Meteorite Smolenice — a new iron of IVA group from Slovakia

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Abstract: On April 3, 2012 a single piece of a meteorite was found in the forest near Smolenice (Trnava County, Slovakia). The latitude and longitude of the find are 48°31.2´N and 17°23.9´E, respectively. The meteorite was slightly weathered (weathering grade W1) and its total mass was 13.95 kg. The bulk chemical composition is dominated by iron (88.7 wt%) and nickel (8.10 wt%). This, along with concentration of Ga (1.80 µg/g), Ge (< 0.7 µg/g), and Ir (1.67 µg/g), suggest the meteorite being a IVA iron. Based on lamellae width of kamacite (average of 0.22 mm), the meteorite can be classified as fine octahedrite (Of). The mineralogy is very simple, the main minerals are iron (kamacite) (5.16–7.36 wt. % Ni) and taenite (16.73–33.93 wt. % Ni), with rare troilite nodules and daubréelite inclusions and thin veinlets. The meteorite shows Widmanstätten patterns and plessite structure is locally present. Analyses of cosmogenic radionuclides (^{26}Al, ^{14}C, and ^{40}K) indicate that the radius of the Smolenice meteorite could be in the range of 30–50 cm, its terrestrial age of about 0.1 Ma and its cosmic-ray exposure age of about 0.2 Ma.

Introduction

A single piece (Fig. 1) of meteorite was found on April 3, 2012 in the cadastral area of Smolenice (latitude 48°31.2´N and longitude 17°23.9´E). The meteorite has an elongated shape with dimensions 25.5×13.5×13 cm. On the oxidized rust-coloured surface of the meteorite, relatively uniform regmaglyptes are observed. The original mass of the meteorite upon recovery was 13.95 kg.

The type specimen of the meteorite Smolenice is deposited in the Mineralogical Museum of Comenius University in Bratislava (24.52 g), other samples are in the Slovak National Museum — Natural History Museum in Bratislava (28.6 g and 37.9 g) and other museums and private collections. The main mass of the meteorite is in the private collection of the finder. On February 9, 2019 the meteorite name Smolenice was approved by the Nomenclature Committee on Meteorites of the Meteoritical Society.

Methods

Wavelength-dispersion electron-microprobe analysis (EMPA-WDS) was carried out with a CAMECA SX100 microprobe at the State Geological Institute of Dionýz Štúr in Bratislava. Operating conditions were as follows: acceleration voltage of 20 kV, beam current of 20 nA, beam diameter 3–5 µm. The following standards and lines were used: $CuFeS_2$ (Cu Kα, Fe Kα, S Kα), Ni (Ni Kα), Co (Co Kα), ZnS (Zn Kα), Mn (Mn Kα), Ge (Ge Kα), GaAs (As Lα), Cr (Cr Kα), V (V Kα), SiO_2 (Si Kα), TiO_2 (Ti Kα), Al_2O_3 (Al Kα), GaP (P Kα), and NaCl (Cl Kα).

Bulk chemical composition of the meteorite was determined at the Science Facilities, Imaging and Analysis Centre of the Natural History Museum in London. Major and minor elements (Fe, Ni, Co and P) were determined by inductively coupled optical emission spectroscopy (ICP-OES) using a Thermo iCap 6500 Duo. Trace elements, platinum group elements and Au were determined by inductively coupled plasma mass spectrometry (ICP-MS) using an Agilent 7700x with the collision–reaction cell (CRC) connected to He (99.9995 % purity) and H_2 (99.99999+ % nominal purity produced by H2PD-150 generator) lines.

Accuracy of the Co and Ni determination was verified by the simultaneous digestion and analysis of the certified reference material (CRM) BCS-251 "Low Alloy Steel". The accuracy of the ICP-MS analysis was checked by analyzing synthetic solutions containing similar amounts of Fe and Ni as studied of meteorite

Fig. 1. Smolenice IVA iron**.** Width of sample is 25.5 cm. Photo: G. Kučerová.

iron. Due to the extremely high Fe/Ge and Ni/Ge ratio in the Smolenice meteorite and the polyatomic interferences on ^{74}Ge, only the potential extent of the Ge content in the meteorite could be determined.

Radionuclide (for gamma-ray emitters ^{26}Al and ^{40}K) was measured for 15 days in the Low-Level Gamma-Ray Spectrometry Laboratory of the Department of Nuclear Physics and Biophysics of the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava (Slovakia). A coaxial low-background High-purity Germanium (HPGe) detector (PGT, USA) with relative detection efficiency of 70 % (for 1332.5 keV gamma-rays of ^{60}Co) was used. The HPGe detector operated in coincidence–anticoincidence regime (with NaI(Tl) and plastic scintillator detectors) in a large low-level background lead/copper shield with outer dimensions of 2×1.5×1.5 m (Povinec et al. 2009, 2015). Because the terrestrial age of the Smolenice meteorite is not known, no decay corrections for investigated radionuclides were applied.

Accelerator Mass Spectrometry (AMS) we used for the 14C analyses of 200 g sample of meteorite. The cosmogenic 14C was extracted in a RF induction furnace in a flow of oxygen, and passing the gases to form CO2. The CO2 was then converted to graphite and analyzed on a 3 MV AMS machine at the University of Arizona (USA). Methodology of 14C determination is given in Jull et al. (1993, 2010).

Results

Mineralogy

Smolenice meteorite shows very simple composition dominanted by iron (kamacite; more than 95 vol. %) with minor taenite, troilite and daubréelite. As shown in the work of Gargulák et al. (in print), the meteorite contains five different types of kamacite. The width of the iron lamellae of the main type of kamacite in the polished section is 0.22 mm (according to Frost 1965 and after correction). Neumann's lines were not observed. The measured lamellae widths correspond to the iron of the fine octahedrite type (Of). Based on 38 analyses, the average chemical composition of kamacite is (in wt. %): Fe 92.66, Ni 6.76, Co 0.52, Ge 0.02, and Cu, P, and Si 0.01.

Taenite occurs in two forms (Fig. 2). The first type of taenite is very abundant and forms individual lamellae in kamacite. The less abundant is the second type forming plessitic texture. Widmanstätten pattern is typical for this meteorite (Fig. 3). The average of chemical composition of kamacite is (in wt. %): Fe 75.13, Ni 24.53, Co 0.28, Cu 0.08, Ge 0.07, Si 0.03, and P 0.01. The range of Ni content in taenite is 16.73–33.93 wt. %. The complex and polyphase structures of the kamacite and taenite point to a complex decomposition of the original kamacite at temperatures below 400 °C (Yang et al. 1996, 1997a; Reuter et al. 1988). The absence of the Neumann's lines in the Smolenice meteorite proves that during the flight in the space no stronger impact, or collision with another object of the cosmos had occurred.

Troilite is rare in Smolenice iron and forms round grains up to 3 mm in the kamacite. Average chemical analysis of the troilite (in wt. %): Fe 62.38, S 36.13, Ni 0.01, Cu 0.02, Ge 0.06, Ga, Si, Ti, and Cl 0.01. Troilite has an increased content of chromium, probably due to nano exsolutions of daubréelite.

Daubréelite was observed only in troilite (Fig. 4) where it forms very thin exsolution lamellae with max. width up to 80 µm. The crystallo-chemical formula of daubréelite is $(Fe_{1.009-1.085}Ni_{0.000-0.002}Co_{0.000-0.001}Cu_{0.001-0.003}Mn_{0.019-0.023})_{\Sigma=1.028-1.114}Cr_{1.978-2.048}(S_4Cl_{0.000-0.003})$. The daubréelite found in the troilite typically has an increased content of manganese (up to 0.42 wt. %=0.023 *apfu*). On the other hand, increased concentrations of Cr are characteristic for the troilite.

According to Wlotzka´s (1993) classification, the weathering grade of Smolenice meteorite is W0 and only the marginal part of the iron indicates weathering grade W1.

Bulk chemistry

The bulk analysis of the Smolenice meteorite suggests two dominant elements, iron and nickel (97.30–99.97 wt. %), cobalt is less abundant (0.38 wt. %). The bulk analysis of the Smolenice meteorite is consistent with the meteoritic iron of the IVA group. This meteorite was classified mainly on the basis of the Ni and Ga content, which clearly ranks it into the IVA group. Similarly, this is also true for the Ni/P ratio, where the Smolenice iron analysis falls to the centre of the IVA group analyses. By comparing the contents of Au to other elements (Ga, Cr, W, Ir, As, Pt), we can see a good match with the data for other IVA iron groups.

Radionuklides

The examination of meteorite Smolenice included the investigation of cosmogenic radionuclides ^{40}K, ^{26}Al, and ^{14}C. The half-life of ^{14}C is 5730 yr, ^{26}Al — 0.717 Ma, and ^{40}K — 1.251 Ga).

Initial analyses of radionuclide ^{14}C indicate a terrestrial age >40,000 yr. Further ongoing AMS analyses can refine and characterise the terrestrial age of the Smolenice meteorite.

The measured ^{26}Al activity in the Smolenice fragment (3.12±0.24 dpm/kg) suggests that the analysed sample

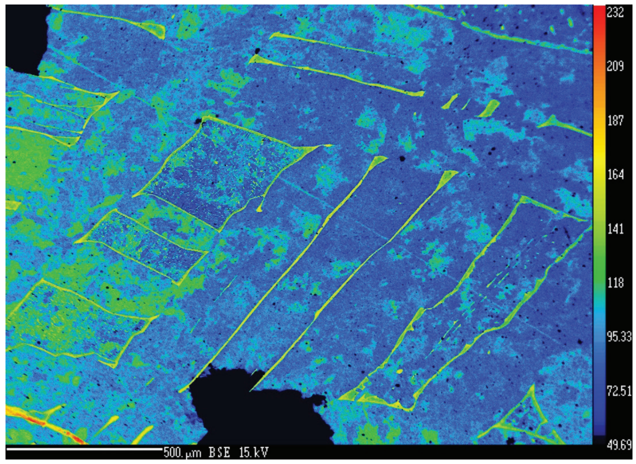

Fig. 2. Two types of taenite – lamellae in kamacite and plessitic texture (in central part).

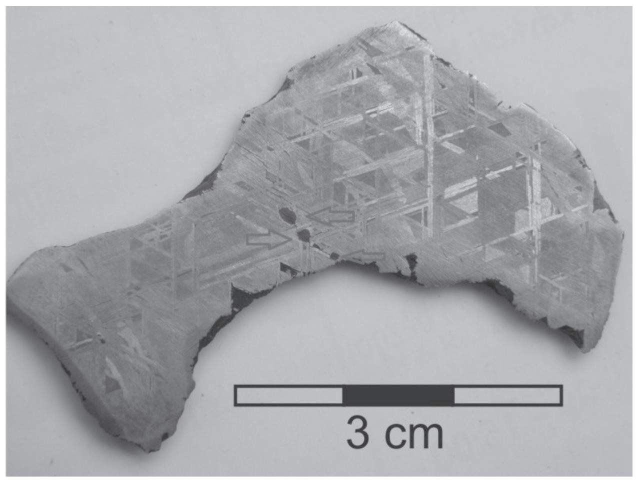

Fig. 3. Characteristic Widmanstätten pattern in the Smolenice iron. The two small dark inclusions are troilite nodules.

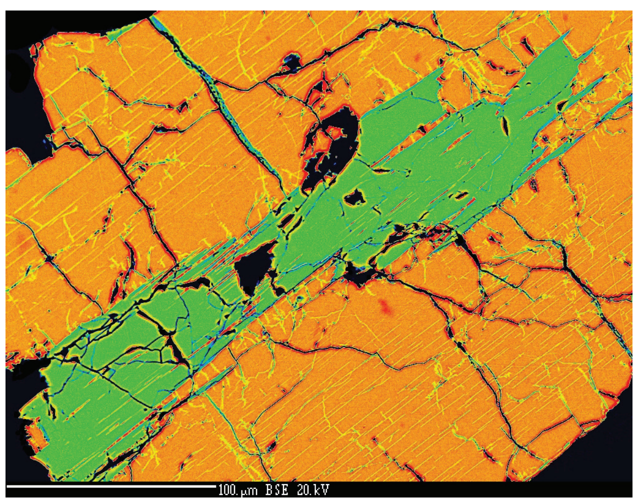

Fig. 4. Daubréelite grain (green) and lamellae (yellow) in troilite (orange). Blue veinlet is form the Fe-oxides. (BSE image)

is extra-terrestrial material. Based on a comparison with other iron meteorites, the measured data fits well with 30–50 cm meteorite radius data, if the terrestrial age of Smolenice would be about 0.1 Ma (Lavrukhina & Ustinova 1990).

The measured cosmogenic ^{40}K activity (following the gamma-ray peak at 1460.8 keV) in the Smolenice meteorite is 22.5±4.9 dpm/kg, indicating that because of the very long half-life of this radionuclide (1.251 Ga) this value represents an unsaturated ^{40}K activity. Comparing this experimental value with theoretical calculations of Lavrukhina & Ustinova (1990) we may estimate that the cosmic-ray exposure age of the Smolenice meteorite would be about 0.2 Ma.

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