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Low-hafnium zircon from alluvial and colluvial placers of northern Bohemia: composition and possible sources

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Abstract Low-hafnium zircon is, together with pyrope, sapphire and magnesian ferri-ilmenite, a widespread heavy mineral in three historical placers of precious stones in N Bohemia. The chemical compositions of zircon from all three localities (Třebenice area, Jizerská louka Meadow, Sýkořı důl Valley) are appreciably similar. Zircon forms large, 1 to 7 mm long homogeneous or oscillatory zoned crystals, generally low in Hf (0.45–1.27; aver. 0.77 wt.% HfO_2), Y, REE, U, Th and Ca. The genetic association of this zircon with nepheline syenite or pegmatite is doubtful as zircon from this rock found in xenoliths in a nearby alkali basalt pipe breccia from Kostălov Hill represents the Hf-rich type (1.57–1.97; aver. 1.73 wt.% HfO_2). Consequently, low-hafnium zircon most probably originated from unknown coarse-grained products of early magmatic crystallisation of an alkali basalt magma forming explosive pipe breccias.

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INTRODUCTION

Zircon as a heavy mineral occurs in numerous alluvial and colluvial deposits in the mountains and piedmont areas in the northern part of the Bohemian Massif, in the Czech Republic. The placers have been locally, panned for precious stones since the 15th century. Despite the substantial quantity of zircon and other heavy minerals in the placers and the long-lasting panning at these sites, no relevant mineralogical data are available and their primary source rocks are still unknown (Bauer, 1959). For this reason a crystallochemical study of zircon from the three most famous placers in N Bohemia was performed to contribute to the discussion of their possible primary source.

GEOLOGICAL SETTING

The following zircon-bearing placers in Quaternary gravels were studied (for locations see Fig. 1):

(1) the Třebenice area in the foothills of the České středohoří Mts., NW Bohemia; an exceptionally rich, mostly colluvial deposit of pyrope ("Bohemian garnet"). Pyrope-rich gravels and sands (up to 6 m thick) lie on the SE slopes of the České středohoří Mts. in the Ohře River Valley, on a Proterozoic–(Paleozoic) crystalline basement (gneisses, granulites, serpentinites, eclogites) covered by Upper Cretaceous sediments. Pyrope, zircon and ilmenite are among the dominant heavy minerals in these gravels; other minerals include corundum (sapphire and ruby), olivine (forsterite), chromian diopside, chromian spinel (picotite), maghemite, rutile, pseudorutile, moissanite, and diamond (?). Altogether, there are ca. 50 mineral species (Fengl, 1996). This was the only area where a rock was found which could represent a source of zircon in the placer. Rare nepheline syenite xenoliths (5 to 10 cm in size) with numerous zircon crystals are present in the alkali basalt pipe breccia fill of the diatreme of Kostălov Hill (481 m a.s.l.) near Třebenice. The xenoliths of nepheline syenite, silicocarbonatite and fenite represent a differentiated subvolcanic alkaline rock association (Kopecký *et al.*, 1970). However, only exceptional zircon crystals (from disintegrated xenoliths?) are known from the alkali basalt breccia of Kostălov Hill and other diatremes such as Linhorka Hill (Bauer *et al.*, 1963; Kopecký *et al.*, 1967).

(2) Jizerská louka Meadow, Jizerské hory Mts., N Bohemia, is the most important European alluvial deposit of sapphire (Blumrich, 1925). These gravels are of variable thickness (0.5–2 m) and are partly covered by peatbog. The stratigraphy of the Quaternary deposits of the upper

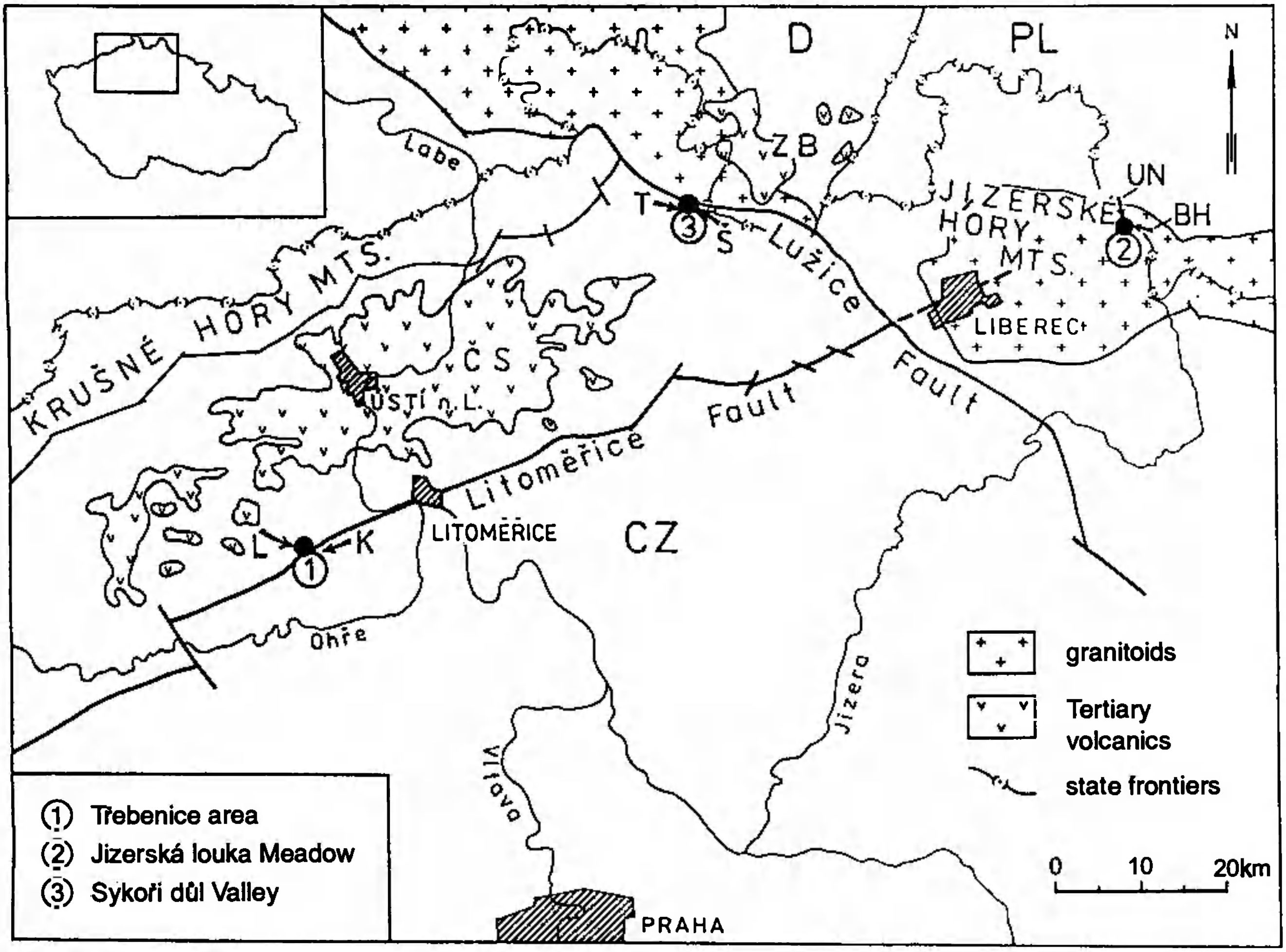

Fig. 1. Geological sketch of the northern part of the Bohemian Massif with locations of the investigated zircon placers and their possible sources. L – Linhorka Hill, K – Košťálov Hill, BH – Bukova hora Hill, UN – Unnamed diatreme, S – Stožec Hill, T – Tolštejn Castle.

reach of the Jizera River is rather complex. The gravels were deposited during a longer interval, which was followed by a period of removal and resedimentation. Thus, the heavy mineral distribution is very irregular and variable. The Variscan Liberec granite body of the Krkonoše-Jizera pluton with numerous pegmatite, aplite, and lamprophyre dykes, and quartz veins, forms the crystalline basement of the deposit. Ilmenite ("iserine"), zircon (hyacinth) and titanite are the most widespread heavy minerals in the gravels, corundum (sapphire) being the most characteristic. Less commonly, the mineral association includes corundum (ruby), iron-rich spinel (pleonaste), rutile, fergusonite-group minerals, and monazite-(Ce), xenotime-(Y); altogether about 50 mineral species. A hidden alkali basaltic diatreme has been geophysically confirmed at the locality (Zemánek, 1965).

(3) Sýkoří důl Valley near Jiřetín pod Jedlovou in the Lužické hory Mts., N Bohemia, is a poorly known historical placer deposit with precious zircon (hyacinth), corundum (sapphire > > ruby), pyrope, spinel group minerals, ilmenite and 20 other mineral species. The extent of the gravels of two streams in the Sýkoří důl Valley with numerous smaller feeders, in particular from the Tolštejn Castle mountain group, is relatively small, reaching up to 1 m in local thickness. A diatreme (50 m in diameter) filled with alkali basaltic pipe breccia containing xenoliths of coarse-grained melilitic rock near Stožec Hill (Fig. 1) is present nearby. However, zircon has never been found in this diatreme.

EXPERIMENTAL METHODS

Zircon crystals from heavy mineral concentrates from the three above mentioned localities were examined in polished sections by microprobe techniques. Five crystals were chosen for investigation from each placer locality and the centres and rims of these crystals were measured. 30 analyses were performed in total (Table 1). Thin sections were used for the study of nepheline syenite xenoliths of the Košťálov Hill diatreme.

A CAMECA SX50 electron microprobe was used to determine the chemical composition of the zircon from

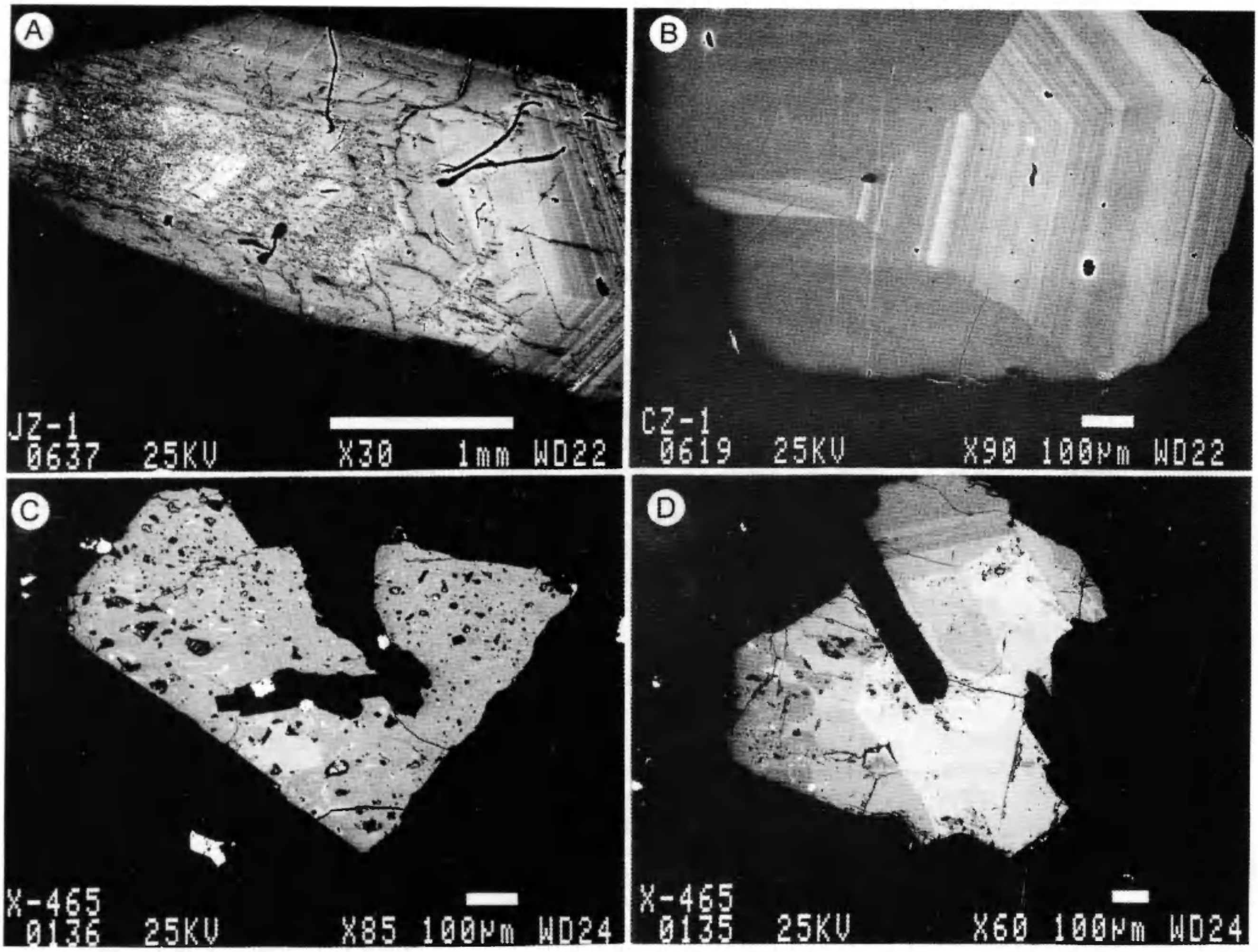

Fig. 2. BSE image of zircon. **A** – Oscillatory zoned crystal with partial metamict zones and numerous thorite inclusions in itscentral part, Jizerská louka Meadow. **B** – Crystal with sector zoning: oscillatory zoned pyramidal sector and homogeneous prismatic sectors, Sýkoří důl Valley. **C** – Homogeneous crystal with small thorite inclusions, nepheline syenite xenolith, Košťálov Hill. **D** – Crystal with its central part formed by thorite, nepheline syenite xenolith, Košťálov Hill.

the placer deposits. The experimental conditions were: 15 kV (30 kV for trace elements) accelerating voltage, 20 and 30 nA beam current, 1–2 µm diameter for spot analysis, 20 s for Si, Zr, Hf, and 40 s for peak measurements. Natural (for Si, Zr) and synthetic (Hf, REE) standards were used, for details see Uher & Černý (1998). The detection limits for REE, U, Th and other trace elements were 0.04 to 0.07 wt.%. A JEOL 733 Superprobe electron microprobe was used to determine the chemical composition of the zircon from the Košťálov Hill nepheline syenite, under analytical conditions analogous to those given above. A JEOL JSM 840 scanning electron microscope was used to determine internal zoning and to provide BSE images of zircons.

RESULTS

Zircon is among to the most common mineral phases in the studied heavy mineral concentrates. Two morphological and colour types of investigated zircon could be recognised:

(1) Relatively large short columnar crystals and their fragments, 3 to 7 mm long with simple combination of (110) and (111) forms. The zircon is pale brown in colour, and mostly translucent. The crystals are commonly partly rounded due to their alluvial transportation; prismatic and pyramidal faces are only locally preserved. This type occurs in the Třebenice area.

(2) Smaller, 1–2.5 mm and 2–4 mm long prismatic columnar crystals occur in the Sýkoří důl Valley and the Jizerská louka Meadow placers, respectively. The studied crystals are ruby red (hyacinth variety) or pale brown and transparent to translucent. BSE images (Fig. 2 A, B) reveal homogeneous or oscillatory zoned patterns of zircon crystals, locally with both patterns in a single crystal due to sectorial zoning with homogeneous (prismatic) and concentric (pyramidal) sectors (Sýkoří důl Valley). Some

Table 1

Electron microprobe compositions (in wt. %) of zircon grains

Třebenice area (T)

	T1C	T1R	T2C	T2R	T3C	T3R	T4C	T4R	T5C	T5R
P_2O_5	0.07	0.06	0.09	0.01	0.08	0.07	0.05	0.06	0.06	0.06
SiO_2	32.45	33.09	32.86	32.31	33.24	32.84	32.90	32.79	32.89	32.94
ZrO_2	62.94	65.08	65.50	65.70	66.24	66.31	66.83	65.31	65.60	66.46
HfO_2	1.25	1.20	0.53	0.60	0.45	0.52	0.81	0.75	0.49	0.55
ThO_2	1.17	0.79	0.62	0.02	0.06	0.02	0.00	0.08	0.22	0.01
UO_2	0.00	0.00	0.10	0.00	0.19	0.00	0.02	0.03	0.14	0.11
Fe_2O_3	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.03
Y_2O_3	0.73	0.66	0.28	0.00	0.06	0.07	0.04	0.58	0.27	0.11
Ce_2O_3	0.07	0.07	0.03	0.03	0.02	0.02	0.00	0.03	0.03	0.02
Sm_2O_3	0.10	0.04	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
Tb_2O_3	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Dy_2O_3	0.01	0.10	0.00	0.03	0.00	0.00	0.00	0.13	0.00	0.03
Er_2O_3	0.15	0.08	0.15	0.04	0.00	0.08	0.05	0.07	0.06	0.02
Yb_2O_3	0.16	0.19	0.06	0.10	0.09	0.10	0.05	0.17	0.08	0.05
F	0.00	0.00	0.12	0.02	0.06	0.14	0.01	0.02	0.17	0.10
O=F	0.00	0.00	-0.05	-0.01	-0.03	-0.06	0.00	-0.01	-0.07	-0.04
TOTAL	99.12	101.36	100.29	98.87	100.49	100.11	100.90	100.01	99.94	100.45

Formula contents on a basis of 16 anions

	T1C	T1R	T2C	T2R	T3C	T3R	T4C	T4R	T5C	T5R
P	0.007	0.006	0.009	0.001	0.008	0.007	0.005	0.006	0.006	0.006
Si	4.040	4.024	4.015	4.001	4.034	4.006	3.996	4.018	4.020	4.007
Zr	3.821	3.859	3.903	3.967	3.920	3.944	3.958	3.903	3.910	3.942
Hf	0.044	0.042	0.018	0.021	0.016	0.018	0.028	0.026	0.017	0.019
Th	0.033	0.022	0.017	0.001	0.002	0.001	0.000	0.002	0.006	0.000
U	0.000	0.000	0.003	0.000	0.005	0.000	0.001	0.001	0.004	0.003
Fe	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.003
Y	0.048	0.043	0.018	0.000	0.004	0.005	0.003	0.038	0.018	0.007
Ce	0.003	0.003	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001
Sm	0.004	0.002	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Tb	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dy	0.000	0.004	0.000	0.001	0.000	0.000	0.000	0.005	0.000	0.001
Er	0.006	0.003	0.006	0.002	0.000	0.003	0.002	0.003	0.002	0.001
Yb	0.006	0.007	0.002	0.004	0.003	0.004	0.002	0.006	0.003	0.002
CATSUM	8.015	8.014	7.993	8.000	7.995	7.988	8.001	8.010	7.988	7.992
F	0.000	0.000	0.046	0.008	0.023	0.054	0.004	0.008	0.066	0.038
O	16.000	16.000	15.954	15.992	15.977	15.946	15.996	15.992	15.934	15.962

Jizerska louka Meadow (J)

	J1C	J1R	J2C	J2R	J3C	J3R	J4C	J4R	J5C	J5R
P_2O_5	0.07	0.10	0.03	0.08	0.07	0.07	0.10	0.09	0.41	0.11
SiO_2	33.26	33.40	33.24	32.79	33.15	32.92	32.40	32.64	32.15	33.14
ZrO_2	65.72	66.15	66.12	66.03	66.13	65.60	66.75	65.98	61.66	65.64
HfO_2	0.84	0.82	0.88	0.87	0.74	0.72	0.63	0.56	1.27	0.99
ThO_2	0.00	0.15	0.00	0.10	0.00	0.03	0.00	0.07	1.44	0.00
UO_2	0.08	0.09	0.07	0.07	0.00	0.00	0.00	0.08	0.15	0.05
Fe_2O_3	0.05	0.01	0.00	0.00	0.03	0.07	0.02	0.04	0.00	0.01
Y_2O_3	0.06	0.16	0.08	0.11	0.00	0.04	0.09	0.06	1.40	0.11
Ce_2O_3	0.00	0.03	0.00	0.02	0.02	0.00	0.01	0.01	0.03	0.02
Sm_2O_3	0.12	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.01	0.00
Tb_2O_3	0.00	0.05	0.00	0.00	0.03	0.00	0.00	0.00	0.04	0.03
Dy_2O_3	0.08	0.05	0.14	0.06	0.00	0.04	0.00	0.00	0.11	0.00
Er_2O_3	0.03	0.02	0.00	0.01	0.02	0.05	0.07	0.05	0.24	0.08
Yb_2O_3	0.05	0.00	0.00	0.07	0.00	0.04	0.03	0.04	0.22	0.04
F	0.00	0.00	0.00	0.11	0.01	0.00	0.04	0.02	0.00	0.00
O=F	0.00	0.00	0.00	-0.05	0.00	0.00	-0.02	-0.01	0.00	0.00
TOTAL	100.36	101.03	100.56	100.27	100.20	99.58	100.17	99.65	99.13	100.22

Table 1 (continued)

Electron microprobe compositions (in wt. %) of zircon grains

Jizerska louka Meadow (J)

Formula contents on a basis of 16 anions

	J1C	J1R	J2C	J2R	J3C	J3R	J4C	J4R	J5C	J5R
P	0.007	0.010	0.003	0.008	0.007	0.007	0.010	0.009	0.043	0.011
Si	4.046	4.039	4.039	4.003	4.035	4.034	3.966	4.005	4.013	4.038
Zr	3.899	3.901	3.917	3.931	3.925	3.92	3.984	3.948	3.753	3.901
Hf	0.029	0.028	0.031	0.03	0.026	0.025	0.022	0.02	0.045	0.034
Th	0.000	0.004	0.000	0.003	0.000	0.001	0.000	0.002	0.041	0.000
U	0.002	0.002	0.002	0.002	0.000	0.000	0.000	0.002	0.004	0.001
Fe	0.005	0.001	0.000	0.000	0.003	0.006	0.002	0.004	0.000	0.001
Y	0.004	0.010	0.005	0.007	0.000	0.003	0.006	0.004	0.093	0.007
Ce	0.000	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001
Sm	0.005	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000
Tb	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.001
Dy	0.003	0.002	0.005	0.002	0.000	0.002	0.000	0.000	0.004	0.000
Er	0.001	0.001	0.000	0.000	0.001	0.002	0.003	0.002	0.009	0.003
Yb	0.002	0.0000	0.000	0.003	0.000	0.001	0.001	0.001	0.008	0.001
CATSUM	8.003	8.002	8.002	7.991	7.999	8.002	7.997	7.999	8.019	8.001
F	0.000	0.000	0.000	0.042	0.004	0.000	0.015	0.008	0.000	0.000
O	16.000	16.000	16.000	15.958	15.996	16.000	15.985	15.992	16.000	16.000

Sýkoří důl Valley (S)

	S1C	S1R	S2C	S2R	S3C	S3R	S4C	S4R	S5C	S5R
P_2O_5	0.05	0.08	0.06	0.02	0.09	0.05	0.06	0.03	0.05	0.07
SiO_2	32.80	32.40	32.78	32.88	32.89	33.06	32.90	32.44	33.03	32.30
ZrO_2	66.03	65.63	65.48	66.57	65.50	66.18	65.93	65.50	65.38	65.52
HfO_2	0.79	0.79	0.73	0.71	1.06	0.78	0.69	0.70	0.66	0.68
ThO_2	0.08	0.00	0.09	0.13	0.00	0.04	0.00	0.00	0.00	0.00
UO_2	0.17	0.03	0.00	0.10	0.01	0.13	0.00	0.07	0.19	0.10
Fe_2O_3	0.00	0.00	0.07	0.02	0.03	0.04	0.07	0.00	0.00	0.00
Y_2O_3	0.14	0.12	0.02	0.23	0.13	0.44	0.00	0.00	0.17	0.13
Ce_2O_3	0.02	0.00	0.01	0.00	0.02	0.04	0.01	0.03	0.01	0.00
Sm_2O_3	0.00	0.02	0.02	0.00	0.03	0.00	0.00	0.07	0.00	0.04
Tb_2O_3	0.00	0.00	0.03	0.00	0.00	0.06	0.00	0.00	0.02	0.02
Dy_2O_3	0.00	0.09	0.00	0.07	0.00	0.10	0.11	0.00	0.02	0.00
Er_2O_3	0.04	0.09	0.06	0.04	0.09	0.10	0.05	0.02	0.06	0.03
Yb_2O_3	0.05	0.02	0.02	0.03	0.09	0.10	0.00	0.00	0.07	0.07
F	0.00	0.10	0.09	0.00	0.07	0.00	0.03	0.07	0.00	0.06
O=F	0.00	-0.04	-0.04	0.00	-0.03	0.00	-0.01	-0.03	0.00	-0.03
TOTAL	100.17	99.33	99.42	100.80	99.98	101.12	99.84	98.90	99.66	98.99

Formula contents on a basis of 16 anions

	S1C	S1R	S2C	S2R	S3C	S3R	S4C	S4R	S5C	S5R
P	0.005	0.008	0.006	0.002	0.009	0.005	0.006	0.003	0.005	0.007
Si	4.011	3.994	4.025	4.000	4.023	4.011	4.024	4.010	4.046	3.995
Zr	3.938	3.945	3.920	3.949	3.906	3.915	3.932	3.948	3.905	3.952
Hf	0.028	0.028	0.026	0.025	0.037	0.027	0.024	0.025	0.023	0.024
Th	0.002	0.000	0.003	0.004	0.000	0.001	0.000	0.000	0.000	0.000
U	0.005	0.001	0.000	0.003	0.000	0.004	0.000	0.002	0.005	0.003
Fe	0.000	0.000	0.006	0.002	0.003	0.004	0.006	0.000	0.000	0.000
Y	0.009	0.008	0.001	0.015	0.008	0.028	0.000	0.000	0.011	0.009
Ce	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.001	0.000	0.000
Sm	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.003	0.000	0.002
Tb	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.001
Dy	0.000	0.004	0.000	0.003	0.000	0.004	0.004	0.000	0.001	0.000
Er	0.002	0.003	0.002	0.002	0.003	0.004	0.002	0.001	0.002	0.001
Yb	0.002	0.001	0.001	0.001	0.003	0.004	0.000	0.000	0.003	0.003
CATSUM	8.002	7.992	7.993	8.005	7.996	8.011	7.999	7.994	8.003	7.996
F	0.000	0.039	0.035	0.000	0.027	0.000	0.012	0.027	0.000	0.023
O	16.000	15.961	15.965	16.000	15.973	16.000	15.988	15.973	16.00	15.977

Table 2
Electron microprobe compositions (in wt. %) of zircon from nepheline syenite xenolith, Košťálov Hill

	1D	1L	2D	2D	2L	2D	3D
	33.07	32.58	32.44	32.34	32.80	33.10	32.45
ZrO_2	64.21	63.15	64.76	66.22	63.18	65.46	64.40
HfO_2	1.71	1.73	1.66	1.57	1.80	1.64	1.97
ThO_2	0.00	0.64	0.24	0.17	1.03	0.18	0.05
UO_2	0.00	0.04	0.04	0.03	0.00	0.15	0.00
Yb_2O_3	0.01	0.51	0.10	0.35	0.27	0.02	0.00
TOTAL	99.00	98.65	99.24	100.68	99.08	100.55	98.87
Formula contents on a basis of 16 anions							
Si	4.078	4.064	4.019	3.968	4.073	4.039	4.029
Zr	3.861	3.841	3.912	3.962	3.826	3.895	3.899
Hf	0.060	0.062	0.059	0.055	0.064	0.057	0.070
Th	0.000	0.018	0.007	0.005	0.029	0.005	0.001
U	0.000	0.001	0.001	0.001	0.000	0.004	0.000
Yb	0.000	0.019	0.004	0.013	0.010	0.001	0.000
CATSUM	8.000	8.005	8.001	8.003	8.003	8.000	8.000
O	16.000	16.000	16.000	16.000	16.000	16.000	16.000

crystals reveal partly metamict central zones with numerous thorite and rare monazite-(Ce) microinclusions of anhedral shape, up to 25 μm in length (Třebenice area, Jizerská louka Meadow).

Representative microprobe compositions of zircon are given in Table 1. Low hafnium content is generally the most characteristic feature for all the studied samples; it is in range 0.45–1.27 wt.% HfO_2; 0.77 wt.% in average, $Zr/Hf_{wt.}$ = 42.4–128.5; 79.9 in average. The differences between the central part of the crystals and their rims are usually small: Δ HfO_2 < 0.1 wt.%, Δ Zr/Hf_{wt} < 10, only locally they are considerably higher (see Table 1). Similarly, there are only negligible differences between the average Zr/Hf_{wt} for the central parts and rims; they reach 79.4, and 80.4, respectively. The average HfO_2 and Zr/Hf_{wt} values per locality are slightly different: 0.72 wt.% and 90.5 for the Třebenice area, 0.83 wt.% and 72.4 for Jizerská louka Meadow, and 0.76 wt.% and 76.9 for Sýkoří důl Valley. Higher hafnium contents (>1 wt.% HfO_2; max. 1.27 wt.% HfO_2) measured exclusively in the central parts of crystals are very rare.

The contents of other elements in zircon (Y, REE, U, Th, Ca, etc.) are very low, near the detection limit of the microprobe, usually <0.1 wt.% of oxides. Elevated contents of Th, Y and REE are present only locally: 0.6–1.4 wt.% ThO_2, 0.3–1.4 wt.% Y_2O_3 and up to 0.7 wt.% ΣREE_2O_3. These Th-, Y- and REE-rich compositions mainly occur in partly metamict core zones of zircon.

Two different types of the studied zircons (in size and colour) were distinguished, both of which reveal very similar low-Hf compositions. Therefore the same or an analogous parental rock can be suggest for both types. For the identification of the possible source rock, study was carried out on various coarse-grained alkaline Zr-rich igneous rocks which occur as xenoliths in the well-documented alkali basalt diatreme of Košťálov Hill, close to the Třebenice placer deposit area. However, coarse-grained zircon was only found in the nepheline syenite xenoliths. Zircon forms semitransparent subhedral to euhedral dipyramidal crystals, 0.4–1 mm in size. Under BSE, zircon is homogeneous or heterogeneous with irregular patchy Th-rich zones, up to 150 μm in size, and regular crystal growth zones are also locally present (Fig. 2 C, D). Anhedral inclusions of thorite, up to 50 μm in size, are widespread. Electron microprobe compositions of zircon in the nepheline syenite xenoliths reveal 1.57 to 1.97 wt.% HfO_2; 1.73 on average and locally also elevated ThO_2 (0.62–1.03) and Yb_2O_3 (0.27–0.51 wt.%) contents (Table 2).

DISCUSSION AND CONCLUSIONS

The BSE and microprobe study of detrital zircon megacrysts from N Bohemian placer deposits reveals broad textural and chemical similarities, despite some features specific to particular crystals, such as size, colour, sectorial zoning, metamict zones, mineral inclusions or slightly Hf-, Th- and REE-enriched zones.

The low hafnium content (0.77 wt.% on average) is the most characteristic crystallochemical feature of all the studied zircons from the placers. Such Hf-poor zircons are characteristic for mantle, basic and mainly alkaline igneous rocks. Zircon from common felsic crustal magmatic rocks, especially granites, usually contains >1 wt.% HfO_2 (Pupin, 1992). The most Hf-poor zircon is known from anorthosites and pyroxene gneisses in Russia (0.05–0.24 wt.% HfO_2; Lyakhovich & Vishnevskii, 1990), charnockites of the Pamir Mts., Tajikistan (0.11 wt.% HfO_2; Krasnobayev, 1986), alkali syenites from the Thor Lake, Canada (0.15–0.31 wt.% HfO_2; Smith *et al.*, 1991) and some nepheline syenite pegmatites from the Ilmen Mts., Russia (0.21–0.31 wt.% HfO_2; Kapustin, 1985). Besides these anomalously Hf-poor zircons, values between 0.7 to 1 wt.% HfO_2, which are the most similar to our N Bohemian detrital zircon, are also typical for zircons from alkaline igneous rocks, such as syenites, nepheline syenites and their pegmatites and rare alkali basalts (Krochuk *et al.*, 1989; Heaman *et al.*, 1990, Kapustin, 1985; Hinton & Upton, 1991). Locally, Hf-poor zircon (0.7–1 wt.% HfO_2) also occurs in alkaline post- to anorogenic hypersolvus A-type granite suites (Pupin, 1992; Uher & Broska, 1996).

Consequently, the source rock(s) of the zircon megacrysts from the placers of N Bohemia is probably related to (i) alkaline and/or (ii) basic igneous rocks of subcrustal origin. If similar alluvial placers of zircon and associated precious stones (corundum, spinels etc.) are correlated theoughout the world, it is noteworthy that they are often spatially associated with explosive basaltic volcanism.

Zircon and corundum (sapphire) e.g., from the Gem fields of New England, Australia, represent products of fractional crystallisation of basanitic magma occurring in explosive pipe breccias (Coenraads *et al.*, 1990). By contrast some megacrysts of zircon, corundum (sapphire) and associated minerals are not in equilibrium with the surrounding basic magma and indicate crystallisation in deeper subcrustal levels. Megacrysts are occasionally present, e.g. in a basaltic pipe breccia in the Chathaburi Gem Province, Thailand (Coenraads *et al.*, 1995) in aggregates formed by zircon + corundum + (Al,Ti)-rich magnetite.

The most probable source of zircon and other heavy minerals in all three placer deposits is associated with post-Variscan, mostly Cenozoic volcanism. The Třebenice placer is associated with diatremes occurring at the southeastern margin of the České středohoří Mts., in the close vicinity of the Litoměřice Fault, which borders the Tertiary Ohře (Eger) Rift (Fig. 1). The Třebenice area is of particular importance due to the only find of coarse-grained zircon-rich nepheline syenite xenoliths in the basaltic breccia filling of the nearby Košťálov Hill diatreme. In addition, the neighbouring alkali basaltic breccia of Linhorka Hill and numerous other smaller pipes may also represent the source of the zircon, and of other heavy minerals in the placers, e.g. ilmenite, sapphire, moissanite and diamond (?). The magnesian ferri-ilmenite from the Třebenice area and the Jizerská louka Meadow gravels (Ulrych & Langrová, 1997), resembling ilmenite megacrysts from kimberlites (Mitchell, 1986) in its chemical composition, indicates its source from the Tertiary picrobasalts and their breccias recognised in both areas (Číčov and Buková hora Hills, respectively). The alluvial pyrope in the Třebenice area originated from garnet serpentinites of the shallow crystalline basement. According to Malíková (1996), the corundum in this area may originate from granulites and eclogites associated with garnet serpentinites and also occurring in the xenoliths of the Linhorka Hill alkali basaltic breccias. However, the microprobe compositions of the zircon from the nepheline syenite xenolith show distinctly higher hafnium contents (1.57–1.97 wt.% HfO_2) than the low-hafnian zircon from all the studied placer deposits (0.45–1.27 wt.% HfO_2), despite locally elevated Th content in both the placer and nepheline syenite zircons. Thus, the studied nepheline syenite probably does not represent the source rock for the Třebenice area alluvial to colluvial zircon.

The Sýkoří důl Valley and the Jizerská louka Meadow placers are also associated with significant tectonic lines: the Lužice (Lusatian) and problematic continuation of the Litoměřice Faults, respectively. In addition, the Sýkoří důl Valley placer occurs in the proximity of a basaltic pipe (ca. 50 m in diameter) with xenoliths of coarse-grained but zircon-free melilitic rock near Stožec Hill (Fig. 1).

A hidden basaltic diatreme has also been geophysically confirmed near the Jizerská louka Meadow locality. The historical placers of Seufzergründel, Saxony, Germany, and Płócki (Seifendorf), Silesia, Poland, belong to this suite associated with master faults. The former mentioned locality is associated with the Hohwiesengestein basaltic pipe (Weidemann, 1961; Mädler, 1991) and the Lužice Fault.

Finally, the present authors suggest that the Late Cretaceous to Tertiary explosive alkali basalt pipe breccias with xenoliths and megacrysts from an early phase of magma crystallisation most probably represent the main primary sources of the zircon in the historical placers of precious stones in N Bohemia. The genetic association of the studied alluvial and colluvial zircon with nepheline syenite and/or nepheline syenite pegmatite is doubtful as zircon from xenoliths of these rocks found in the alkali basalt pipe of Košťálov Hill contains smaller crystals of a relatively Hf-rich type. The source of heavy minerals in the placers of N Bohemia may commonly be associated with hidden hypabyssal Late Cretaceous alkaline complexes (e.g. Osečná, Dvůr Králové) spatially linked with the Lužice Fault (Ulrych *et al.*, 1989, 1996). It is less probable that the source of Hf-poor zircon is the charnockitic (anorthositic?) rock suite (Opletal & Vrána, 1989) present as xenoliths, e.g., in a basaltic dyke in Myštice near Litoměřice, due to the scarcity of zircon in these rocks. However, Malíková (1996) supposed that the sapphire of the Jizerská louka Meadow originated from alkali basalts, especially from their early magmatic coarse-grained exsolutions sensu Coenraads *et al.* (1995). The zircons studied were most probably derived from a similar source.

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