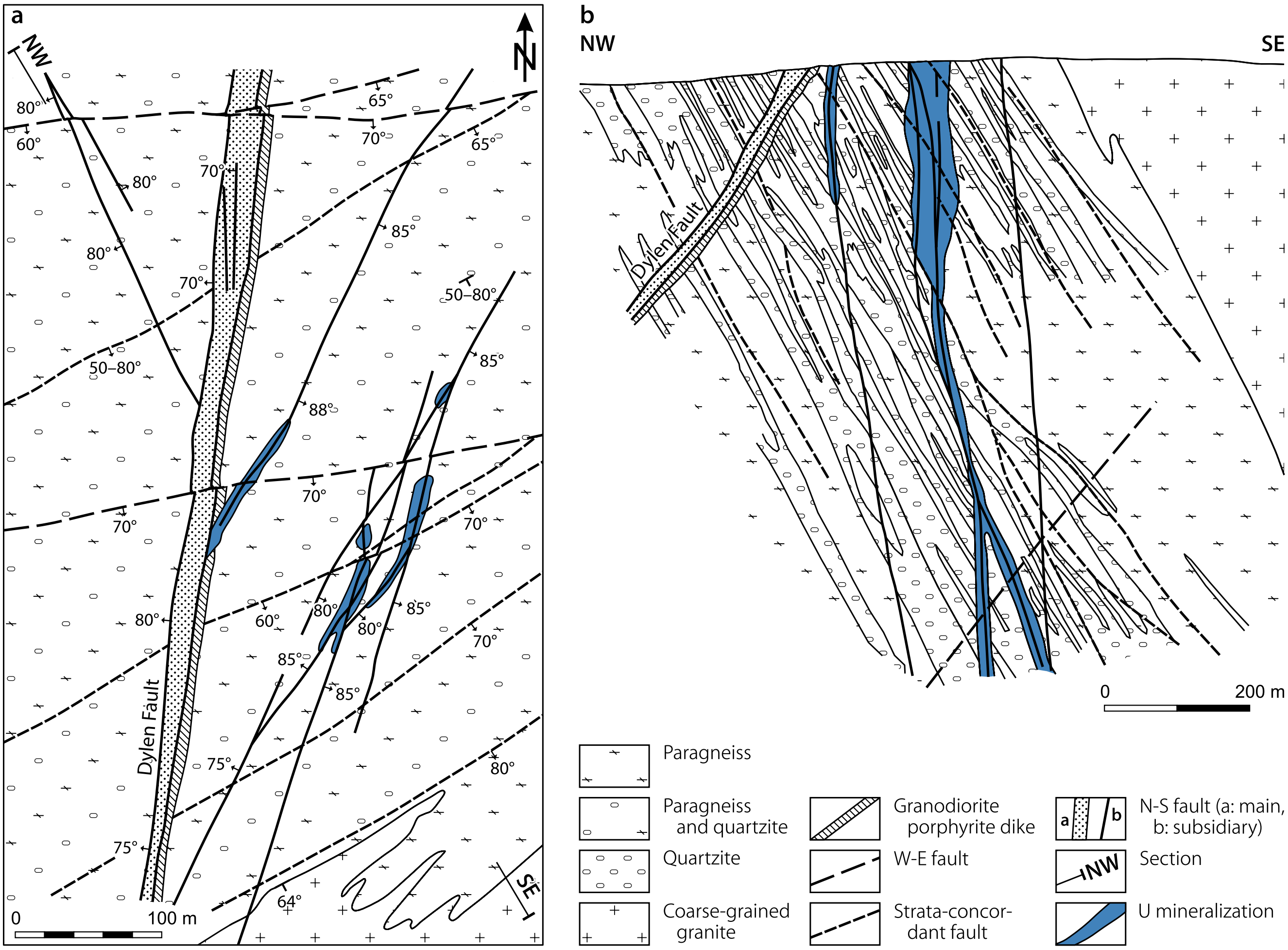
Original reserves were 1 300 t U, of which 1 100 t U has been mined by underground methods to a depth of 1 200 m. Grades averaged 0.1–0.2% U.

Geological Setting of Mineralization

The deposit is on the eastern flank of the Tachov Anticline, at the immediate northwestern exocontact of a Hercynian coarse- to medium-grained biotite granite (Fig. 3.17). This granite is different from granites of the Bor Massif and supposedly constitutes an extension of the Falkenberg Granite exposed a few kilometers to the west at Tirschenreuth, Germany. Country

Fig. 3.17.

Dyleň, a geological map, and b NW–SE cross-section documenting the affinity of mineralization to structures subsidiary to the Dyleň Fault. (After Kolektiv 1984)



rocks belong to the Moldanubian Varied Group and consist of migmatized, fine to medium-grained biotite, sillimanite-biotite, and quartzitic paragneisses, which alternate with quartzite. The metasediments dip monoclinally 50–80° SE. The schistosity inclination is 50–70° SE. Pegmatite dikes are numerous; aplite dikes are rare. Younger dikes include lamprophyre and granodiorite-porphyrite.

Two disjunctive structure systems dissect the rocks. Older faults strike E–W and dip 60–70° S. They are 1–2 m wide, up to several hundred meters long, and filled with gouge and rock fragments. Longitudinal fractures in these structures are 10–20 cm wide and can be mineralized particularly along the paragneiss-quartzite contact.

Younger faults trend N–S; they include the 60–80° W-dipping Dyleň Fault. This fault is a several tens of meters wide zone composed of numerous subparallel, 10–40 cm wide, shears. A number of steeply dipping subsidiary and horsetail structures branch off the Dyleň Fault. Those in the footwall of the Dyleň Fault trend NE–SW and those in the hanging wall strike NW–SE. Weathering effects are noticed along faults to a depth of approximately 300 m.

Host Rock Alteration and Mineralization

Pre-ore stage alteration phases form a zoned halo around mineralized structures. The outer zone is characterized by sericite-chlorite, the intermediate zone by quartz-chlorite, and the inner zone by quartz-hydromuscovite-chlorite. Strongly altered rocks near the central part of the fault zone show a gain in Al_2O_3, FeO, Fe_2O_3, MgO, P_2O_5, S, C_{org}, and H_2O.

Ore stage minerals are coffinite and minor brannerite associated with apatite, chlorite, pyrite, and quartz in the upper levels, and pitchblende-carbonate in the lower levels. Ore shoots are surrounded by an aureole of Fe^{3+}, Mo, Ni, Pb, and radiogenic Pb-bearing minerals.

Post-ore quartz stage minerals include pyrite, hematite, and organic substances, which are present as disseminations and stringers, and as impregnations in quartz veins.

Post-ore carbonate stage phases are represented by carbonate veinlets containing Cu-, Fe-, Pb-, and Zn sulfides.

Nests and a few veins (<1 m thick) of fluorite and youngest quartz occur locally.

Quartz and carbonate exist in more or less equal quantities throughout the deposit. Zeolite prevails at depths below 720 m.

Shape and Dimensions of Deposits

Uranium mineralization occurs in an area of ca. 200 m by 150 m in which it is essentially restricted to N to NE-trending, steeply dipping subsidiary structures, which branch in the footwall off the Dyleň Fault. Some mineralization occurs locally within this fault (Fig. 3.17).

In the upper 400 m, disseminated uranium minerals concentrate in lenses. These ore shoots are a few centimeters to a few meters thick, several meters to less than 100 m, rarely up to about 150 m long, and up to 60 m, rarely a few hundred meters deep. Wall boundaries of lenses are sharp. They pinch out along strike at facies changes from gneiss to quartzite. Lenses become irregularly shaped in segments of structural complexity i.e., at sites of branching, horse-tailing, and cross-cutting faults. Below the 400 m level, lenses grade into distinct pitchblende-carbonate-hematite veins, which persist to a depth of some 1 200 m.

The bulk of the ore is hosted by paragneiss. Quartzitic rocks are unfavorable. Quartzite layers tend to have acted as barriers to ore-forming fluids. Uranium mineralization is also concentrated near pegmatite bodies, when these are cut by mineralized structures.

3.2.0.2 Zadní Chodov (Hinterkotten), West Bohemia

This deposit is located 30 km southeast of Cheb (Eger) at the northwestern edge of the Bor Massif. Although the spatial setting is perigranitic to the Bor Massif and suggests a perigranitic vein-type deposit, certain parameters put the same restrictions on such a classification as mentioned for the Dyleň deposit.

Original reserves were 5 300 t U, of which 4 151 t U (DIAMO, web side 2012) were exploited by underground mining to a depth of about 1 200 m. The mining grade averaged 0.194% U.

Geological Setting of Mineralization

The *Zadní Chodov (Hinterkotten)* deposit is hosted in Proterozoic metasediments immediately at the northwestern contact of a Hercynian granite. Country rocks are migmatized biotite and biotite-cordierite paragneisses, amphibole gneiss, quartzite, amphibolite, and amphibole-pyroxene-calc-silicate rocks of the Moldanubian Varied Group. Schistosity trends generally N–S and dips monoclinally 50–80° E. Fine-grained diorite and medium to coarse-grained granite bodies occur subparallel to schistosity. Aplite, pegmatite, and lamprophyre dikes are rare.

Repeated tectonism resulted in a rather complex structural disposition. Most prominent is the Zadní Chodov Fault, which represents a northern extension branch of the Bohemian Quartz Dike. It is cut by NW–SE faults. The Zadní Chodov Fault zone is 50–150 m wide, trends about N–S, and dips 60–80° E in the southern and central sections of the deposit. In the northern part of the deposit, the fault bifurcates (Fig. 3.18). Structures in its footwall turn to the NW while faults on the hanging wall side divert to the NNE paralleling the metasediment trend. Individual faults and shears are a few decimeters to 2 m wide and filled with graphitized breccias and gouge.

Host Rock Alteration and Mineralization

A wide zone of alteration envelops the interval of ore-bearing intense brittle deformation. Four stages of alteration-mineralization are noticed:

Pre-ore stage alteration minerals include albite, chlorite 1, clay minerals, epidote, hydromica, quartz, and hematite. Groups of these minerals are arranged in a marked zonal pattern as reflected by zones dominated by (from fresh to altered rocks): chlorite-sericite-albite, followed by epidote and epidote with clay minerals, then chlorite-sericite-leucoxene, chlorite-quartz-leucoxene, and finally chlorite. Minerals of this stage are corroded and partly replaced by phases of subsequent stages.

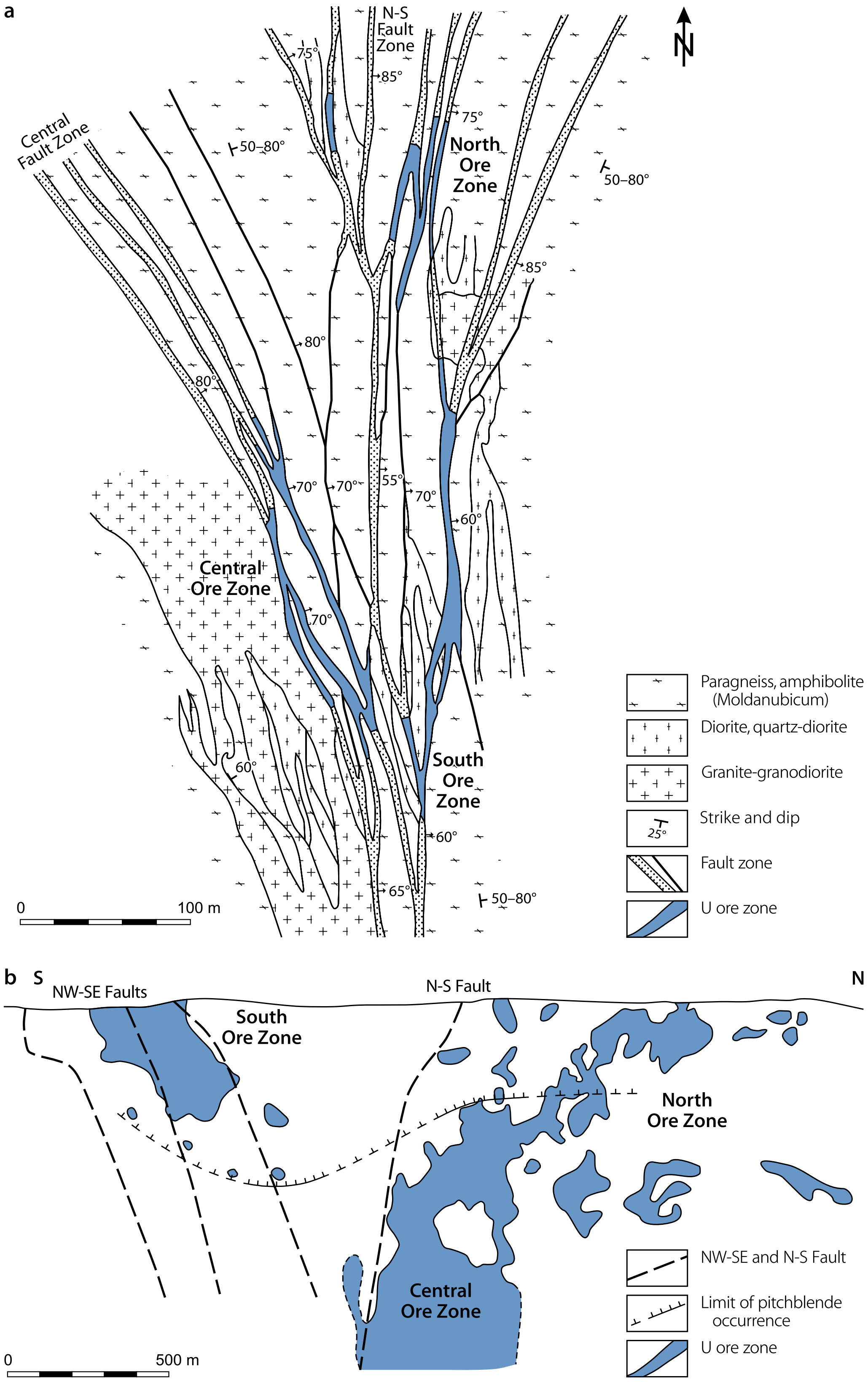
Ore stage alteration phases are apatite, chlorite 2 (clinochlore, prochlorite), quartz, and Ti oxides (rutile, anatase). Ore minerals are metamict coffinite and minor brannerite, which both associate with chlorite 2 and minor pyrite 1. Organic substances including hard bitumen occur locally in ore zones but appear to be of post-ore origin. Uranium ore may contain 0.9 to 1.4% organic material.

Post-ore quartz stage phases include widespread and extensive greenish chlorite 3 (pennine, thuringite), pyrite 2, and quartz. These minerals precipitated coeval with organic material. Veinlets of comb-quartz, and minor galena, pitchblende, pyrite, and specularite cut chlorite 3.

Post-ore carbonate stage minerals include several generations of calcite, chalcopyrite, galena, pyrite, sphalerite, and very minor pitchblende. In the central ore zone, this assemblage is accompanied by Ag-, Cu-, and Pb selenides (bergelianite, clausthalite, eucairite, and umangite). Co-, Fe-, and Ni arsenides, bornite, digenite, hematite, and native silver and bismuth are present locally. Dolomite replaces calcite. Minor amounts of coffinite and brannerite have been replaced by secondary pitchblende in open fissures of the upper levels.

Repeated cataclasis associated with alteration and remobilization of uranium affected the primary mineralization. As a result, uranium ore is present in a broken, reconsolidated, and once again disintegrated consistency.

Fig. 3.18. **Zadní Chodov (Hinterkotten), a** generalized geological-structural map showing major faults and related uranium ore zones. **b** S–N section with distribution of ore zones. Uranium mineralization extends to depths of 1 700 m. (After Kolektiv 1984)



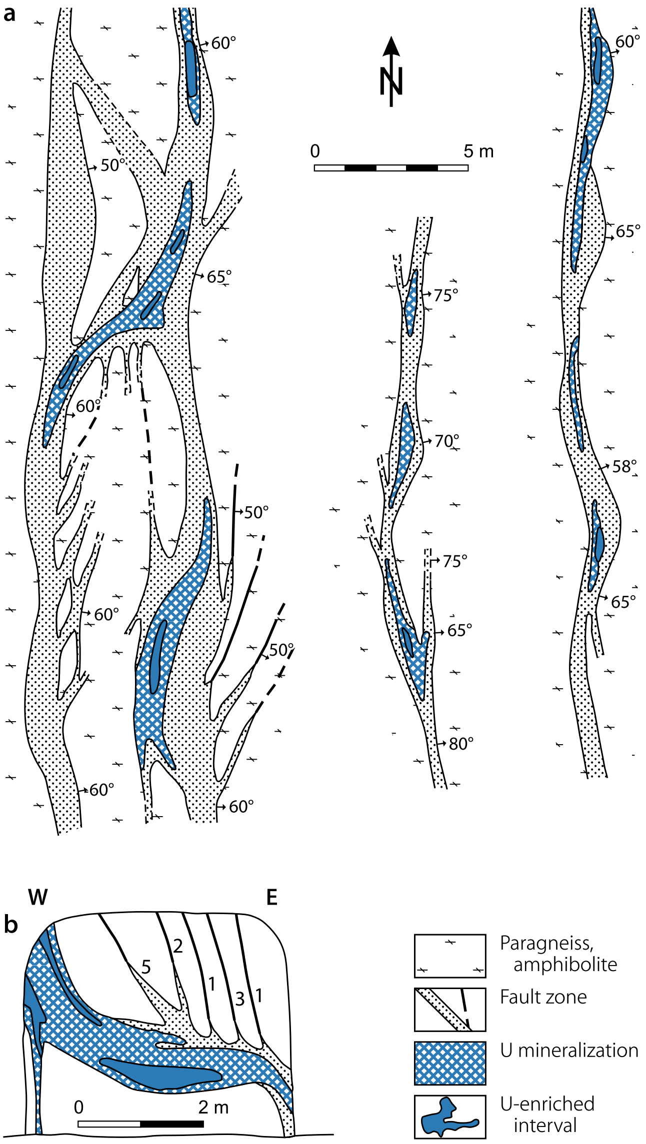
Disintegrated mineralization occurs as lenses and bands in which ore minerals are arranged in a fluidal pattern. Consolidated ore forms lenses surrounded by dark-green chlorite and graphite. Mylonitized ore consists of fine aggregates of hydromica and variable chlorites that fill intergranular spaces between rock mineral relics. This assemblage is interspersed with coffinite and more rarely brannerite, apatite crystals, finely dispersed anatase, rutile, and Fe sulfides. Albite rims, graphitic matter, and a brownish organic substance locally impregnate this authigenic assemblage.

Ore zones exhibit individual structural and textural peculiarities. The southern ore zone contains relatively rich coffinite and coffinite-pitchblende stringers and disseminations within chlorite-albite and chlorite-hydromica-albite rocks enclosed in cataclastic paragneiss and granite. Ore shoots of the northern and central ore zone are hosted by metasediments of the Varied Group. This ore consists predominantly of finely disseminated coffinite locally associated with brannerite within chlorite-hydromica material that contains apatite, Fe sulfides, and organic substance. At lower levels, the bulk of the ore is concentrated in the central ore zone.

Shape and Dimensions of Deposits

Uranium mineralization occurs in an area 2 000 m long and, in the central section, up to 150 m wide (Fig. 3.18a). Mineralization persists to a depth of 1 400 m. Ore bodies are lens shaped and primarily controlled by about N–S-oriented structures. An example of the distribution of uranium mineralization is provided in (Fig. 3.19). Uranium is particularly concentrated at intervals of sudden expansion of shattered rocks, bifurcations, approaches, and vertical and horizontal flexures of structures.

Fig. 3.19.
Zadní Chodov (Hinterkotten), examples of uranium distribution in fault zones, a in planview, b in W–E section. (After Kolektiv 1984)



Major ore bodies group in three zones (Fig. 3.18). The northern and southern ore zones are associated with the Zadní Chodov Fault zone. The central ore zone occurs in depth at the junction of the Zadní Chodov Fault with the NW–SE-oriented central fault system. The *northern ore zone* occupies the terrane of marked change in direction of principal structures. Erratically distributed ore shoots plunge southward to a depth of some 800 m, where they join ore bodies of the central zone. The *southern ore zone* is bounded by a system of N–S structures. It is limited to the north by the central zone and to the south by two subparallel NW–SE faults. Ore bodies plunge north and persist to a depth of ca. 400 m. The intensity of mineralization is variable. Better grade intervals are confined to strongly cataclastic ground. The *central ore zone*, located at depth between the northern and southern ore zones, is distinct from the two others as mineralization also occurs in NW–SE structures.

Ore grade uranium is erratically distributed in the deposit. Several ore lenses of complex configuration exist in the northern and southern ore zones. With increasing depth, mineralization becomes more and more confined to en echelon arranged lenses within several splays of the Zadní Chodov Fault. Due to a centripetal plunge, these lenses approach the central ore zone. The intensity of mineralization improves concurrently with increasing depth and finally concentrates in a relatively thick central zone ore body. This ore body is up to 2 m thick on the upper levels and widens to 8 m at the 28th level (= deepest mining level).

3.2.0.3 Vítkov II, West Bohemia

This deposit is situated in the west-central part of the Bor Massif, about 10 km south of Zadní Chodov (Hinterkotten). Vítkov II is classified as an intragranitic vein uranium deposit, but the metallogenetic relationship to the host granite is not fully understood.

The original reserves were 4 500 t U, 3 973 t U of which were recovered by underground techniques to a depth of about 1 050 m (DIAMO, web side 2012). The mining grade averaged 0.15–0.3% U.

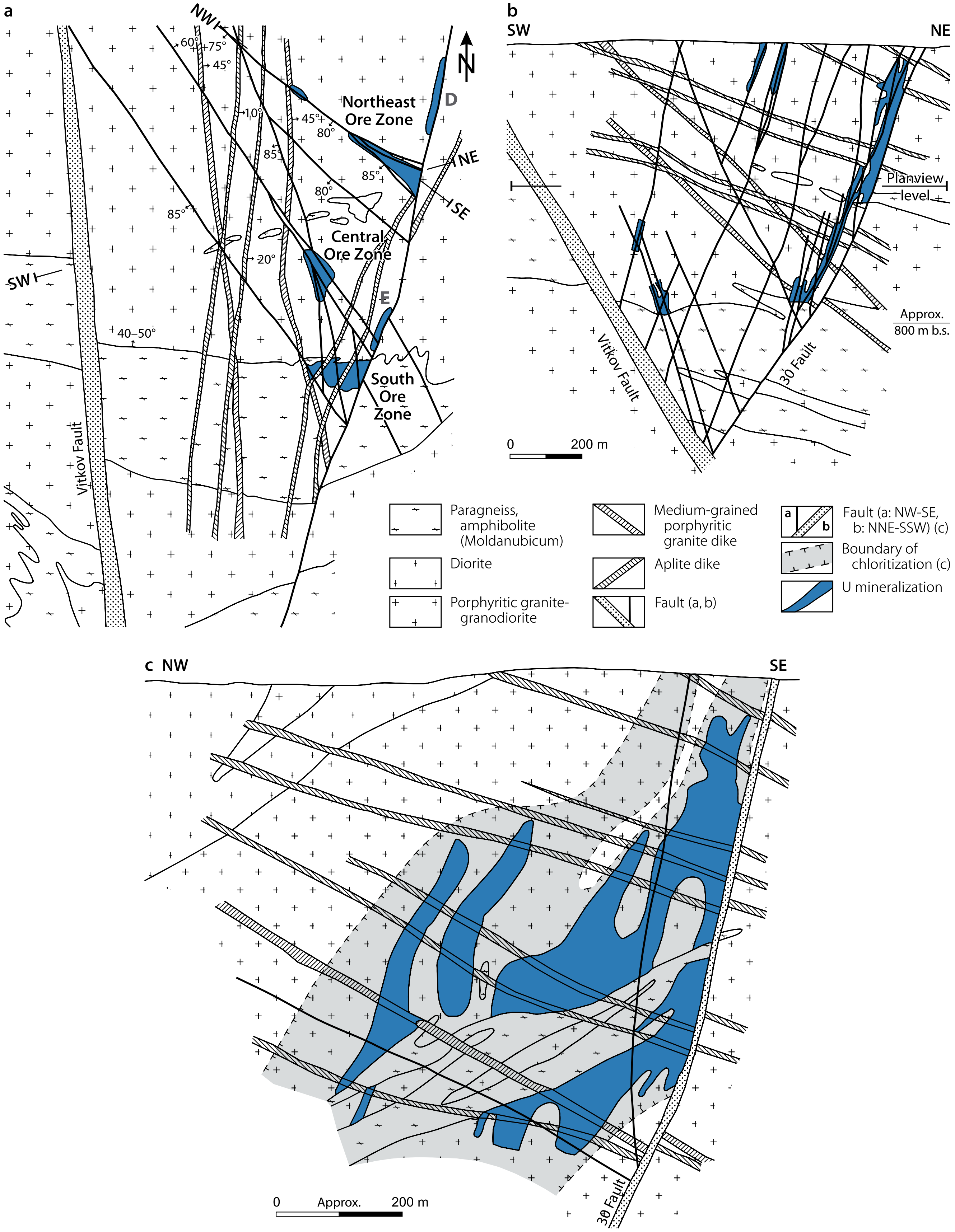
Geological Setting of Mineralization

Igneous rocks include two groups. Younger porphyritic, coarse-grained biotite granite hosts the deposit, while older diorite and granodiorite is present on the flanks and outside thereof. Porphyritic and medium-grained granite dikes are rare, while subhorizontally dipping fine-grained aplite-granite and aplite dikes are common. The youngest are lamprophyre dikes.

Moldanubian, medium to fine-grained biotite and amphibole-biotite paragneiss and amphibolite occur westerly adjacent to, and as xenoliths within, the igneous complex. Exocontact

Fig. 3.20.

Vítkov II, a generalized geological planview with the position of the Central, Northeast and South uranium zones, and ore shoots associated with the '30' Fault. b SW–NE section documenting the vertical distribution and extension of ore shoots. c NW–SE-longitudinal section through the NE ore zone. (After Kolektiv 1984)



metasediments strike N–S and dip monoclinally 50–70° E. Xenoliths become more and more frequent with depth. They are of variable size. Two prominent ones are 100–300 m thick, strike E–W, and dip from 40° to 50° N (Fig. 3.20).

Three episodes of brittle deformation are recognized, pre-dike, pre-ore, and post-ore. Pre-dike faults trend N–S, have a shallow dip, and contain aplite-granite and aplite dikes.

Pre-ore structures form about N–S and NW–SE-oriented, medium to steeply inclined fault zones. They include the '30' Fault, a zone which trends NNE–SSW, dips 60–80° W and is 5–7 m wide; and the NNW–SSE-striking, 50–75° E-dipping, and up to 10 m wide Vítkov Fault, which is a northern branch of the Bohemian Quartz Dike. Both structures are filled with altered rock fragments, gouge, minor quartz and carbonates, and locally some uranium. Movements along these two major submeridian faults generated about NW–SE- and N–S-trending subsidiary faults and horsetail structures in the central part of the deposit. Post-ore tectonism produced only a few minor fractures.

Host Rock Alteration and Mineralization

Alteration-mineralization is present in four stages. The intensity of the individual stages is variable; most prominent are stages 1 and 3.

Pre-ore stage alteration minerals occur in a bizoned halo around mineralized zones. The outer zone is characterized by chlorite 1-sericite, and the inner zone by quartz-albite-chlorite 1.

Ore stage minerals include brannerite and coffinite. Coffinite is present as <0.1 to 0.4 mm euhedral crystals. *Associated minerals* are chlorite 2, albite, quartz and apatite. Coffinite is largely replaced by secondary pitchblende and calcio-uranoite.

Post-ore quartz-hematite(-pitchblende) stage components are reflected by disseminations, stringers, and veins of quartz-hematite (partly specularite) with minor pyrite and magnetite. Where these phases are in contact with primary ore, pitchblende and kalzuranoite replace coffinite often by pseudomorphing prismatic coffinite crystals. Pitchblende rarely forms veinlets in which pitchblende aggregates occasionally exhibit a spherulitic habit.

Post-ore carbonate(-sulfide) stage constituents include calcite or other carbonates, minor Cu-, Fe-, Pb- and Zn sulfides, and rare fluorite and plate-like crystals of desmine. These minerals occur as veins up to a few meters long and stringers. Veinlets of pitchblende 2, carbonate and pyrite, 10–20 cm long and <5 mm thick, occur locally.

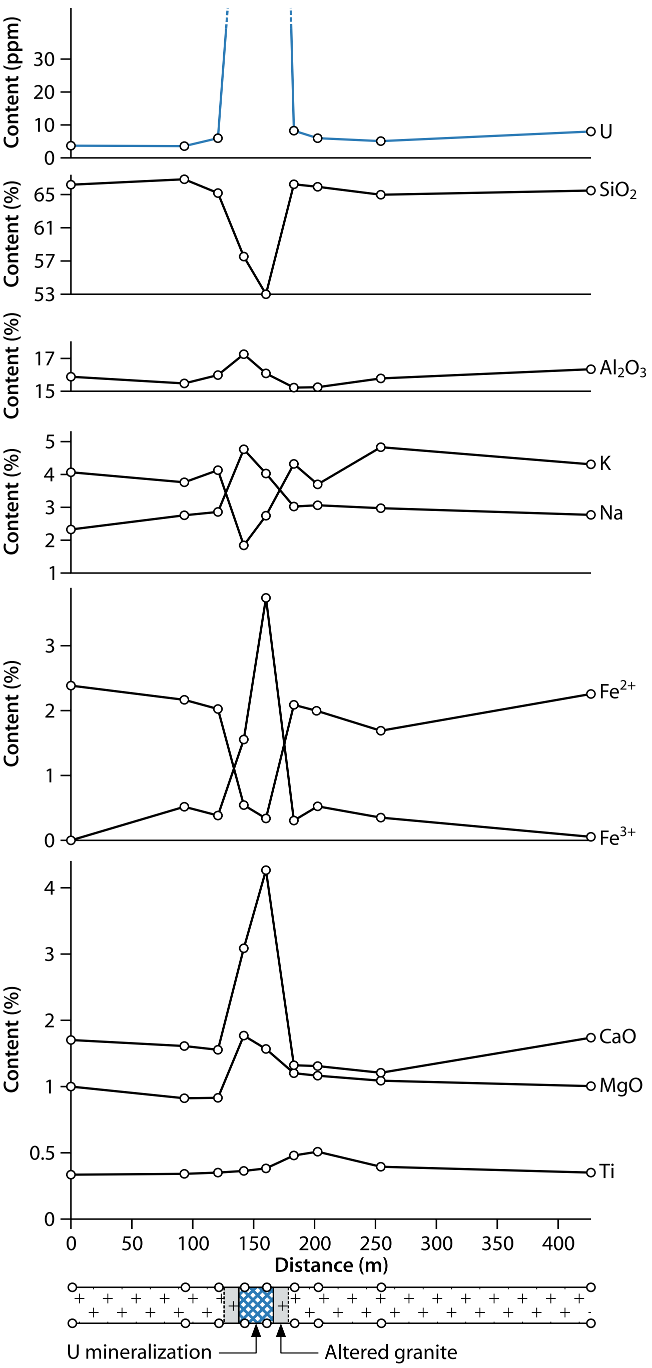
U^{6+} minerals exist to a depth of 700 m along structures with primary mineralization.

Ore bodies occur essentially in subsidiary structures adjacent to, and in the hanging wall of the '30' Fault. The host rock is altered granite. Ore bodies are lens-shaped and composed of finely disseminated uranium minerals in fault material and adjacent altered wall rocks. The position of lenses is controlled by increased rock porosity, which developed at sites of anastomosing and horse-tailing fractures, approaching subparallel faults, and changes of attitude of structures. Ore also occurs at and below aplite dikes, which cut paragneiss xenoliths. Aplite is thought to have acted as a barrier to mineralizing solutions.

Distinct chemical changes are noticed in vicinity of mineralized zones (Fig. 3.21). K and Si are depleted, while Ca, Cu, Mg, Na, Ti, normal and radiogenic Pb, and U show a gain. Hematitization resulted in higher Fe^{3+} values, but the amount of total Fe remains the same as that in fresh granite. Increased

Fig. 3.21.

Vítkov II, chemical changes in porphyritic granite adjacent to a uranium vein (*dots* indicate sampling sites). (Kolektiv 1984)



Ca and Mg contents reflect the formation of later carbonates and chlorite. Radiogenic Pb produced the widest and most consistent halos, several tens of meters around ore bodies. This lead very probably derived from uranium ore by redistribution into wall rocks and over wider distances along structures.

Shape and Dimension of Deposits

The Vítkov II deposit covers an area 1 200 m long in N–S direction and 300–400 m wide confined between the Vítkov and '30' Faults. Mineralization persists to a depth of ca. 1 100 m.

Ore lenses are spatially arranged in a way that they add up to three, relatively large *ore columns*, i.e., stockworks along interlinked fracture zones in the hanging wall of the '30' Fault (Fig. 3.20).

The **NE ore column** is situated at the junction of a NW–SE-oriented fault zone with the '30' zone. The maximum thickness of this stockwork is several tens of meters. Length along strike varies from level to level between some tens and few hundred meters. Ore commences 60 m below surface and persists to 800 m, where it pinches out (Fig. 3.20).

The **central ore column** incorporates lens-like ore bodies in that segment where NW–SE-oriented subsidiary faults bifurcate near the '30' Fault. This column extends from surface to a depth of several hundred meters. Horizontal dimensions vary significantly; they range along strike from several hundred meters on upper levels to 15 m at depth, and in thickness from a few meters to several tens of meters.

The **southern ore column** is controlled by the intersection of bifurcating NW–SE and N–S structures with the '30' Fault. Mineralization begins a few hundred meters below surface and terminates against a xenolith of paragneiss at depth. The column is composed of lenticular to isometric ore shoots with horizontal extensions of several hundred meters.

In addition to the mentioned ore columns, several ore bodies exist in various branches of the '30' Fault zone (Fig. 3.20). The 'D' ore body comprises a number of small- and medium-sized lenses. It extends from near the NE ore column to a point some hundreds of meters northward; persists to a depth of several hundred meters, and is up to several meters thick.

3.2.0.4 Svatá Anna, West Bohemia

The *Svatá Anna* deposit is located 8 km southeast of Zadní Chodov (Hinterkotten), at the northeastern edge of the Bor Massif (Fig. 3.15). Underground mining produced 125 t U at a mining grade between 0.1 and 0.3% U.

The geological position of the vein-type mineralization is perigranitic, but it remains doubtful as to whether or not the ore is granite-related. Compared with other uranium deposits of the West Bohemian uranium region, the Svatá Anna deposit is morphologically and mineralogically distinctly different.

Geology and Mineralization

Svatá Anna is positioned at the exocontact of the granitic Bor Massif. Host rocks are amphibolite, biotite and biotite-amphibolite gneisses of the Moldanubian Varied Group. The metasediments are folded into a NE–SW-oriented and SE-dipping monocline. The granite-metasediment contact is of a complex nature. NE-oriented granite apophyses penetrate into metasediments. Diorite occurs as xenoliths in porphyritic granite.

Several subparallel NW–SE-trending and mostly steeply SW-dipping faults of the Mariánské Lázně Lineament are prominent at the deposit. These structures are filled by a mixture of gouge intersected by veinlets and lenses of carbonate and quartz, and locally pitchblende-carbonate veins. Pitchblende forms small but rich ore shoots within veins. Ore minerals include pitchblende, Fe- and Co arsenides, bornite, chalcopyrite, covellite, and rare nickeline and proustite. Accumulations of galena and sphalerite occur locally. Kolektiv (1984) reports a U/Pb age of 265 Ma for pitchblende. Ore control is by structure and lithology. Lithological control is reflected by restriction of minable ore to vein intervals in amphibolite. Uranium mineralization pinches out, where veins enter granite.

3.2.1 Other Uranium Deposits in West Bohemia

A number of uranium occurrences of similar geological setting as the deposits mentioned above occur in western Bohemia; they are depicted and listed in Fig. 3.15. There are also several small uranium deposits at the southwestern extremity of the Karlovy Vary Massif, situated to the northwest of the West Bohemian district, viz. *Dolní Žandov*, *Kladská*, *Kynžvart*, and *Smrkovec* (Fig. 3.2). Original resources of these deposits were on the order of up to some tens of tonnes uranium at grades ranging from 0.05 to 0.2% U.

3.2.1.1 Kladská, Northwest Bohemia

The *Kladská* deposit is located 25 km southwest of Karlovy Vary (Karlsbad). Mineralization is of perigranitic "Iberian" type. Original resources were some tens of t U, at a grade of ca. 0.1% U.

Geology and Mineralization

Muscovite-sericite phyllite of the Monotonous Series of the Proterozoic Moldanubicum hosts the deposit. The up to 120 m thick metamorphic unit is a large roof pendant in granite composed of "Gebirgsgranite" and autometamorphic "Erzgebirgsgranite". Metasediments are contact metamorphosed to andalusite-biotite and quartz-biotite hornfels for up to 150 m from the granite contact.

A system of up to 2 m wide, E–W-trending and 50–80° N- or S-dipping shear faults cut the metamorphic rocks. These shears narrow to few centimeters when entering granite. Narrow subsidiary fractures splay at flexures from main faults.

Fractures of this system are filled with 20–50 cm and rarely up to 1.2 m wide veins composed of carbonate, quartz, chalcopyrite, pyrite, and, locally uranium minerals.

Hexavalent uranium minerals, strongly altered pitchblende and, at depth, rare pitchblende constitute the ore. These minerals occur in 0.1–0.5 m, rarely up to 1.2 m thick lenses that extend laterally for 7–8 m and downdip for 12–15 m. The best mineralization is found at sites of off-branching subsidiary fractures and where shears cut andalusite-biotite hornfels near the granite contact. Uranium mineralization is absent in granite (Kolektiv 1984).

3.3 Central and Southwest Bohemian Uranium Region

The central and southwestern Bohemian uranium region occupies the Central Bohemian Pluton and its surroundings. The region is 60–70 km wide and extends for about 120 km in NE–SW direction. It includes the *Příbram* district, the largest and most important uranium vein district in the former ČSSR, now Czech Republic, which will be discussed below. Other uranium deposits include *Nová Ves pod Pleší*, *Mníšek*, *Vrančice*, *Předbořice*, *Heřmaničky*, and *Kojetín Petrovice*. A great number of additional uranium occurrences are known. Noteworthy ones are listed in Sect. 3.3.2 and depicted in Fig. 3.22. Original reserves of the region are estimated to have been in excess of 60 000 t U.

Sources of information. Boitsov et al. (1977), Kolektiv (1984), Komínek (1997), Matolín et al. (1981), Petroš et al. (1986), Sattran and Čadek (1967), Vlašímský et al. (1995), Žák and Dobeš (1991), pers. commun. by Hrubý J, Komínek J, unless otherwise stated.

Regional Geological Features of the Central Bohemian Uranium Region

This uranium region is located in the core of the Bohemian Massif, a segment within the Moldanubian Zone of the Hercynian Orogen. Two lithotectonic units and a large Hercynian granodioritic-granitic batholith, the *Central Bohemian Pluton*, dominate the region. To the NW of the batholith is the *Teplá-*

Fig. 3.22.
Central Bohemian Pluton region, lithostructural map with location of major uranium deposits and occurrences. Letters *a* to *f* denote main deposits/vein clusters of the Příbram district (for details of lithologies see Tables 3.2–3.4). (After Kolektiv 1984)

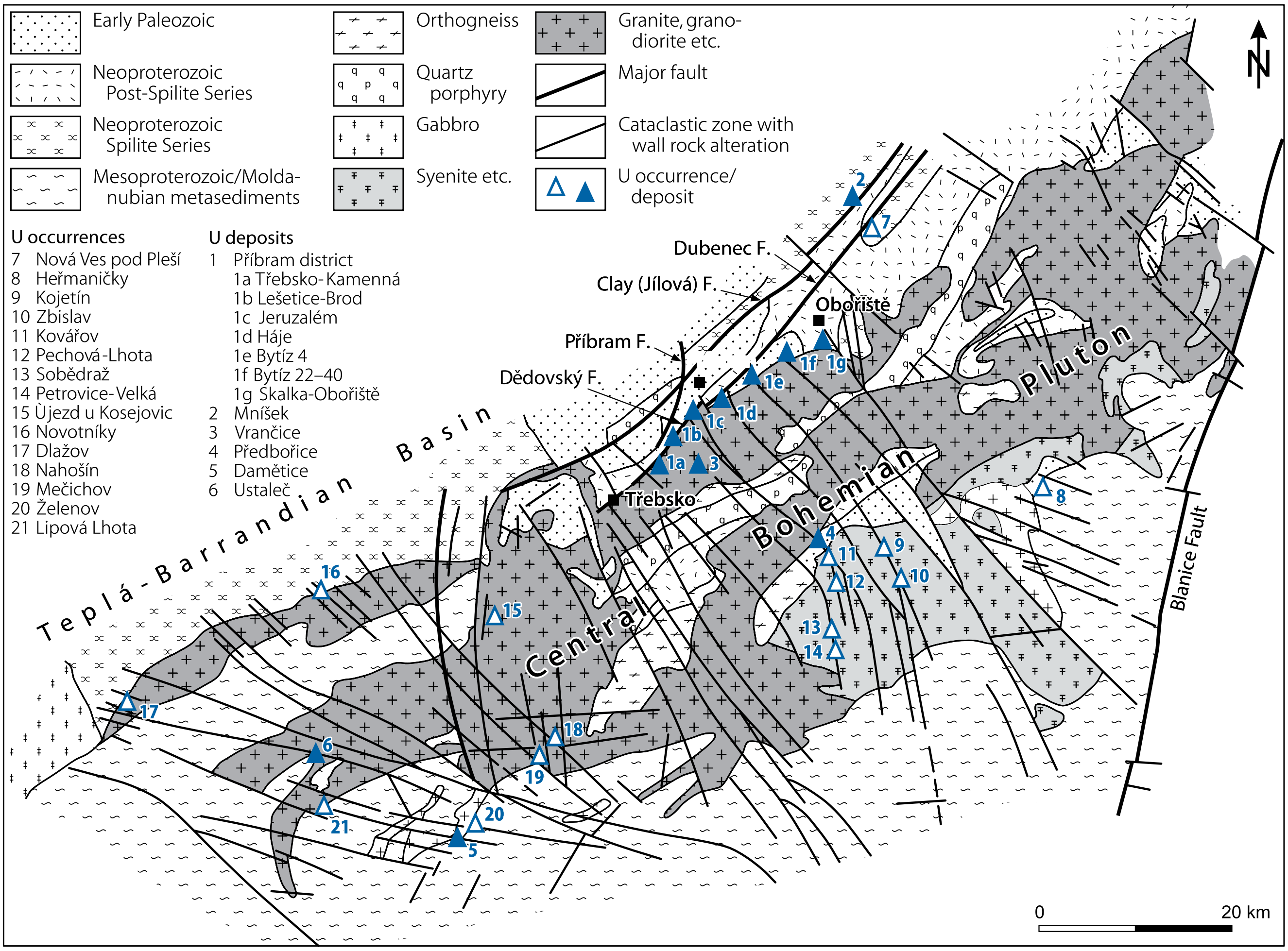


Table 3.2.
Central Bohemia, stratigraphy of (meta)sediments surrounding the Central Bohemian Pluton. (After Kolektiv 1984; Ruzicka 1971; Žák and Dobeš 1991)

Paleozoic (2 800 m thick)		
Ordovician-Silurian		Geosynclinal sediments, including black graptolitic shale
Cambrian-Eocambrian		Molasse sediments: conglomerate, quartzose sandstone, arkose, greywacke, minor slate with volcanics; near intrusions contact metamorphism with biotite and biotite-cordierite hornfels and spotted schists
Proterozoic		
Barrandian-Algonkian/ Neoproterozoic	Post-Spilite Series (2 000–3 000 m thick) (= *Štěchovice Group*)	Weakly metamorphosed flyschoid sediments including pelitic-psammitic sediments with minor conglomerate, coarse-grained (greywacke, conglomerate etc.) and pelitic sediments
	Spilite Series (Kralupy-Zbraslav Group)	Weakly metamorphosed silicified black shale with tuffaceous material (*Lečice Beds*), intermediate and felsic effusives and pyroclastics (quartz-porphyry, quartz keratophyre, Davle Formation), greywacke, quartzite, sandy shale with pyritic intercalations, and spilitic-tholeitic volcanics (spilite, diabase and related tuffs partly altered to amphibolite and skarn, *Blovice Unit*)
Moldanubian/ Mesoproterozoic	Varied Group	Paragneiss of katazonal metamorphic grade with intercalated amphibolite, marble, erlans, quartzite, and graphitic gneiss subdivided into an • Upper Sequence with predominance of calcareous rocks and a • Lower Sequence with predominance of amphibolite

Barrandian Basin (or Synclinorium) of weakly metamorphosed Neoproterozoic and Early Paleozoic sediments and volcanics. To the south and east is the *Moldanubian Dome* of Mesoproterozoic metamorphic rocks of the "Varied Group" (for stratigraphy and lithology see Table 3.2).

The batholith was intruded along the boundary between the two lithotectonic units, which roughly coincides with the NE–SW-oriented Central Bohemian Lineament. Permian and Cretaceous sediments transgressed the northeast rim of the pluton. Steeply dipping, 5–10 m and locally up to 30 m thick diabase dikes presumably of Cambrian age cut the (meta)sediments. The dikes frequently group to swarms, which can locally constitute as much as 20% of the total rock volume.

The NE–SW-elongated *Central Bohemian Pluton* is exposed over an area 120 km long, 30–50 km wide, and covering ca. 3 500 km^2 (Fig. 3.22). This pluton is of heterogeneous composition as documented by about 25 igneous lithologies ranging from granodioritic to granitic and syenitic facies (Table 3.3). The oldest rock is granodiorite at the eastern margin of the pluton, while postkinematic tonalite (= quartzose diorite with biotite and amphibole) associated with diorite and granodiorite constitute the prevailing facies. They are particularly abundant in the northwestern part of the pluton. A peraluminous granite, referred to as marginal granite facies, forms the pluton margin along the Příbram uranium district. Other facies include some biotite adamellite with muscovite in the northeast part and diopside-bearing rocks formed by assimilation of erlan and limestone at various locations. Plutonic rocks are associated with an abundance of dikes and sills of leucocratic (granitic, aplitic, pegmatitic) and intermediate to mafic nature (granodiorite-porphyrite, porphyry, lamprophyre) (Bernard and Dudek 1967).

Table 3.3.
Central Bohemian Pluton, igneous rock facies and their ages. (Ruzicka 1971 after Svoboda et al. 1966)

Facies	Age[a] (Ma)
Amphibole-biotite granodiorite	417
Amphibole-biotite granodiorite	371
Two-mica granite	370
Biotite granodiorite	367
Two-mica granite	359
Biotite granodiorite	353
Pyroxene-biotite syenite	343
Melanocratic series of syenite	330
Marginal biotite granite	324
Porphyritic granodiorite	290
Amphibole-biotite granite	285

[a] The given ages require verification and should therefore be considered only as preliminary.

The northwestern contact of the pluton, which lies against the Neoproterozoic–Paleozoic sequences, is of intrusive nature and fairly straight except locally where disrupted by longitudinal NE–SW and perpendicular NW–SE step faults. In the central section, at the Příbram district, the contact has a

70–80° NE dip, which results in a positioning of granite over sediments. The southeastern and southern contact of the pluton is of a more complex nature. Apophyses persist from the parent body into, and concordantly with the structural grain of Moldanubian metamorphic rocks.

Moldanubian metasediments were regionally metamorphosed to amphibolite and granulite grade facies by the Assyntian Orogeny of Neoproterozoic age. The Assyntian Orogeny was accompanied by basic spilitic magmatism. This suite and the Barrandian–Algonkian sediments were subsequently involved in the Caledonian and Hercynian orogenies. Associated Hercynian magmatic activity is exemplified by the Central Bohemian Pluton. Contact metamorphism modified sediments at distances of up to 1 200 m from the pluton. Alpine tectogenesis is manifested by brittle deformation and block faulting with the formation of horsts and grabens.

Fold planes of Moldanubian metasediments trend NE–SW and N–S and dip westerly on the east flank of the pluton. The strike turns to E–W and NW–SE and the dip to the north on the south side of the pluton. Younger folds are superimposed on older ones. Upper Proterozoic–Paleozoic (meta)sediments of the Teplá-Barrandian depression are un- to mildly metamorphosed up to greenschist facies but are intricately folded into anticlines and synclines. Fold axes trend dominantly NE–SW but are locally overprinted by parallel and oblique folds. Remnants of this suite occur as roof pendants in the central part of the batholith.

Major postgranitic faults trend NW–SE, NE–SW, and N–S. The first two systems parallel regional lineaments. The two most prominent are the NW–SE-trending Jáchymov Lineament (also referred to as Gera-České Budějovice Lineament) and the NE–SW-oriented Central Bohemian Lineament. Faults of the NE–SW system are prominent along the NW margin of the pluton, where they are represented by the major Jílový, Dědovský, Dubenec, and Druhlice Faults. Faults of the NW–SE system transect the Central Bohemian Pluton for more than 40 km. Individual faults are of complex configuration and characterized by 100–200 m wide cataclastic zones and marked alteration. At the northwestern margin of the pluton, these zones splay into 0.5–1 m wide faults and persist for less than 1 to 2 km beyond the pluton contact. All these faults pinch out to the east of the NE–SW-trending Dědovský-Dubenec-Druhlice Faults (Figs. 3.22 and 3.23a). Many of these faults host diabase dikes or vein mineralization.

Principal Types of Mineralization

A variety of metallic vein mineralization occurs abundantly within and adjacent to the Central Bohemian Pluton. Veins are dominantly hosted by NW–SE and NE–SW structures and to a minor degree by N–S faults. Besides minor occurrences of Mo, Sn, W, and other metals, four *principal mineral associations* are recognized (from oldest to youngest) (Kolektiv 1984):

1. *Au-quartz veins* ("quartz formation") filling narrow fissures and irregular fractures throughout the region. Veins of greater width are found within granite and Moldanubian metasediments and metavolcanics in the northeast part of the region. Grades range from fractions of a gram to a few grams of Au t^{-1}, rarely to 9 g Au t^{-1} (*Jílové deposit*).
2. *Pb-Zn-Ag in quartz-carbonate veins* locally with Cu and/or U ("polymetallic formation" or "siderite-sulfide formation"). The most significant deposits are *Březové hory* and *Bohutín* near Příbram hosted by Cambrian (meta)sediments a few kilometers distant from the northwestern contact of the pluton. At Březové hory, ore is in NE–SW veins at the intersection of the Clay Fault and Příbram Fault. Veins of the Březové hory and Bohutín deposits produced a total of 3 500 t Ag, 520 000 t Pb, 260 000 t Zn, and 80 000 t Sb (Vlašímský 1982). Polymetallic veins are rare near the granite contact, i.e., in the Příbram uranium district, but some are within the pluton such as Vrančice (in biotite granite) and *Radětice*, which occur at the intersection of smaller N–S structures with NW–SE fault zones. In other deposits, the siderite-sulfide formation may constitute the oldest, commonly thin, infill of a vein.
3. *U in carbonate veins* associated with minor amounts of sulfides ("carbonate-pitchblende formation") (distribution see below).
4. *Calcite veins* (or "calcite-sulfide formation") are found throughout the region. Calcite fills short and irregular fissures as well as open spaces in the interior of polymetallic and pitchblende veins. It typically forms marginal extremities of mineralized veins.

Uranium veins show the following lithological affinity and spatial relationship to the Central Bohemian Pluton:

1. *Exocontact deposits* along the northwest margin of the pluton are hosted in Algonkian (Neoproterozoic)–Cambrian sediments; deposits include *Dlažov*, *Mníšek*, *Nová Ves*, *Novotníky*, and *Příbram*.
2. *Exocontact deposits* along the east, southeast, and south margins of the pluton occur in Moldanubian metamorphics; deposits include *Chanovice*, *Damětice*, *Heřmaničky*, *Klatovy*, *Kasejovice*, *Lipová Lhota*, *Ùjezd*, *Ustaleč*, and *Želenov*.
3. *Endocontact deposits* within metamorphosed Ordovician roof pendants are represented by *Předbořice*.
4. *Endocontact occurrences* within igneous rocks of the pluton comprise *Kojetín*, *Kovářov*, *Mečichov*, *Nahošín*, *Pechová-Lhota*, *Petrovice Velká*, *Sobědraž*, *Vrančice* (polymetallic), and *Zbislav*.

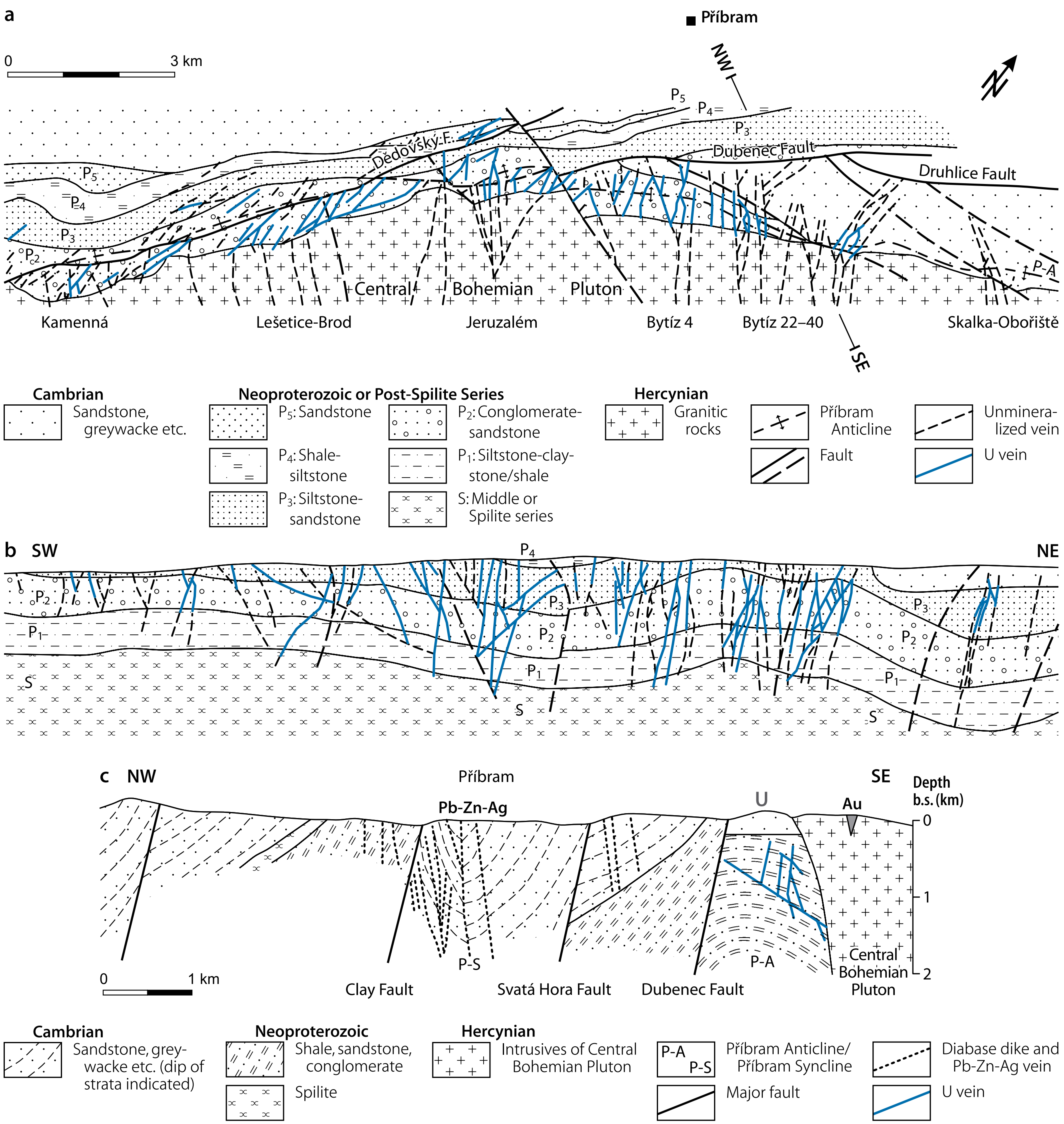
3.3.1 Příbram District, Central Bohemia

The town of Příbram is located 60 km southwest of Prague. The nearby district has been one of the largest vein uranium districts of the world. It contains perigranitic vein uranium deposits in a some 20 km long and 1–2 km wide, NE–SW-elongated strip between the settlements of Obořiště to the northeast and Třebsko to the southwest of Příbram.

Exploration started in 1947, first in the Pb-Zn-Ag mines of the Příbram-Březové hory and Bohutín districts, which are about 2–4 km to the northwest of the main uranium zone. These

Fig. 3.23.

Příbram district, a geological map with the distribution of the most important vein systems/deposits; b curvilinear SW–NE section off the Central Bohemian Pluton contact; c NW–SE section across the regional structural grain. a and b show the restriction of uranium veins to a narrow zone along the pluton contact and the attitude of principal veins. c Illustrates in a schematic mode the location of Pb-Zn-Ag, and U and Au veins with respect to the overhanging pluton contact. Structures of the Central Bohemian Lineament trend NE–SW, those of the Jáchymov Lineament NW–SE. (After a, b Petroš et al. 1986; c Ruzicka 1971 based on Kettner 1926)



multimetallic veins contain some uranium on the upper levels. Several thousand pitchblende veins have been discovered since; about 1 200 have been mined. Most of the veins are grouped in clusters forming the deposits shown in (Figs. 3.23a and 3.32). Two deposits occur at the northeastern extremity of the district, *Mníšek* and *Nová Ves pod Pleši*.

Uranium mining was by underground techniques and lasted from 1950 to 1991. Sixty-eight shafts, including internal shafts, serviced the operations. Main shafts are shown in Fig. 3.32. The deepest shaft, shaft 16 near Háje, that delivered ore from the *Bytíz* deposit, was 1 836 m deep. The lowermost mining level was at a depth of 1 400 m.

The Příbram district has yielded 48 432 t U (Komínek 1997). Production peaked at about 1 900 t U yr^{-1} in the 1960s. By 1976, production had dropped to 900 t U yr^{-1} and to less than 500 t U yr^{-1} in the early 1980s (Hrádek 1995). In total, about 155 mio t of ore and waste have been mined (spec. gravity 2.6, broken material 1.7), 85 mio t of which have been hoisted to surface and the remainder used underground as backfill. Reserves of the district are practically depleted. Mined ore varied considerably in grade but averaged 0.18% U.

Sources of information. Kolektiv (1984), Komínek (1997), Petroš et al. (1986), Škvor (1977, 1978), Vlašímský (1982), Vlašímský et al. (1995), pers. commun. by Hrubý J, Komínek J.

Geological Setting of Mineralization

Uranium veins of the Příbram district occur within the southeastern limb of the Barrandian Synclinorium at the immediate margin of the Hercynian Central Bohemian Pluton (Figs. 3.22 and 3.23a,c). Host rocks are dominantly Upper Proterozoic flyschoid schists of the 2 000 to 3 000 m thick Post-Spilite Series (Table 3.4) and, locally, Cambrian clastic sediments, which rest unconformably on the Proterozoic.

Table 3.4.
Příbram district, lithology of the ore-hosting Upper Proterozoic Post-Spilite Series and Cambrian sediments. (After Kolektiv 1984)

Unit		Lithology	Thickness (m)
Cambrian		Polymict conglomerate, quartz conglomerate, greywacke, sandstone	>2 000
>Unconformity<			
Neo-proterozoic	P 5	Sandstone	200
	P 4	Clay–siltstone; indistinct bedding	>200
	P 3	Siltstone–sandstone; grey, fine- and medium-grained, polymict, with few thin conglomerate beds	400–450
	P 2	Conglomerate–sandstone; grey, polymict variably-grained sandstone with extensive conglomerate horizons	350–600
	P 1	Siltstone–claystone/shale, alternating carbonaceous/graphitic locally pyritic shales, siltstone and fine-grained sandstone	450–500

Note: Intraformational, 0.5 to 70 m thick, polymict conglomerates are intercalated in the whole Proterozoic sequence and most abundant in unit P 2. All sediments are mildly regionally metamorphosed up to greenschist facies, and contact-metamorphosed along the Central Bohemian Pluton border.

Sediments are mildly regionally and contact metamorphosed. Contact metamorphism extends for 300–1 200 m away from the pluton contact. An inner, up to 400 m wide zone, consists of hornfels without any sedimentary texture, whereas the outer, up to 900 and locally to 1 200 m wide, zone retained remnants of sedimentary texture. Contact-metamorphic rocks are characterized by recrystallization of biotite, feldspar, quartz, and, more rarely, cordierite, sillimanite and garnet, which replace hydromicas, clay minerals, and fine-grained quartz of the sediments.[3] Sediments are complexly folded and faulted and are intruded by a great abundance and variety of dikes, sills, apophyses, and stocks.

The heterogeneous Central Bohemian Pluton is composed of some 25 igneous facies. Its northwestern contact with sediments trends 30–80° NE and dips 35–85° SE to a depth in excess of 2 000 m. Lithologies bordering the uranium district to the northeast include a border facies of dominantly coarse-grained to porphyric and equigranular adamellite, which is followed inwards, at a distance of about 50–500 m from the contact, by biotite and two-mica granodiorites (Blatenský or Blatno type). Both facies are petrogenetically-related. Their mutual boundary is complex ranging from interfingering to, more rarely, gradational. Both facies enclose xenoliths of Cambrian conglomerates and gabbro-diorite, from few centimeters to 100 m and more in size. Three gabbro-diorite stocks also occur in sediments peripheral to the pluton. Granitic apophyses are relatively frequent. They extend for up to 300 m along bedding planes into sediments.

Dikes include pre-granite diabase of N–S orientation and post-granite quartz porphyry, diorite porphyry, granodiorite porphyry, lamprophyre, pegmatite, and aplite. Dikes are 0.5–15 m and greater wide and persist for some tens to a few thousand meters laterally and vertically. All dikes except those of aplite and pegmatite have a steep inclination. Dikes of all varieties and directions are particularly abundant proximal to the pluton. Aplite and pegmatite dikes, which mostly strike NE–SW and dip 20–50° NW have accumulated in a 200 m wide zone paralleling the pluton contact.

The sedimentary sequence is folded into an asymmetric anticline and a westerly adjacent syncline (Příbram Anticline and Syncline). The anticline is 25 km long. Its axis strikes curvilinear around NE–SW and plunges at up to 30° in either a NE or SW direction. The southeast wing dips variably 30–70° SE, whereas the northwest wing dips, on average, 60°. Granitic stocks related to the Bohemian Pluton were intruded into the southeast wing of the anticline.

The Příbram district is at the junction of the NE–SW-trending Central Bohemian Lineament and the NW–SE-oriented Jáchymov Lineament. The Jílový, Dubenec, and Dědovský Faults are part of the NE–SW lineament and root in the Proterozoic. The northwestern contact of the pluton also follows the NE–SW direction. NW–SE-trending structures are prominent in the pluton, while only major faults extend into adjacent metasediments (Figs. 3.22 and 3.23a).

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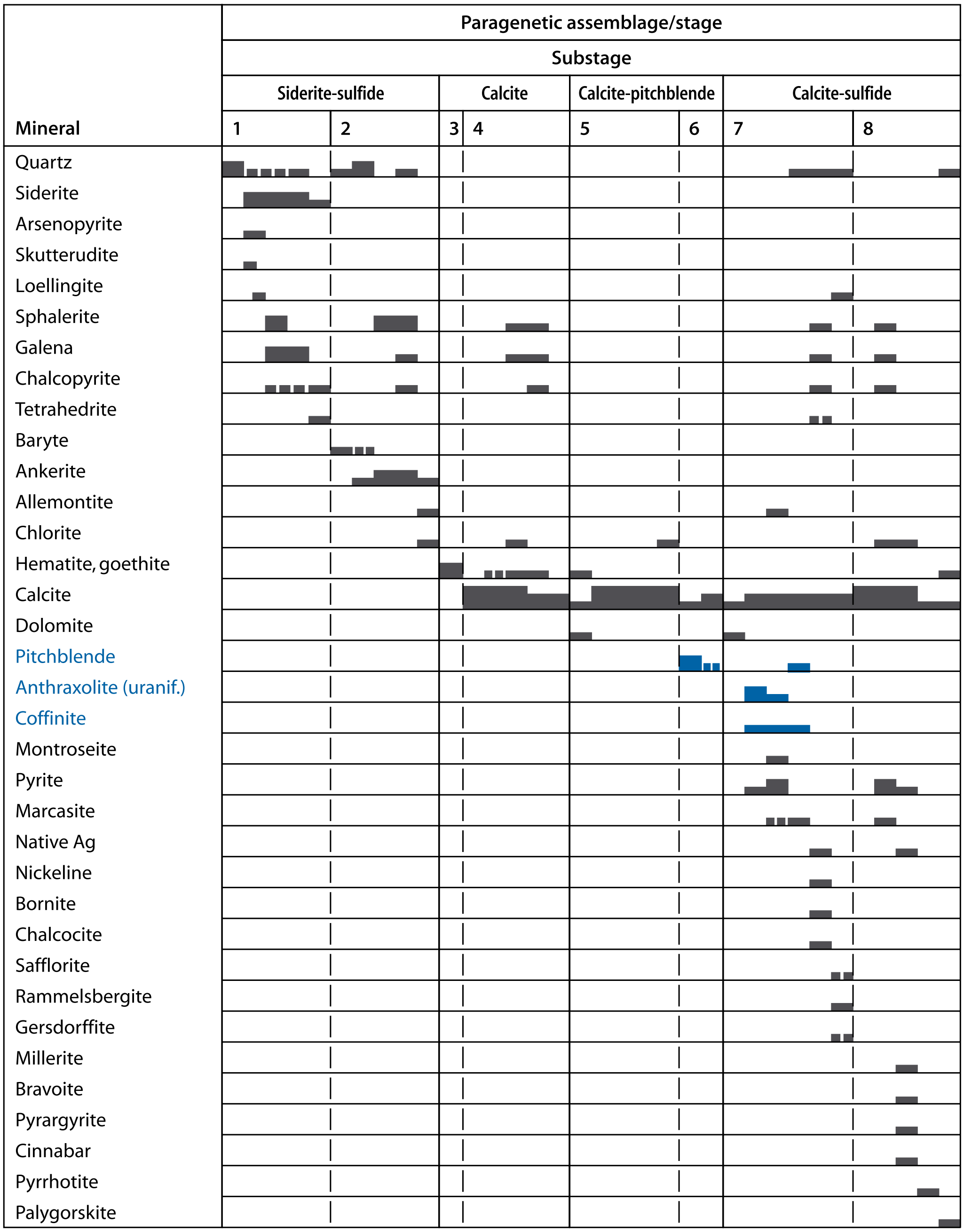
[3] Kolektiv (1984) applies, for descriptive reasons, the sediment nomenclature for host rocks, which is subsequently used in this compilation.

Petroš et al. (1986) group displacement structures within the uranium district into two categories with respect to their size and position in relation to the Příbram Anticline, viz. *(a)* regional and *(b)* local longitudinal, diagonal, and cross faults.

Two prominent regional longitudinal structures are represented by the NE–SW-trending Dědovský Fault and the NE-continuing but step-like offset Dubenec Fault. Both together constitute the northwestern limit of the uranium district. They are 10 and 30 km long, respectively, and dip ca. 75° NW to a depth greater than 1 500 m. Both consist of up to 50 m wide shear zones. Repeated reactivation caused displacements of 100–200 m horizontally and 300–1 200 m vertically, thrusting Cambrian locally over Proterozoic rocks.

Regional NW–SE faults typically occur as up to 200 m wide cataclastic and altered zones within the pluton, as mentioned above. They narrow to 0.5–1 m wide structures near the contact and pinch out within 100–2 000 m away from the intrusion, where some contain uranium veins. None of these structures persist westwards beyond the Dědovský and Dubenec Faults (Fig. 3.23a). Regional diagonal faults occur preferentially in the center and NW section of the district. They may be 2–3 km long and as much as 1 000 m deep. The Příbram Fault is a typical example (Fig. 3.22). Local faults are abundant throughout the district. They extend from some tens of meters to a few kilometers and experienced repeated reactivation with displacements commonly less than 30 m. Three types are distinguished by Kolektiv (1984), unmineralized, mineralized, and dike-bearing structures.

Fig. 3.24. **Příbram district, paragenetic scheme of uraniferous veins. (After Kolektiv 1984)**



Host Rock Alteration

Wall rocks along veins are modified by a variety of alteration features. Kolektiv (1984) attributes the alterations to the various stages of mineralization (see below) as follows:

- siderite-sulfide stage: sericitization of plagioclase and biotite;
- early calcite stage: illitization and sericitization as above, but less intense, associated with carbonatization, chloritization, and hematitization. Hematite and goethite replace sulfides and impose a pink hue on the wall rocks for up to 2 m from veins;
- calcite-pitchblende stage: continued sericitization and hematitization at the initial phase of this stage followed by chloritization (without hematite) in up to 5 cm wide rims during pitchblende deposition;
- calcite-sulfide stage: similar to the previous stage.

Extension of the alteration into wall rocks is a function of cataclasis and vein fill. Alteration aureoles in sediments commonly persist for 0.1–3 m from veins but are more extensive in intrusive rocks. In segments of multiple veins where the zones of cataclasis and vein filling overlap, alteration may spread over intervals tens of meters in width.

Mineralization

Pitchblende is the principal uranium mineral. Coffinite and uraniferous anthraxolite occur in minor amounts, as do sulfides of mainly Fe, Pb, and Zn. Calcite is the dominant gangue mineral present in six generations (DK and K1 to K5). In total, more than fifty minerals, including thirty-five ore minerals, have been identified in Příbram uranium ore (Fig. 3.24). They form four principal mineral parageneses/generations as presented in Table 3.5 (Petroš et al. 1986).

The siderite-sulfide stage, which correspondents to a large extent with the polymetallic veins elsewhere in the Příbram area, is the earliest vein infill. Next is the pre-uranium, early calcite stage, which includes Mn and Pb enriched calcite (K1 averages 3.3% Mn, 2 700 ppm Pb, Cílek et al. 1984).

Characteristics of the carbonate-uranium assemblages include pitchblende 1 formed between calcite K3 and K4 and which occurs as botryoidal aggregates, veinlets and disseminations, and crack fillings within and coatings on calcite DK to K3. Figure 3.25 presents a schematic section of the relationship of pitchblende 1 and gangue minerals. *Uraniferous*

Fig. 3.25.
Příbram district, schematic section of distribution and zoning of pitchblende 1 and associated gangue minerals in a vein. *DK* and *K1* to *K5* denote calcite generations. Ankerite is fine-grained, pale yellow or brown, strong hematitic; calcite *K1* white or altered to grey; *K2* prismatic, brown, hematitic; *K3* grey or brown, hematitic; *K4* medium-grained, brown-yellow; *K5* coarse-grained, white (for more information see Table 3.5). (After Petroš et al. 1986; Kolektiv 1984)

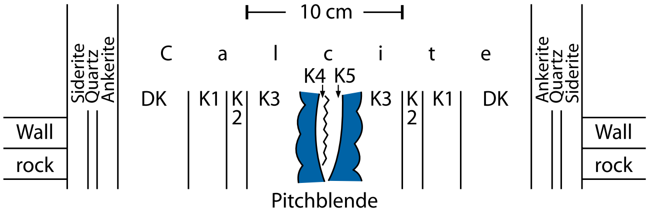


Table 3.5.
Příbram district, paragenetic mineral assemblages/generations in uranium-bearing veins (from oldest to youngest) (see also Figs. 3.24 and 3.25). (After Komínek and Prokeš in Petroš et al. 1986 and Kolektiv 1984)

Stage	Mineral association	Remarks
1. Siderite-sulfide	Siderite, dolomite-ankerite, quartz, baryte, chlorite; galena, sphalerite, some chalcopyrite, tetrahedrite and probably allemontite, skutterudite, löllingite and others	Minerals mostly as marginal bands of vein; ca. 5–10 vol. % of vein fill, locally up to 90 %, then forming minable 'polymetallic formation'
2. Early calcite	Calcite DK and K 1 with elevated Mn contents, chlorite; hematite and goethite, some galena, sphalerite, chalcopyrite, sometimes native Ag	Constitute 25–30 vol. % of vein fill; Fe-oxides derived from decomposition of siderite-ankerite
3. Calcite-pitchblende	Calcite K 2, K 3, and K 4, dolomite, chlorite; pitchblende 1, hematite	Constitute 25–30 vol. % of vein fill; pitchblende 1 formed between K 3 and K 4
4. Calcite-sulfide	Calcite K 5 in several varieties/generations, minor quartz, chlorite and palygorskite; some uraniferous anthraxolite[a], coffinite, pitchblende 2, commonly restricted to zones with pitchblende 1; several generations of pyrite; minor marcasite, pyrrhotite, sphalerite, montroseite, chalcopyrite, bornite, chalcocite, tetrahedrite, pyrargyrite, native Ag, millerite, nickeline, rammelsbergite, safflorite, allemontite, native As and Sb, and others	Constitute up to 40 vol. % of vein fill, formed by repeated replacement, dissolution and recrystallization of earlier minerals

[a] Uraniferous anthraxolite is a highly polymeric bitumen containing pitchblende, coffinite, calcite, and sulfides.

anthraxolite is always closely associated with pitchblende 1, which it transects, coats, or replaces. Uraniferous anthraxolite forms oval shaped pods, lenses, and veinlets within, and irregular reniform intergrowth with, calcite DK to K4 and the earliest specimen of K5, which it also *replaces*. Anthraxolite is cut by younger K5 calcite. Coffinite occurs commonly as fine disseminations, veinlets and coatings on pitchblende, often associated with anthraxolite, and as euhedral crystals. Pitchblende *2* replaces coffinite and forms spherulitic coatings on pitchblende 1. It is always associated with calcite K5.

Several phases of anthraxolite are distinguished in the Příbram uranium veins by Žák and Dobeš (1991): "drop-like" without uranium, "resinous" with a medium uranium content, and "coke-like" anthraxolite with the highest uranium content.

The mineral assemblages listed in Table 3.5 form both discrete and hybrid veins. Kolektiv (1984) recognizes four types of vein infillings based on the quantitative presence of the respective assemblages:

- Siderite-sulfide veins containing 60–90 vol.-% of stage 1 siderite-sulfide assemblage.
- Calcite-pitchblende veins containing 90 vol.-% of minerals of stages 2 to 4.
- Calcite veins containing 100 vol.-% of minerals of stage 4 calcite-sulfide assemblage.
- Mixed veins containing minerals of all stages.

The various ore and gangue minerals occur in variable quantities and distribution as documented in Table 3.6.

Three types of recoverable ores are distinguished based on the predominance of distinct ore minerals: pitchblende ore, uraniferous anthraxolite ore, and sphalerite-galena-Ag ore. The first two types occur preferentially in calcite-pitchblende veins and mixed veins with both types grading into each other. Minable sphalerite-galena-Ag ores are either related to siderite-sulfide veins or mixed veins. In the latter case, base metals are concentrated in intervals devoid of uranium.

A distinct zoning is reflected by the distribution of uranium minerals. Intrinsic and extrinsic veins proximal to the intrusive contact contain only pitchblende. Veins farther from the contact also contain uraniferous anthraxolite, which increases in amount as distance from the contact increases. The amount and relative fraction of anthraxolite also increases from district margins toward district center, where major vein clusters developed and where veins have the greatest depth persistence. The relatively large quantity of anthraxolite in vein clusters is associated with the presence of methane and hydrocarbons. Kolektiv (1984) suggests that this indicates a genetic relationship between the organic material and fracturing. A source of organics may be carbonaceous/graphitic constituents of the Spilite Series underlying the deposit.

The various mineral associations show preferences for different structure systems and some zonation in lateral and vertical directions, as demonstrated in Fig. 3.26:

a Diagonal and cross veins of N–S orientation associated with major faults are of mixed type. They contain mineral assemblages composed of 40–50% of the calcite, 20–30% of the siderite-sulfide, 20–25% of the calcite-sulfide, and 10–15% of the calcite-pitchblende stages. The mineralized section of these veins is ca. 15 cm thick. Siderite-sulfide and calcite-sulfide have the largest plane of vein distribution, whereas the calcite-pitchblende association occupies only vein intervals of greater thickness. Vein thickness decreases gradually with depth.

b Longitudinal veins of NE–SW direction are of calcite-pitchblende type. They are composed of 50–55% calcite, 25–30% calcite-sulfide, 10–15% calcite-pitchblende, and 5–10% siderite-sulfide assemblages. The mineral fill averages a thickness of 20–25 cm. Minerals of all associations occur in sections of greater vein thickness. Late calcite prevails in marginal or pinch out zones. The average thickness of all mineral associations increases to a depth of 600–700 m, but the maxima of width of the youngest generation is reached on a higher level than that of the oldest generation, which is deepest. This suggests a grad-

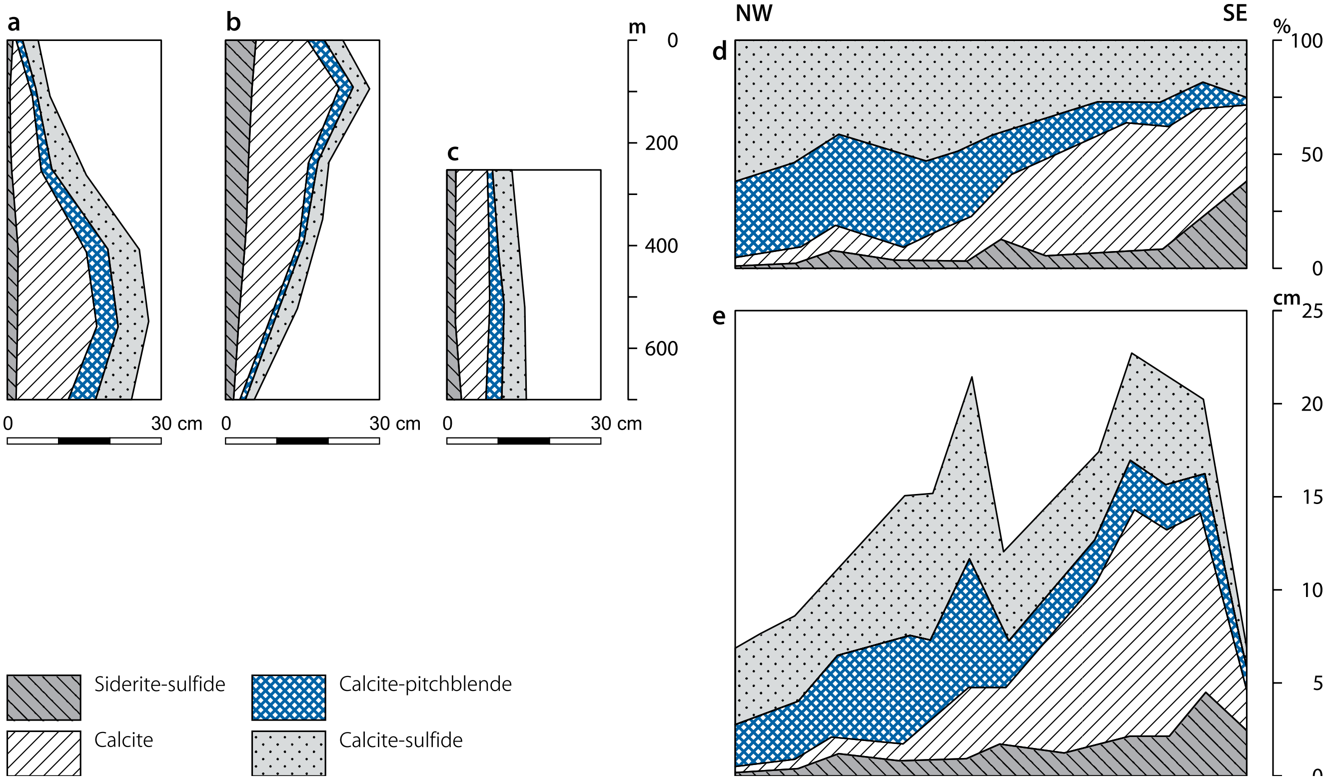
Table 3.6.

Příbram district. Abundance and distribution of hypogene minerals of carbonate-uranium-sulfide mineralizations. (After Kolektiv 1984)

Abundance	Occurrence	Minerals		
		Gangue	Ore	
Very common	Important concentrations in veins, lenses, nests	Calcite, Mn-calcite	Pitchblende, anthraxolite	
	Small concentrations in veins and impregnations	Ankerite, dolomite, siderite, quartz	Pyrite, galena, sphalerite, hematite, goethite	Marcasite, coffinite, chalcopyrite
Sporadic	Small occurrences in nests and lenses	Chlorite, baryte, illite	Skutterudite, safflorite, rammelsbergite, löllingite	Arsenopyrite, montroseite
	Minor occurrences, local disseminations	Palygorskite, aragonite dickite, gisengerite, montmorillonite, fluorite, zeolite, Mn-oxide	Tetrahedrite, tennantite, bornite, chalcocite, allemontite, gersdorffite, pyrrhotite, native Sb, native Ag, argentite	Bornite, native Hg, cinnabar, pyrargyrite, proustite, millerite, nickeline, bravoite, bournonite, antimonite

■ **Fig. 3.26.**

Příbram district, examples of vertical (a, b, c) and horizontal (d, e) variations of mineralogical vein fillings and thickness of veins. a Longitudinal veins; b diagonal veins bound to longitudinal structures; c cross-cutting veins bound to tectonic zones and anticlines; d relative abundance, and e average thickness of mineral assemblages along a NW–SE section. (After Kolektiv 1984)



ual opening of the vein structures from bottom upwards. Thickness begins to decrease from about 600–700 m downwards.

c NW–SE and more rarely N–S veins associated with NW–SE tectonic zones and the Příbram Anticline preferentially belong to the calcite-pitchblende type. They contain ca. 50% calcite-sulfide, 20–40% calcite-pitchblende, 5–15% calcite, and 5–10% siderite-sulfide assemblages. A few veins of this system can be attributed to the mixed or siderite-sulfide type. The youngest mineral associations are of the largest plane of vein distribution. Thickness of the siderite-sulfide association does not change much with increasing depth, but thickness of other assemblages increases to a certain depth and then decreases.

A lateral mineral change from southwest to northeast is reflected by the northeastward-decreasing abundance of older siderite-sulfide and mixed veins, which prevail in the southwest, with a simultaneous increase of younger calcite-pitchblende and calcite veins toward the northeast. This rejuvenation process of vein fill is accentuated by the marked boundary between the southwestern section of the district, where the bulk of longitudinal and diagonal veins occur, and the northeast section, where cross veins prevail.

Zonal transitions in NW–SE direction, i.e., perpendicular to the trend of essential structural elements of the district, are in evidence in several sections of the district. In the southwestern section, where mixed veins prevail, the fraction of siderite-sulfide association decreases in favor of calcite-pitchblende association. In the northeast section, in the zone of calcite-pitchblende veins, the two older associations remain concentrated around the axis of the Příbram Anticline and rarely progress to the granite contact. Veins of greatest thickness have developed in this zone and minerals of calcite-pitchblende assemblage have been deposited in a wider belt. Distribution of post-ore calcite overlaps that of all older mineral assemblages.

Lithology imposed a twofold control on deposits. Physical-mechanical properties influenced the location and development of structures, and chemical composition affected the chemistry of mineralizing fluids. Correspondingly, rocks reacting to tectonic stress by more brittle deformation and wider cataclastic extension provided adequate permeability and allowed these rocks to react best to mineralizing fluids. Rocks amenable to brittle deformation typically occur in the contact-metamorphosed aureole.

Barrier effects were generated by intraformational conglomerate beds as indicated by *(a)* dip deviation of veins in the footwall of these beds, and *(b)* (associated with movements during mineralization) a thickening and enrichment of veins, particularly in longitudinal veins. Similar barrier effects are found below Cambrian sediments, thicker intrusive dikes, and overhanging granite walls (➲ Figs. 3.27–3.30).

Fig. 3.27.
Příbram district, illustration of relationship of uranium lodes a to the overhanging granite contact of the Central Bohemian Pluton and to intrusive dikes, and b to intraformational conglomerate beds. The mineralized zones consist of ore shoots of highly variable size separated by barren intervals. (After Kolektiv 1984)

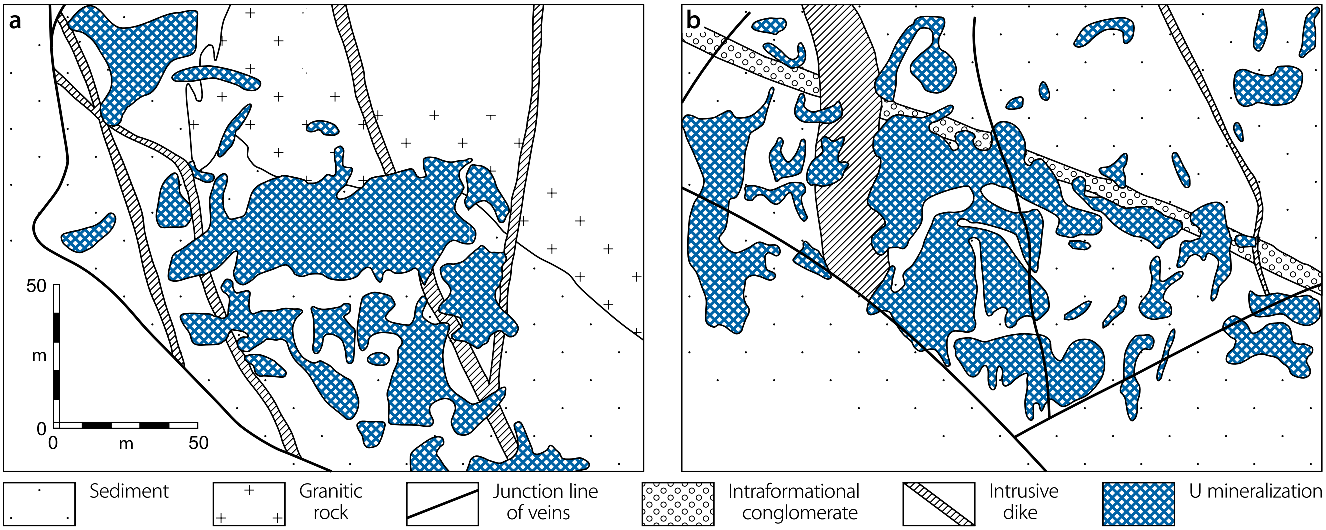
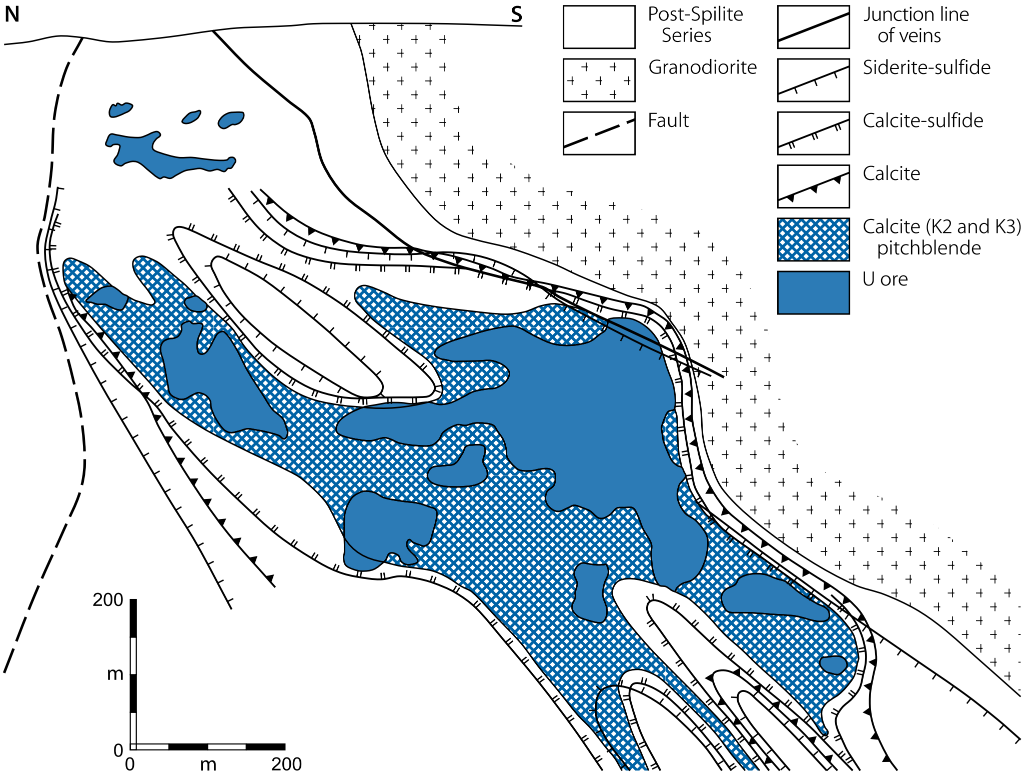


Fig. 3.28.
Příbram district, northern part of Bytíz (Bt 4), N–S-longitudinal section with vertical projection of the distribution and zoning of ore and gangue mineral assemblages in a uranium vein positioned under the roof of the Central Bohemian Pluton. (After Kolektiv 1984)



General Shape and Dimensions of Deposits

The Příbram district hosts in excess of 2 000 veins, some 1 200 of which contain uranium ore lodes and about 25 of which contain Pb-Zn-Ag ore without minable uranium. The bulk of ore-bearing veins occurs within an up to 1.5 km wide zone peripheral to the contact of the Central Bohemian Pluton. Veins at Bytíz and *Jeruzalém*, however, persist for up to 2.5 km from the contact. The upper limit of ore lodes plunges regionally at about 10–15° towards the NE. Only in the southwestern part of the zone of mineralization were some surface expressions of uranium found.

Based on *dimensions of ore-bearing veins*, three groups of veins can be separated:

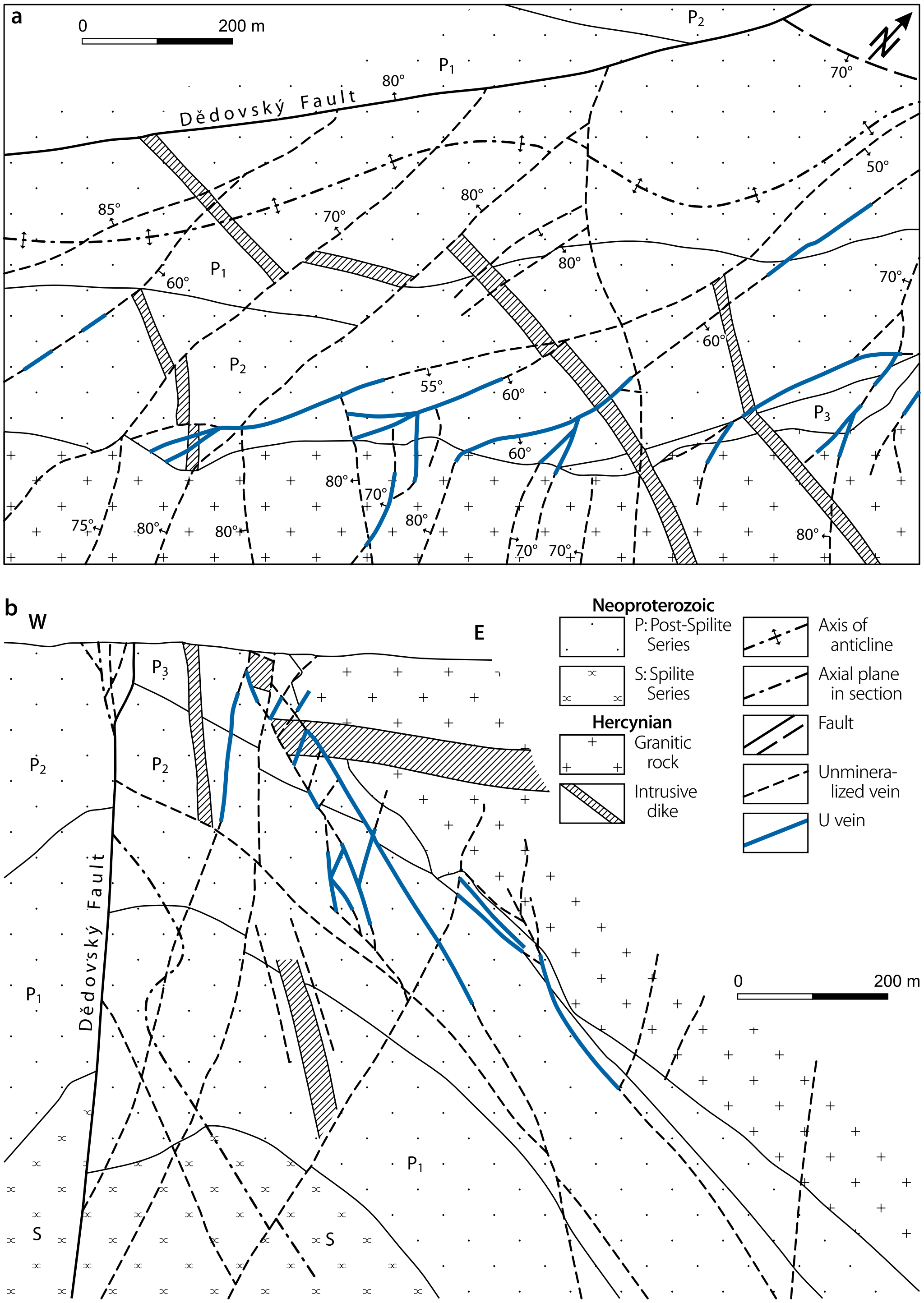
- Large veins extend laterally and vertically for 500–1 000 m and more (some veins persist to a depth of more than 2 000 m) at a thickness of 5–100 cm; in extreme cases, some veins can be up to 12 m thick. Large veins constitute the principal structures of vein clusters and account for approximately 5% of all veins of the district.

- Medium veins are 100–500 m long and 1–50 cm thick and only exceptionally thicker. These veins commonly occur as subsidiary veins to large veins and account for 45% of all veins.
- Small veins are up to 100 m long and less than 50 cm thick. They occur subsidiary to larger veins and constitute ca. 50% of all veins.

Mineralized veins occupy three *structure systems* in the following percentages: N–S (43%), NW–SE (44%), and NE–SW (13%). The first two, the so-called diagonal and cross veins, dissect bedding and foliation, whereas longitudinal veins are both parallel and discordant to bedding. Mineralized veins commonly have a steep inclination of 70–90° except those concordant to bedding, which dip 40–70°.

Petroš et al. (1986) note that diagonal veins, which are closely associated with major faults, are best developed in the upper part of the deposit, veins that trend parallel to bedding are best developed on intermediate levels, and cross veins are best developed in intermediate and lower levels.

Fig. 3.29. Příbram district, southern part (Lešetice-Brod area), **a** plan of underground level; **b** W–E section approximately perpendicular to the Central Bohemian Pluton contact and fold trend. The figure illustrates the interrelationship of uranium mineralized vein clusters, N–S and NE–SW structures joining with the Dědovský Fault, and the overhanging pluton contact. (After Petroš et al. 1986; Kolektiv 1984)



Mineralized veins commonly aggregate in *vein clusters* by multiple veins closely paralleling, approaching, or intersecting each other within a narrow segment. Two varieties of vein clusters are distinguished based on their relationship to principal structural elements:

- The first variety consists of veins formed within and in the course of reactivation of larger faults. These veins closely follow the attitude of host faults from which they rarely splay off. Host faults are larger N–S and NE–SW structures, and particularly those, which bifurcate from regional faults such as the Dědovský and Dubenec Faults (Fig. 3.29). Smaller veinlets of variable orientation developed during movements along larger mineralized structures.
- The second variety of vein clusters is associated with NW–SE faults that cut and are perpendicular to the Příbram Anticline. Veins are best developed in the apex part of the anticline. Reactivation of faults generated zones of small tensional or shear structures of a N–S direction, which were then mineralized (Fig. 3.30).

The *morphology of a vein* is a function of the physical properties of host rocks and the type or order of host structure (main or subsidiary fault). Modifications of vein morphology are often observed at junctions with dikes as reflected by a change in width, strike, and/or dip. A greater thickness is typical for segments of intense cataclasis, below a shallow dipping granite contact, or an intraformational conglomerate bed. NW–SE veins increase to their greatest thickness in the axial zone of the Příbram Anticline and proximal to the pluton contact. Maximum thickness is attained, where several of the above-mentioned parameters coincide. Generally, vein width decreases with increasing depth.

Ore lodes occur as tabular to lenticular bodies in one or several branches of structures. These pay-streak lodes are of complex geometry and texture. They are composed of gangue with irregularly intercalated pitchblende, anthraxolite, and/or coffinite in the form stringers, coatings, botryoidal aggregates, and pods. Pay streaks range in size from a few mm to some tens of centimeters thick (Fig. 3.26), and extend laterally and vertically for less than one meter to several hundreds of meters. Most veins contain only one ore body, but larger and more extensive veins may host up to 15 individual ore bodies.

Lodes have irregular boundaries and alternate with nonuranium vein material (Figs. 3.27, 3.28 and 3.31). Together, they form bodies with dimensions of about 1 000 to 100 000 m^2. Thickness of mineral fill (ore with gangue) is proportional to thickness of the cataclastic zone and constitutes 40–50% of the

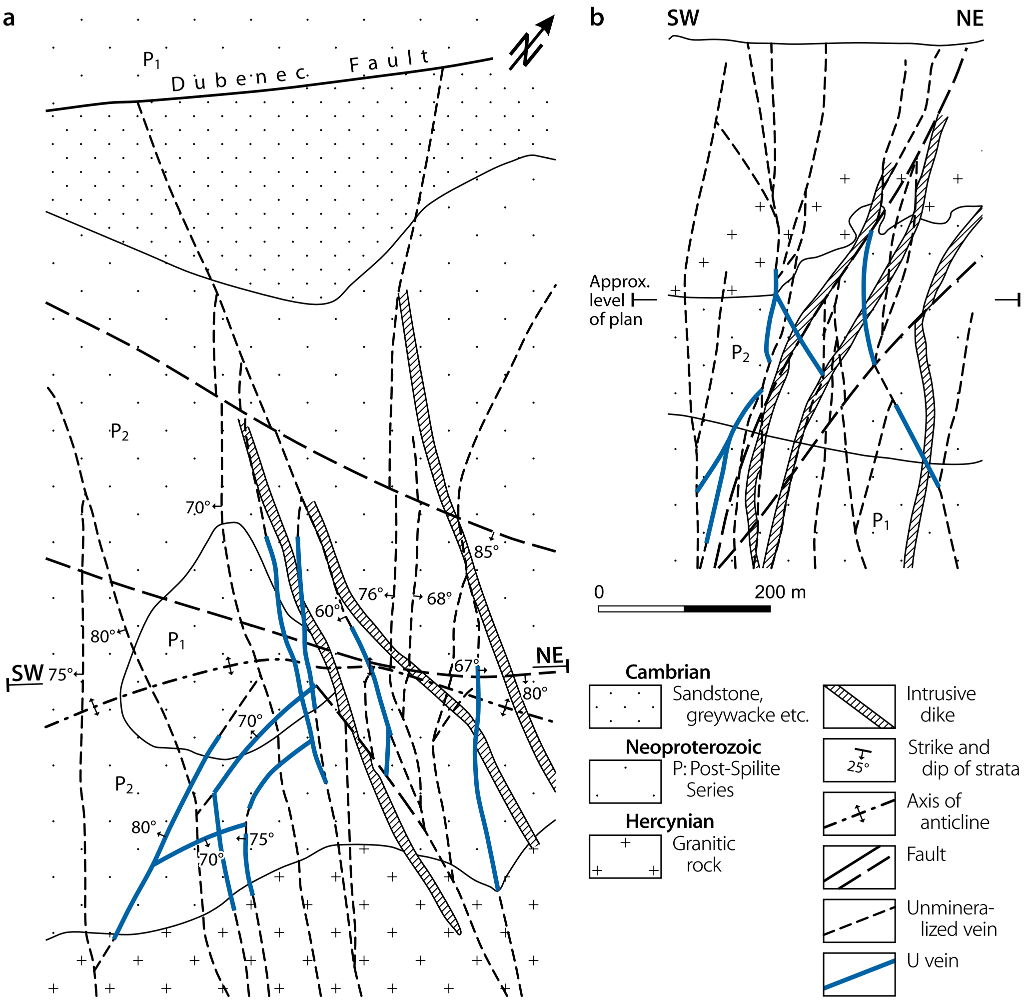
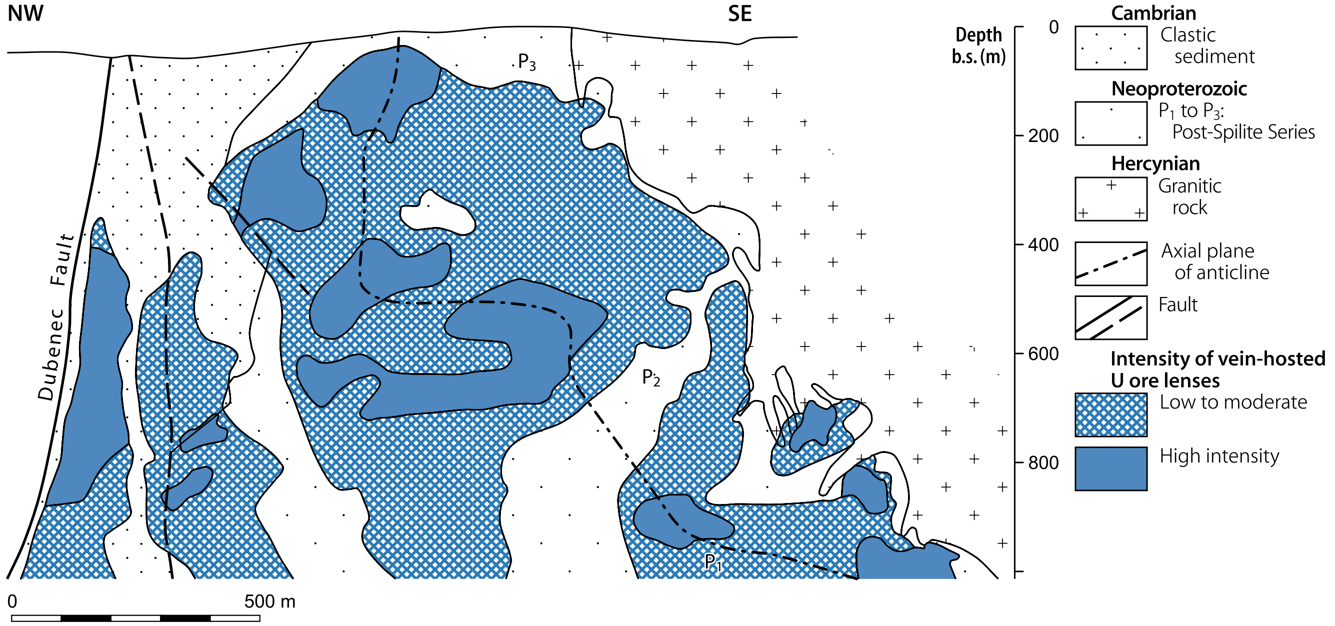


Fig. 3.30. **Příbram district, northern part (Bytíz area), a plan of underground level; b SW–NE section aproximately parallel to the Central Bohemian Pluton contact. The figure displays the interrelationship of a uranium-bearing vein cluster, longitudinal faults (Dubenec Fault), intrusive dikes, and the pluton contact (*P1*, *P2* see Table 3.4). (After Kolektiv 1984)**

Fig. 3.31.

Příbram district, Bytíz, vertical projection of the NW–SE-oriented BT 4 uranium vein. Loosely stippled areas identify mineralized zones with low to moderate distribution of ore lenses separated by barren vein intervals. Densely stippled areas document zones of high concentration of ore lenses including large lenses (*P1*, *P2*, *P3* see Table 3.4). (After Kolektiv 1984; Petroš and Komínek 1986)



host structure. The pay streak part of the vein may constitute 1 to 50% of the total vein infill, which corresponds to a coefficient of uranium mineralization (*Kr*: i.e., the ratio of the ore-bearing plane to the total plane of the vein) ranging from 0.01 to 0.5. Approximately 60% of the ore bodies have a *Kr* value between 0.04 and 0.16. *Kr* values above 0.3 are only known from small ore bodies (Kolektiv 1984).

As can be seen from Fig. 3.32, minable mineralization was found in nine deposits (or sectors) in an area about 20 km long; but, as documented in te enclosed table, the bulk of the ore, i.e., approximately 25 000 t U or about 50% of the total original reserves of the district, was concentrated in a 3–4 km long zone in the Bytíz sector. One vein cluster in the Bytíz sector, Bt-4, yielded 8 793 t U. The upper limit of minable ore in this sector was in the southwestern section (near shaft 16 in Háje sector) near the surface, whereas about 3 km further to the northeast (near shaft 19 in BT 40) the upper limit was about 250–300 m below the surface. Veins persist to a depth of over 2 000 m.

The quantitative ore distribution in the Bt-4 vein cluster (mined from shaft 16) showed, in vertical projection, the following frequency curve: Uranium mineralization commenced near surface (upper 50 m to first level: ~300 t U) augmenting with depth down to some 500 m, where it reached the major culmination, then dropping off down to about 900 m depth. It increased again further down at a depth of approximately 1 000 m. From there, it decreased moderately to a depth of about 1 400 m, where the mineralization curve leveled off and remained stable downwards to almost 2 000 m, where the ore pinches out. About 21% of the minable uranium of the Bt-4 vein cluster occurred between surface and 450 m deep (10th level), approximately 58% between 460 and 910 m deep (20th level), and approximately 21% between 910 and 1 430 m deep (28th level).

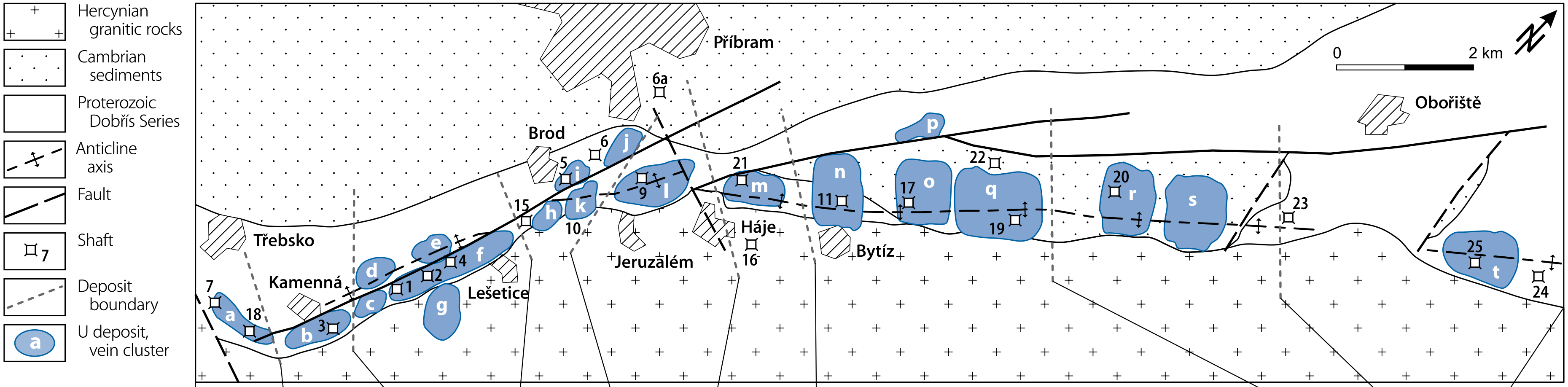
Vertical quantitative ore distribution near shaft 19 (Bt-40 vein cluster) showed a similar development. Minable ore began about 250–300 m below surface, increased markedly down to about 1 000 m, where the highest grades and the bulk of the ore occurred (veins attained a width of up to 6 m). A steady drop in the amount of ore took place down to about 1 500 m. From about 1 500 m to 2 000 m and more, the distribution curve was stable.

Regional Geochronology

Isotope ages of some igneous rocks of the Central Bohemian Pluton are given in Table 3.3. These may be only approximate values, however. Žák and Dobeš (1991) state that only granodiorite samples dated by the Rb/Sr method have yielded a reliable age of 331 ±4 Ma (van Breemen et al. 1982; Bendl and Vokurka 1989) while age datings of other magmatic rocks give less precise ages. Such is the case for granites of the marginal facies adjacent to the uranium district, where variable K/Ar ages ranging from 320 to 200 Ma were obtained. This variance is thought to be caused by a loss of Ar during post-intrusion events. Pre-Hercynian diabase dikes are believed to have been formed during the Upper Cambrian (Vlašímský 1982).

U/Pb datings yield ages varying for pitchblende 1 between 250 and 290 Ma, anthraxolite between 280 and 260 Ma, and coffinite between 260 and 240 Ma (Matolín and Šuráň 1989). Lippolt (1984) reports an age of 265 ±15 Ma for pitchblende 1.

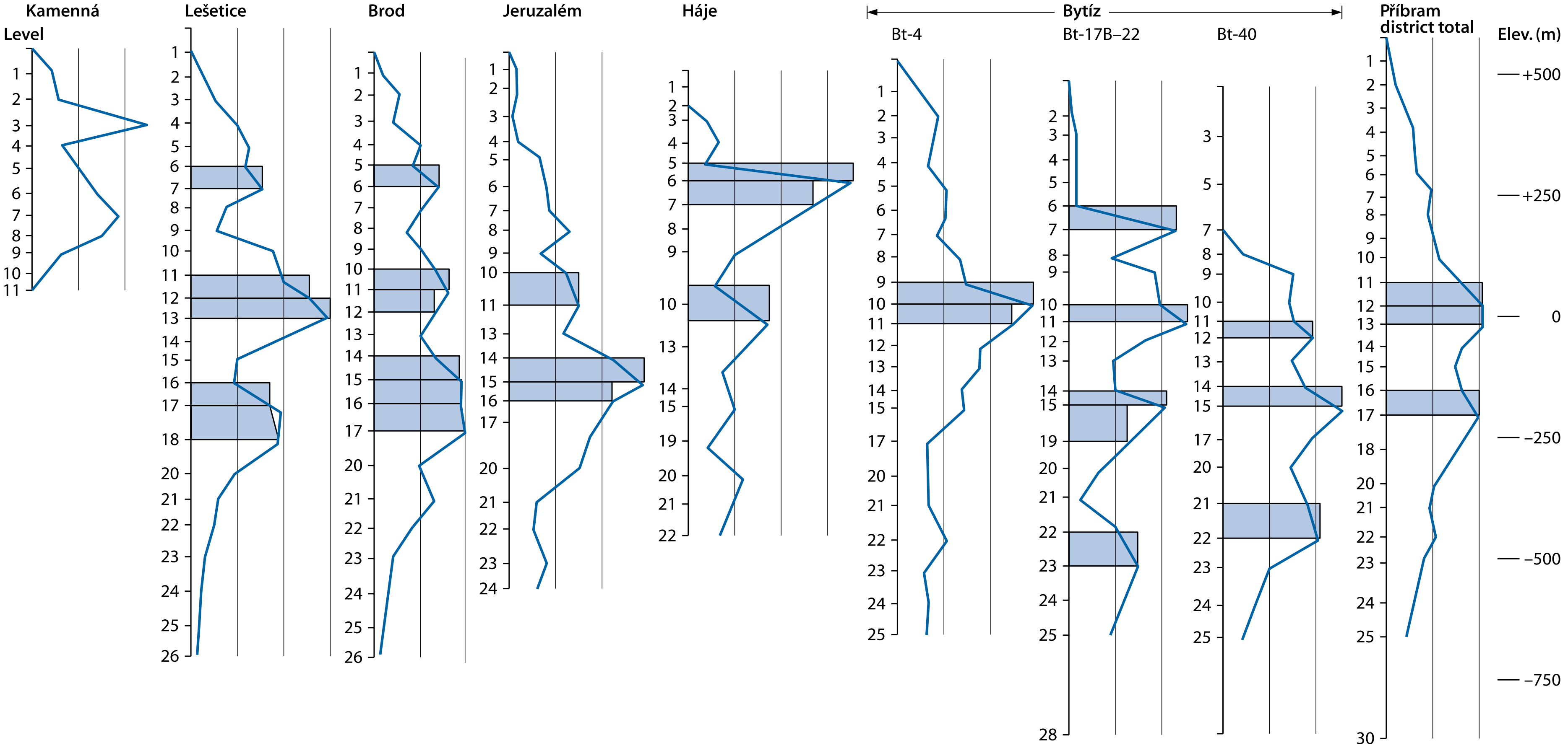
Fig. 3.32a.
Příbram district, schematic map of deposit (or sector) sites. As can be seen on the attached table, a total of 48 432.2 t U were recovered from the Příbram district, 31 004 t U (64% of total production) were extracted from 88 veins containing in excess of 100 t U, and 17 428 t U (36%) came from 1 553 veins yielding 0.1 to 100 t U. (After Komínek 1997)



Deposit	Třebsko	Kamenná	Lešetice	Brod	Jeruzalém	Háje	Bytíz					Skalka	Oboriště	Others
Vein cluster	**a** T1–T33	**b** K27-47–K42	**c** D101–D109 **d** D88–D90 **e** L9–D3 **f** L1–B34 **g** L17R–L162A	**h** B128 **i** B98–B104 **j** B12 **k** B28	**l** J1–J38	**m** H29–H30	**n** Bt-4	**o** Bt-17B–22	**p** Bt-Db1–Db5	**q** Bt-40	Bytiz Σ	**r** Skl–Sk2 **s** Sk6–Sk12	**t** Ob8–Ob27	
Production (t U)	17.2	622.4	9 449.8	4 485.9	7 103.3	997.2	(8 792.8)	(6 796.6)	(57.9)	(9 389.5)	25 009.8	270.7	25.1	450.3
Percentage of total production	0.05	1.3	19.7	9.3	14.8	2.1	(18.3)	(14.1)	(0.1)	(19.6)	52.1	0.6	0.05	
No. of veins	72	155	349	281	551	150	(179)	(272)	(17)	(314)	782	95	83	
No. veins yielding >500 t U	–	–	5	–	2	–	(2)	(3)	–	(2)	7	–	–	
No. veins yielding 100–500 t U	–	–	9	9	12	2	(9)	(16)	–	(17)	42	–	–	
No. veins yielding 0.1–100 t U	6	75	240	188	385	83	(114)	(201)	(4)	(216)	535	27	14	

Fig. 3.32b.

Příbram district, depths distribution of relative uranium quantities recovered from deposits (Kamenná to Háje), vein clusters of Bytíz (Bt 4 to Bt 40), and from the district in total as cumulative average. (After Komínek 1997)



Stable Isotopes and Fluid Inclusions

Stable isotopes and fluid inclusions of minerals from Příbram uranium veins have been studied only in a limited way. Žák and Dobeš (1991) provide stable isotopes and fluid inclusions data available from older literature and from their own investigations, which are summarized in Table 3.7 and below.

Early carbonates (DK and K1) of pitchblende-carbonate veins have δ^{18}O values in a range from +2 to +6‰ (SMOW). The δ^{18}O values decrease progressively to –4 to +3‰ (SMOW) for the late calcite K5.

Useful phases of fluid inclusions were only found in calcite K3 and K5. Inclusions in these calcite generations attest to a low salinity with a maximum of 5 wt.-% NaCl equivalent for ore-forming solutions. Such low salinity suggests a derivation from local meteoric water because formational or relict waters usually have higher salinities.

Marked changes of oxygen fugacity of fluids are also indicated by sulfur isotopes. Sulfur isotopes ratios also testify that a fraction of the sulfur derived from country rocks. At the same time, carbon isotopes hint to a continued influx of CO_2 mainly from a deep-seated source.

Sulfur isotopes of S of the pitchblende-carbonate stage yield δ^{34}S values between –10 and +20 suggesting a sulfur source from early vein sulfides and from sediments of the Davle Formation. The latter tends to be a likely source because accessory sulfide minerals in the sediments have positive sulfur isotope ratios.

Vaněček et al. (1985) interpret the Pb isotope ratios of galena of the older sulfide generation in uraniferous veins (and of polymetallic veins) to suggest a most likely Pb origin from either the lower crust or upper mantle. The authors also established practically identical lead isotope compositions in galena of older sulfide mineralization and in galena of younger uranium associated assemblages, which points to a remobilization process with lead of younger galena derived from pre-uranium galena.

Since isotopes and fluid inclusion compositions of minerals of older sulfide and younger uranium assemblages differ significantly, Žák and Dobeš (1991) postulate separate source areas for hydrothermal fluids that generated these two mineralizations. Fluids of the early sulfide stage were waters of deep, possibly magmatic or metamorphic provenance, whereas fluids of the uranium stage were mostly shallow-circulating meteoric waters, or, at least, waters with a significant meteoric component.

Carbon isotopes of anthraxolite from Příbram uranium veins yield δ^{13}C values from –41 to –57‰ (PDB). Žák and Dobeš (1991) evaluate the extremely low δ^{13}C values of anthraxolite to mean that only thermal or hydrothermal mobilization of a small portion of hydrocarbons from sedimentary carbonaceous matter could have caused these low values, and under unusual conditions.

Potential Sources of Uranium

The source of uranium for the Příbram district is still enigmatic. Uraniferous granitoids or (meta)sediments are considered a potential source, but uranium may also have been introduced by late magmatic(?) solutions. Uranium tenors in various granodioritic and granitic facies range from about 3 to 10 ppm U (Kolektiv 1984). Upper Proterozoic sulfidic black shale beds with tuffitic admixtures and mafic tuffaceous rocks have anomalous values of uranium and other metals. Uranium tenors of selected black shale samples from western Bohemia range from a few to 37 ppm (Kovalová and Litochleb 1992).

Ore Controls and Recognition Criteria

Uranium deposits of the Příbram district are of vein type and correspond to granite-related, perigranitic, monometallic veins

Table 3.7.
Příbram district, stable isotope data and physico-chemical formational conditions of uranium veins. (After Žák and Dobeš 1991)

Stage	Level	Temp. (°C)	H_2S/SO_4	δ^{34}S (‰ CDT)	H_2CO_3/HCO_3	δ^{13}C (‰ PDB)	$\delta^{18}O_{fluid}$ (‰ SMOW)	Salinity (wt % $NaCl_{eq}$)
Siderite-sulfide	?	?160–230	Variable, locally $H_2S > SO_4$	?+1 to –3	$H_2CO_3 \gg HCO_3$	Siderite: –12 to –14 Dolo-anker: –6 to –8	+3 to +8	Not studied
Calcite	–1 500 m	180–230						
Calcite Dk, K1	Surface	100–150	Extremely low f_{S2} in fluids	?	$H_2CO_3 > HCO_3$	–6 to –10	+2 to +6	Not studied
Pitchblende-calcite	–1 500 m	110–170	?	?	Variable	–6 to –10	–1 to +5	1–5
K2, K3, K4	Surface	70–130						
Calcite-sulfide	–1 500 m	90–150	Extremely variable (?)	Variable, from negative to +20 (?)				
K5	Surface	70–130			$H_2CO_3 < HCO_3$	–6 to –10	–4 to +3	0.5–4

hosted by (meta)sediments. Following Petroš et al. (1986) and Kolektiv (1984), ore controls and/or recognition criteria are of structural, lithologic, and mineralogical nature as follows:

Host Environment

- Localization of the Příbram district is (Figs. 3.22 and 3.23)
    - peripheral to a large heterogeneous granitic-granodioritic pluton (Central Bohemian Pluton of Caledonian–Hercynian age) intruded into Proterozoic–Paleozoic (meta)sediments
    - at the intersection of two lineaments (NW–SE-oriented Jáchymov and NE–SW-trending Central Bohemian Lineaments)
    - in a 1–2 km wide zone of folded (meta)sediments between the pluton and the Dědovský-Dubenec Faults
    - along the axial zone of the Příbram Anticline
- Host rocks are
    - pelitic and psammitic sediments metamorphosed up to greenschist facies, and overprinted by contact metamorphosis
    - folded into major anticlines and synclines
    - predominantly constituents of the Proterozoic Post-Spilite Series (which contain 97% of all uranium lodes), whereas Cambrian sediments, tuffite of the Spilite Series, and granite only contain 3% of the lodes
- Amazingly, the sulfide-rich Spilite Series and the sulfide-rich layers (up to 8% sulfide) at the boundary between Spilite and Post-Spilite Series did not impose any noteworthy impact on the precipitation of uranium (Kolektiv (1984) assumes that in the case of the thicker veins coating/sealing of the veinskirts by early mineral assemblages prohibited an interaction of uraniferous solutions with sulfidic wall rocks)
- Lithology-related controls on the deposits include
    - chemical rock composition affecting the chemistry of mineralizing fluids, and
    - physical-mechanical properties that influenced location and development of structures such as rocks reacting to tectonic stress by more brittle deformation and wider cataclastic extension, and thereby providing enlarged volumes and adequate permeability to permit optimal reactions of mineralizing fluids with the rocks
    - rocks amenable to brittle deformation, which are particularly typical for contact-metamorphosed facies
    - barrier effects created by intraformational conglomerate beds, footwall interface of Cambrian sediments, thicker intrusive dikes, and overhanging granite walls, as reflected, in the footwall of these inhomogeneities, by deviation of the dip of veins and, associated with movements during mineralization, a thickening and enrichment of veins, particularly in longitudinal veins

Alteration

- Principal alteration phenomena of wall rocks include carbonatization, chloritization, hematitization, illitization, and sericitization
- Alteration aureoles in sediments commonly persist for 0.1–3 m from veins; at vein clusters, alteration may spread over intervals tens of meters in width

Mineralization

- Ore is essentially monometallic though composed of a great variety of minerals that formed during several stages
- Principal *uranium minerals* are pitchblende, coffinite, and uraniferous anthraxolite
- Associated metallic minerals are mainly pyrite, and minor sulfides and arsenides of Ag, Co, Cu, Fe, Ni, Pb, Zn, and other elements; hematite can be abundant
- Calcite is the dominant gangue mineral; others are other carbonates, baryte, chlorite, and quartz
- The amount of ore-related calcite closely correlates with the amount of uranium in any given lode
- Individual ore lodes are principally associated with the older calcite generation
- Younger post-ore solutions caused replacement of pitchblende and older calcite and dilution of the ore
- Regional structural elements, that control the distribution of ore-bearing veins, are reflected by
    - accumulation of lodes in the apex part of the Příbram Anticline and in its SE limb close to the pluton contact (NW–SE cross veins in the northeastern and central section of the district are richest near the anticlinal axis. They developed particularly, where undulations, local brachyanticlinal folds or closures and virgation modify the main axis, i.e., where tensional strain has generated a large width of cata-clasis along open fractures and wide subsidiary fissures)
    - remarkable concentration of ore pods and lenses in veins at sites where the pluton contact forms a roof overhanging the (meta)sediments for a width of as much as 2 km
- Local structural and lithological elements that control the distribution, size, and grades of ore lodes, include the
    - configuration, nature, and interrelationship of fault, fracture, and cleavage systems
    - morphology, attitude, and degree of cataclasis of ore-hosting structures
    - nature of host rocks
- Major ore bodies are restricted to large veins, whereas ore shoots mainly occupy subsidiary structures
- Rich lodes, lenses, pods occur preferentially at
    - distinct bending of veins, which caused opening of fissures during movement along mineralized fractures
    - ramification of veins
    - junction of subsidiary and horsetail fractures with major faults
    - intersection with other structures associated with increased width of cataclasis
    - intersection of major veins with intrusive dikes causing a change in vein thickness
    - intervals immediately below a shallow-dipping pluton contact or below Cambrian sediments and intraformational conglomerates associated with a complication of vein morphology (Figs. 3.27–3.30)
    - above a level of 600–700 m below surface, and particularly where several of the above listed parameters overlap

- Below a level of 600–700 m, veins decrease in size and intensity (more barren ground between veins), length (averaging 450–500 m long above this level), bifurcation, ramification, and payload material. This decrease is caused by the following negative parameters:
    - increasing distance to significant features such as major faults, anticlinal axis, and pluton contact
    - local alignment of anticlinal axis parallel to the direction of veins associated with a decrease of cataclasis and vein fill
    - larger amounts of intrusive dikes delimiting the space for vein development

Metallogenetic Aspects

A number of concepts on the metallogenesis of, or on individual processes possibly involved in formation of uraniferous veins of the Příbram district have been forwarded. A comprehensive metallogenetic concept has apparently not yet been established, however. The veins are evidently of epigenetic hydrothermal origin and associated with the Hercynian Central Bohemian Pluton, but the source of uranium and other ore constituents, composition of ore-forming fluids, transport and precipitation conditions, and age relationships among igneous activity, metamorphism, formation of sulfide mineralization and that of uranium mineralization are still not well understood due to limited isotopic, geochronologic, and/or geochemical research.

Petroš et al. (1986) propose a close relationship of uranium ore formation and granites of the Central Bohemian Pluton. Transport of uranium occurred in the form of carbonate complexes in alkaline solutions of medium to low temperature. Precipitation of pitchblende resulted from degassing and decarbonization of fluids, and changes in pH and Eh conditions. Granite-contained uranium is postulated to have originated from sediments, which underwent anatexis/granitization. Uranium became enriched during magma differentiation. Leaching of uranium from granitic rocks occurred by fluids migrating along NW–SE-oriented faults. Isotope studies suggest that a certain supply of uranium may have derived from residual magmatic solutions. Contact metamorphism may also have mobilized uranium within metasediments. A direct relationship between ore formation and granite intrusion has to be disputed, however, due to the large time gap of at least 20 Ma (for references of the various aspects see Petroš et al. 1986).

Strnad (1986) refuses (meta)sediments and obviously also granites as a uranium source because their uranium content is only on the order of Clarke values or less. Strnad argues that the district is located at the intersection of deep-seated lineaments and that this situation conditioned the development of Hercynian uraniferous vein accumulations from Proterozoic precursors.

Žák and Dobeš (1991) arrive, mainly from isotopes and fluid inclusions studies, at the following metallogenetic conclusions for Příbram uranium veins. Field evidence suggests a relative sequence of geological events. After deposition of Early Paleozoic sediments, diabase dikes were intruded presumably during the Upper Cambrian, followed successively – in Hercynian time – by emplacement of most granodiorites, granites, polymetallic sulfide mineralization, and finally by uranium mineralization.

Only Rb/Sr dating of granodiorite of the Central Bohemian Pluton has yielded a reliable age of 331 Ma, while age determinations of other magmatic rocks are less precise and require corrections. Granite of marginal facies adjacent to the uranium district, which is thought to be of potential significance to uranium metallogenesis, yielded highly variable ages ranging from 320 to 200 Ma. Žák and Dobeš (1991) explain the evidently faulty younger ages as due to a loss of Ar during post-intrusion time. They reason that a prolonged cooling time could have been promoted by radiogenic heat generated by anomalous tenors of K, Rb, Th, and U in peraluminous granite of marginal facies. Radiogenic elements produced sufficient heat for a long time after emplacement to maintain a temperature well above the Ar-blocking temperature for tens of millions of years.

The oldest uranium phase, pitchblende 1, yields U/Pb ages between 250 and 290 Ma (Matolín and Šuráň 1989), which means that pitchblende crystallization has occurred some tens of million years after consolidation of the last intrusive phase of the Central Bohemian Pluton. As such, pitchblende formation in the Příbram district occurred with a similar time gap after magmatic intrusion as established for vein uranium deposits in the Jáchymov district, Krušné hory (Erzgebirge), and in the Hercynian massifs in France.

In spite of insufficient precise datings of the igneous rocks and vein material, Žák and Dobeš (1991) consider the presumed time span of several tens of million years between metamorphism and emplacement of most granites and the earliest uranium stage as being too long to support any direct genetic link of uranium mineralization to magmatic and/or metamorphic fluids of Hercynian events, as suggested by various authors. Instead, these authors favor other types of fluids in the upper crust to be responsible for formation of the uranium stage in the Příbram district as outlined below. Circulation of such a fluid may have been triggered in the upper crust by a change from the Hercynian compressive to a tensional tectonic regime, allowing surface-derived fluids to migrate along open fissures.

A critical parameter for an understanding of uranium metallogenesis of the Příbram district is the relationship of ore veins to the Central Bohemian Pluton. While the older, pre-uranium sulfide generation, which, by isotope composition (see below), is practically identical with polymetallic mineralization elsewhere in the region does not display any apparent relationship to the pluton, younger uranium mineralization shows a distinct spatial relationship to marginal granite facies of the Central Bohemian Pluton.

Mineralogical evidence documents uranium paragenesis superimposed on early sulfides. The difference in absolute age of these two generations is unknown, however. Stable and radiogenic isotope and fluid inclusion data attest to significant differences in formation of the two stages. Compared with the older sulfide stage ($T = 150–300$ °C), the uranium stage occurred at markedly lower temperatures between 80 and 200 °C, and uranium minerals probably crystallized between 80 and 130 °C.

Lead minerals in uranium veins at Příbram consist of radiogenic and normal lead. Isotopic ratios of the latter are consistent with those of other polymetallic ores in the core of the Bohemian Massif. Vaněček et al. (1985) interpret these Pb isotopes ratios of galena of the older sulfide generation in uraniferous veins (and of polymetallic veins) to suggest a most likely Pb origin from either the lower crust or upper mantle.

Hydrothermal fluids of the carbonate-uranium stage had a low salinity with a maximum of 5 wt.-% NaCl equivalent, and they had $\delta^{18}O$ values that decreased progressively with time. Early minerals (calcite DK and K1) of the carbonate-uranium stage were deposited from fluids with fairly similar $\delta^{18}O$ values of +2 to +6‰, while late minerals (calcite K5) precipitated from fluids with values of about 0‰. Since $\delta^{18}O$ values close to 0‰ for fluids in continental settings are suggestive of either relicts of formation waters or meteoric waters, which underwent partial oxygen isotopic exchange with rocks but without high-temperature interactions with rocks, a deep, magmatic or metamorphic origin can be excluded for these ore-forming solutions.

With respect to the metallic source of post-uranium sulfide minerals, Vlašímský (1982) established that the lead isotopic composition of post-uranium galena corresponds to that of the older, pre-uranium galena generation. This is supported by Cathelineau and Žák (in Žák and Dobeš 1991), who found that tiny crystals of galena in pitchblende cracks were not only made up of radiogenic lead, but also that some galena crystals were composed of common lead with an isotopic composition very similar to that of galena of the older polymetallic mineralization. Consequently, younger galena is thought to be most probably a mobilization product of the older polymetallic stage, which is in agreement with the observation that remobilization of older vein minerals by younger fluids is a common feature in the Příbram uranium veins.

Sulfur isotopes ratios testify that sulfides contain sulfur derived from early vein sulfides and from country rocks. The $\delta^{34}S$ values also indicate marked changes in oxygen fugacity of sulfide-forming fluids, and carbon isotopes to a simultaneous, continued influx of CO_2 mainly from a deep-seated source.

The chemistry of vein carbonates varies with the distance from the pluton contact, a situation which may imply an impact from border granite (Cílek et al. 1984). Various vein calcite generations also show variable chemical compositions. Pre-uranium calcites (DK, K1, K2, K3) are rather different in geochemical character from those of post-uranium deposition (K5). Similarly, pre-uranium fluids had H_2CO_3 as the dominant carbonate-carbon species, whereas HCO_3^- was typical for post-uranium solutions. Since no significant temperature difference between calcite K3 and K5 could be established, a pH increase with time may have been the reason for this change.

Žák and Dobeš (1991) conclude from the above presented data, that different sources and processes separately generated early sulfide and later uranium stages of Příbram uranium veins. The first originated from deep-seated sources and the latter from shallow sources. The uranium assemblage was most likely formed by hydrothermal fluids of meteoric provenance that migrated in the upper crust. Low salinity and low $\delta^{18}O$ values attest to a derivation of these fluids from local meteoric waters. At a certain point in circulation history, some critical change occurred that caused uranium to precipitate. This change can presumably be linked to a change of tectonic conditions that permitted fluids of shallow circulation to penetrate into open fissure systems. Additionally, liquid or gaseous hydrocarbons, derived from black shale, might have changed the redox potential, which led to deposition of uranium minerals. Another cause for deposition of uranium minerals might have been an increase in pH.

3.3.2 Other Uranium Deposits/Occurrences in Central and Southwest Bohemia

A great number of small uranium deposits and occurrences exist in intrusive rocks and metasediments adjacent to, and in roof pendants within the Central Bohemian Pluton (▶ Fig. 3.22). These mineralizations are of vein type or of structurally-controlled dissemination type and are commonly emplaced along graphitic shear zones. Resources of individual deposits range from less than one ton to a few hundred tonnes uranium. Grades are generally low, rarely more than 0.15% U.

Northwest Margin of the Central Bohemian Pluton

Nová Ves pod Pleší and *Mníšek*, located ca. 25 km to the northwest of Příbram, are positioned at the intersection of NE–SW with NW–SE-trending faults. Host rocks are Neoproterozoic, Post-Spilite Series metasediments intruded by quartz porphyry. Pitchblende occurs in carbonate veins and in shear zones. Nová Ves and Mníšek accounted for the production of 4 t U.

Novotníky and *Dlažov* are located ca. 50 and 75 km, respectively, to the southwest of Příbram. Veins are NW–SE oriented and consist of carbonates, mainly calcite with irregularly distributed pitchblende. Host rocks are, at Novotníky, Proterozoic slate, siltstone, and greywacke with spilite immediately adjacent to granitic intrusions, and at Dlažov, Proterozoic slate and granodiorite of the Klatovy apophysis of the Central Bohemian Pluton.

Southwest Part of the Central Bohemian Pluton

Ceřnic, *Damětice*, *Lipová Lhota*, *Mečichov*, *Ustaleč*, and *Želenov* are situated in the *Horaždovice* area at the southwest margin of the pluton. Host rocks are Moldanubian metamorphics, mainly paragneiss and migmatite immediately adjacent to magmatic intrusions. Uranium is essentially confined to graphitic shear zones. Production from Ustaleč and Damětice was 115 and 92 t U, respectively.

Central and Southeastern Part of the Central Bohemian Pluton

Deposits in metamorphic roof pendants are represented by *Předbořice* (25 km south-southeast of Příbram), and deposits in felsic igneous rocks by *Vrančice* (10 km south of Příbram), which accounted for production of 248 and 323 t U, respectively. The geological position of these deposits together with a number of occurrences is controlled by a NNW–SSE-oriented structural belt. *Heřmaničky* occurs at the southeast contact of the pluton.

Vrančice is a polymetallic vein deposit hosted by biotite-amphibolite granodiorite and biotite granodiorite with large inclusions of gabbro and gabbro-diorite. Bernard et al. (1968) note two mineral assemblages, a calcite-sulfide assemblage of As-, Fe-, Pb-, and Zn sulfides associated with ankerite, calcite, and quartz, and a siderite-sulfide assemblage of As-, Cu-, Ni-, Pb-, Zn sulfides and native Ag associated with baryte, calcite, hematite, quartz, and siderite. The difference from the Příbram uranium veins is in the greater abundance of silver minerals and willemite. Pitchblende intergrown with carbonate minerals occurs predominantly in a marginal zone of one of the main veins at a depth of about 300 m. Pitchblende is present as pockets and veinlets within older calcite. Uranium is preferentially concentrated in fault branches and particularly at intersections of veins with granite aplite or gabbro-diorite.

3.4 Southeast Bohemian Region

The southeast Bohemian uranium region stretches, for a large part, along the Labe (Elbe) Lineament from the *Železné hory* in southeastern Bohemia into western Moravia, where it includes the major *West Moravian district*. Uranium deposits in the Železné hory (Eisengebirge, Iron Mountains) occur in post-Moldanubicum and those in the West Moravian district in Moldanubicum metamorphic lithologies (Fig. 3.33).

3.4.1 Železné Hory and adjacent Areas

The Železné hory (Eisengebirge, Iron Mountains) is a NW–SE-elongated mountainous belt in southeastern Bohemia. It contains the *Bernardov*, *Chotěboř*, and *Licoměřice-Březinka* deposits, which were mined, and several noteworthy occurrences (Fig. 3.33). The most northwestern deposit, Bernardov, is located 75 km southeast of Prague.

Deposits in this belt are of structurally-controlled, monometallic impregnation- and/or vein type. All known deposits are small containing up to a few hundred t U. Original resources amounted to some 600 t U. Grades average between <0.1 and 0.3% U. 588 t U have been extracted by underground methods from the above mentioned deposits.

Sources of information. Kolektiv (1984), amended by pers. commun. by Hájek A, Pluskal O, Komínek J, CSUP/DIAMO staff.

Regional Geological Setting of Mineralization

Deposits occur in the Železné hory (Eisengebirge, Iron Mountains) zone, a segment of a fold belt at the eastern margin of the Moldanubian Elevation. The two tectonic units are separated by the Labe (Elbe) Lineament; two branch faults of which with major displacements, the NW–SE-trending Železné hory and Chotěboř Faults, constitute the southwestern boundary of the Železné hory zone against the Bohemian Block of the Moldanubian Elevation. Other NW–SE- and NE–SW-oriented faults separate the region into a number of tectonic blocks.

The Železné hory and the southeasterly continuing Moravian–Silesian zone consist of variably, commonly lower grade metamorphosed Upper Proterozoic and Lower Paleozoic rocks intruded by Hercynian biotite granite and aplite-granite as found in the Chvaletice and Nasavrky Massifs.

Principal Host Rock Alteration

Alteration characteristics of host rocks include carbonatization, chloritization, graphitization, pyritization, and locally argillization and hematitization. Alteration products are partly present in pre- and post-ore, and ore-related stages (for details see description of individual deposits).

Regional Characteristics of Mineralization

Mineralization consists of two assemblages/stages: (1) a Late Hercynian vein-type pitchblende-carbonate paragenesis, and (2) a younger, organic-rich, uraniferous bitumen-(anthraxolite)-pitchblende-coffinite assemblage. The latter developed along pitchblende-carbonate veins by redistribution of older uranium into adjacent structurally remodeled rocks.

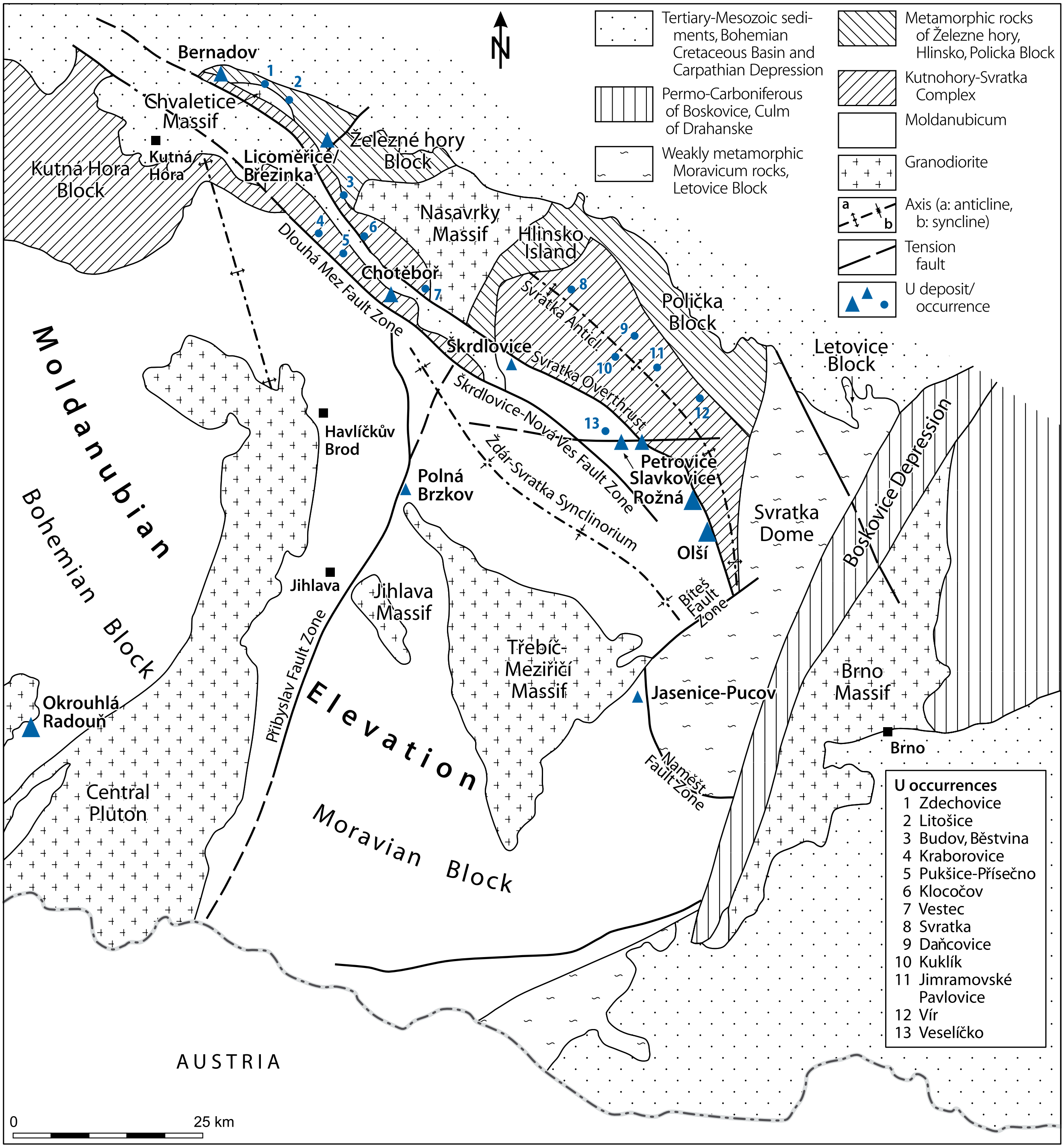
Type 1 mineralization is typical for the Březinka and Chotěboř deposits, and the *Pukšice-Přísečno*, *Kraborovice* and *Běstvina* occurrences; type 2 prevails at Bernardov and Licoměřice, and in the *Zdechovice*, *Litošice*, and *Budov* occurrences.

Uranium mineralization occurs as fault-controlled stringers, disseminations, and veins commonly to a depth of about 100 m but locally as deep as 400 m. Ore lodes are hosted by Neoproterozoic or Lower Paleozoic rocks of the Železné hory Block in close proximity to the Moldanubicum contact and to Hercynian granitic intrusions. They are controlled by structurally complex sections in the hanging wall of the regional Železné hory Fault in the northwestern part of the district and, in the southwestern part, also in the footwall.

Geochronology

Pitchblende of the older pitchblende-carbonate stage yields a U/Pb age of 265 ±15 Ma (Kolektiv 1984). Anthraxolite of the younger stage from the Bernardov deposit was dated 70 to 50 Ma old (Pluskal O, pers. commun.); while this age figure is doubtful, it may represent either a relatively young rejuvenation event or an error in analysis (Komínek J, pers. commun.).

Fig. 3.33.
SE Bohemian and western Moravian region, schematic tectonic map with principal structural elements and locations of uranium deposits and occurrences in the Železné hory and West Moravian district and adjacent areas. (After Kolektiv 1984)



Metallogenetic Concepts

The complex tectonic situation and relationship of mineralized structures associated with repeatedly rejuvenated and telescoped mineralogical composition of ore due to the position of deposits along a major lineament and at the contact of several tectonic units makes it difficult to decipher the actual origin of uranium mineralization.

A general view is that original mineralization is represented by carbonate-pitchblende veins and that these formed during Late Hercynian time. Later reactivation processes resulted in a redistribution of ore elements and generation of the pitchblende-coffinite-anthraxolite assemblage associated with a restructuring of ore bodies.

The spatial geological position near uraniferous granites of Hercynian age may suggest attribution of deposits to the perigranitic class of vein-type uranium deposits, but the genetic relationship to granite remains ambiguous.

3.4.1.1 Bernardov, Southeast Bohemia

Bernardov is located at the northwestern end of the Železné hory district, ca. 15 km northeast of Kutná Hora (Fig. 3.33). 56 t U were produced from the deposit. The ore grade was 0.1–0.25% U.

Geology and Mineralization

Country rocks are Neoproterozoic sericite and pyritic graphite schists and, locally, quartzite schists intercalated with pyroclastics of the Železné hory Complex. These rocks are epizonally metamorphosed and folded into an anticline. Granite, the Chvaletice Granite, occurs in the southeastern part of the deposit. The intrusion imposed a contact-metamorphic halo on country rocks.

The NW–SE-trending Železné hory Fault is a prominent structure in the area, in the hanging wall of which is the Bernardov deposit. A NE–SW-oriented, 70° SE-dipping fault zone, several tens of meters wide, transects the ore zone obliquely. NNW–SSE-trending, 60° E-dipping subsidiary faults, 1–5 m wide, bifurcate from this zone. NNW–SSE faults are filled with gouge, mylonite, and porphyry dikes. Fault fill displays chloritization, kaolinitization of porphyry dikes, and contains pyrite in the form of stringers, nests, and disseminations.

Mineralization is intermittently distributed in NNW–SSE structures and consists of pitchblende associated with bitumen and pyrite. Bitumen is present as pellet-like aggregates and drop-like grains distributed in mineralized intervals and feather joints. Veins of coarse-grained white carbonate occur in the main ore zone as well as in barren intervals. Uranium decreases with depth while carbonate increases.

3.4.1.2 Licoměřice-Březinka, Southeast Bohemia

These two adjacent deposits are located 20 km east of Kutná Hora, in the central part of the Železné hory (Eisengebirge, Iron Mountains) (Fig. 3.33). 383 t U were produced (DIAMO, web side 2012). The grade averaged 0.2% U.

Geology and Mineralization

Host rocks are Neoproterozoic biotite and biotite-muscovite schists intercalated with quartzite and amphibolite. Lower grade metamorphic rocks, biotite-chlorite phyllite and actinolite and tuffite schists of Late Proterozoic and Eocambrian age occur adjacent to the east. The sequences are monoclinally folded with local plications. Schistosity trends NW–SE paralleling the Železné hory Fault. Most faults at the deposits trend about NW–SE and dip medium-steep NE. N–S and NNE–SSW faults are less frequent. The Železné hory boundary fault, a NW–SE-oriented, 50° NE-inclined zone of subparallel dislocation faults and shears, is the most prominent structure in the area. The deposits are in the hanging wall of this fault zone.

Uranium mineralization occurs in two assemblages/stages:

1. an older pitchblende-calcite-pyrite stage present as lenses with sharp contacts within veins of gangue minerals, and
2. a younger pitchblende-coffinite-bitumen stage associated with quartz and Fe- and Zn sulfides forming dispersed nests and stringers in larger structures and adjacent feather joints. This latter variety is by far more abundant than the former.

The spatial and mineralogical interrelationship between bitumen and pitchblende reflects a critical influence of bitumen on the depositional restriction of pitchblende-coffinite-bitumen ores. This type of ore obviously derived by remobilization of older pitchblende-carbonate vein mineralization.

Uranium is distributed in several parallel NW–SE-striking fracture zones separated by 100–200 m wide sections of weakly broken rocks. Surrounding rocks are altered by carbonatization, chloritization, hematitization, and pyritization. Alteration developed predominantly during a pre-ore stage. Most structures in mineralized terrane are filled with rock fragments, carbonates, grey quartz, and pyrite.

Ore lodes are restricted to NW–SE-oriented subsidiary, third order structures, which bifurcate from N–S faults. Ore shoots are of columnar configuration plunging about 50° SE with dimensions of several meters to some tens of meters in length, and up to few meters in width. Ore persists to a depth of about 400 m; it is limited by the junction line of the subsidiary structures with the Železné hory Fault in the footwall of the deposits.

Within mineralized structures, uranium is preferentially concentrated at flexures and at intervals affected by pre-ore alteration. Unfavorable segments are characterized by quartz enrichments and graphitic gouge.

3.4.1.3 Chotěboř, Southeast Bohemia

Chotěboř is located at the southeastern end of the Železné hory (Eisengebirge, Iron Mountains), 35 km southeast of Kutná Hora (Fig. 3.33). Production amounted to 149 t U at an average ore grade of ca. 0.15% U.

Geology and Mineralization

Chotěboř is situated at the southwestern edge of the Železné hory Block adjacent to the contact with the Moldanubicum. Country rocks are of lower metamorphic grade than in the Moldanubicum and consist of a NW–SE-striking and NE-dipping suite of muscovite and biotite-muscovite orthogneisses, strongly granitized paragneiss, calc-silicate rocks, marble, amphibolite, and quartzite. Prominent structure systems trend N–S, NW–SE, and NE–SW; a heavily fractured zone at the intersection of several of these faults controls the position of ore lodes. Gouge, rock fragments, and quartz-carbonate veins fill the faults.

Uranium minerals include pitchblende and alteration products thereof, which occur as fracture fillings and disseminations. *Associated minerals* are carbonates, chlorite, and pyrite. Three stages of mineralization are recognized: quartz-pyrite, carbonate-pitchblende with pyrite and chlorite, and carbonate-sulfide.

The deposit is of wedge shape limited on two sides by major faults, the Přibyslav mylonite zone to the west, and the Chotěboř Fault (part of the Dlouhá Mez Fault) to the southwest. Uranium occurs in discontinuously distributed, irregularly lens-shaped ore shoots composed of stockworks of mineralized fractures and joints. Mineralization extends to a depth of about 100 m.

3.5 West Moravian Region

This region includes the large *Rožná* and *Olší* and the small *Přísečnice* deposits, which make up the West Moravian district some 40 km north-northwest of Brno (Brünn). Deposits of this district may be classified as structurally-controlled, non-granite-related monometallic type. They include two varieties of ore settings: veins and shear zone-controlled impregnations. Original resources of the district were some 25 000 t U. Mining grades ranged from 0.08 to 0.15% U. Mining began in 1957. Exploitation was (and is) by underground methods except for Přísečnice where open pit methods were also applied. Mining at Rožná reaches to a depth of about 1 100 m and is still ongoing (status 2012). Olší and Přísečnice are depleted.

Other uranium deposits of similar type as Rožná-Olší in the wider West Moravian region include *Jasenice-Pucov*, *Nová Ves*, *Polná Brzkov*, *Slavkovice-Petrovice*, and *Škrdlovice*, and a number of occurrences shown on (Fig. 3.33).

Cumulative production of the West Moravian region amounts to some 23 300 t U (site specific production figures are given at individual deposits further below).

Sources of information. Kolektiv (1984), pers. commun. by Hájek A, Hrubý J, Komínek J, Pluskal O.

Regional Geological Setting of Mineralization

Uranium deposits of the West Moravian district occur in the Moravian Block, which represents the eastern segment of the Moldanubian Elevation within the Hercynian orogenic belt. Petrographic facies of the Moravian Block include Mesoproterozoic or older metasediments and metavolcanics (Monotonous and Varied Groups of the Moldanubicum). Mafic to felsic igneous rocks were intruded during the Moldanubian, Cadomian/Assyntian, Middle Paleozoic (Caledonian ?), and Hercynian orogenies. Hercynian intrusions, 350 to 300 Ma old, include dikes and stocks of biotite-amphibole granite, aplite granite, and syenite.

Folding deformed Moldanubian rocks and generated the Ždár-Svratka Synclinorium as the most prominent feature in the uranium region. The synclinorium axis trends NW–SE and plunges NW. Subsidiary folds complicate the flanks of the synclinorium and control, in combination with faults, the position of major deposits in the Rožná-Olší area.

Regional and associated subsidiary faults of the Labe (Elbe) Lineament are prominent in the uranium region. They change direction from NNE to NE near Rožná-Olší. The Svratka Overthrust is a significant element of the lineament. Moldanubicum was thrusted over rocks of the younger Moravicum along this overthrust. Other pronounced structures trend E–W and N–S.

Major deposits are restricted to the northeastern margin of the Moravian Block, where they occur along marked fault zones. In the West Moravian district, deposits are associated with structures of the Svratka Overthrust and are positioned at sites, where this fault cuts a local anticline on the northeastern flank of the Ždár-Svratka Synclinorium (Fig. 3.33). Host rocks are metasediments of the Moldanubicum, which are locally, particularly at depth, metasomatized to albitic facies.

Principal Host Rock Alteration

Various kinds of rock transformation or alteration have affected the uranium region. They are depicted in Fig. 3.34. Figure 3.35 gives additional information on the physico-chemical conditions of metamorphic stages and associated mineral formations.

The most prominent uranium-related alteration features include chloritization, pyritization, sericitization, and silicification. Hematitization accompanies younger uranium redistribution. Pre-uranium Na metasomatism is reflected by albitization, which is well developed at greater depth (for details see description of individual deposits).

Regional Characteristics of Mineralization

Uranium deposits consist of various stages of structurally-controlled mineralization. Figure 3.36 provides a synoptical scheme of these stages and related minerals. As shown, two uranium assemblages/stages are identified in addition to several pre-uranium sulfide stages:

a an *older calcite-chlorite-uranium paragenesis* with pitchblende and coffinite as dominant uranium minerals, and
b a younger albite-chlorite-coffinite-hydromica stage.

Ore bodies are predominantly formed of network lenses, whereas distinct veins are less common. Network ore bodies are composed of stringers and disseminations along shear and breccia zones. They are embedded within lower grade mineralization that occupies a system of subparallel, anastomosing, and intersecting structures, which border and enclose variably fractured rock segments (see Fig. 3.40 in Sect. 3.5.1.1 *Rožná-Olší, Moravia*).

Network ore bodies are a few tens to several ten thousand square meters in area. Small- to medium-size ore bodies are

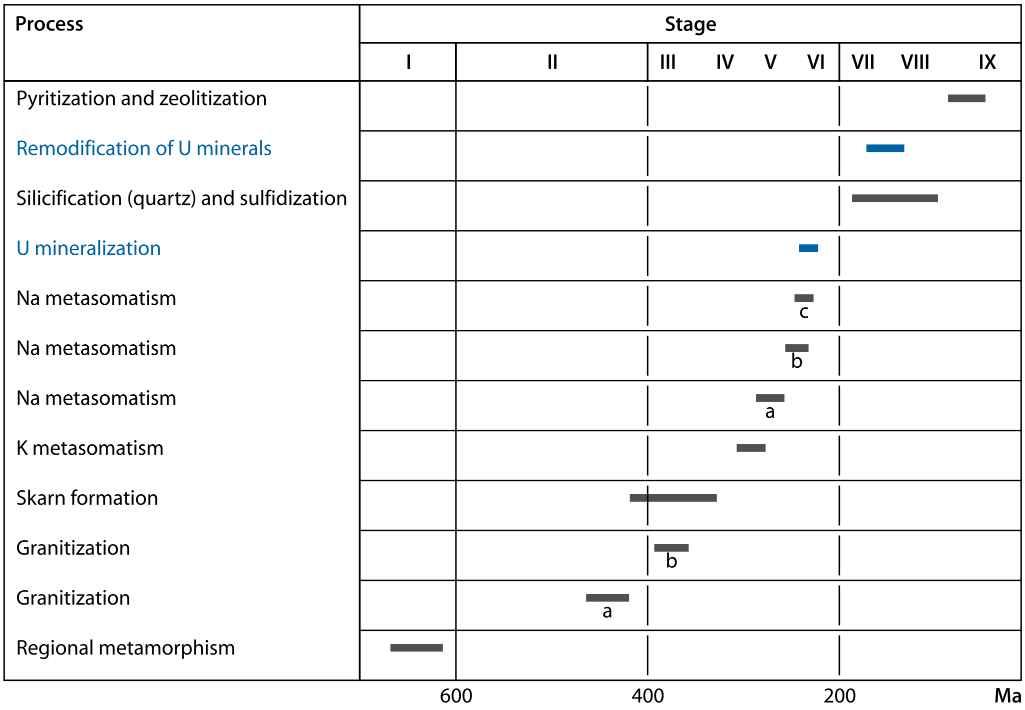
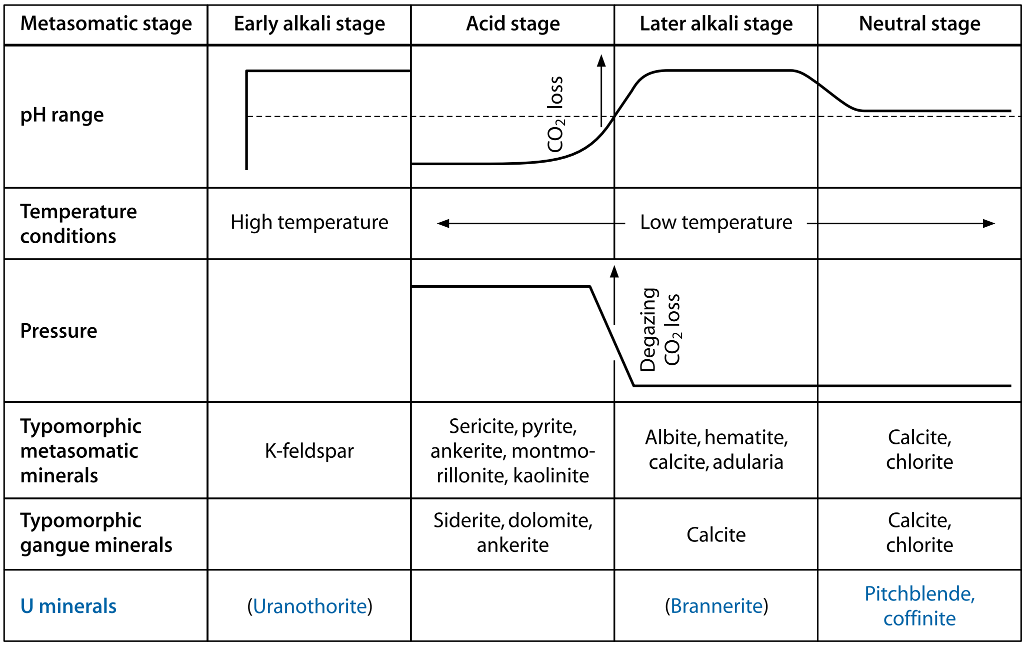


Fig. 3.34. West Moravian district, succession of geological and mineralizing events. (Hájek A, pers. commun. 1990)



Metasomatic stage	Early alkali stage	Acid stage	Later alkali stage	Neutral stage
pH range		CO_2 loss		
Temperature conditions	High temperature	←	Low temperature	→
Pressure			Degazing CO_2 loss	
Typomorphic metasomatic minerals	K-feldspar	Sericite, pyrite, ankerite, montmorillonite, kaolinite	Albite, hematite, calcite, adularia	Calcite, chlorite
Typomorphic gangue minerals		Siderite, dolomite, ankerite	Calcite	Calcite, chlorite
U minerals	(Uranothorite)		(Brannerite)	Pitchblende, coffinite

Fig. 3.35. West Moravian district, metasomatic evolution, physico-chemical conditions, and mineral formations in uranium mineralized areas. (After Hájek A, Ivanov, Jurgenson, Uhlík Z, pers. commun. 1990)

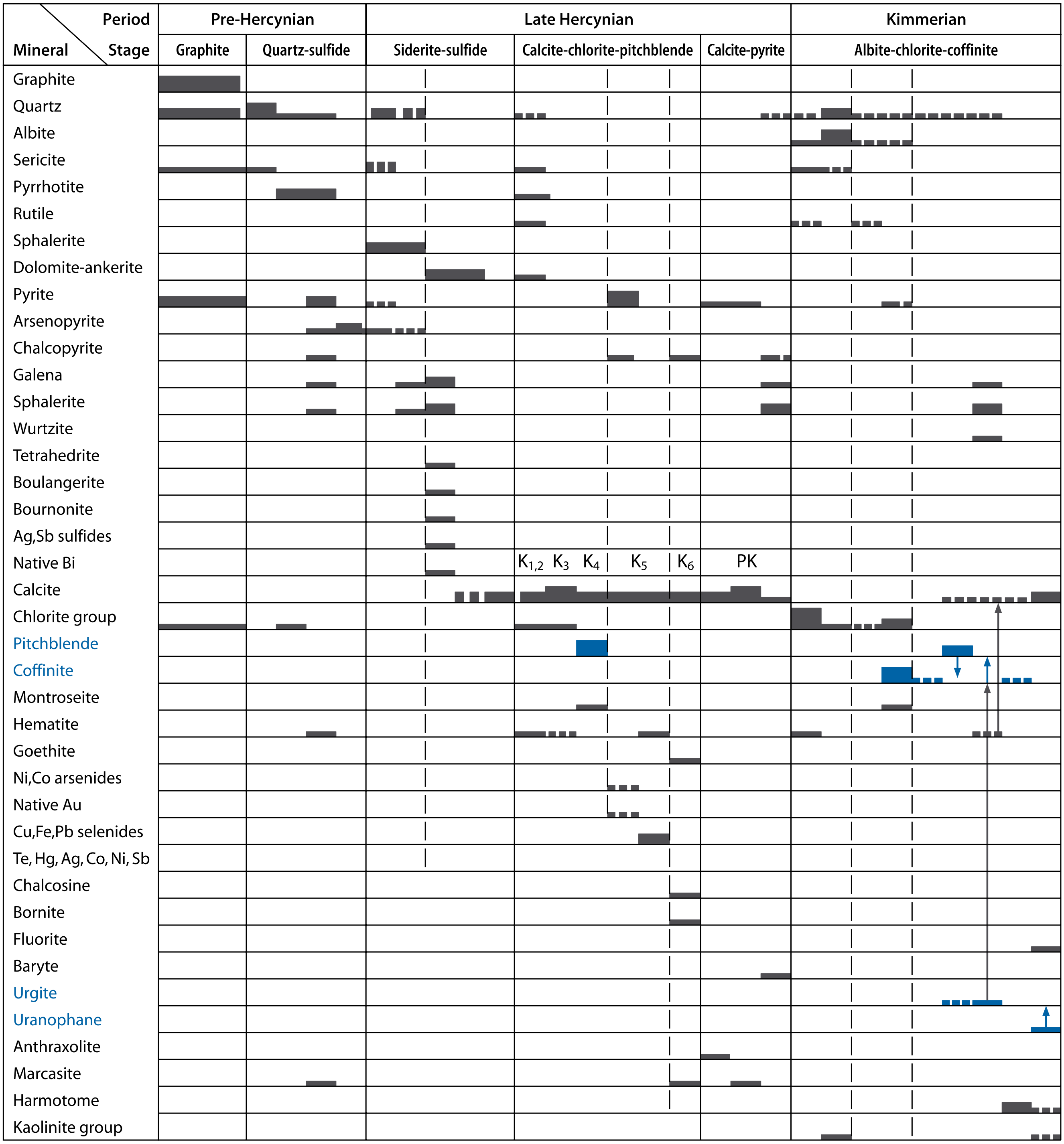
numerous, but the bulk of the ore is contained in a few large ore bodies. Ore persists to a depth in excess of 1 500 m. Rožná and Olší are the principal deposits of this variety.

Geochronology

Uranium mineralization formed during several stages. The oldest pitchblende generation of the Rožná and Olší deposits yields an apparent U/Pb age of ca. 270 Ma. Remobilization occurred about 230 to 220 Ma, and 120 Ma ago. Host rocks give a Rb/Sr age of ca. 640 Ma, which reflects the time of the last regional metamorphism in the Moravian region. Youngest intrusions are dated at about 430 Ma (Hájek A, pers. commun. 1991).

Kolektiv (1984) provides the following U/Pb ages for ore of the Rožná and Olší deposits. Pitchblende of the calcite-pitchblende stage yields 270 ±15 Ma corresponding to the Saalian phase of the Hercynian Orogeny. This age correlates well with the 265 ±15 Ma of the oldest pitchblende in the Železné hory district. The albite-chlorite-coffinite-hydromica stage is dated at 190 ±15 Ma, which is thought to be a result of reactivation time equivalent with the Early Kimmerian phase of the Alpine Orogeny.

Fig. 3.36.
West Moravian district, general paragenetic scheme of ore and associated minerals in uranium deposits. (After Kolektiv 1984)



Principal Ore Controls, Recognition Criteria, and Metallogenetic Aspects of West Moravian-Type Uranium Deposits

Most deposits of the West Moravian district (and likewise Chotěboř in the Železné hory (Eisengebirge, Iron Mountains), Okrouhlá Radouň in south Bohemia, and deposits in the Western Bohemian uranium region such as Dyleň and Zadní Chodov (Hinterkotten)) display, in contrast to granite-related vein uranium deposits, the following parameters, which may be significant in any metallogenetic modeling:

- Restriction to the Middle Proterozoic or older Moldanubicum (mostly to the Varied Group), the oldest stratigraphic unit in the Bohemian Massif.
- Position in the Moldanubicum is marginal to the presumed paleounconformity separating the Moldanubicum from Neoproterozoic–Lower Paleozoic metasediments.

- Rocks are affected locally by Na metasomatism.
- Depth persistence is at least 1 500 m below the present surface, which would mean that mineralization probably had an original depth extension in excess of 2 000 m considering the amount of previous erosion.
- Uranium mineralization is of simple, monometallic nature consisting of pitchblende, coffinite, and rare brannerite.
- Associated metallic elements are present only in trace to subeconomic amounts.
- Gangue minerals commonly occur in limited amounts.
- Primary mineral zonation is lacking.
- Ore is predominantly of low grade and present in the form of structurally-controlled uranium impregnations.
- Better grade uranium accumulations occur predominantly in bundles of subparallel fracture fillings or network-style mineralization combined with disseminations, but only rarely in classical veins.
- Larger, high-grade ore pods are rare.
- Mineralization occupies up to 50% of the host structures, i.e., it is more continuous than in classical veins, where the mineralization coefficient is less than 15% and mostly 5–10%.
- Most of the uranium is concentrated in structures, which trend subparallel to the strike of the host strata.
- There is only an ambiguous genetic affinity to uranium fertile granitic intrusions or other magmatic uranium sources.

These parameters suggest an attribution of the deposits to a structurally-controlled, non-granite-related, monometallic type although some deposits occur spatially in a perigranitic position. These granites, however, do not seem to have the composition characteristic for uranium-fertile granites.

Due to their structurally-controlled character, metallogenetic hypotheses favored a magmatic hydrothermal origin for this type of deposit for a long time. The lack of any exposed granite in the vicinity of these deposits, as is the case in the West Moravian district, was explained by the assumption that mining would ultimately encounter deeper seated granitic intrusions as the source of ore-forming fluids. But this has not been verified to date.

The above listed parameters compare partly with vein deposits not related to granite such as the Schwartzwalder Mine, USA, and partly with epimetamorphic-subunconformity deposits as exemplified by the Beaverlodge deposits, Canada. These deposits are hosted by rocks of similar composition and age, affected by similar kinds of alteration. As in the case of Beaverlodge, the deposits in Moravia and Bohemia occur in the vicinity of a major paleounconformity, namely that which separates the Moldanubicum from Upper Proterozoic–Lower Paleozoic metasediments. The major difference from the geological setting of the Beaverlodge deposits is the multiple metamorphic overprint of the Moldanubian region, which must have affected and modified any former uranium deposit.

The given situation suggests that any metallogenetic modeling should include the possibility that uranium of the respective deposits in Bohemia and Moravia may have perhaps derived from a subunconformity-related precursor type of mineralization, if not from uraniferous Moldanubian metasediments, to form the now known deposits chiefly by Late Hercynian hydrothermal processes. Later events only remodified the mineralization at least twice during the Mesozoic.

3.5.1 Description of Selected Deposits of the West Moravian District

Sources of information. Kolektiv (1984), pers. commun. by Pluskal O, Hájek A, and other DIAMO/CSUP staff, unless otherwise cited.

3.5.1.1 Rožná-Olší, Moravia

These two adjacent deposits, the largest in the Moravian uranium region, are located 40 km north-northwest of Brno (Brünn). Mineralization occurs in two diagonally offset zones. Combined they are about 15 km long and up to 1.5 km wide each (Fig. 3.37).

The deposits are of structurally-controlled, monometallic network-impregnation and vein type. Original resources including production were some 21 000 t U in Rožná, and 4 000 t U in Olší.

Rožná has produced from 1958 through 2011 ca. 18 800 t U by underground methods to depths of 1 100 m. Olší was mined from 1959 to 1989 to depths of 900 m and delivered 2 922 t U. The average mining grade of both deposits varied between 0.08 and 0.15% U.

Rožná also contains massive baryte ore (discovered 1990) with reserves estimated at more than 2 mio t with an average grade of 62% baryte, 3.2% Zn, and 1.8% Pb (Kříbek et al. 1996).

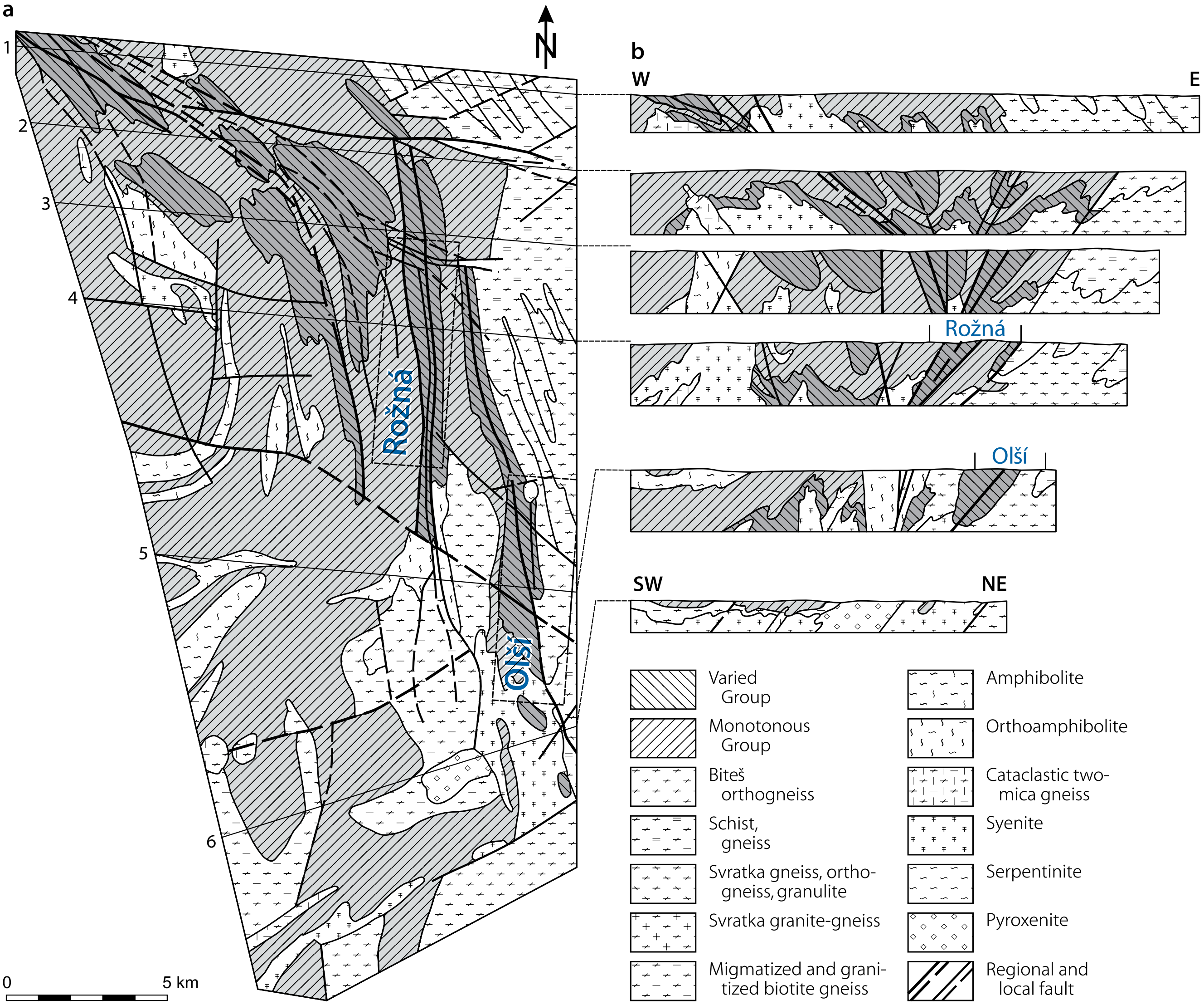
Geological Setting of Mineralization

Rožná and Olší are situated at the northeastern margin of the Moravian Block. Country rocks belong to the 1 200 m thick Monotonous Group (mainly biotite-sillimanite gneiss) and the 1 800 m thick Varied Group of the Moldanubicum. The Varied Group hosts the uranium deposits. It consists of partly graphitic biotite gneiss and amphibole gneiss with abundant intercalations of ortho- and para-amphibolite, quartzite, and marble; locally (at a depth interval from about 600 to 1 000 m), the Varied Group contains strata-bound, massive baryte-sulfide lenses (Kříbek et al. 1996). Aplite-granite dikes dissect the sequence. The rocks are Na metasomatized into albitic facies at depths below some 400 m.

The deposits are positioned at a structurally complex site on the eastern flank of the Ždár-Svratka Synclinorium; the flank is deformed by an anticlinal modification (Rožná-Olší Anticline), and the transection of the Labe (Elbe) Lineament. The Rožná-Olší Anticline is about 15 km long and 1.5–2.5 km wide. Its axial plane trends NNW–SSE and is overturned to the east. Both flanks dip isoclinally 45–65° W. Flexuring complicates the flanks. Highly metamorphosed gneisses form the core of the anticline, gneiss and amphibolite the flanks.

Fig. 3.37.

West Moravian district, a geological map, and b W–E sections showing the complex structural setting of the Rožná and Olší deposits along the N–S-trending Labe (Elbe) Lineament, where it cuts the anticlinally modified eastern flank of the Ždár-Svratka Synclinorium. Host rocks belong to the Proterozoic Varied Group. (After Kolektiv 1984)



Rožná is situated on the western and Olší on the eastern flank of the anticline.

Major faults trend generally NNW–SSE and dip 45–70° W, parallel or subparallel to bedding/schistosity. Attitude, morphology, and branching of the faults are influenced by the stance of anticlinal limbs. These faults can be 10–15 km long, a few meters to occasionally 25–30 m wide, persist to depths in excess of 1 000 m, and are mostly filled with gouge, rock fragments, and small amounts of gangue minerals (calcite, pyrite, associated with graphite). Numerous subsidiary faults branch off main faults splaying into tension gashes, feather joints, and horsetails. Rocks are intensely fractured, altered, and locally dissected by granite-aplite dikes and carbonate veins in zones of fault branching and feathering. Faults oblique to the metasedimentary trend are generally of simple nature. They have smaller dimensions, different morphologies and mineral fillings than longitudinal faults.

Host Rock Alteration

Besides the earlier mentioned, depth-restricted Na metasomatism, six stages of alteration(-mineralization) are recognized in the mineralized area (Fig. 3.36). Characteristics of the six stages are as follows:

Stage 1 and 2 pre-ore graphite-pyrite and quartz-sulfide. Graphitization, pyritization, and silicification affected all tectonized zones invading wall rocks locally for several tens of meters. Graphite and pyrite replace mafic rock constituents particularly biotite. The intensity of graphitization diminishes relatively rapidly at margins of altered zones.

Stage 3 pre-ore carbonate-sulfide. A halo of intense bleaching, 0.1–0.5 m wide surrounds carbonate-sulfide veins. Rocks within the halo are pale-green or pale-grey and lose their laminated texture. Rock constituents of paragneiss have been replaced by carbonate, hydromica, and clay minerals. This zone grades into bleached rock with a preserved rock texture for another 1–2 m from veins. Associated chemical changes include depletion of Na, Fe, and Si, and increases in Ca, K, Mg, H_2CO_3, and H_2O. Low-temperature fluids of increased alkalinity and relatively high K/Na ratios are considered to be responsible for this alteration. The process was associated with oxidation of wall rocks around carbonate-sulfide veins resulting in a decrease of reduction potential. This is assumed to be the reason that bleached zones became unfavorable for uranium precipitation.

Stage 4 calcite-chlorite-uranium. Alteration associated with the main stage of uranium mineralization is restricted to the immediate vicinity (few centimeters) of mineralized structures. Biotite and, in part, feldspars are replaced by albite, chlorite, hydromuscovite, and sericite. As the ore contact is approached, chlorite pseudomorphs after biotite. Plagioclase and biotite become carbonatized. All rock minerals except quartz are replaced by carbonate, chlorite, and silica immediately at the ore contact. This mineral transformation is accompanied by a loss of laminated rock texture. Chemical changes associated with the chloritization event include depletion of K and Si, and introduction of Fe and Mg. The increase of Fe^{2+} indicates reducing conditions, which are considered a critical factor for uranium precipitation.

Stage 5 post-ore calcite-pyrite. Alteration consists of minor carbonatization of wall rocks immediately adjacent to pyritic carbonate veins.

Stage 6 albite-chlorite-coffinite. In segments affected by this type of alteration, which is associated with uranium redistribution, gneiss is altered in a 1.5–2 m wide halo around uranium-mineralized structures. Pink recoloration is the most obvious feature, or blackening where finely disseminated hematite has formed. Quartz, albite, and chlorite are the principal authigenic phases. Biotite is replaced by chlorite, muscovite, and carbonate; feldspar grains turn pink; acidity of plagioclase increases. Translucent albite grows as rims around plagioclase. Intensely modified sections are reflected by a complete alteration of the rocks into an assemblage of albite, fluorite, quartz, and montmorillonite-type clay minerals. Chemical changes include depletion of Fe, K, Mg, and Si, and addition of Ca, Na, and H_2CO_3. A direct correlation of U with Na, and U with rock porosity is noticed.

Mineralization

Six prominent mineral stages including at least two of uranium formation and redistribution are recorded (Kolektiv 1984). Their principal features are as follows (see Fig. 3.36 for paragenetic minerals of each stage):

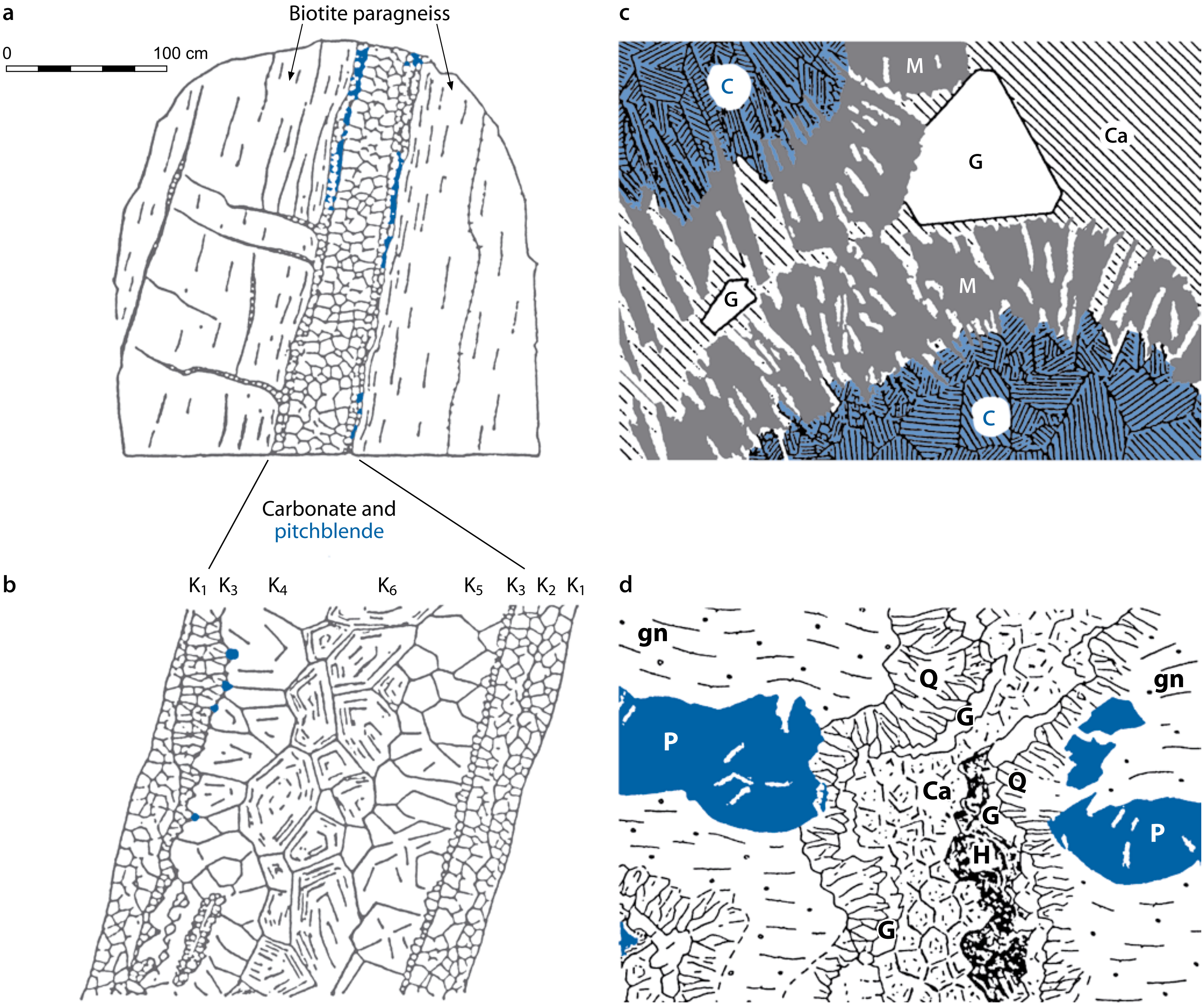
1. *graphite-pyrite stage:* Rocks along almost all major longitudinal, NNW–SSE-oriented structures were affected by this early stage. Graphite, pyrite, and quartz accumulated within fractured zones and particularly along individual dislocation faults. This stage presumably started during the Moldanubian Orogeny.
2. *quartz-sulfide stage:* Small lenses and impregnations of arsenopyrite, pyrite, and pyrrhotite, with minor galena, sphalerite, and quartz formed along schistosity planes in gneiss, and locally, together with chalcopyrite, in marble. This stage is only weakly developed and occurs predominantly at lower levels of deposits.
3. *carbonate (siderite)-sulfide stage:* Veins of Ca-, Fe-, and Mg carbonates preferentially fill oblique faults. Older siderite is more or less replaced by dolomite-ankerite and calcite. Galena and sphalerite are the prevailing sulfides; arsenopyrite, chalcopyrite, boulangerite, bournonite, pyrite, and tetrahedrite occur in minor quantities. Sulfides associate with calcite and dolomite. There is no obvious relationship of this stage to the subsequent uranium ore stage.
4. *calcite-chlorite-uranium stage:* Pitchblende and minor coffinite 1 are the principal uranium minerals. Their distribution is restricted to graphitized and pyritized longitudinal fault swarms, which transect chloritized rocks. The principal gangue minerals are chlorite and, particularly in veins, calcite. Calcite is present in several generations (Fig. 3.38). Some hematite apparently developed early in this stage.
5. *calcite-pyrite stage:* Coarse-grained rose calcite with pyrite, and rare baryte and fluorite form veins within main and subsidiary structures including those that contain the carbonate-pitchblende assemblage. The latter is intersected by calcite-pyrite veins.
6. *albite-chlorite-*coffinite *stage:* Quartz, albite, and chlorite form stringers and veins along some intervals of longitudinal structures. They also impregnate adjacent biotite gneiss thereby transforming gneiss into albitized and silicified rocks. Some of these altered zones are flooded with finely disseminated hematite; these hematitic sections enclose small veinlets of comb-quartz intergrown with galena, wurtzite, pyrite, zeolite (harmotome), calcite, and coffinite 2. Locally, these veinlets also contain montroseite (Fig. 3.38d). Coffinite also penetrates the wall rock as minor impregnations. Veinlets of this stage cut pitchblende of the main ore stage (Fig. 3.38). Primary *uranium minerals* are replaced by coffinite 2, uranophane, quartz, zeolite, and clay minerals. Redistributed ore of this stage is in radiometric disequilibrium in favor of uranium. Zeolite is always radioactive due to incorporated decay products of uranium. The albite-chlorite-coffinite 2 assemblage increases distinctly with depth with a simultaneous diminuation of main stage uranium minerals and redistribution of uranium into wall rocks.

At Rožná, the stage 2 and 3 mineral assemblages are restricted to the footwall zone of longitudinal structure systems.

Two settings of mineralization are evident: *network-disseminations* prevailing in major fault zones, and *veins* filling subsidiary structures.

Fig. 3.38.

Rožná-Olší, a example of a carbonate-pitchblende vein in biotite paragneiss; b enlargement of the vein showing the texture, distribution of the various carbonate generations (*K1–K6*), and position of pitchblende; c example of coffinite-montroseite mineralization and its interrelationship with each other and other minerals (*M* montroseite with margins replaced by pitchblende, *C* coffinite, *G* galena, *Ca* calcite) (polished section, magnification ca. 70×); d example of a harmotome (*H*)-comb quartz (*Q*)-calcite (*Ca*)-galena, and wurtzite (*G*) veinlet cutting pitchblende (*P*). Host rock is silicified gneiss (*gn*) (polished section, magnification ca. 30×). (After Kolektiv 1984)



Network-disseminations. Two mineral assemblages are distinguished, *(a)* calcite-chlorite-pitchblende with coffinite 1, and *(b)* coffinite-montroseite. Pitchblende and coffinite 1 form massive aggregates and stringers as well as cement in altered, cataclastic gneiss. These minerals associate locally with montroseite (Fig. 3.38c). Coffinite replaces pitchblende and partly montroseite and impregnates chlorite. Disseminated coffinite crystals (0.5–1 mm in size) contain minute inclusions of galena.

Veins. Subsidiary structures of main faults contain veins, often of breccia structure. Two kinds of vein composition exist: *(a)* calcite-chlorite-pitchblende, and *(b)* calcite-pitchblende-selenide. The latter is restricted to margins of the Rožná deposit. *(a)* Spherulitic pitchblende and calcite of the K4 generation grew contemporaneously. Pitchblende also associates with chlorite, which fills interstices between pitchblende and calcite. *(b)* Pitchblende and selenides occur as nests and aggregates up to a few tens of centimeters in diameter within carbonate veins. The principal Se minerals are berzelianite and umangite. Bukovite, clausthalite, crookesite, eskebornite, eucairite, ferroselite, klockmannite, and tryllite occur in minor amounts. Selenides crystallized closely to but later than pitchblende. The appearance of selenides is associated with enhanced ore grades, but dimensions of ore bodies are reduced.

Some horizontal and vertical *mineral zoning* is noticed in the Rožná deposit. Calcite-chlorite-pitchblende-coffinite 1 paragenesis prevails in the central part of the deposit, whereas calcite-pitchblende-selenide assemblage dominates in the wings. Vertical zoning is reflected by an inverse distribution of uraniferous mineral assemblages. The older pitchblende stage prevails on upper levels and diminishes with depth giving way to the younger coffinite 2 stage.

There is a principal *structural correlation* of position, dimension, and mineralogy of ore bodies. The order of structures (main, subsidiary, horsetail; Fig. 3.39) and properties of structures (bending, thinning/widening, anastomosing) govern the extent of structurally prepared ground receptive for ore emplacement, and the attitude of ore bodies. Lithologies impose only a minor influence on the position of ore because main structures are oriented more or less parallel to the attitude of strata.

Localization of ore shoots in longitudinal faults is largely controlled by the geometry of these structures. Ore accumulated particularly at deviations in strike and dip of the host structure, morphologically complex sections at branchings, intersections, and anastomosing of structures, and transections of structures with folds.

Ore bodies in semipermeable segments of main structures are of elongated, lenticular shape. Trends and inclinations of these lenses may be controlled by flexures of the host fault, and by the way the fault transects the orientation of a fold. For example, at Rožná, where the generally NNW–SSE-oriented faults become morphologically complex and wider due to branching, and subsidiary faults cut strata obliquely, rocks at these sites are intensily fractured, altered, and intruded by aplite-granite dikes and vein carbonates. At sites where a fault bends from NW to N, subsidiary faults developed in the hanging wall of the main fault. These subsidiary faults trend NNW–SSE and have a 20–30° N-plunging connection line with the main structure. Where the main fault turns to the northwest, NE–SW-trending subsidiary structures opened in the footwall, and the connection line of both plunges 20–30° S. Accordingly, ore lenses in these intervals have different inclinations. The longitudinal axis of ore bodies plunges 20–30° N in the first case, and 20–30° S in the second.

In addition to structural implications, mineralogical and geochemical factors enhanced precipitation of uranium. Abundant pyrite in graphitic zones and pre-ore chlorite provided a favorable environment for ore formation. According to the particular prevailing factor, the position of ore bodies varies.

Shape and Dimension of Deposits

Uranium ore bodies are controlled by a few main structures and off-branching subsidiary structures (Fig. 3.39). The majority of ore is associated with main structures as exemplified by the Rožná deposit; about one hundred structures are mineralized, but while only 2% are main faults, they contain some 75% of the total reserves. The remaining 25% is hosted by subsidiary structures.

As mentioned earlier, two principal varieties of ore bodies are distinguished based on structural setting, morphology, composition, and dimensions: ore bodies composed of networks with disseminated uranium, and vein-type ore bodies. Vein-type mineralization prevails on upper levels. It diminishes with depth giving way to disseminated network ore. An additional low-grade variety of network-type mineralization occurs in albitized rocks at depth.

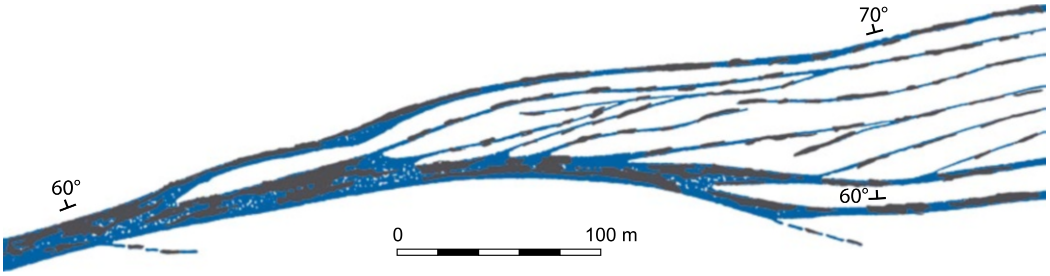
Network-disseminated ore. This variety consists of lens-shaped ore bodies composed of an internal structural network with disseminated ore. Their distribution is restricted to cataclastic intervals of larger fault zones in which lenticular bodies occur in en echelon fashion as documented in Fig. 3.40. Ore bodies are mostly of relative large dimension extending for up to several hundred meters along strike and dip. Width is up to 10 m but may locally attain 18 m. Boundaries of ore shoots are irregular. Grades range from <0.05 to 0.2% U. Mineralization is relatively continuous occupying as much as 50% of the host structure. The footwall contact of ore shoots is always sharp and accompanied by a 10–40 m thick gouge layer. The hanging-wall contact is gradational.

Larger ore bodies are almost invariably bound to displacement structures. These structures often bifurcate and anastomose resulting in segments of complex networks, which host mineralization. Uranium occurs as disseminations in sections of altered, cataclastic rocks, but it occasionally also invades wall rocks.

Vein-type ore. Mineralization occurs overwhelmingly in tension gashes and horsetails of subsidiary faults (Fig. 3.9), which cut strata obliquely, and dip more steeply than the main structure from which they branch off. Only 4–5% of total volume of main structures contains veins. Ore distribution is more

Fig. 3.39.

Rožná, first ore zone, diagram of a favorable site for enhanced uranium accumulation controlled by flexure-related ramification of a main fault. Veins occupy 4–5% of the volume of large structures (schematically indicated by blue color). Ore shoots occur in irregular distribution. They are few meters to several tens of meters long, up to 1.5 m in thickness, and grade 0.15–0.3% U or more. (After Kolektiv 1984)



irregular and unpredictable, and dimensions of ore shoots are smaller, but grades are better in veins than in disseminated network ore. Mineralized structures contain barren sections filled with gouge intervening with carbonate or quartz-carbonate infill. Pitchblende is essentially confined to carbonate intervals (Fig. 3.38). Therefore high-grade sections alternate with low-grade or barren intervals. The ore-wall rock contact is commonly sharp. Ore shoots range in length from a few meters to several tens of meters along strike and dip. Widths are up to 1.5 m and rarely 2 m. Grades range from 0.15 to >0.3% U.

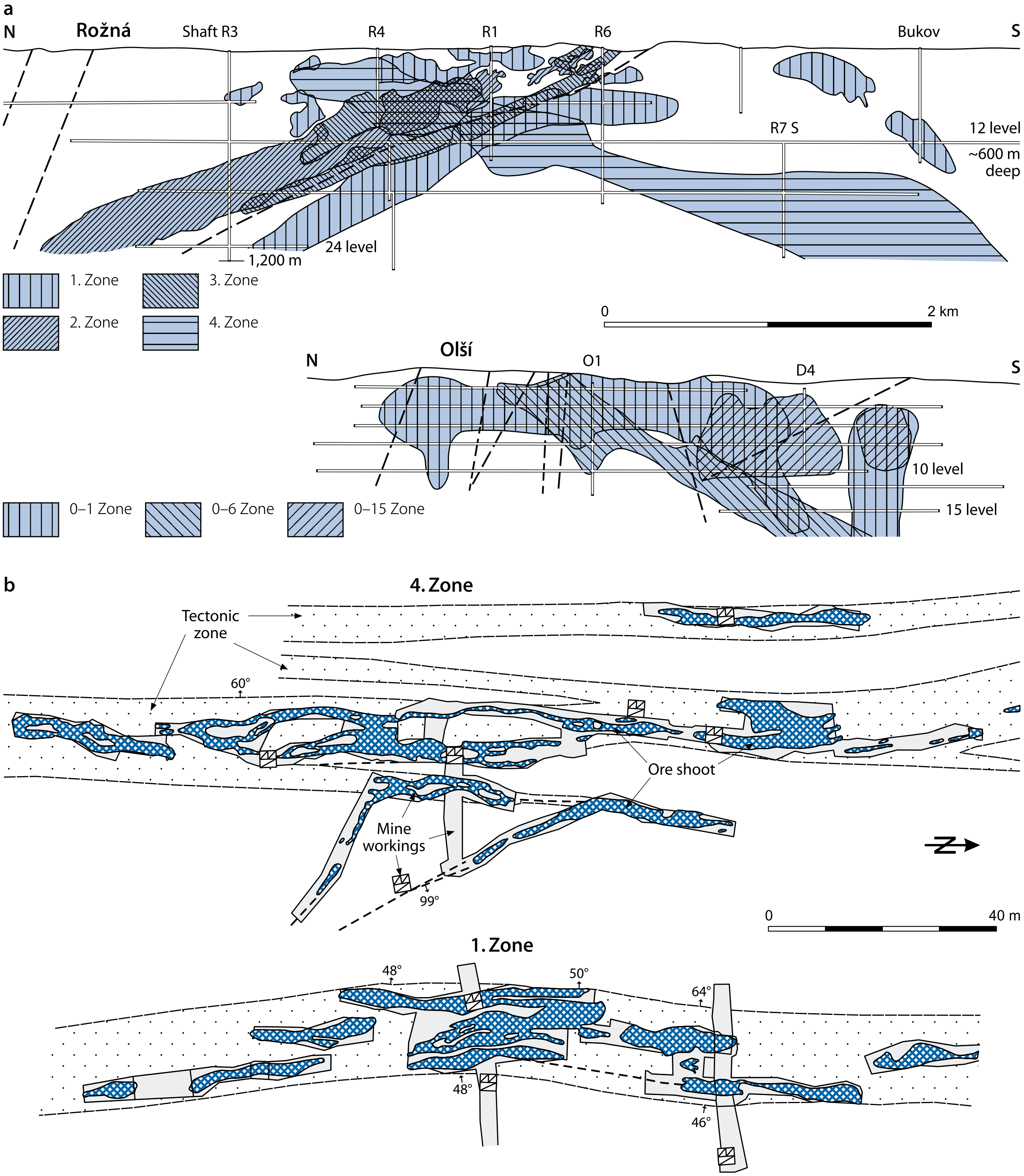


Fig. 3.40.
Rožná-Olší, a N–S sections with vertical projections of uranium mineralized zones. b Planview of tectonic structures with distribution and shape of ore shoots in the first and fourth ore zone. (After Kolektiv 1984)

Ore in albitized rocks. Mineralization consists of veinlets, stringers, nests, and lenses of coffinite and radioactive zeolite emplaced in albitized, silicified, and hematitized biotite-plagioclase gneiss in between approaching fault zones. Dimensions of these mineralized zones are 60–100 m long, 400–500 m deep, and 5–6 m wide. The width of albitized zones is up to 40 m. Grades are low, often less than 0.1% U.

Reserve distribution by ore types. About 85% of reserves occur in network-disseminated ore, ca. 10% in veins, and about 5% in fractured albitized rocks. The relationship of uranium grades in the three ore varieties shows that grades in veins are 2–3 times higher than those of network ore, and grades of network ore are about 2–3 times as much as those of albitite-hosted ore (Hájek A, pers. commun.).

Ore Control and Recognition Criteria

The Rožná-Olší deposits are primarily controlled by structure and secondly by altered lithologies. Salient ore controls and/or recognition criteria include the following:

Geological Environment

- Host rocks are complexly folded gneisses of the Middle or older Proterozoic Moldanubicum
- Deposit position in the marginal zone of the Moldanubicum near the contact to Upper Proterozoic to Lower Paleozoic metasediments. Although camouflaged by structural overprinting, the contact can be identified as a paleounconformity
- Complex structural setting caused by the intersection of the Labe (Elbe) Lineament, a deep rooted tectonic zone of displacement faults and shears, with a local anticline that deformed the eastern flank of a major synclinorium
- Granitic and syenitic rocks (dikes, stocks) have elevated uranium contents averaging about 10 ppm U and a U/Th ratio of about 1.1, metasediments average 5 ppm U

Alteration

- Albitization metasomatized Moldanubian rocks at depth
- Wall rocks are modified by several pre-, syn, and post-uranium alteration stages
- Graphitization, pyritization and chloritization along major fault zones are the most prominent alterations associated with uranium mineralization

Mineralization

- Primary mineralization is monometallic consisting of pitchblende and minor coffinite associated with chlorite and calcite
- Redistributed mineralization consists essentially of coffinite, is of lower grade and wider spread than primary ore
- Mineralization occurs predominantly in lens-shaped ore shoots composed of flat networks associated with disseminations, and subordinately in veins
- Lenticular ore shoots occur within larger structure zones, often in en echelon manner
- Veins prevail in subsidiary structures
- Distribution of lenticular ore shoots is fairly continuous, they occupy roughly 50% of the host structure
- Principal ore-bearing structures are longitudinal, NNW–SSE oriented dislocations of the Labe (Elbe) Lineament which roughly parallel bedding/schistosity
- Secondary ore-bearing structures are higher-order faults (open gashes, tension joints, horsetails) subsidiary to main faults
- Most favorable sites for major ore concentrations are morphologically complex fault intervals such as
  - sites where host rocks have been dislocated at flexures of longitudinal structures
  - fault bends within limbs of anticlinal folds
  - connection lines of structures of different order, i.e., where subsidiary faults branch from main faults
  - intersections of major longitudinal faults with oblique faults

Metallogenetic aspects of the Rožná-Olší deposits have been discussed earlier within a broader spectrum in Sect. 3.5 *West Moravian Region*.

3.5.2 Other Uranium Deposits in the Western Moravian Region

Other uranium deposits in the wider West Moravian region include *Slavkovice-Petrovice* (production 175 t U), *Škrdlovice*, (76 t U) and *Nová Ves* (1.5 t U), all located northwest of Rožná, and *Jasenice-Pucov* (311 t U) situated south-southwest of Olší. Škrdlovice and Nová Ves are located to the northwest and southeast, respectively, of Slavkovice and are similar to that deposit. *Polná Brzkov*, located some 40 km west of Rožná, produced 65 t U. All these deposits may be classified as structurally-controlled, monometallic impregnation and/or vein type. Their in-situ grades ranged from <0.1 to 0.6%.

3.5.2.1 Slavkovice-Petrovice, Moravia

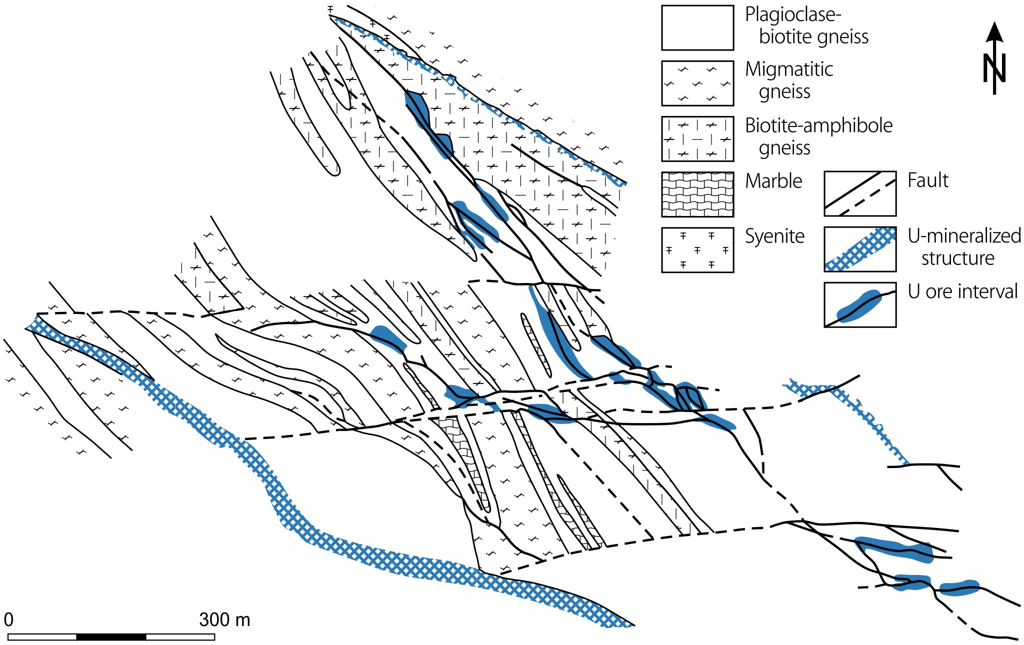
Slavkovice and the adjacent *Petrovice* deposit are located 15 km northwest of Rožná at the eastern edge of the Moravian Block (Fig. 3.33). These two deposits produced about 175 t U at an average grade of ca. 0.2% U.

Geology and Mineralization

Country rocks are plagioclase-biotite gneiss, biotite-amphibole gneiss, amphibolite, marble, and calc-silicate rocks of the Moldanubian Varied Group. These rocks are intensely migmatized, and intruded by two syenite stocks and strata-concordant aplite-granite dikes. The general strike of these metasediments is NW–SE, and dip is 15–35° NE, but local plications complicate the attitude of the strata.

The Slavkovice deposit is located at the intersection of two major disjunctive fault systems, the E-W-oriented Křídla Fault and NW–SE-trending faults of the Labe (Elbe) Lineament. Three fault sets are recognized in the deposit (Fig. 3.41):

Fig. 3.41. **Slavkovice, geological map showing the unpredictable distribution of uranium ore shoots along main and subsidiary faults. Lithologic units dip 15–35° NE. Aplite granite dikes occur at deeper levels. (After Kolektiv 1984)**



a NW–SE faults with a shallow, 20–30° NE inclination; these faults more or less parallel the rock bedding,
b NW–SE faults with a steep, 70–80° NE and SW dip; feather fractures interconnect these faults with shallow dipping faults,
c W–E-trending, 25–80° S-dipping faults, which cut and displace NW–SE faults.

Faults are 0.1–2 m wide and filled with gouge, rock fragments, and rare carbonate veinlets. Intense chloritization and hematitization altered the fault fill. Bleaching surrounds mineralized sections.

Pitchblende is the principal uranium mineral. *Associated minerals* include sulfides (bornite, chalcocite, chalcopyrite, marcasite, pyrite) and minor selenides (berzelianite, eskebornite, eucairite, umangite). Gangue consists of several generations of carbonates.

Three vein-forming mineral stages are recognized by Kolektiv (1984): pre-uranium quartz-carbonate, syn-uranium carbonate-pitchblende-selenides, and post-uranium calcite-pyrite. These mineral assemblages are similar to those of the southern zone of the Rožná deposit. But in contrast to Rožná, quartz-carbonate veins, which prevail in the bleached aureole surrounding ore sections, are almost barren of sulfides, coffinite is lacking, chlorite is less abundant, and the graphitic association with uranium is less pronounced.

Pitchblende occurs in veins, small nests, and disseminations in all three fault sets. Some structures with a width of 0.5–2 m are filled with massive ore that grades outwards into mineralized breccia fragments and disseminations. Tectonic reworking fractured much of the vein material. Veins account for about 80% of the ore. Disseminations constitute the remaining 20%.

Ore-grade uranium distribution is irregular and discontinuous resulting in a low ore/structure fill coefficient estimated at less than 0.20(?).

Mineralization is restricted mainly to biotite gneiss adjacent to the contact with marble and calc-silicate intercalations. Little mineralization is in biotite-amphibole gneiss. Migmatized gneiss is barren of ore.

The principal ore control is by structure. Favorable intervals of ore accumulation are intersections of shallow faults with steeply dipping, NW–SE-oriented faults; intersections of NW–SE with W–E-trending faults; and intervals of bifurcating and anastomosing structures.

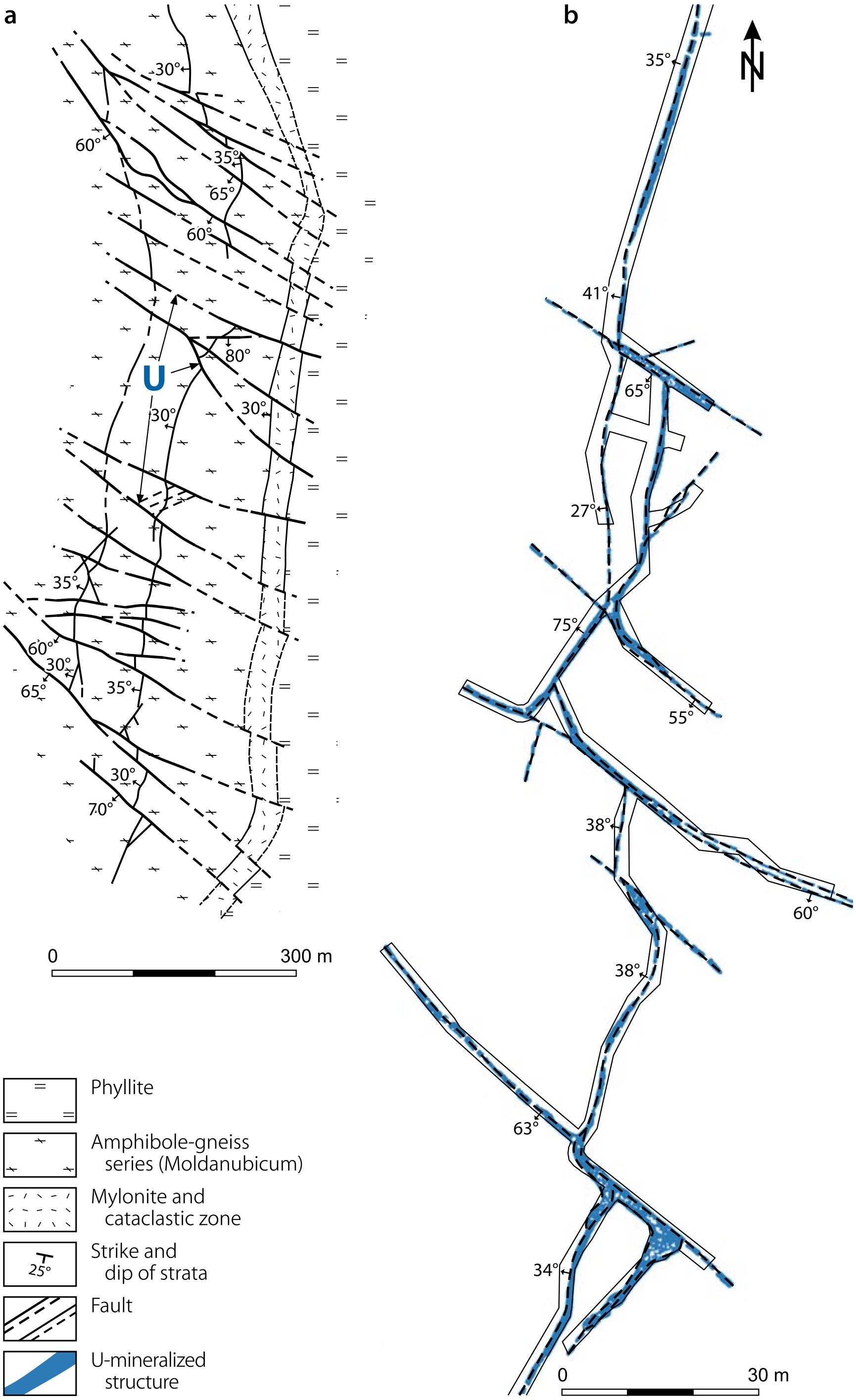
3.5.2.2 Jasenice-Pucov, Moravia

This deposit is located 25 km south of Rožná, offset to the southwest from the West Moravian district (Fig. 3.33). The deposit was mined 1963–1967 and 1974–1991 and produced 311 t U by open pit and underground methods to depths of 400 m (DIAMO, web side 2012). Mining grade was about 0.12% U.

Geology and Mineralization

Jasenice is at the eastern margin of the Moravian Block. Country rocks include plagioclase-biotite gneiss, biotite-amphibole gneiss, amphibolite, and rare intercalations of marble of the amphibole gneiss series of the Moldanubicum. Strike is N–S and dip is 30–60° W. The deposit is within a wedge of these rocks bounded to the east by the N–S-oriented, 25–40° W-inclined Náměšt Fault, and to the northwest by the NE–SW-trending Bíteš Fault. The Náměšt dislocation fault is up to 20 m wide and consists of a zone of sheared, cataclastic, and graphitized material. The Bíteš Fault is intruded by Late Hercynian aplite-granite dikes over long sections. Two additional fault systems of minor order affected the deposit site. The first system includes faults that trend subparallel to the Náměšt Fault and parallel to bedding. They displace the rock sequence due to

Fig. 3.42. **Jasenice, a geological plan with lithologies, structures, and position of the U-mineralized zone (*U*) (*myl* mylonite zone, *ph* phyllite, *am* amphibolite-gneiss series, Moldanubicum); b detailed plan documenting the structure-controlled distribution of U mineralization (*U*). (After Kolektiv 1984)**



a shallower 25–30° W dip. Two of these structures are the most important ore hosts (Fig. 3.42). These faults are 3–40 cm wide but extend for up to a few kilometers in length. Their attitude is fairly straight except for local horizontal or vertical flexures at intersections with cross faults. The second system consists of NW–SE-oriented, 45–75° E or W-dipping cross-structures. These faults are particularly abundant in gneisses near the Náměšt Fault. They offset the Náměšt Fault and mineralized structures for 2–50 m. Longitudinal and cross-structures are associated with cataclastic and sheared rocks, which are intensely graphitized and chloritized.

Mineral assemblages, stages, and structural setting at Jasenice are similar to mineralized shear zones in Rožná-Olší deposits. The principal *uranium mineral* is pitchblende. *Associated minerals* are several generations of calcite, and minor chalcopyrite and pyrite. This assemblage corresponds to the calcite-chlorite-pitchblende stage at Rožná. Minor quantities of coarse-grained, white calcite formed during the post-uranium stage. Pre-uranium mineralization is absent.

Uranium occurs to a depth of >400 m in small lenticular ore lodes, commonly of low grade, composed of primarily structure-controlled disseminated, irregularly distributed pitchblende. Most ore bodies are restricted to intervals of fault intersections (Fig. 3.42). The largest ore bodies occur at sites of greatest displacement of longitudinal faults by cross faults. Both longitudinal and cross faults are mineralized.

3.5.2.3 Polná Brzkov, Western Moravia

This deposit is located in the Moldanubian Elevation near the town of Jihlava (Iglau), some 40 km west of Rožná. Original resources were some 2 000 t U. 65 t U were mined 1988–1990 by underground methods to depths of 300 m. About 1 000 t U of the remaining resources are attributed to the <U.S.$80 per kg U RAR category. The grade is between 0.15 and 0.25% U (DIAMO web side 2012; Hrádek 1995 manusc.; Pluskal O, pers. commun.).

The Polná Brzkov deposit is controlled by the NNE–SSW-trending Přibyslav Fault zone, a regional structure separating the Moravian Block from the Bohemian Block (Fig. 3.33). Host rocks belong to the Strazek crystalline complex and include amphibolite, erlans, marble, paragneiss, skarn, and pegmatite of Proterozoic age.

Ore bodies are 0.1–10 m wide and extend to a depth of at least 300 m. They are hosted by a series of NW–SE-trending, 60–70° NE-dipping structures. Pitchblende and coffinite are the principal uranium minerals.

3.6 South Bohemian Region

3.6.0.1 Okrouhlá Radouň, South Bohemia

Okrouhlá Radouň was discovered in 1962 and is located 10 km north of Jindřichův Hradec, ca. 50 km southwest of Jihlava (Iglau) in southern Bohemia. Mining of this vein-type uranium deposit began in 1972 and continued until 1990. Mining was by underground methods to a depth of ca. 600 m and produced 1 340 t U (DIAMO, web side 2012). The mining grade was 0.1–0.2% U.

Sources of information. Kolektiv (1984), amended by CSUP/DIAMO staff, pers. commun.

Geological Setting of Mineralization

Okrouhlá Radouň is within the southeastern part of the Moldanubian Zone (Fig. 3.33). Country rocks consist of an alternating sequence of amphibole gneiss, amphibolite, calc-silicate rocks, granulite, marble, orthogneiss, paragneiss, quartzite, and serpentinized ultrabasic rocks. The lithologies are tentatively attributed to the Proterozoic Varied Group, but the overprint by regional and contact metamorphism as well as migmatization hampers a definite attribution to this lithostratigraphic group. The metasediments are folded into a NE–SW-oriented and 30–40° NW-dipping monocline.

Ultrabasic, pegmatitic, aplitic, and granitic sills (from oldest to youngest) are abundant. Fine-grained two-mica granite and granodiorite of Hercynian age occur as shallow-dipping tabular bodies up to 100 m thick. The youngest intrusive is an NE–SW-oriented diorite-porphyrite dike up to 5 m thick. The N–S-elongated Klenov Massif, located to the northwest of the deposit, is composed of Hercynian biotite and two-mica granite.

A NE–SW-striking fault zone, several kilometers long, and three subparallel faults N–S-trending, 1.5–2 m wide and a few kilometers long are the most prominent structures in the area. The central N–S fault, referred to as Radouň Main Fault, is complex in nature and controls the deposit. The Radouň Main Fault dips 60–80° W and consists mostly of two 10–15 cm wide, gouge-filled dislocation shears, which bound a median zone of intensely brecciated rocks. The cataclastic interior is heavily altered, sulfidized, cut by carbonate veins, and hosts uranium mineralization. The Radouň Fault bifurcates into NW–SE, but mainly NE–SW-oriented subsidiary feather structures at the northern limit of the deposit, while it splits into several branches at the southern end (Fig. 3.43a,b).

Host Rock Alteration

Alteration is most intense along cataclastic zones. Alteration products partly rely on the composition of the protolith.

Pre-uranium albitization and hematitization are prominent in granitic rocks, whereas chloritization is dominant in migmatite. Carbonatization, sericitization, and silicification are less pronounced but ubiquitous. Chlorite 1 (pennine), leucoxene and Fe hydroxides formed after biotite. The most intensely affected lithologies are transformed into rocks composed of ca. 65% albite, 20% chlorite, 5% carbonate, 5% kaolinite, and 5% quartz plus hematite.

Syn-uranium alteration phases include chlorite 2 (prochlorite) and hydromica.

Uranium-mineralized intervals are characterized by a strong redistribution of Fe, K, Mg, and Na. Na and U were introduced, and Zr and Ti contents increased, while SiO_2 decreased. As a result of alteration, host rock porosity increased; in granite, the increase was about 2–10%.

Mineralization

Uranium and associated minerals are listed in paragenetical order in Fig. 3.44. Uranium occurs primarily as coffinite and minor pitchblende and other uranium oxide phases. Lattice constants of uranium oxide phases range from 0.537 to 0.543 Å. Coffinite occurs as irregular aggregates up to 1 mm across, as colloform rims around pyrite and zircon, and, rarely, as short prismatic metacrystals within chlorite and hydromica. Coffinite

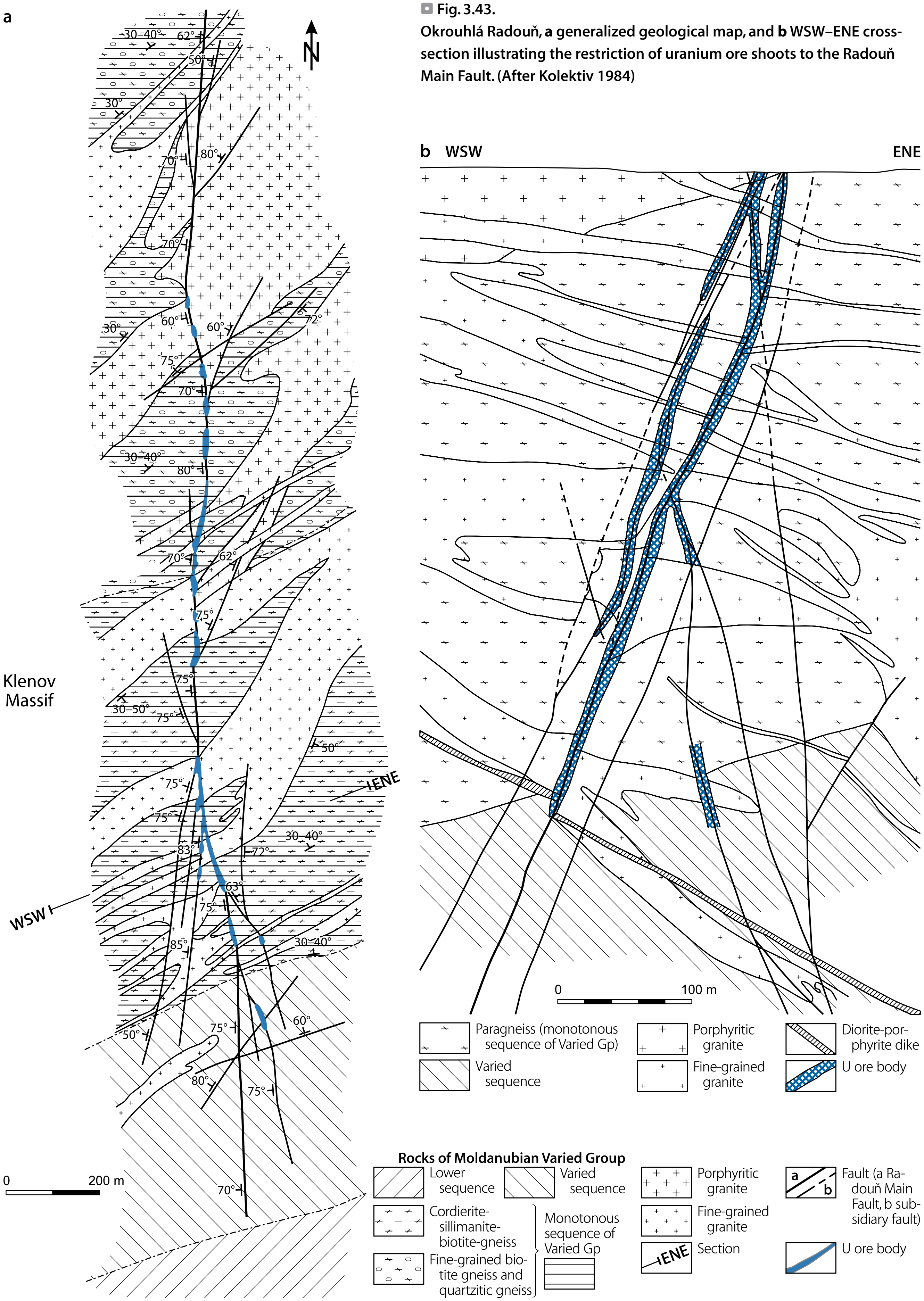
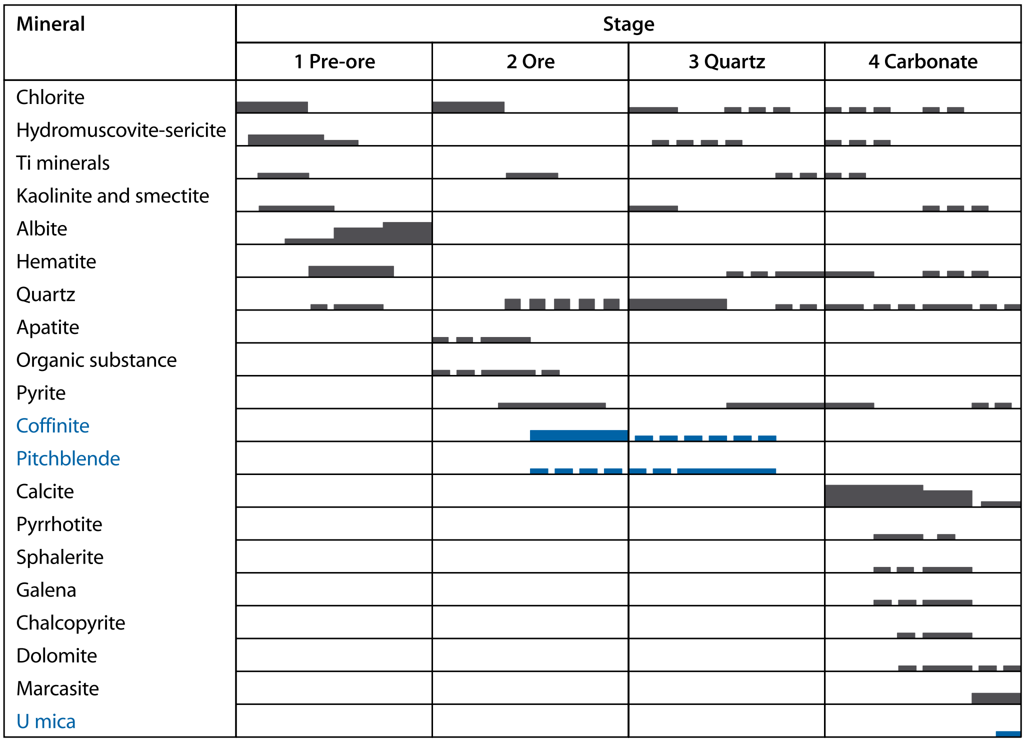


Fig. 3.43. Okrouhlá Radouň, **a** generalized geological map, and **b** WSW–ENE cross-section illustrating the restriction of uranium ore shoots to the Radouň Main Fault. (After Kolektiv 1984)

Fig. 3.44. **Okrouhlá Radouň, mineral stages and paragenesis of uranium mineralization. (After Kolektiv 1984)**



is often metamict or decayed into quartz and uranium oxide. Coffinite is intergrown with sphene and apatite. Pitchblende associates with later carbonates and quartz. U^{6+} minerals occur in zones of supergene influence.

Post-uranium-ore stage minerals include several generations of calcite, dolomitized calcite, hydromuscovite-montmorillonite, some quartz, and minor Fe-, Cu-, Pb- and Zn sulfides. Strongly altered vesicular rocks contain gas composed of 90–95% N, 1.1% Ar, and Rn and CO_2.

Shape and Dimensions of Deposits

Uranium mineralization is hosted by the Radouň Main Fault, associated subsidiary fractures and adjacent cataclastic ground, which combined are commonly 2–3 m wide but expand up to 7 m at bends and branchings of structures.

Ore shoots, composed of disseminated uranium minerals, minor fissure fillings, and rarely veins, are discontinuously distributed over a length of almost 3 000 m along the Radouň Fault, and extend to a drill-intercepted depth of approximately 600 m. In vertical projection, ore occurs in irregular intensity and distribution within a single mineralized zone. Ore shoots are elongated along structural planes, have gradational contacts and a complex texture. The core is commonly high grade fading out towards the boundaries (Figs. 3.45 and 3.46).

Geochronology

U/Pb systematics of pitchblende (61.39% U) yield an age of 247 Ma, while Pb-isotope ratios of galena give slightly older ages of 250 to 280 Ma (Kolektiv 1984).

Ore Controls and Recognition Criteria

Mineralization at Okrouhlá Radouň is supposedly of non-granite-related vein type. Ore-controlling and/or recognition criteria include structural, petrologic, and mineralogical features including

- a major N–S-trending, medium-steep to steeply dipping fault,
- complication of this fault by branching and feathering at both ends of the deposit,
- positioning of uranium ore shoots at horizontal and vertical changes in attitude of faults and where subsidiary fractures occur,
- apophyses and horizontal sills of granite and gouge-filled fractures acting as impermeable barriers,
- ore shoots confined to cataclastic, altered intervals,
- uranium associates spatially and paragenetically with intervals of older chloritization and pyritization,
- uranium mineralization in granite restricted to cataclastic zones cutting xenoliths of altered, highly chloritized paragneiss,
- correlation of uranium with albitization (in granite) and older hydromicazation.

Metallogenetic Aspects

Metallogenesis at Okrouhlá Radouň is not clearly understood. Isotopic ages of galena and pitchblende suggest that the principal metallogenetic event occurred about 265 Ma ago during the Saalian phase of the Hercynian Orogeny. Later redistribution of uranium presumably took place during Alpidic time. It is speculated that these ore-forming processes were similar to those in the West Moravian uranium region (see Sect. 3.5 *West Moravian Region*).

Fig. 3.45. Okrouhlá Radouň, planview and W–E cross-sections through the Radouň Main Fault with details of uranium distribution. (Kolektiv 1984)

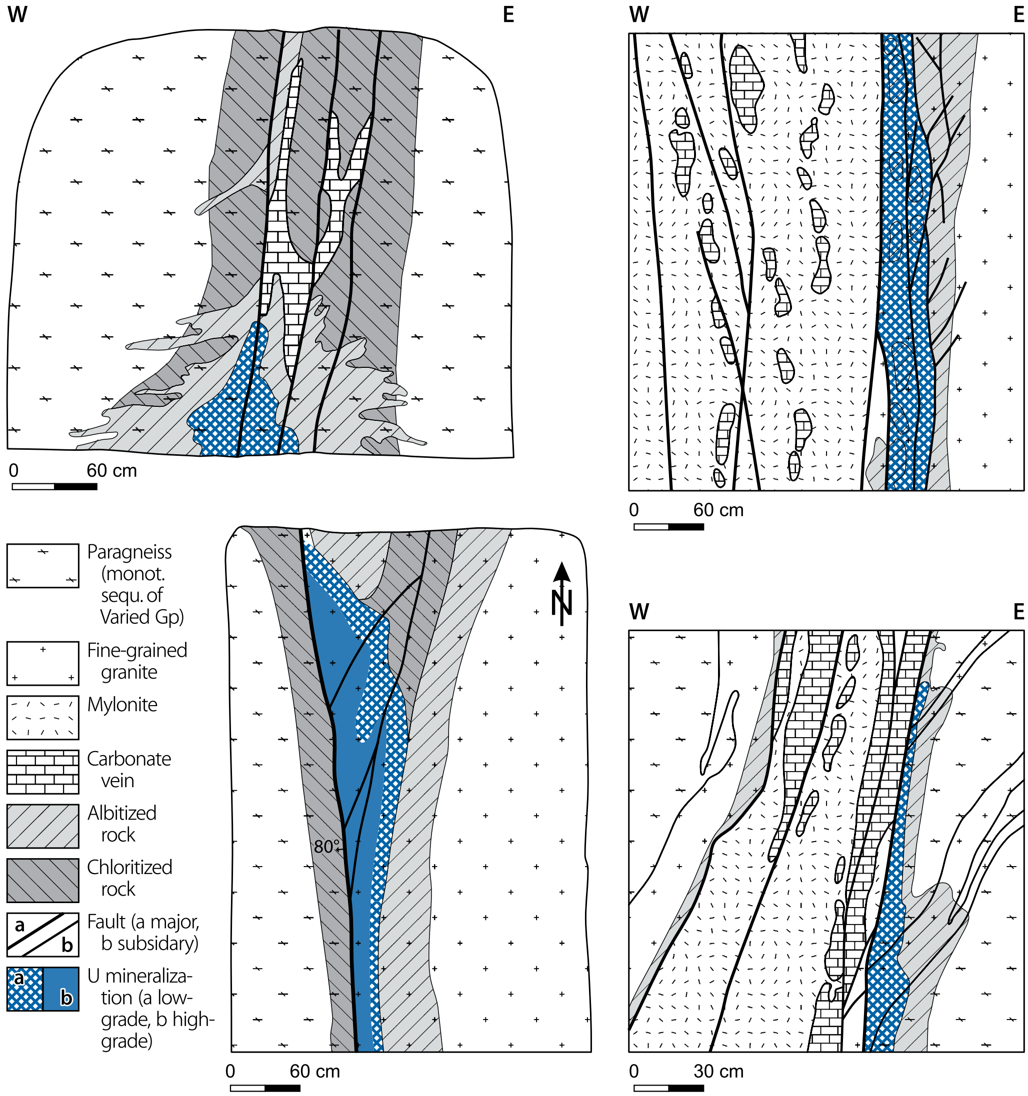
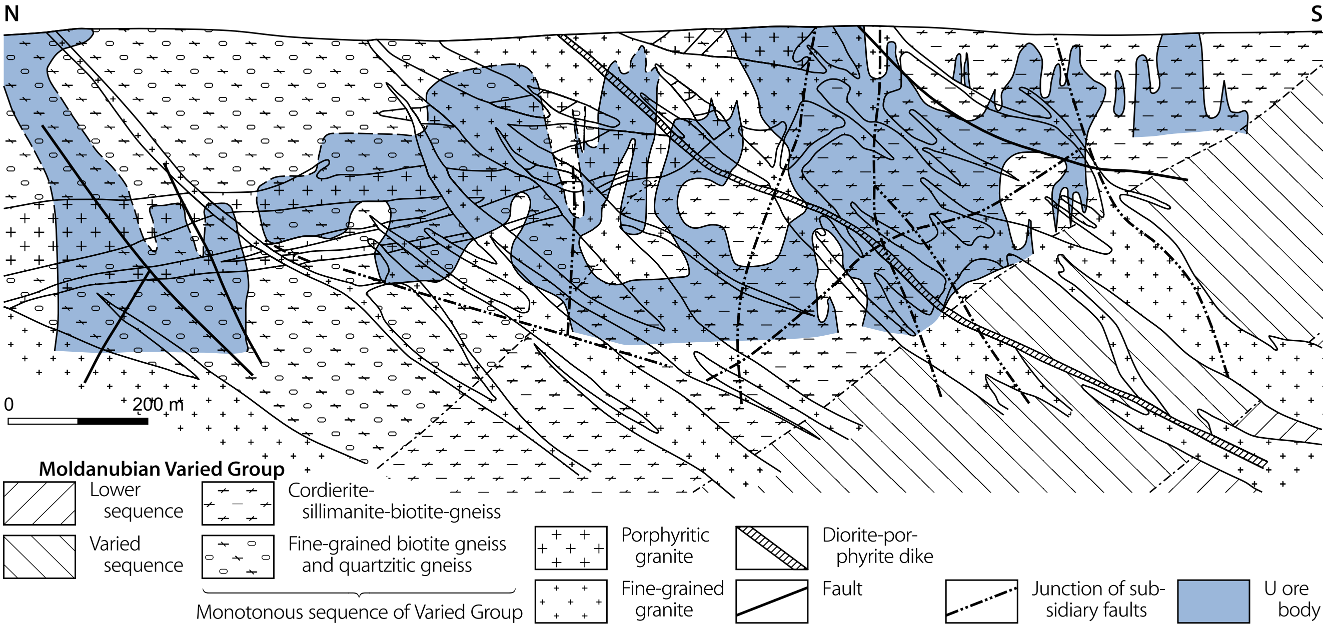


Fig. 3.46. Okrouhlá Radouň, longitudinal N–S section with vertical projection of uranium mineralization along the Radouň Main Fault. (After Kolektiv 1984)



3.7 Westsudetic-Silesian Region, East Bohemia

The Westsudetic-Silesian zone is the southeastern extension of the Saxo-Thuringian metallotectonic domain. It straddles the border between Bohemia, Czech Republic, and Silesia, Poland. A number of vein and strata-bound uranium occurrences and a few small deposits are known on both sides of the border, e.g., the polymetallic uranium deposits Kowary (Schmiedeberg) and Kletno in Poland. In the Bohemian sector, vein-type uranium mineralization is known in the *Rychlebské hory (Reichensteiner Gebirge)*, *Orlické hory*, and *Krkonoše Mountains (Riesengebirge)*. The intermontane *Intra-Sudetic* or *Žacléř-Svatoňovice Basin* contains uranium associated with coal-bearing arenaceous beds of Permo-Carboniferous age (➲ Fig. 3.1).

Sources of information. Kolektiv (1984), pers. commun. by Pluskal O, CSUP/DIAMO staff.

3.7.1 Rychlebské Hory-Orlické Hory District, East Bohemia

The Rychlebské hory (Reichensteiner Gebirge/Mountains) and Orlické hory (Adlergebirge) are part of the southeastern Sudetes. Reported uranium occurrences include *Bilá Voda*, *Jelení vrh*, *Velká Morava*, and *Zálesí-Javorník* in the Rychlebské hory, and *Kamenec*, *Klášterec*, *Mladkov*, *Nebeská Rybná*, and *Říčky* in the Orlické hory. Mining operations were conducted at Zálesí-Javorník and Kamenec.

Regional Geological Setting of Mineralization

Uranium mineralization occurs within the core of the Orlické hory Block or Dome, which is composed of metasediments, orthogneiss, and migmatite of the Proterozoic Stron Series. Dikes and stocks like the Javorník Granodiorite were intruded into the series. Numerous deformation zones often characterized by shearing and diaphthoresis developed along the contact between ortho- and paraseries. Vein-type uranium mineralization accumulated at flexures and intersections of structures within metasediments.

The eastern part of the dome, which forms a portion of the Rychlebské hory, hosts the Zálesí-Javorník deposit and Jelení vrh occurrence in the Travno-Ladek Member of the Stron Series. Uranium occurrences in the western part of the dome (Orlické hory) such as Kamenec and Říčky are found in metasediments of the Zaklety Series.

3.7.1.1 Zálesí-Javorník Deposit, East Bohemia

This deposit is located about 40 km north of the town of Sumperk. It is a structurally-controlled deposit, which produced 405 t U at a mining grade of about 0.1–0.2% U.

Geology and Mineralization

The Zálesí-Javorník deposit is hosted by a sequence of biotite, garnet-biotite and two-mica schists, gneiss with intercalated quartzite layers, marble, and calc-silicate rocks of the Travno-

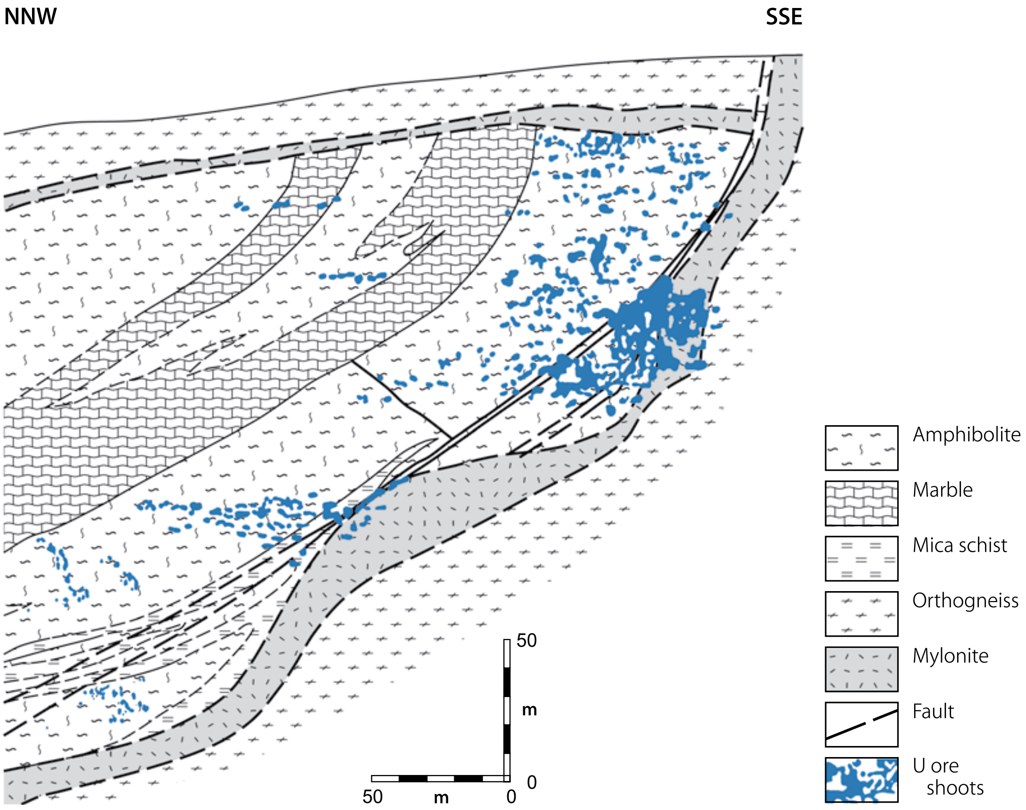


Fig. 3.47. Zálesí, NNW–SSE cross-section showing the setting of uranium mineralization controlled by a mylonite zone and amphibolite. (After Kolektiv 1984)

Ladek Member/Stron Series. This sequence forms a small E–W-elongated syncline within orthogneiss. A marked, E–W-trending and N-dipping mylonite zone marks the southern contact of metasediments against orthogneiss. NW–SE and N–S-oriented, easterly dipping faults cut metasediments in the hanging wall of the mylonite zone. Fractures, from a few tens of meters to 500 m long, and 20–30 cm, rarely 1 m wide, are largely filled with cataclastic material derived from transected wall rocks, but they also contain uranium mineralization.

Three mineral assemblages have been identified: quartz-sulfide-dolomite, carbonate-pitchblende, and carbonate-arsenides. Uranium occurs as pitchblende and sooty pitchblende, and in oxidized zones as uranium micas. Sulfides are predominantly Cu-, Fe-, Pb-, and Zn minerals. Ni- and Co arsenides, and native silver are sporadically present. Gangue minerals include several generations of quartz and carbonates.

Uranium mineralization occurs in cataclastic fracture fill, in which it is restricted to metasedimentary intervals. Amphibolite and calcareous schists are favored host rocks. Ore minerals occupy fine joints, which group to stockworks forming columnar ore shoots in faults in the hanging wall of, and within about 50 m of the prominent mylonite zone (➲ Fig. 3.47). Mineralized columns extend for several hundred meters in depth plunging northerly, roughly parallel to the inclination of the mylonite zone. Copper mineralization (chalcopyrite with some chrysocolla and malachite) occurs in shallow dipping ore bodies in marble.

3.7.2 Krkonoše Mountains (Riesengebirge) District, East Bohemia

The Krkonoše Mountains (Riesengebirge) form the northwestern part of the Sudetes in northeastern Bohemia at the border with Poland (➲ Fig. 3.1). Vrohlab is a major town in the southern foothills of these mountains.

Some fifteen perigranitic uranium occurrences with mineralization similar to Iberian-type uranium deposits were explored in the 1950s. Some small deposits were mined in the 1950s including *Medvědin* (24 t U production), *Labská/Přehrada* (17 t U), *Harrachov*, and *Přichovice*; total production was less than 100 t U.

Geology and Mineralization

Neoproterozoic–Lower Paleozoic metamorphic rocks, that mantle the Hercynian Jíserské hory-Krkonoše (Isergebirge-Riesengebirge) granitic massif, host uranium mineralization in the exocontact zone of the intrusion. Three zones with uranium mineralization are discerned.

The *first* or *mica schist zone* spreads along the southern side of the granitic massif. The Medvědin and Harrachov deposits occur within the inner contact-metamorphic aureole. Host rocks are schistose hornfels, amphibolite schist, biotite schist, and phyllite with quartzitic and calc-silicate intercalations. Aplite dikes up to 500 m long are common. Argillization, chloritization, silicification, and limonitization affected the host rocks.

Uranium mineralization is controlled by three fault sets oriented NW–SE, dipping 55–85° SW, NE–SW/30–50° NW, and E–W/70–80° N. These structures are filled predominantly with gouge, three generations of quartz, and subordinate amounts of younger carbonates. The amount of carbonates increases at depth. Uranium occurs in small ore shoots a few centimeters wide and up to a few meters long and deep, mostly at flexures and at intersections of host faults.

Uranium occurs as pitchblende and, in weathered zones, as U^{6+} phases including sooty pitchblende. *Associated minerals* include arsenopyrite, chalcopyrite, galena, and nickeline.

The *second* or *phyllite zone* contains the Přichovice and *Rádlo* occurrences at the southwestern margin of the granitic massif. Host rocks are Ordovician phyllite intercalated with quartzite and mica schist adjacent to two-mica granite. NW–SE-oriented fractures contain quartz-pitchblende veinlets.

The *third zone* accommodates the Labská/Přehrada deposit, which is hosted by mica schist, graphitic phyllite, and orthogneiss. Uranium mineralization occupies N–S- and E–W-oriented narrow joints and shears, which are up to several meters long. These structures are associated with N–S-trending faults that follow the metasediment-orthogneiss contact. These faults are filled with rock fragments and two generations of quartz. Chloritization, pyritization, sericitization, and silicification altered wall rocks of mineralized fractures. *Uranium minerals* are pitchblende and, near surface, uranium silicates.

3.8 North-Bohemian Cretaceous Basin

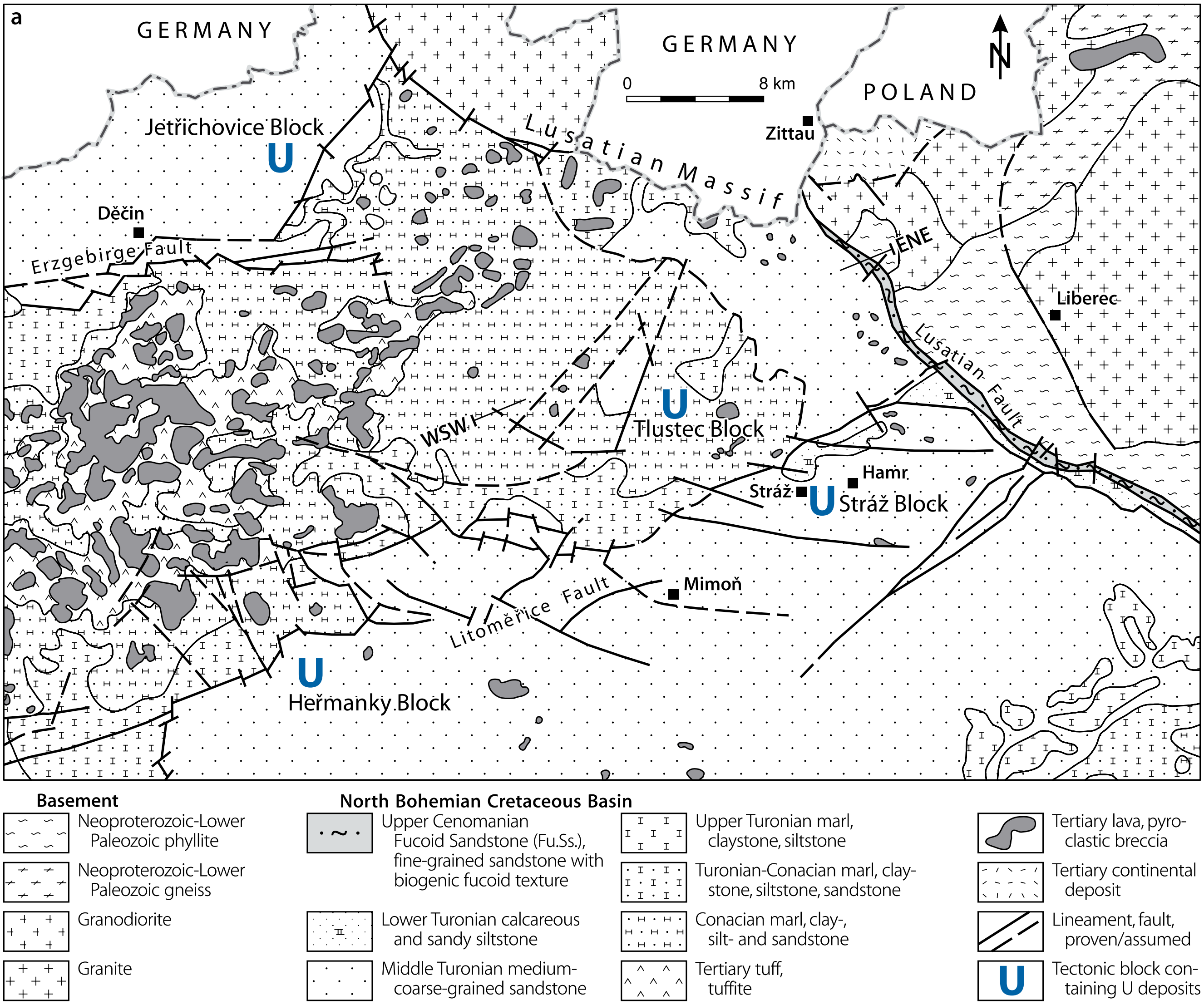
This uranium region is located in northern Bohemia, 80–100 km north-northeast of Prague (➲ Fig. 3.1). The first uranium indications were discovered in 1963. Four districts are known, separated by regional faults and therefore referred to as blocks: *Stráž*, *Tlustec*, *Heřmanky*, and *Jetřichovice* (➲ Fig. 3.48).

Uranium deposits in the North-Bohemian Basin are predominantly of tabular sandstone type and display characteristics of basal-channel-type mineralization. Some roll-type deposits also occur.

Potential in-situ resources of the region are in excess of 200 000 t U. The grade varies considerably between <0.03% U (cutoff grade) and 1% U, locally higher. Approximately a third of the resources grade less than 0.03% U. Mining was restricted to the Stráž Block (see further below).

Sources of information. Anderson et al. (1985), Beneš and Slezák (1997), Čadek (1980), Čadek et al. (1975, 1979), Fiedler and Slezák (1993, 1995), Hrádek (1995), Kolektiv (1984), Novák and Vavřín (1980), OECD-NEA/IAEA (1994, 1996, 1998, 2000, 2008), Scharm (1991), Scharm (1991), Scharm et al. (1978, 1980), Slezák (1995), Šorf and Kozyrev (1984), Šorf et al. (1987), Syka et al. (1978), pers. commun. by Komínek J, Kühn P, Šenkerik M, and other staff of CSUP/DIAMO, unless otherwise cited.

Fig. 3.48.
North Bohemian uranium region, generalized geological map showing the geotectonic setting, regional faults, and uranium districts (termed blocks) of the northern part of the Bohemian Cretaceous Basin. (After Kolektiv 1984)



Regional Geological Features of the North-Bohemian Basin

The North-Bohemian uranium region occupies the northern part of the Bohemian Cretaceous Basin and adjacent areas. An appendage of the basin extends northward into Saxony, Germany, where uranium was also mined (see Sect. 7.3.1 *Elbtal Zone*). The Cretaceous Basin in northern Bohemia is surrounded to the east, north, and northwest by metasediments and a variety of igneous rocks including granites of the Hercynian chain (West Sudetes-Lusatian Massif-Erzgebirge, from E to W), which also constitute a large part of the basement. Sediments and metasediments of Proterozoic and Paleozoic age provide the frame and basement for the western and southern part of the basin (Fig. 3.48).

Major uranium deposits are clustered in the northern part of the basin. This part is heavily deformed by two intersecting lineaments, the NW–SE-oriented Labe (Elbe) and the NE–SW-trending Erzgebirge Lineament. Repeated tectonic activity including block faulting affected the basement and platform cover, influenced the deposition of Cretaceous sediments, Tertiary volcanism, hydrogeology, and evolution of uranium mineralization.

3.8.1 Stráž Block, North Bohemian Basin

The Stráž Block covers ca. 230 km^2 in the eastern part of the North Bohemian uranium region. Deposits include (from NE to SW) *Křižany*, *Břevniště*, *Osečná-Kotel*, *Hamr North* and *South*, *Holičky*, *Stráž*, *Srní Potok*, *Pavlín*, *Mimoň*, *Vranov*, and *Hvězdov* (Fig. 3.49). Stráž and Hamr are the largest deposits accounting for over half of the about 90 000 t U original proven and estimated reserves of the Stráž Block.

Fig. 3.49.

Stráž Block, geological map with principal lithologies, structural pattern, and location of uranium deposits. (After Kolektiv 1984)

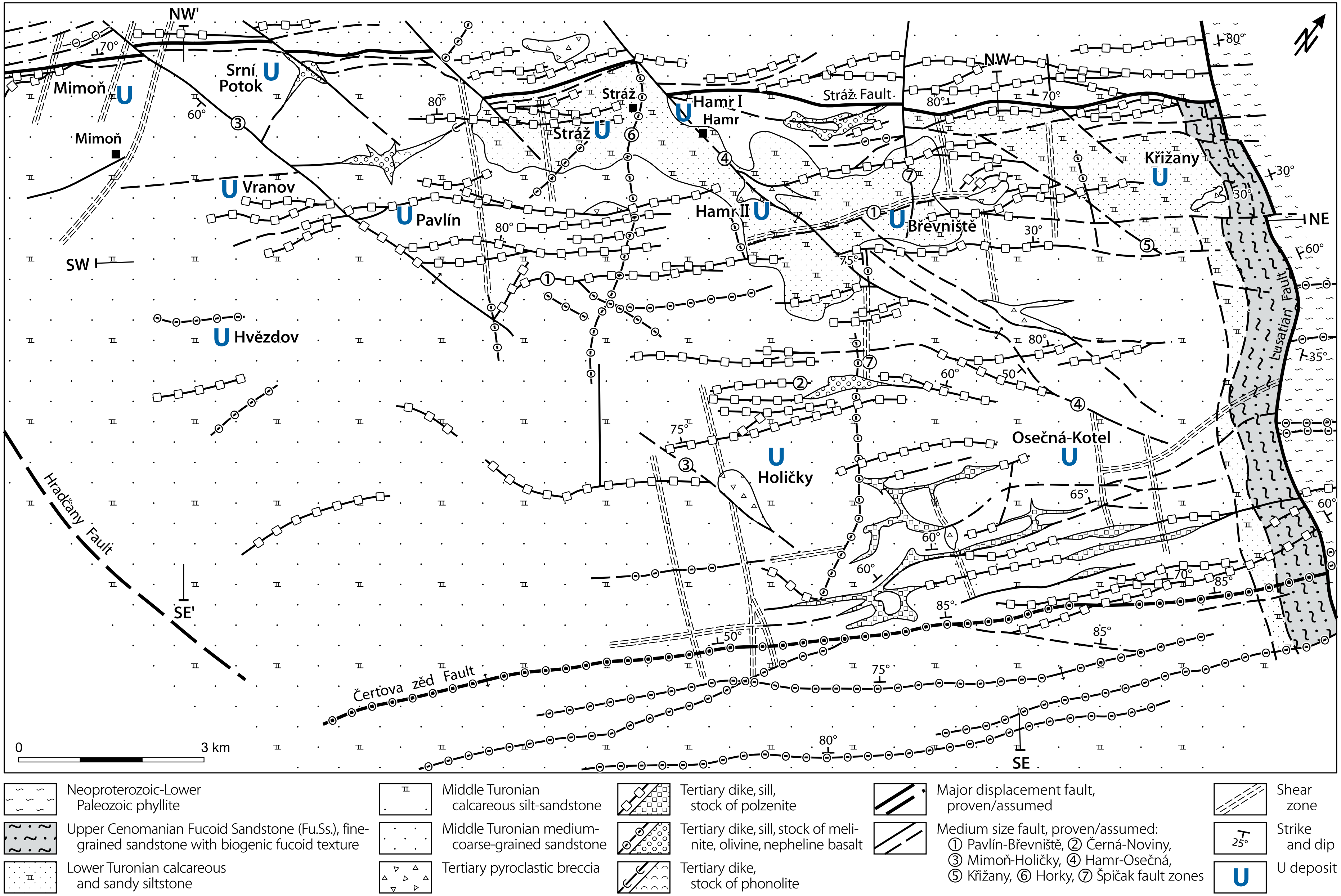
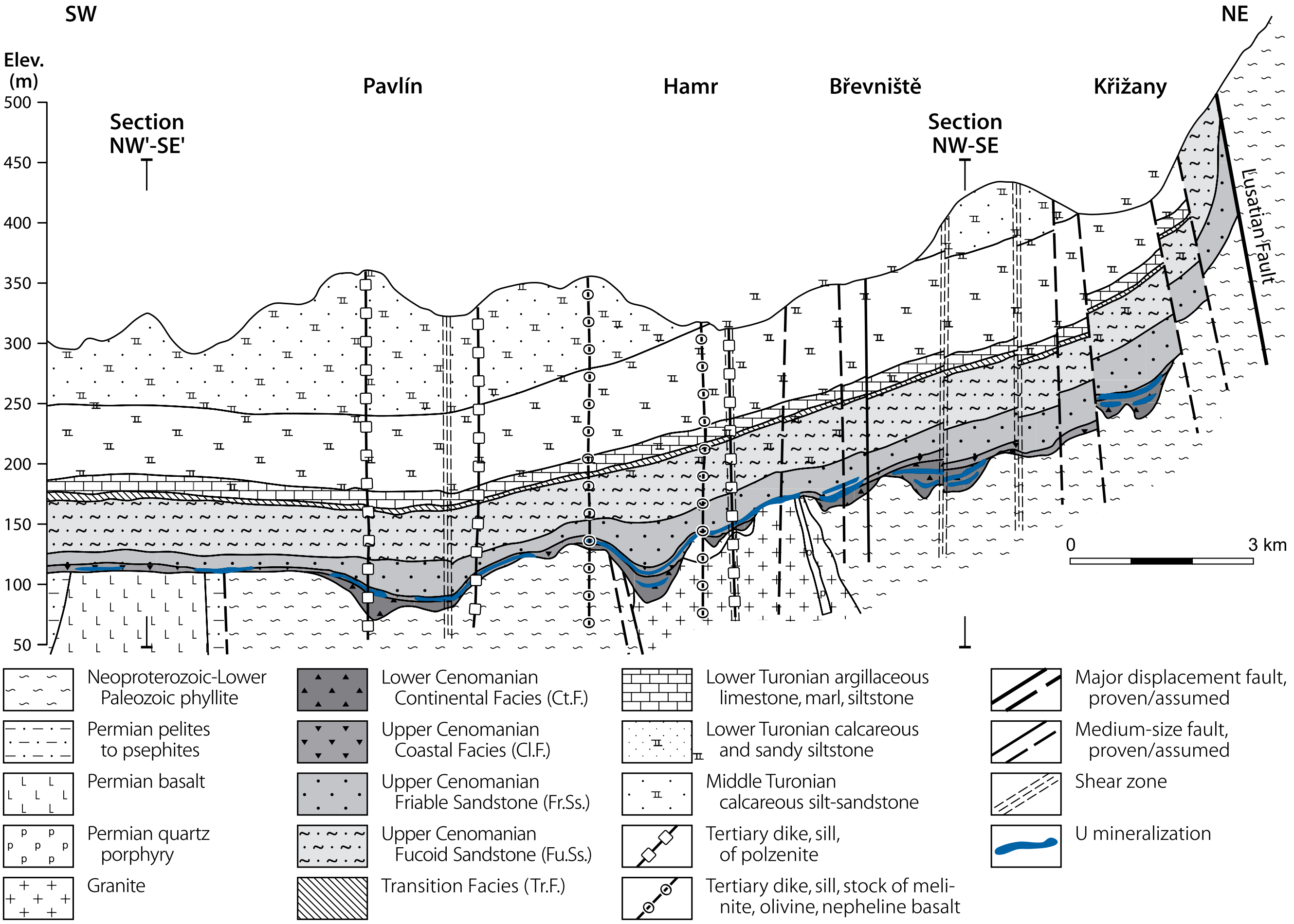


Fig. 3.50a.
Stráž Block, simplified SW–NE section with position of uranium deposits projected into the profile. See Fig. 3.49 for position of sections and deposits. (After Kolektiv 1984)



Almost 32 000 t U were recovered through 2011 including 17 522 t U by ISL and rehabilitation of well fields since 1996. Mining grades averaged 0.09–0.12% U at a cutoff grade of 0.03% U. About 25–30% of the reserves in the Stráž and Hamr deposits grade over 0.2% U. Conventional underground mining (150 to 250 m deep) at Hamr lasted from 1967 to 1993 and at Břevniště from 1983 to 1990; production totaled about 13 100 t U. ISL techniques have been applied at the Stráž deposit since 1967 and produced ca 17 500 t U through 2009. All underground mining had ceased by 1993, while the Stráž ISL facility continued uranium production on a reduced basis within a rehabilitation program for the contaminated ISL fields. A hydrometallurgical mill operated near Stráž from 1973 to 1993.

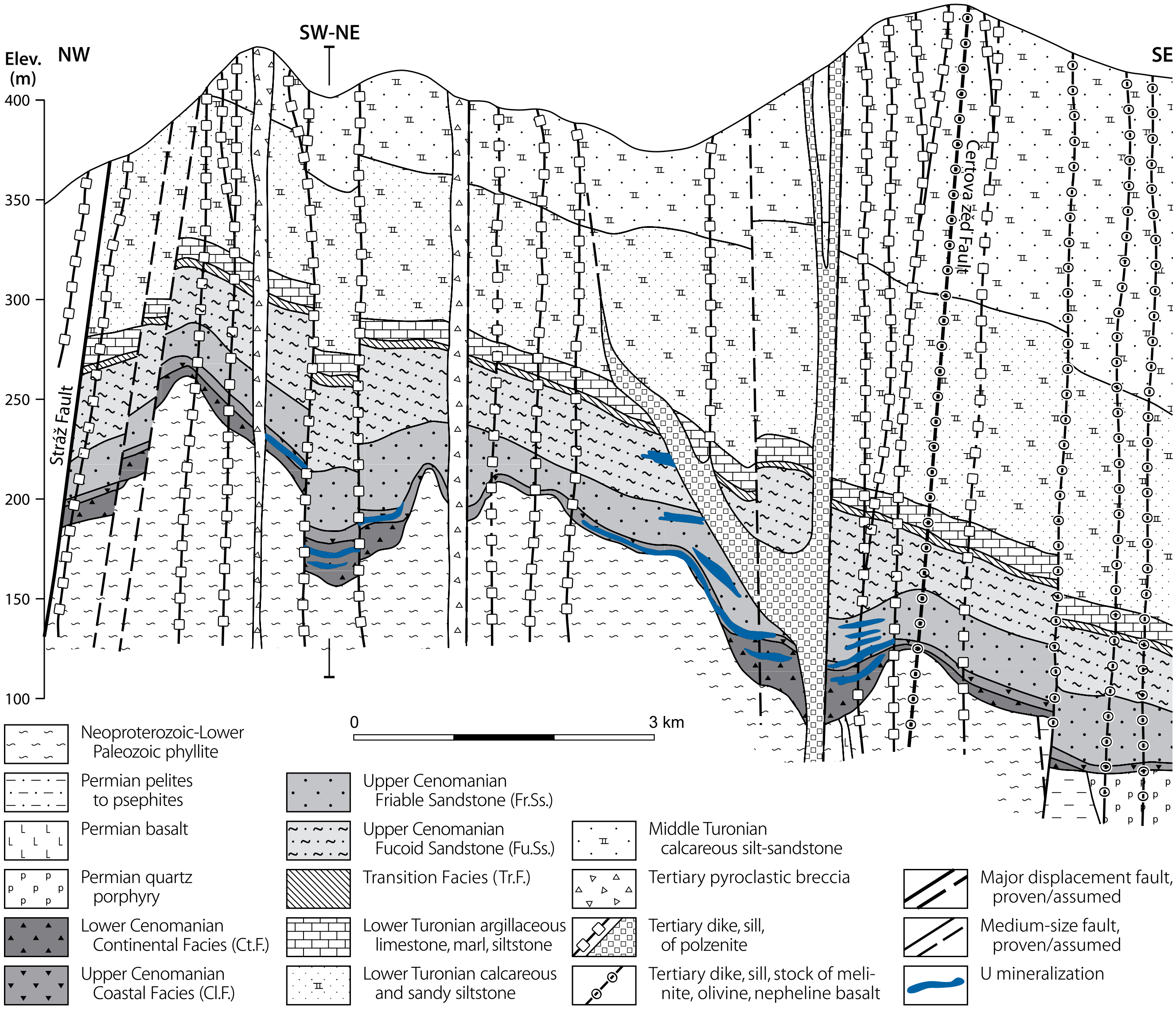
Regional Geological Setting of Mineralization

The Stráž Block is bounded by branch-faults of the NW–SE-trending Labe (Elbe) and the NE–SW-oriented Erzgebirge Lineament. All sides of the block are bordered by downfaulted blocks of Mesozoic sediments except for the northeast side, which is formed by the crystalline Lusatian Massif (Figs. 3.48 and 3.49). The basement of the Cretaceous basin consists of Upper Proterozoic and Hercynian igneous rocks including granites, Neoproterozoic–Lower Paleozoic metasediments of Sudetic facies, Permian clastic sediments (arkose, sandstone, etc), and Permian felsic to mafic volcanics (Fig. 3.50a–c). The Lusatian Massif provided most of the Permian, Cretaceous, and younger sediments and also controlled the hydrodynamics in the Stráž Block i.e., sediment transport and groundwater flow was essentially from the northeast. Prior to the Cretaceous sedimentation, intense weathering affected crystalline rocks as reflected by regolithic alteration more than 50 m deep below the Mesozoic paleounconformity.

The pre-Cretaceous unconformity has, in general, a 2–4° SSW inclination but displays an undulating relief of commonly NE–SW- and NW–SE-oriented erosional-structural lows separated by elongated elevations. This is particularly the case in the northern and central part of the block, where the Břevniště, Osečná-Kotel, Hamr, Stráž, and Holičky deposits are located. The largest depressions are up to 10 km long, 2.5 km wide, and generally less than 15 m deep except for paleovalleys in the northern Stráž Block, which can be as much as 70 m deep. This pre-Cenomanian paleorelief and perhaps also synsedimentary tectonism influenced Cenomanian sedimentation. Large,

Fig. 3.50b.

Stráž Block, NW–SE section across the northeast part of the block. Numerous faults and Tertiary dikes and sills cut the Cretaceous sequence. Uranium ore bodies occur in all Cenomanian facies, particularly above paleodepressions. See Fig. 3.49 for position of sections and deposits. (After Kolektiv 1984)



homogenous brachyformal structures with a NE–SW axis attest to this impact.

Turonian and Cenomanian sediments of the Stráž Block are between 150 and 350 m thick (average 220 m), whereas Cretaceous sediments in the downfaulted Tlustec Block to the NW of the Stráž Block achieve a thickness of as much as 700 m. Cenomanian sedimentation began with continental sediments followed by marginal marine deposits. Turonian sedimentation occurred in a shallow sea. Coniacian sediments rest upon the Turonian in the Tlustec Block. Quaternary fluvio-glacial sediments, up to 10 m thick, of redistributed Turonian material occupy depressions along surface water courses.

A lithostratigraphic section of Cretaceous strata includes, on a regional scale, the units listed below, while Fig. 3.51 depicts the local lithostratigraphic situation at the Stráž deposit.

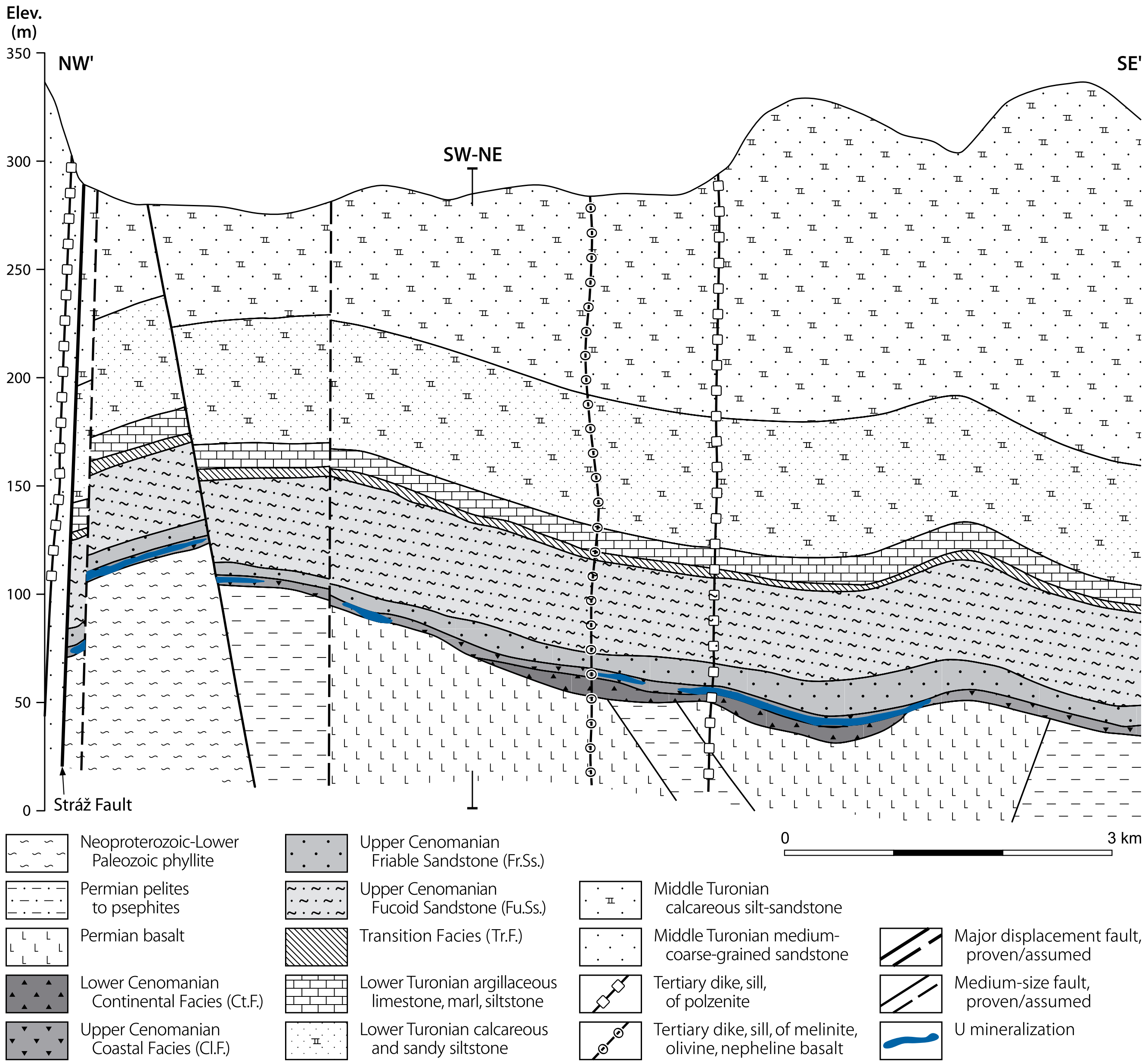
Middle Turonian: 10–150 m thick, alternating thin claystone, siltstone, and gravel beds topped by consolidated, grey to tan, coarse-grained, blocky sandstone.

Lower Turonian: up to 100 m thick, marl, clay, and siltstone grading downward into argillaceous limestone.

Cenomanian lithologies are divided into a transitional, littoral to shallow marine, and continental unit:

- *Transitional Facies* (Cenomanian–Turonian, up to 4 m thick): Argillaceous siltstone with belemnites rests with distinct contact upon the Fucoid Sandstone.
- *Littoral to Shallow Marine Facies* (Upper Cenomanian): Three subfacies, cumulatively 50–130 m thick with greatest thickness in the north, are distinguished: Fucoid Sandstone,

Fig. 3.50c.
Stráž Block, NW'–SE' section across the southwest part of the block. Uranium ore bodies here are essentially confined to the Lower Cenomanian Continental Facies. See Fig. 3.49 for position of sections and deposits. (After Kolektiv 1984)

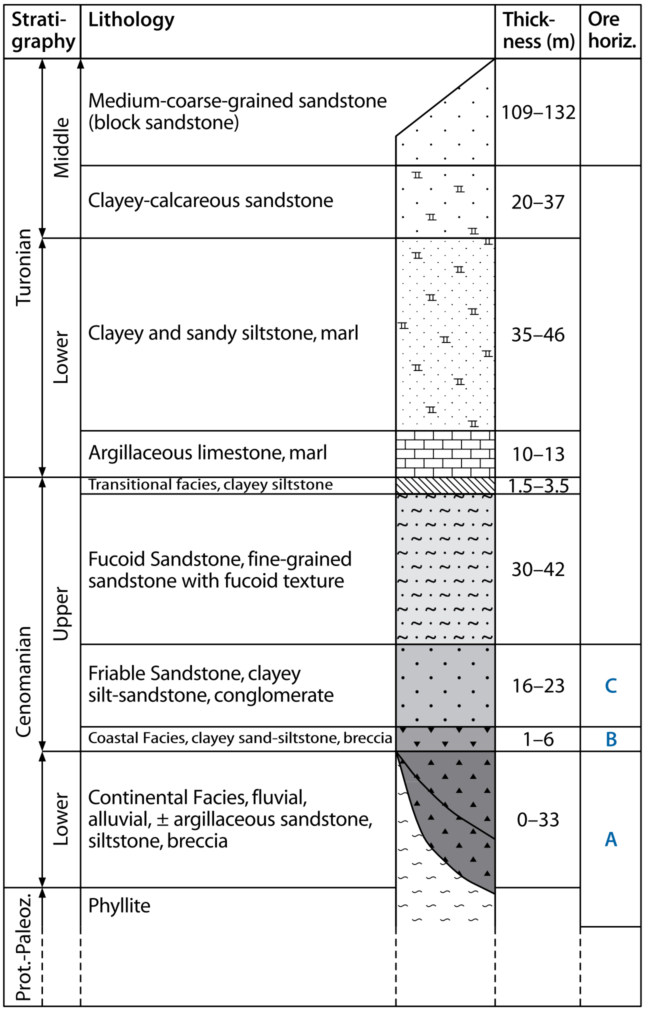


Friable Sandstone, and Coastal Subfacies.

- *Fucoid Sandstone* (10–65 m thick, thinning southwards): monotonous, fine-grained sandstone with weakly developed bedding and a typical biogenic Fucoid texture, which suggest deposition in a calm shallow sea. The clay content in sands and thin (maximum 2 m thick) silt and clay beds increases in the southern portion of the block. The Fucoid Sandstone occurs throughout the Stráž Block and rests with a relatively sharp contact on the Friable Sandstone unit;
- *Friable (or Crumble) Sandstone* (up to 70 m thick, thinning towards southwest): Lithologies range from sandy siltstone to sandy conglomerate deposited in alternating beds during two to three cycles in a shallow sea. Medium-grained, sorted, friable/crumbly sandstone predominates. These sediments rest conformably upon the Coastal Subfacies and cover almost the whole block except in the southwest and northwest where lagoonal facies prevail;
- *Coastal Subfacies* (1–10 m thick): siltstone, sandstone, and breccias of coastal beach, barrier, lagoonal, and deltaic provenance; organic material is ubiquitous and imposes a blackish color on the rocks. This subfacies occurs throughout the Stráž Block. A basal unit, termed "Washout Horizon", occurs locally with a thickness of up to 25 m. It overlies continental Cenomanian in the center of subbasins and on paleoweathered basement on flanks of depressions.

- *Continental Facies* (Lower Cenomanian/Albian?): About one third of the Stráž Block is intermittently underlain by eluvial, alluvial, and lacustrine sediments, 5–15 m thick in broad depressions, and exceptionally up to 70 m thick in some paleovalleys. The latter prevail along fault zones in the northern part of the block. The following lithologies make up the Continental Facies:
  - The top of the Continental Facies is composed of dark-grey to black, well-bedded lacustrine pelites and psammites, containing substantial quantities of carbonaceous matter partly as coalified and pyritized roots and plant fragments;
  - grey fluvial/alluvial psammites deposited by low-energy streams in the form of NE–SW and NW–SE-elongated lenses, which are up to 5 m thick and cover about 10% of the area.
  - a grey facies, as much as 20 m thick, composed of light-grey to black, unsorted, and unbedded breccias, conglomerate, and minor sand- and siltstone. Carbonaceous matter is abundant;
  - a basal dark-red breccia with minor argillaceous sand- and siltstone, up to 15 m thick.

Fig. 3.51.
Stráž Block, diagrammatic lithostratigraphic section at the Stráž deposit. (After Šenkerik M, pers. commun.)



Stratigraphy		Lithology	Thickness (m)	Ore horiz.
Turonian	Middle	Medium-coarse-grained sandstone (block sandstone)	109–132	
		Clayey-calcareous sandstone	20–37	
	Lower	Clayey and sandy siltstone, marl	35–46	
		Argillaceous limestone, marl	10–13	
Cenomanian	Upper	Transitional facies, clayey siltstone	1.5–3.5	
		Fucoid Sandstone, fine-grained sandstone with fucoid texture	30–42	
		Friable Sandstone, clayey silt-sandstone, conglomerate	16–23	C
		Coastal Facies, clayey sand-siltstone, breccia	1–6	B
	Lower	Continental Facies, fluvial, alluvial, ± argillaceous sandstone, siltstone, breccia	0–33	A
Prot.-Paleoz.		Phyllite		

Other tectonic blocks in the North-Bohemian Cretaceous Basin contain Upper Cenomanian to Coniacian pelites and psammites upon which Paleogene–Neogene pyroclastics rest.

Tertiary volcanism is reflected by dikes, sills, and stocks of basalt, carbonatite, polzenite, phonolite, and pyroclastic breccias. Dikes are several decimeters to 10 m, rarely 50 m thick, and 100 m to several kilometers, occasionally up to 15 km long. They group preferentially in NE–SW-oriented major fault zones. A few dikes trend NW–SE and E–W. Peneconcordant sills are 30–50 m thick and laterally extensive. They are spread over an area of as much as 15 km^2 as at the Osečná-Kotel and Holičky deposits.

Brittle deformation occurred repeatedly until the Pleistocene. Major structural systems that are often of step-like arrangement trend NW–SE and NE–SW. Faults of these systems form the border of the Stráž Block but are also common within the block. Other faults trend E–W and some N–S (Figs. 3.48–3.50). Subhorizontal faults are up to 1.5 km long and caused intraformational disruptions. A part of these structures has become the site of dike and sill emplacement as mentioned earlier.

The NW–SE fault system includes the Lusatian Fault, a more than 1 km wide zone of echeloned, 30–80° NE-dipping structures. Crystalline rocks of the Lusatian Massif were uplifted along these structures for an estimated 2 000 m and were thrust southwestward over the Mesozoic sediments (Fig. 3.50a). Baryte-fluorite-pitchblende mineralization was drill intercepted within this fault zone. The likewise NW–SE-oriented Hradčany Fault, which is a branch of the complex Česká Lipa Fault zone, limits the Stráž Block to the southwest.

Two NE–SW-trending regional faults of the Litoměřice Fault zone, which is a branch of the Erzgebirge Lineament, form the NW (Stráž Fault) and SE boundaries (Čertova zěd Fault) of the Stráž Block. The Stráž Fault is a 1 km wide zone, along which Cretaceous sediments of the northwesterly adjacent Tlustec Block are downdropped for 300–500 m. E–W and some NW–SE faults displace the Stráž Fault laterally for more than 1 km. The SE border structure, the Čertova zěd Fault, is a 2.5 km wide zone of steeply dipping echeloned faults. Vertical displacement along individual shears ranges up to a few tens of meters.

Hydrogeology within the Stráž Block is rather complex. Two groundwater horizons are present, one in Turonian and the other in Cenomanian sediments. They are separated by the almost impermeable Transition Facies. Turonian strata contain phreatic groundwater and Cenomanian aquifers contain artesian water. The most prominent Cenomanian aquifer is the Friable Sandstone. Basement rocks contain water along structures particularly in phyllitic units. Structures influence groundwater flow.

Principal Host Rock Alterations

Reducing and oxidizing processes have affected all permeable Cenomanian strata. Several alteration assemblages are recognized. They form partly superimposed zones as documented schematically in Fig. 3.52. Zones influenced by reduction

Fig. 3.52.

North Bohemian uranium region, diagrammatic section illustrating the distribution of alteration zones and uranium mineralization in Cenomanian sediments. Not especially marked is the locally developed washout horizon, which tops the Continental Facies and is a major uranium host. (After Kolektiv 1984)

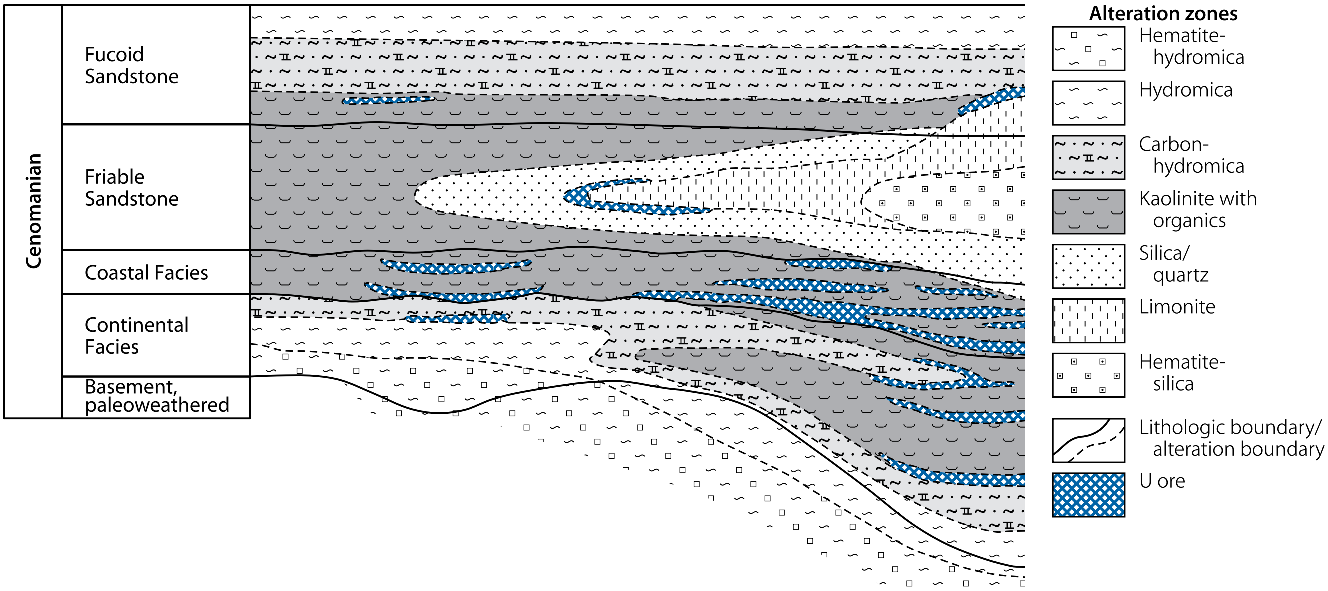


exhibit mineral assemblages of hydromica(-hematite), hydromica-carbon, kaolinite, and silica. Oxidized zones display hematitization, limonitization, and silicification. Alteration zones show the following characteristics:

Hydromica(-hematite) zone. Originally pink and grey, permeable sediments are transitionally altered by authigenic hematite and hydromica (pink sediments), and hydromica (grey sediments) formation. Pink sediments turned to violet in an irregular manner but over wide areas. Where they are completely reduced, they are green to grey-green and depleted in iron. Associated neoformations include some chlorite, kaolinite, quartz, and minor siderite, and pyrite. In impermeable Upper Cenomanian horizons, this alteration phase resulted in the partial to complete decomposition of glauconite in sandy siltstone, and recrystallization of carbonate in silt-claystone. Alteration zones of this type are up to a few meters thick.

Hydromica-carbon zone (with or without pyrite). Several generations of hydromica (hydrosericite) and coaly substance (anthraxolite) form several paragenetic associations. Most widespread are 0.1–0.5 mm thick stringers of fine-flaky mica associated with a lusterless, black organic substance, which are found in interbedded fine-grained sandstone and siltstone. Anthraxolite contains minute disseminations of microglobular uranium minerals (<1 vol.-%), galena, pyrite, sphalerite, and kerite-type coaly matter. This alteration assemblage typically occurs in Coastal and Continental Facies with high fractions of plant remains. The authigenic phases concentrate locally in 1–3 m thick zones at the base of impermeable intercalations within the Continental Facies. Increased tenors of uranium and pyrite are present in the vicinity of clay-siltstone intercalations. Consolidated rocks affected by this type of alteration are commonly black. The hydromica-carbon zone grades transitionally into the hydromica zone.

Kaolinite zone. Kaolinitization preferentially affected water-bearing horizons. Carbonate, hydromica, and finely disseminated pelitic material are almost completely destroyed. Rocks in this zone are vuggy, friable, and bleached. The iron content is very low. Authigenic kaolinite concentrates at interbed faces and as radial precipitates. Anatase, metacolloidal zircon, pyrite, and pitchblende often replace rims and cleavages of kaolinite. Pyrite occurs as porphyroblasts. Drop-shaped anthraxolitic material is common in kaolinized cataclastic zones. Silicification is noticed in kaolinized sediments. Kaolinitization is conspicuous in Cenomanian sediments but its intensity varies with rock composition and deformation.

Silica zone. Silicification affected the most permeable lithologies and particularly the Friable Sandstone. Matrix material is leached and detrital quartz grains are corroded. Amoeba-shaped quartz, opal, and chalcedony have formed as replacements of kaolinite, and cement the rock. Columnar quartz overgrowth on detrital quartz grains is most prominent at the interface with kaolinite zone. Hydromica precipitated in cavities. Sediments of the silica zone are porous, cavitied, friable, and light-grey in color. This mode of silicification occurred under reducing conditions apparently in a front ahead of invading oxidizing solutions (Fig. 3.52).

Reducing processes have similarly altered basaltic rocks except where the carbon facies is extremely weakly developed and chlorite is abundant. Some basalts are completely kaolinized.

Oxidation processes were active along and at the boundaries of the groundwater horizons in the Cenomanian and Turonian sediments in the northern segment of the Stráž Block but are lacking in the southern part. Oxidation transgressively overprinted all previous alteration products mentioned earlier and also affected altered basalts. Fe hydroxides (limonite, hydrogoethite) are the principal oxidation products. Organic material is completely removed, but relics of U and U-Zr mineralization are still found near pre-existing coaly matter.

Principal Characteristics of Mineralization

Uranium mineralization in the Stráž Block has been classified as peneconcordant sandstone type, but with an unusual association of U-Zr-P-Ti elements (Čadek et al. 1975) and minerals as shown in Table 3.8. The principal *uranium minerals* are black uranium oxides (sooty pitchblende) and metacolloidal uraniferous hydrozircon, while coffinite, gelbaddeleyite, ningyoite, pitchblende, and U-Zr-bearing leucoxene (with 0.6–12.9% U, 0.1–14.4% Zr) occur subordinately. Pitchblende has a lattice constant of 5.380 to 5.394 Å, and black uranium oxides 5.36 Å. Detrital uraniferous minerals include apatite, rutilized sphene, uranothorite, uranium titanates (brannerite, davidite), and zircon.

Associated sulfides are predominantly pyrite, minor bravoite and some CdS, HgS, and ZnS minerals. Phosphate minerals of the crandallite group are scarce but occur ubiquitously throughout the entire district. Thorium, mainly contained in brockite, uranothorite, and very rarely rhabdophane, is present in very low concentration in ore. REE minerals occur in negligible amounts; they include florencite (with Ce, La, Nd), rhabdophane (Ce), and synchysite (Nd). Carbon in various modes is a common ore constituent.

Uranium minerals range in size from 0.001 to 0.01 mm and rarely to 0.1 mm, and occur disseminated as minute grains or colloform masses in the host rock matrix and pore spaces, or as microstringers. Uranium oxides, coffinite, and ningyoite are preferentially found in fine- to medium-grained rocks associated with carbonaceous matter and/or pyrite. Uraniferous hydrozircon prevails in kaolinitic, medium- to coarse-grained sandstone (Čadek et al. 1975; Kolektiv 1984; Scharm 1991).

Quartz is the dominant host rock mineral, and Ti minerals, tourmaline, topaz, and plant remains are prominent detrital accessory constituents. The principal authigenic host rock components are kaolinite, carbonized material, silica/quartz, and pyrite. Table 3.9 provides a summary of allogenic and authigenic minerals and Fig. 3.53 a paragenetic scheme of diagenetic and epigenetic mineral assemblages. Almost all epigenetic phases are present in several generations, for example, pyrite in six generations.

Three uranium mineral assemblages are distinguished: pitchblende-black U oxides, pitchblende-black U oxides-U hydrozircon, and U hydrozircon. These assemblages are grouped into two ore types of simple uranium mineralization (essentially black U oxides) and complex U-Zr mineralization with black uranium oxides/pitchblende-hydrozircon-ningyoite. The latter tends to be restricted to the vicinity of the Stráž Fault.

Pitchblende associates with black uranium oxides, bravoite, coffinite, pyrite, pyritized plant relics, sphalerite, and rarely hydrozircon. This assemblage is preferentially hosted by fine- to coarse-grained pyritic and carbonaceous sandstone and breccias.

Black U oxides associate with marcasite, melnicovite, pyrite, and carbonaceous matter and typically occur in dark, medium- to coarse-grained sediments and slightly kaolinized sandstone containing plant remains, shells, fucoids, and pyrite concretions.

Uraniferous (metacolloidal) hydrozircon is 0.01–0.1 mm in size, has an anhedral to euhedral habit, and an average chemical composition of (in wt.-%): 42.36% ZrO_2, 16.22% UO_2, 14.25% SiO_2, 6.18% P_2O_5, 2.18% CaO, 0.71% Fe_2O_3, 0.69% Al_2O_3, 0.61% Na_2O, 0.60% K_2O, 0.01% TiO_2, 3.06% H_2O, and 12.35% H_2O (Kolektiv 1984). Hydrozircon contains uranium in three modes. Ca. 25% is present as an easily leachable phase, 1–2% is in the lattice, and the remainder occurs as a weakly crystalline, metastable, not yet identified phase, which is liberated only upon complete decomposition of the zircon. This zircon corrodes all clastic and authigenic minerals including pitchblende and pyrite, impregnates hydromica and kaolinite along cleavages, and coats anatase, bravoite, brockite, and pyrite but is dissected by microveinlets of pyrite and compact black uranium oxides. Hydrozircon occurs predominantly in kaolinized sandstone

Table 3.8.
North Bohemian region, ore minerals of the U-Zr-P-Ti association in sandstone-type uranium deposits. (After Scharm 1991)

Uranium mineral	Uraniferous mineral	Zirconium	Phosphate	Titanium
Autunite	Brockite ?	Gelbaddeleyite	Brockite	Leucoxenes s.l.
Black U oxides	Crandallite group	Hydrozircon	Rhabdophane (Ce)	"Mixed gels" with Ti ±Zr ±U
Coffinite	Gelbaddeleyite	"Mixed gels" with Zr ±U ±Ti	Ningyoite	
Ningyoite	Hydrozircon		Crandallite group • Arsenoflorencite (Ce) • Florencite (Ce, La, Nd) • Crandallite • Gorceixite • Goyazite • Plumbogummite	
Pitchblende	Leucoxenes s.l.			
Vyacheslavite	Rhabdophane (Ce)			
Zippeite group	Synchysite (Nd)			
	"Mixed gels" with U ±Zr ±Ti			

Table 3.9.
North Bohemian region, associated minerals in sandstone-type uranium deposits. (After Kolektiv 1984)

Allogenic/sedimentary minerals				Authigenic (not-uranium) minerals			
Clastic			Cementation				
Not-ore	Ore + associated						
Baryte	Anatase	Monazite	Chalcedony	Apatite	Fluorite	Bravoite	Leucoxene
Biotite	Apatite	Rutile	Clay-carbonate with Ba + Sr	Baryte	Gypsum	Brockite	Limonite
Chlorite	Brookite	Staurolite	Fe hydroxide	Brookite	Hydrobiotite	Chalcopyrite	Magnetite
Feldspars	Cassiterite	Titanite	Siderite	Carbonate	Hydromica	Galena	Marcasite
Glauconite	Garnet	Titanomagnetite		Chalcedony	Illite	Goethite	Melnicovite
Muscovite	Gold	Topaz		Chlorite	Kaolinite	Hematite	Molybdenite
Opal	Ilmenite	Tourmaline		Coal, hard bitumen	Montmorillonite	Hydrogoethite	Pyrite
Plant fragments	Kyanite	Uranotitanate		Fine-dispersed coaly matter	Pseudobrookite	Hydrohematite	Sphalerite
Quartz	Leucoxene	Xenotime			Quartz		
	Magnetite	Zircon, malacon			Sericite		

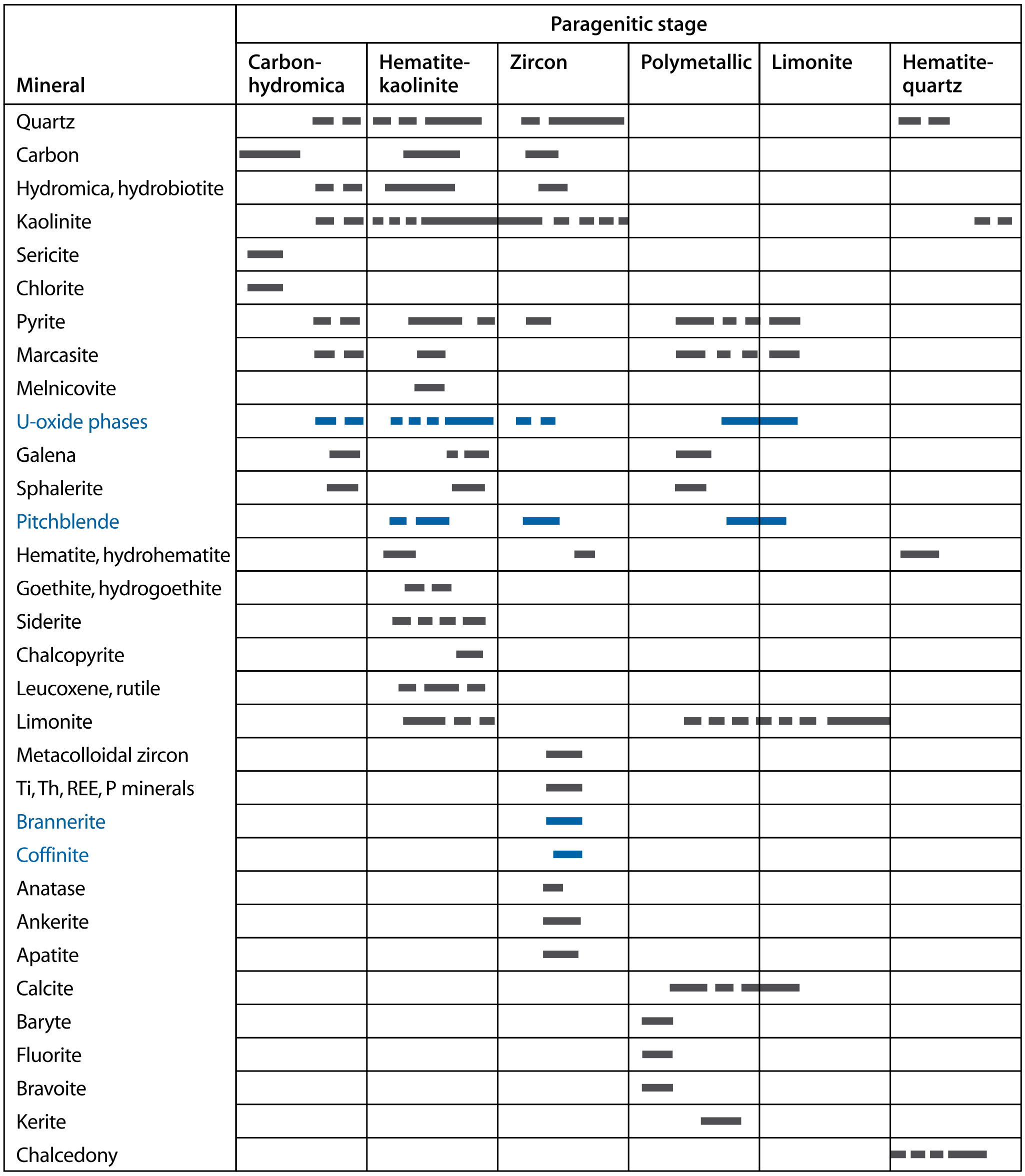
and along oxidized sandstone intervals of the Coastal Facies. Minor amounts are found in argillized rocks of the basement, basalt, and eruptive breccias.

Coaly material associates with marcasite, melnicovite, micrograined pyrite, and dispersed black uranium oxides. It occurs as veinlets and homogenously dispersed in fine-grained sediments and breccias of the Continental and Coastal Facies on which it imposes a black hue. Coaly matter containing uranium is dull, whereas coaly veinlets which are commonly barren of uranium are lustrous. The veinlets cut through coal-enriched rocks. Uranium ore always contains a large amount of coalified plant remains, which are often transected by epigenetic coaly matter.

Six paragenetic stages of mineralization-alteration are documented (Fig. 3.53):

- *Stage 1 – carbon-hydromica*: During sedimentation and early diagenesis, coaly substance, hydromica, and kaolinite associated with minor Fe sulfides, quartz, and uranium oxides formed preferentially in micaceous rocks. Uranium is present as microdispersed uranium oxides which associate with coaly material and leucoxenized Ti minerals. This assemblage is homogeneously disseminated in bands separated by carbonaceous clayey laminae and copies the texture of sediments. Uranium accumulations of this mode are noticeable in the Continental and Coastal Facies, but are absent in other units supposedly due to removal by later processes.
- *Stage 2 – hematite-kaolinite*: Formation of carbonized matter, hydromica, pyrite, and silica followed by marked kaolinitization and some hematitization widely affected both sediments and intrusives. Basaltic dikes are in part completely decomposed to argillaceous rocks. Uranium mineralization of this stage consists of disseminated or bands of black uranium oxides concentrated at the interface of carbon-hydromica alteration zones with hydromica zones, or within kaolinized zones. Processes of this stage played a significant role in formation of complex alteration aureoles found in rocks altered by redox processes.
- *Stage 3 – zircon*: Principal minerals are anatase, hydromica, kaolinite, pyrite, quartz, and metacolloidal, uraniferous hydrozircon. U oxides, coalified organic matter, ankerite, and apatite occur in minor amounts. This assemblage characteristically contains anomalous amounts of Nb, REE, and Th. Economically significant uranium hydrozircon ores were generated during this stage. They occur within kaolinized, variably porous rocks in the central part of stage 3 alteration zones.
- *Stage 4 – polymetallic paragenesis*: Veinlets of Fe-, Pb-, and Zn sulfides, black uranium oxides, pitchblende, baryte, and quartz occur sporadically.
- *Stage 5 – limonitic oxidation*: More recent oxygenated solutions produced, along transmissive horizons, Fe hydroxides, which replace sulfides, penetrate kaolinite and uranium hydrozircon, and impose a tan hue on rocks. Uranium was liberated and redeposited not only at redox boundaries but also ahead of this front within pyrite-rich lithologies. Uranium minerals occur in disseminated form and in irregularly distributed stringers and pockets. Black uranium oxides and coffinite are found as coatings, particularly on aggregates and phenocrysts of pyrite and pyritized plant fragments, which occur near permeable kaolinized sandstone. This type of alteration-mineralization is prominent in sediments hosting uranium hydrozircon ore.
- *Stage 6 – hematite-quartz*: Locally, late processes produced chalcedony, (hydro-)hematite, kaolinite, and quartz.

Fig. 3.53. North Bohemian uranium region, scheme of epigenetic and diagenetic mineral parageneses in Cenomanian sediments. (After Kolektiv 1984)



Elevated uranium values are ubiquitous in altered Cenomanian sediments but are exceptionally high and extensive in kaolinite and carbon-hydromica-altered facies of the lithologically heterogeneous Coastal Facies and lower Friable Sandstone, and to a minor extent in the upper Friable Sandstone, Fucoid Sandstone, and Continental Facies.

Uranium minerals occur as disseminations, pockets, microstringers, and veinlets, most commonly in the form of peneconcordant blankets or lenses, and less often as roll-type or stack-type mineralization in permeable lithologies and at structural inhomogeneities.

Oxidation of Cenomanian strata during stages 5 and 6 resulted in uranium remobilization along the Lusatian, Čertova zěd and Stráž Fault zones. Redeposition took place in the hanging and footwall sections of oxidized layers adjacent to impermeable lithologic contacts and partly in typical rollfront configurations. Concomitantly, uranium was redistributed into fractures of volcanic bodies and small ore pockets in paleoweathered basement.

Alteration of primary pitchblende and black uranium oxides by the advancing oxidation front resulted, ahead of the redox interface and in the presence of pyrite, in precipitation of new uranium minerals upon older uranium phases. This is considered the reason for the chemically complex and mineralogically diverse appearance of uranium mineralization. A characteristic feature of mineralization related to oxidation is the lack of authigenic coaly substance.

General Shape and Dimensions of Deposits

Figure 3.54 shows the location of uranium deposits and distribution of complex U-Zr and simple uranium mineralization in the Stráž and adjacent Tlustec Block. Minable uranium ore in this block is confined to Cenomanian strata. The footwall boundary of the ore-bearing sequence is given by the basement unconformity and the upper limit is set by the impermeable Transitional Facies, which separates Cenomanian

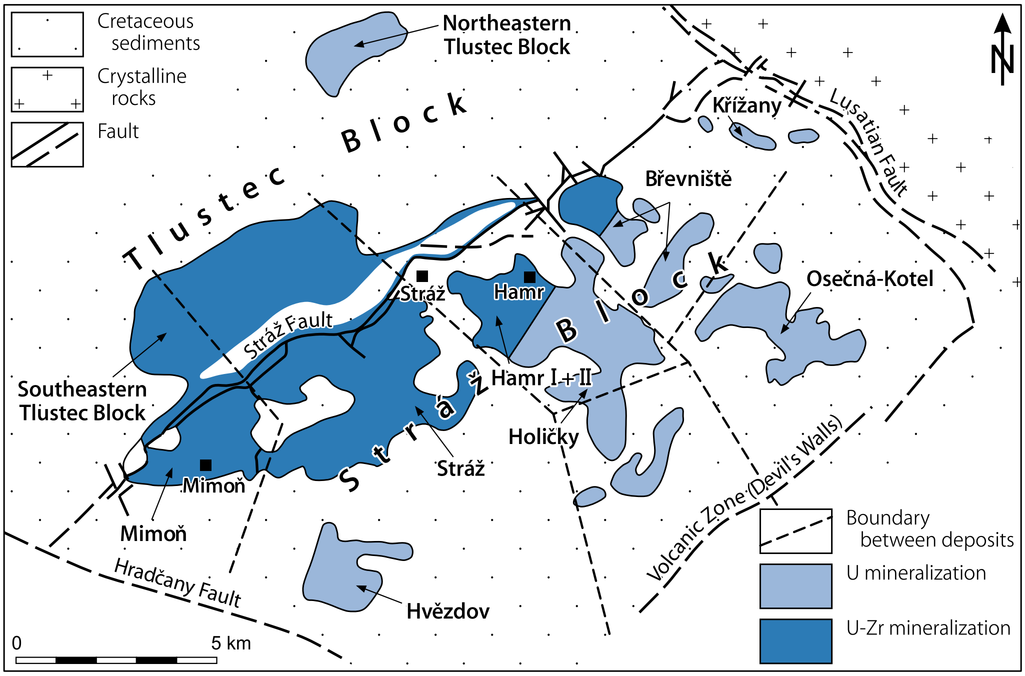


Fig. 3.54. Stráž Block, distribution of complex U-Zr and simple uranium mineralization. (After Scharm 1991)

from Turonian. This section has a cumulative thickness of 100–150 m and occurs at depths ranging from about 150 m in the northern part of the Stráž Block to 300 m in the southern part (Fig. 3.50a–c).

Ore bodies are predominantly of a tabular configuration and have grades ranging from 0.03% U (cutoff grade) to a few percent uranium with an average of 0.08–0.12% U. Roll-shaped and structurally-controlled stack-type mineralization occurs locally. Boundaries of ore bodies are transitional into ubiquitously weakly mineralized ground.

Ore-grade uranium concentrations occur mainly in the Coastal Facies, particularly in basal brackish sediments and in the "Washout Horizon", which rest locally upon the Continental Facies, and lower Friable Sandstone. Together they host approximately 90% of minable resources. Ore bodies in these units are large and, in planview, mainly of tabular, more rarely of lens or curvilinear shape fingering and wedging out at basement paleohighs. About 10% of minable resources occur in the basal Continental Facies. The Fucoid Sandstone and upper Friable Sandstone host only small occurrences.

Most productive deposits are located above depressions incised into the basement, at brachyformal flexures, along faults separating displaced blocks, and at intersections of these structures (Fig. 3.52). At these sites, ore is of greater thickness and vertically stacked. High-grade mineralization commonly prevails at the interface of permeable and impermeable lithologies, near volcanic dikes and sills, and along brittle structures.

Tabular and lens-like ore bodies of small to medium size prevail in the northern part of the Stráž Block. Downdip towards the south, the thickness and lateral dimension of ore bodies increase, and ore can occur in several horizons, particularly in paleodepressions. In the latter case, ore bodies on lower and medium levels of such depressions are typically tabular to lens-shaped. Roll-shaped ore bodies, which may be of simple or complex configuration occur locally. Large blankets of ore of relatively consistent lateral persistence and thickness prevail in the upper mineralized Cenomanian section, particularly on inclined flanks of flexures. The middle and upper section of the Friable Sandstone and less often the Fucoid Sandstone contain smaller satellite ore lenses adjacent to large ore bodies. Some deposits consist essentially of a large single ore body, e.g., Hamr, whereas others contain multiply stacked ore lenses e.g., the Stráž deposit.

Regional Geochronology

Isotope dating of uranium ores yields a wide range of ages between 90 and 3 Ma (90 Ma, Legierski and Vavřín 1972; 28–23 Ma, Anderson et al. 1985; 9–3 Ma, Šorf et al. 1987; all cited in Scharm 1991); Hrádek (1995) gives two U/Pb ages of 25 ±3 and 6 ±3 Ma for the time of ore formation.

Potential Sources of Uranium and Zirconium

Proterozoic and Paleozoic igneous, metasedimentary, and sedimentary rocks outcropping to the northeast of, and underlying the Cretaceous basin are considered potential sources for uranium. Granitic rocks are most favored because most uranium deposits are located in the vicinity of granitic complexes. The Lusatian Massif contains biotite granodiorite with 5.7 ppm U (10.0 ppm Th, Th/U = 1.75) and porphyritic biotite granite with 6.3 ppm U (12.3 ppm Th, Th/U = 1.95) (Lepka 1973 in Kolektiv 1984). Two-mica granite from the Krkonoše-Jiserské hory (Riesengebirge-Isergebirge) Massif (Tannwaldgranite) has 9.1 ppm U and 9.6 ppm Th (Th/U = 1.05) (Fatková 1969 in Kolektiv 1984). The Th/U ratios suggest that part of the uranium is probably present in leachable form and as such these rocks constitute viable uranium sources.

The source of zirconium is still open to debate. Speculations include intrusive dikes in ore-hosting sediments or granitic rocks containing elevated Zr values. Since many dikes are strongly, and in part, completely altered by kaolinitization, zirconium may have been liberated by the alteration processes.

Principal Ore Controls and Recognition Criteria

Uranium deposits in the Stráž Block in the northern Bohemian Cretaceous Basin are classified as peneconcordant sandstone type, but with an unusual association of elements. Uranium mineralization is restricted to Cenomanian strata in which minable uranium ore bodies are confined to distinct lithostratigraphic units. The following ore controls and/or recognition criteria characterize these deposits:

Host Environment

- Intermontane basin surrounded and underlain by Proterozoic–Paleozoic crystalline rocks including granite with elevated uranium contents
- Basin fill consists of two units of continental and shallow marine Turonian and Cenomanian sediments
- Dip of strata is generally 5–10°
- Intrusive dikes and sills of variable lithologies are common
- Faults partly with major displacements were generated and reactivated during several tectonic episodes
- Two groundwater stockworks separated by an impermeable horizon occupy the Turonian and Cenomanian units
- Groundwater in Cenomanian sediments is artesian
- Influx of water is both laterally from outcrop down the S to SW-oriented sedimentary gradient and vertically through faults
- Uranium host rocks occur in three members (facies) of the Cenomanian sequence:
    - Friable Sandstone host rocks are shallow marine psammitic and psephitic beds of several sedimentary cycles
    - Coastal Facies host rocks predominantly consist of poorly sorted, indistinctly bedded silt-sandstone of beach deposits, but uranium also has accumulated in all other lithologies
    - Continental Facies host rocks include highly permeable pebbly sandstone, silt-sandstone, conglomerate and, locally, breccias with sandy-clayey matrix deposited within lower and middle levels of erosional-tectonic depressions
- Characteristic features of ore-hosting sediments are
    - pronounced lithological changes laterally and vertically as typically found in deep depressions
    - presence of abundant pyrite and organic material
    - ubiquitous elevated to low-grade uranium tenors in Cenomanian strata

Alteration

- Reduction-related alteration is primarily reflected by formation of anthraxolite, chlorite, hydromica/hydrosericite, kaolinite, and minor pyrite, siderite, associated with violet and grey-green recoloration
- Oxidation resulted in limonitization and minor hematitization and apparently affected only the upper section of the Cenomanian sequence from the Transitional Facies down to the Friable Sandstone
- Silicification particularly affected highly permeable psammites

Mineralization

- Uranium mineralization is restricted to Cenomanian strata
- Mineralization consists of a unique association of U, Zr, P, and Ti minerals
- Principal uranium minerals comprise black uranium oxides (sooty pitchblende) and uraniferous hydrozircon; other uranium minerals such as pitchblende, ningyoite, coffinite, U(-Zr)-Ti phases are less frequent
- Associated phases include mainly pyrite and carbonized matter, and subordinately other sulfides and REE-bearing crandallite group phosphates
- Thorium occurs in very small amounts
- Ore and associated minerals are present in several generations
- Two types of ore are distinguished: uranium only, and uranium with zirconium
- U-Zr ore tends to be primarily bound to the vicinity of the Stráž Fault
- Mineralization concentrates predominantly in lenses and blankets
- Roll-shaped bodies occur subordinately and are restricted to upper levels (in Friable Sandstone)
- Ore bodies have no sharp boundaries but grade transitionally into ubiquitous low-grade uranium mineralization
- Ore concentrates at contacts of highly permeable sandstone with less-permeable or impermeable siltstone and argillaceous siltstone
- Alteration-controlled ore distribution is reflected by
    - affinities of tabular ore for the contact of kaolinite and carbon-hydromica-altered zones
    - position of roll-shaped ore bodies at the interface of limonite-altered sediments
    - silicified segments contain only few and small ore bodies
- Ore bodies in arenite of the Continental Facies consist of small, irregularly shaped lenses at contacts with and locally within impermeable layers
- Ore bodies in littoral to shallow marine sediments (Friable Sandstone and Coastal Facies) are often large blankets or lenses which occur preferentially on upper levels of paleo-depressions filled with heterogeneous lithologies, and at several levels in wide, shallow brachyformal subbasins of shallow marine sediments
- Large ore bodies persist often interstratigraphically from the Continental Facies upwards into the Coastal and occasionally into the basal Friable Sandstone when intervening permeable layers are present
- Smaller ore pods may group to larger deposits of often complex configuration
- Stack-type ore occurs at the contact of volcanic intrusions, which acted as aquitards and complicated the hydrodynamics of groundwater flow

- At steeply dipping dikes, ore forms vertical zones and invades adjacent permeable sediments in complex style
- At shallow-dipping sills, more extensive ore blankets occur at the footwall contact
- Steeply and shallow inclined faults filled with gouge contain mineralization similar to that in volcanic intrusions
- Permeable faults and fault intersections are locally mineralized
- Where permeable faults cut tabular ore and interconnect permeable horizons, these horizons and the fault may contain stacked ore
- Principal reductants are plant remains, carbonized organic matter, and diagenetic iron sulfides, mainly pyrite
- Mineralized rocks are dark to light grey and rarely whitish with dark speckles

Metallogenetic Concepts

Mineralization of the North Bohemian Cretaceous Basin displays certain similarities with sandstone-type uranium deposits elsewhere in the world but also distinct deviations. The principal differences are as follows. Much of the ore consists of U-Zr phases. Zoning of elemental suites (V, Se, Mo etc.), as typical for rollfronts in the Wyoming Basins and Texas Coastal Plains as well as for some tabular deposits on the Colorado Plateau, does not exist. Host rocks are predominantly sand-siltstones and not arkoses. Mineralizing solutions entered the host lithologies both laterally, percolating down the sedimentary gradient from the outcrop area, and vertically along faults.

Deciphering ore-forming processes is hampered by the complex and overlapping interrelationship of repeated epigenetic events. According to the description of mineral parageneses, distribution of alteration and ore zones, ore body configurations, and host rock lithologies provided by Kolektiv (1984) the following multistage metallogenetic evolution may be envisaged. As outlined earlier, six paragenetic mineral stages are established (Fig. 3.53) among which four principal U-mineralizing stages may be simplistically distinguished:

- *Stage 1*. Early introduction of uranium occurred perhaps synsedimentary or shortly thereafter. Mineralizing solutions that originated from the Proterozoic–Paleozoic basin margin, where they had picked up uranium, migrated down the sedimentological gradient. Uranium was precipitated where fertile solutions encountered reducing conditions provided by detrital carbonaceous matter and/or sulfidized ground. Finely dispersed black uranium oxides associated with coaly matter and pyrite found predominantly in the Continental Facies and locally in the Coastal Facies may be of this origin. This type of mineralization is absent in other Cenomanian units perhaps due to destruction by later processes, if indeed it ever existed. This assumption would be more or less consistent with formation of basal-channel uranium deposits as, e.g., in the Chinle Formation on the Colorado Plateau, USA.
- *Stage 2*. Continued or renewed influx of solutions into the buried sediment pile resulted, particularly in marine Cenomanian, in intense kaolinitization and a second generation of mineralization as reflected by disseminations and bands of black uranium oxides and minor pitchblende. Ore minerals precipitated not only within the altered kaolinized aureole but also along the interface between carbon-hydromica and hydromica alteration zones. This position may suggest that two solutions were involved in uranium precipitation. An older water reservoir with reducing capability resided in basal Cenomanian lithologies. Where invading uraniferous solutions interacted with this resident water, their hydrochemistry was changed to an extent that uranium could precipitate.
- *Stage 3*. U-Zr mineralization, which occurs essentially in vicinity of the Stráž Fault is characteristic for this stage. It may have been generated during a single or several perhaps interconnected phases after renewed tectonism. Groundwater could percolate not only into favorable host facies downdip along the sedimentological gradient, but also along reactivated or newly developed transmissive structures as reflected by the structure-related position of some ore bodies. Fluids must have been sufficiently oxygenated and of such a physico-chemical nature to liberate preexisting uranium and zirconium along their pathways and to transport these elements simultaneously to a favorable site of deposition. Whether these waters introduced new uranium or not remains uncertain. Redeposition of uranium and zirconium occurred as metacolloidal hydrozircon either along reduced rock facies provided particularly by organic-rich pelitic interbeds, and/or at the interface of chemically different groundwater units (for more details see further below). Hydrodynamic conditions must have been rather complex as reflected by the irregular configuration of ore bodies of this type, which partly exist in stack-like fashion along faults. Ore of this stage has formed in the Coastal Facies and in the lower Friable Sandstone.
- *Stage 4*. After revived tectonism, oxidizing solutions again entered along permeable strata but particularly along dilation faults into upper ore horizons in the Friable Sandstone and Fucoid Sandstone. Host rocks were limonitized and preexisting mineralization was destroyed. Uranium was redistributed and redeposited as black uranium oxides and pitchblende in roll-type bodies at the head of the advancing oxidation front and as elongated lenses at reduced pelitic layers in the hanging wall, footwall, and intercalations of the permeable horizon. This process separated uranium from its daughter products hence ore of this stage is in radiometric disequilibrium.

Scharm (1991) summarizes evolution of U-Zr mineralization in the Stráž Block as follows: Granitoids provided clastic material for Cretaceous sediments and also uranium in the course of their weathering. There is a possibility that some uranium had preconcentrated in isolated embayments, swamps, and marshes (Čadek et al. 1979). The mineralization process was active over a long time span as indicated by the wide range of isotope ages between 90 and 3 Ma, and the present distribution of uranium reflects a complex involvement of a variety of agents; consequently Šorf et al. (1987) suggest a polygenetic origin.

Two principal types of mineralization, uranium only and uranium-zirconium, characterize deposits of the Stráž Block. Uranium-zirconium mineralization is essentially spatially bound to the vicinity of the Stráž Fault, a fact that naturally intrigues the question whether or not this mineralization is the product of multiple processes, perhaps involving the following stages. An early uranium stage was followed and partly overprinted by a later invasion of zirconium-bearing solutions, which led to partial dissolution of uranium minerals, uranium was redistributed and, coupled with zirconium, generated the uranium-zirconium assemblage.

Majer and Čadek (1979) have suggested a geochemical model for formation of uranium-zirconium mineralization, which was later modified by Čadek (1980). This model is based on two assumptions, namely that mineralization took place at a low temperature and by a mutual precipitation of uranium and zirconium as may be concluded from the joint occurrence of both elements in hydrozircon.

Although transport and precipitation of uranium may occur under a wide range of pH and Eh conditions, the presence of zirconium and titanium, which have an unusually low mobility in natural waters, put a distinct restriction on the geochemical conditions of ore formation. It is therefore assumed that transport of uranium and zirconium took place at a low redox potential in an acid environment under a favorable effect of fluorine in solutions. A low redox potential is evidenced by the presence of organic matter and sulfides. In the course of the mineralizing processes, an increase in pH occurred as can be deduced from the presence of phosphates (crandallite, ningyoite, etc.). This increase caused decomposition of fluorine complexes, and led to hydrolysis of dissolved components, and to evolution of solid mineral phases. According to this concept, the salient mechanism was not reduction, but hydrolysis, and the newly formed mineral substance had a mode of amorphous precipitates.

The colloidal and metacolloidal features still preserved in many ore minerals attest to an origin from gels, often of mixed nature. The present minerals with a higher or lower degree of structural ordering developed gradually by ageing of these gels associated with dehydration and recrystallization. This process of material and structural reordering of the gels has not been completed as evidenced by the still existing various stages of differentiation and recrystallization of gels.

In addition to the postulated hydrolytic processes, which may be considered a valid mechanism for generation of uranium-zirconium mineralization, sorption and reduction (related particularly to organic matter) tend to have also played a significant role in concentration of uranium. This assumption is based on the common affinity of maximum uranium concentrations to organic substances.

Subsequent processes, e.g., changes of the groundwater regime related to faulting or volcanism, caused remobilization and redistribution of uranium.

Čadek et al. (1975) address the physico-chemical conditions involved in U-Zr ore formation. Mobilization of these two elements, which can coexist in ionic state in solutions with a pH of 5–9, resulted from hydrolytic processes. Solutions involved in this model were presumably mildly oxidizing to reducing, weakly acid to neutral (pH 5–7) and contained relatively high tenors of fluorine (1–10 ppb). Uranium was transported as uranyl-carbonate or -fluoride complexes depending on the concentration of CO_3^{2-} and F^- ions. A carbonate source is provided by marginal marine sediments and fluorite may have derived from occurrences known in the basement in the vicinity of the deposits. Migration of Zr was as ZrF_6^2 and ZrF_5^- or as mixed hydrox-fluoride complexes. Mobilization of Ti occurred, probably over only a limited range as $TiOF^+$ and $TiOF_2$ complexes. The presence of fluoride ions permitted an Al activity up to a pH of 6–7.

The presence of phosphorous is considered a significant factor for the postulated hydrolytic processes. Sufficient P was available in the form of phosphorite concretions particularly in basal beds of the Lower Turonian and marine Cenomanian. Reduction and precipitation of uranium occurred in zones enriched in pyrite and organic substances.

The authors support their model by hydrological data researched by Jetel (1970, in Čadek et al. 1975). The Cretaceous basin contains a three-partitioned stockwork of compositionally different groundwaters. Lower levels host water of a saline nature containing NaCl and NaCl–HCO_3. Intermediate levels contain $NaHCO_3$-bearing water. Water on the upper levels is of mixed $CaNaHCO_3$ type with locally high contents of SO_4 ions. In both lower levels, fluorine is relatively high amounting to 2–5 ppb and locally to as much as 10 ppb. The partial pressure of CO_2 is high in the basin and thereby influences the pH of groundwater. It decreases the pH value particularly at greater depth hence groundwater is, on average, more acid here than would be expected from its bulk chemistry. A change in the partial pressure of CO_2 due to release of CO_2 occurred at transmissive faults, and thereby contributed to ore formation.

Description of Selected Deposits in the Stráž Block, North Bohemia

See Figs. 3.49 and 3.50 for location of deposits.

Sources of information. Beneš and Slezák (1997), Fiedler and Slezák (1993, 1995), Hrádek (1995), Slezák (1995), pers. commun. by other CSUP/DIAMO staff, unless otherwise cited.

3.8.1.1 Hamr North and South, North Bohemia

Hamr North lies about 20 km southwest of Liberec and in proximity to the Stráž Fault, the northwestern boundary of the Stráž Block. *Hamr South* is located 1.5–2 km east of Hamr North. Uranium occurs in the basal part of the Cenomanian sequence. It is predominantly concentrated in the up to 10 m thick, brackish, highly carbonaceous "Washout Horizon", which tops the 0–30 m thick Lower Cenomanian Continental Facies. Approximately 85% of geological resources are in this horizon, about 10% in the Continental Facies, and 5% in overlying medium-grained sandstone of the Upper Cenomanian Coastal Facies.

The Hamr North (Hamr I) ore zone covers an area of 1.2 × 1.5 km and consists essentially of a single, continuous, 2–12 m thick tabular ore body. Mineralization is complex and is composed of black uranium oxides/pitchblende, ningyoite, and uraniferous hydrozircon. Original recoverable reserves were some 22 000 t U, 13 206 t of which were recovered from 1972 until the cessation of mining in mid-1993. Remaining reserves in the <\$80 per kg U RAR category are 9 000 t U, with 2 000 t U in higher cost categories. The mining grade averaged 0.11% U, but about a third of the original reserves had grades up to twice as high. Mining was underground by the room and pillar method at a depth of 100–200 m, served by two shafts.

At Hamr South (Hamr II), two to six stacked ore bodies of variable thickness are distributed over the whole productive sequence. Mineralization is simple with black uranium oxides/pitchblende. Original recoverable reserves amounted to 18 400 t U, 1 400 t of which were mined underground (2 shafts) at a depth of 150–200 m between 1981 and 1988. Remaining reserves are 17 000 t U in the higher cost EAR I category. The grade averages 0.08–0.15% U.[4]

3.8.1.2 Stráž, North Bohemia

This deposit is located 3 km west-southwest of Hamr North and was discovered in 1967. It straddles the southeastern side of the Stráž Fault and has a downfaulted continuation in the Tlustec Block to the northwest. Mineralization in the Stráž Block extends over an area of about 3 × 3 km with extensions to the west and southwest. The geological setting is stratigraphically and lithologically identical to Hamr except that volcanics of Mt. Ralsko have extruded the sedimentary sequence at its southwestern margin. The volcanic event caused intense faulting, the faults are often occupied by basaltic and melilitic rocks.

Uranium occurs at a depth of about 150–220 m in as much as eleven superjacently stacked ore lenses within a 30 m thick stratigraphic section of the same three basal Cenomanian units as in Hamr. Individual lenses are from less than one meter to a few meters thick. Their cumulative thickness is 5–12 m. Mineralization is complex and is composed of ningyoite, black uranium oxides/pitchblende, and uraniferous hydrozircon.

Original recoverable reserves were about 24 000 t U. A total of 17 525 t U were extracted, 15 562 t U of which were recovered by ISL techniques from 7 km^2 of 35 well fields from 1967 through 1995 (DIAMO, web side 2012). Subsequent groundwater restoration in the well fields yielded 1 960 t U from 1996 through 2010 (OECD-NEA/IAEA 2012). 330 mio m^3 of dilute sulfuric acid solution were circulated in the well fields and a total of 4 mio t H_2SO_4, 0.3 mio t HNO_3, 0.1 mio t NH_4 and 0.03 mio t HF were injected from 1967 to 1993 when injection was terminated.

Remaining reserves are some 3 000 t U in the <\$80 per kg U RAR category; the remainder are in higher cost categories. The grade is highly variable but averages 0.1–0.15% U. About a quarter of the resources had grades better than 0.2% U.

3.8.1.3 Břevniště, North Bohemia

The *Břevniště* deposit was discovered 4 km to the east of the Hamr North in the central-eastern Stráž Block in 1966. Two ore zones with geological settings similar to that at Hamr are delineated; the northwestern zone is about 1 × 2 km in size and contains mainly complex mineralization (black uranium oxides/pitchblende, uraniferous hydrozircon), while the southeastern zone, 3 km long in NE–SW direction and 0.5 to 1 km wide, carries simple mineralization (black U oxides/pitchblende).

3.8.1.4 Křižany, North Bohemia

Křižany is located 8 km northeast of Hamr North close to the edge of the Cretaceous Basin. Original recoverable reserves were 5 800 t U. Underground mining from 1982 to 1990 produced 1 008 t U from depths to 190 m (DIAMO, web side 2012). Remaining resources are in higher cost categories. The mining grade averaged 0.09% U.

3.8.1.5 Hvězdov and Osečná-Kotel, North Bohemia

These two deposits were both explored by drilling and occur in a geological setting similar to that of Hamr. *Hvězdov* is situated 10 km southwest of Hamr in the western Stráž Block. Uranium mineralization in form of black uranium oxides/pitchblende and ningyoite is spread over an area of approximately 1.5 × 2 km. Recoverable resources are estimated at 8 000 t U, 5 000 t of which are attributed to the <\$80 per kg U EAR II category. The ore grade is estimated at 0.1–0.15% U. *Osečná-Kotel* is located 7 km east of Hamr South in the eastern Stráž Block. Mineralization consists essentially of black uranium oxides/pitchblende. Recoverable resources are estimated at 14 400 t U in higher cost categories.

3.9 Permo-Carboniferous Basins in Eastern and Central Bohemia

Uranium is a common constituent of the Permo-Carboniferous platform cover of the Bohemian Massif. Noteworthy occurrences are known from the *Intra-Sudetic Žacléř-Svatoňovice* and *Krkonoše/Riesengebirge Foreland Basins* in eastern Bohemia, the *Central Bohemian Kladno-Rakovník Basin*, and the *Plzen Basin* in western Bohemia (for localities see Fig. 3.1).

The intermontane basins are filled with a few hundred meters to 3 000 m of basal eluvial, fluvial, and lacustrine sediments mostly with pyroclastic components of Visean–Namurian (in a few basins) or Westphalian to Lower Permian age. Middle and Upper Carboniferous facies include variably carbonaceous, pink and grey beds of conglomerate, sandstone, arkose, mudstone, and coaly and bituminous shale with intercalated coal seams. Mafic and felsic volcanic rocks and their tuffs occur locally. The Lower Permian is represented by pink terrigenous sediments with grey coal-bearing beds in their lowermost section. Some basins contain thick volcanic effusives of intermediate to felsic composition.

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[4] DIAMO (web side 2012) reports a production of 13 206 t U for Hamr I and a mining depth of 106 m.

Uranium mineralization is of sandstone and lignite/coal type and thought to be of epigenetic-diagenetic origin with later redistribution into fractures. Uranium concentrations are found in high ash coal, and highly carbonaceous sandstone within the coal sequence. Uranium tenors are also increased in bituminous and carbonaceous shales. Paleochannels contain uranium locally where the channel intersects a coal seam. Uranium is present as urano-organic complexes, adsorbed on coalified plant remnants, and, rarely, sooty pitchblende. *Associated minerals* include pyrite, marcasite, and minor amounts of chalcopyrite, galena, and sphalerite. Vanadium accompanies uranium in some occurrences.

Resources of individual deposits range from less than one tonne to about a hundred tonnes uranium. Grades are highly variable ranging from some ten ppm to one percent or more in small pockets.

Uranium was mined from the *Rybníček*, *Stachanov*, and *Zdeněk* deposits in the Intra-Sudetic Basin. Some uranium was recovered from the *Rynholec* deposit in the Central Bohemian Kladno-Rakovník Basin (Kolektiv 1984; CSUP/DIAMO staff, pers. commun.).

3.9.1 Intra-Sudetic Žacléř-Svatoňovice Basin, East Bohemia

Located to the east of the town of Trutnov, this basin covers an area of 100 × 30 km extending from eastern Czechia into Poland. A number of sandstone- and lignite/coal-type uranium occurrences have been delineated (see listing in Fig. 3.1). Three of these occurrences, *Rybníček*, *Stachanov*, and *Zdeněk*, were mined prior to 1970 and produced about 100 t U. Original resources are estimated at several hundred t U. Grades vary between a few hundred ppm and 0.2% U.

Sources of information. Kolektiv (1984), pers. commun. by CSUP/DIAMO staff.

Regional Geological Setting of Mineralization

The intermontane Intra-Sudetic Basin is a brachysynclinal structure filled with molasse sediments with intercalated coal beds, and downdropped into a basement and surrounding massifs of crystalline rocks including granitic intrusions. Permo-Carboniferous strata dip at less than 25° and include the following lithostratigraphic units:

- *Upper Permian*: red-brown Zechstein sediments
- *Lower Permian*: mostly pink, continental sediments with coal seams and bituminous shales in the footwall section, overlain by a 1 000–1 500 m thick unit of mafic (melaphyre) and felsic (feldspar- and quartz-porphyries) volcanics
- *Westphalian-Stephanian*: Odolov Series composed of Svatoňovice and Jivec strata (mostly coarse-grained clastics with interbeds of fine-grained sediments and thin coal measures), 1 500 m thick
- *Namurian-Wesphalian*: Žacléř Series composed of Lampertice, Dolní Zdař, and Petrovice strata (conglomerate, sandstone, subordinate siltstone, mudstone, coal, and, locally, subvolcanic bodies of quartz porphyry), 700 and 1 200 m thick in western and eastern parts of the basin, respectively. The principal coal seams occur in Westphalian strata

Uranium mineralization is concentrated in a few stratigraphic units:

- *Upper Stephanian* coal seams and lowermost Permian as in the *Rybníček* uranium deposit and the *Chvaleč* uranium occurrence (predominantly low-grade uranium mineralization)
- *Jivec strata*, Radvanice (coal seam) Sequence (Stephanian): uranium deposit in the *Stachanov* mining sector
- *Svatoňovice strata*: uranium deposit in the *Kolektiv* mining sector
- *Zdař strata*: uranium occurrences in the *Pětiletka* and *Lambertice* mining sectors

Principal Characteristics of Mineralization

Most uranium mineralization is bound to upper parts of coal seams, where it often occurs immediately below arkose or sandstone beds, which may be mineralized locally. Preferential host rocks are coal-bearing sandstones and lusterless or fusinite-type coals, and particularly those intervals with pyrite.

Uranium ore bodies are lenticular or tabular in shape, and are arranged in groups. Individual mineralized beds average 3–20 cm in thickness. Lateral dimensions are greatest in the Radvanice Sequence, where uranium persists over a length of 15 km. Stacked uranium mineralization extends to a depth of 1 000 m at some sites in this sequence.

Black uranium oxides are the principal uranium phases; pitchblende is rare. *Associated minerals* include sulfides of As, Cu, Fe, Mo, Pb, and Zn. Uranium correlates best with Pb, and to some extent with Ca, P, Ti, and Zr.

Characteristics of Individual Deposits

Uranium mineralization of the three mined deposits exhibit the following characteristics:

Kolektiv mining sector. This field contains four coal seams. Uranium occurs in small lenses, up to 50 m^2 in size, within an 8–15 cm thick layer at the top of the upper seam, below an arkosic sandstone bed. Uranium is preferentially hosted by thin fusite coal laminae in which uranium concentrations associate with dispersed pyrite accumulations. Fractured seam intervals contain uranium in breccia cement. The principal uranium phase is sooty pitchblende dispersed in the coal mass and fine-grained pitchblende in sulfidic-organic concretions. Collomorphous pitchblende was found only in fine cleavages cutting strongly silicified arkose. *Associated minerals* include chalcopyrite, galena, pyrite, and sphalerite.

Stachanov mining sector. The field comprises six coal seams. Uranium was recovered from two lower seams, the Baltazar seam and Seam No. 2. The *Baltazar seam* consists of 0.8–1.3 m thick, finely laminated lustrous coal of durite-klarite type with thin shale intercalations. Tiny fractures are filled with calcite, galena, pyrite, and sphalerite. Uranium is concentrated in coaly shale and coal with interbedded lustrous vitrite within the upper and middle part of the seam. Vitrite is practically barren of uranium. Uranium lenses are 0.1–0.2 m thick and as much as 10 m^2 in size. Some uranium occurs in 5–10 cm thick layers in arkosic sandstone immediately above the coal seam. Uranium mineralization in *Seam No. 2* is similar to that in the Baltazar seam.

Rybníček uranium deposit. Uranium is hosted by the upper Radvanice coal seam of Jivec strata and by a coal seam in footwall conglomerate of the Lower Permian. Uranium is particularly concentrated in the upper part of the seams but is less common in middle and lower sections. Intercalations of arkosic sandstone are also mineralized specifically where they contain thin coal beds or coalified plant remnants. Ore bodies consist of small, 0.1–0.3 m thick stratiform lenses hosted by lusterless coal with finely dispersed pyrite. Disseminated black uranium products (sooty pitchblende?), are the most common uranium phases; pitchblende is rare. Associated elements include <1.8% Cu, <0.6% Mo, <0.5% Pb, and <0.9% Zn. Uranium mineralization in the Chvaleč occurrence is similar to that at Rybníček.

The mining sectors of Pětiletka and Lambertice contain small uranium lenses in Žacléř strata, and in the hanging wall of the Krenov Conglomerate (Westphalian-G).

3.9.2 Krkonoše (Riesengebirge) Foreland Basin, East Bohemia

Some uranium occurrences of sandstone-lignite type such as *Valteřice* and *Štěpanice* are found to the southeast of Trutnov in the western part of the Krkonoše Foreland Basin, between the settlements of Velke Svatoňovice and Rtyně (Fig. 3.1). Resources of individual occurrences are up to a few tonnes of uranium. Grades range from few hundred ppm to more than 0.1% U but, due to the commonly thin uraniferous layers, the average grade is too low for mining.

Geology and Mineralization

Uranium is hosted in 1–10 m thick beds of Svatoňovice and Petrovice strata, which are composed of sandstone and conglomerate of small-size pebbles with thin laminae containing coaly trash and finely disseminated organic matter, and bituminous shale. Carbonaceous substances also fill or coat cracks. The formations dip 25–30° towards the center of the basin.

Uranium occurs finely dispersed in several centimeters to several tens of centimeters, rarely 1 m or more thick stratiform lenses most commonly within the upper part of fluvial beds. These lenses are distributed over a vertical interval from surface to 1 000 m deep.

Pitchblende, coffinite, and a titanium-uranium phase are the principal uranium minerals. They occur in less than 1 mm large globules, finely disseminated in the matrix of the host rocks, and as coatings on grains. Locally, uranium associates with a coaly substance and pyrite, copying to some extent the original plant texture. The U-Ti phase constitutes about 50% of the uranium endowment (Kolektiv 1984, CSUP/DIAMO staff, pers. commun.).

3.9.3 Kladno-Rakovník Basin, Central Bohemia

A number of lignite- and sandstone-type uranium occurrences (for listing see Fig. 3.1) have been investigated in the Upper Paleozoic Kladno-Rakovník Basin. Characteristics of the three more important occurrences are as follows as summarized from Kolektiv (1984) and CSUP/DIAMO staff (pers. commun.).

Geology and Mineralization

Coal-bearing areas may contain uranium in grey sediments of fluvial (paleochannels, deltas), lacustrine, and paludal provenance. Coal and sandstone constitute the principal host rocks. Uranium mineralization of the small *Rynholec* deposit (<100 t U) occurs in stratiform lenses, up to two meters thick and several tens of meters long, within impoverished intervals in the upper section of the Kladno Main-Coal Seam. The *Jiří II* occurrence occupies impoverished intervals in the upper Lubno Seam. Uranium in both occurrences is primarily present as urano-organic complexes, adsorbed on coal and coalified plant remains; and rarely as sooty pitchblende, uranophane, autunite, and torbernite. *Associated minerals* include pyrite, sphalerite, and minor chalcopyrite. Vanadium accompanies uranium in significant amounts. Mineralization is concentrated along the facies transition from coal to argillaceous sediments. Regularly disseminated mineralization is typical for laminated layers, while better grades are restricted to fractures and pyritic concretions in coal.

Most uranium of the *Jedomělice* occurrence is hosted by coaly mudstone, siltstone, and arkosic sandstone with minor coal intercalations of the Carboniferous Kamen-Most Formation. Increased uranium values also occur in basal Permian iron-rich mudstone-sandstone. Mineralized beds average 5 m in thickness. Most uranium is adsorbed on organic material. Sooty pitchblende is rare. Epigenetic mineralization composed of uranium, chalcopyrite, galena, marcasite, pyrite, sphalerite, and siderite occurs in a very distinct manner.

References and Further Reading for Chapter 3 · Czech Republic

For details of publications see Bibliography.

Anderson et al. 1985; Anonymous (web side 2012); Baumann 1967; Baumann and Krs 1967; Bendl and Vokurka 1989; Beneš and Slezák 1997; Bernard and Dudek 1967; Bernard et al. 1968; Boitsov et al. 1977; Breiter et al. 1997, 2005, 2006; Čadek 1980; Čadek et al. 1975, 1979; Cílek et al. 1984; DIAMO web side 2012; Dymkov 1961, 1996; Fiedler and Slezák 1993, 1995; Hrádek 1995; Kirchheimer 1963; Kohl 1954; Kolektiv 1984; Komínek 1997; Komínek and Veselý 1986; Komínek et al. 1994; Kovalová and Litochleb 1992; Kraus 1916; Křibek et al. 1996; Legierski 1966; Legierski and Sattran 1967; Legierski and Vavřín 1972; Leutwein 1957; Lippolt 1984; Majer and Čadek 1979; Matolín and Šuráň 1989; Matolín et al. 1981; Mrňa and Pavlů 1967; Mrňa 1963a,b, 1967; Mrňa and Sattran 1980; Novák and Vavřín 1980; OECD-NEA/IAEA 1993, 1995, 1997, 2000; Oelsner 1958; Ondruš et al. 1997a,b; Petroš et al. 1986; Pluskal 1970, 1991, 1992a, 1992b, 1998; Pluskal and René 1976; Prokeš 1974; Ruzicka 1971; Sattran and Čadek 1967; Scharm 1991; Scharm et al. 1978, 1980; Schumacher 1933; Škubal and Vachuška 1973; Škvor 1977, 1978; Slezák 1995; Šorf et al. 1987; Šorf and Kozyrev 1984; Štemprok 1982, 1986, 1992, 1993; Štemprok et al. 2003; Strnad 1986; Šuráň and Veselý 1983, 2001; Syka et al. 1978; van Breemen et al. 1982; Vaněček et al. 1985; Velichkin et al. 2004; Veselovský et al. 1997a,b; Veselý 1985, 1986; Vinogradov et al. 1959; Vlašímský 1982; Vlašímský et al. 1995; Vogl 1856; Žák and Dobeš 1991; Zückert 1926; pers. commun. by Hájek A, Hrubý J, Komínek J, Kühn P, Pluskal O, Šenkerik M, Slezák J, Zuckermann, CSUP/DIAMO staff.