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GEOCHEMISTRY

Ultrahigh-Pressure Liquation of an Impact Melt

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Abstract—Liquation structures were described in ultrahigh-pressure impact glasses of the Kara astrobleme (Pai-Khoi) with differentiation into the bisilicate, aluminosilicate, and ore components for the first time. The sequence of separation of mineral phases upon solidification of an ultrahigh-pressure impact melt was established: coesite, silicate glass, augite, aluminosilicate glass of albite composition, and pyrite. The discovered impact glasses are highly resistant to postimpact alterations.

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Problems of the structure, phase composition, and properties of glasses attract serious attention from physicists, chemists, and researchers and specialists in material science [1–4]. Mineralogists have a continual interest in glasses as well, since they consider glasses as a source of information on geological processes. Impact varieties in large astroblemes [5–9] occupy a special place among widely abundant natural glasses. Impact glasses are formed as a result of the influence of ultrahigh pressures (35–90 GPa and higher, up to hundreds GPa) and high temperatures (up to 3000°C and higher) on target rocks [10–12]. Being metastable, natural impact glasses may preserve their structural patterns over millions of years, forming relatively huge volumes in comparison with high-pressure experimental products, which allows us to study them for

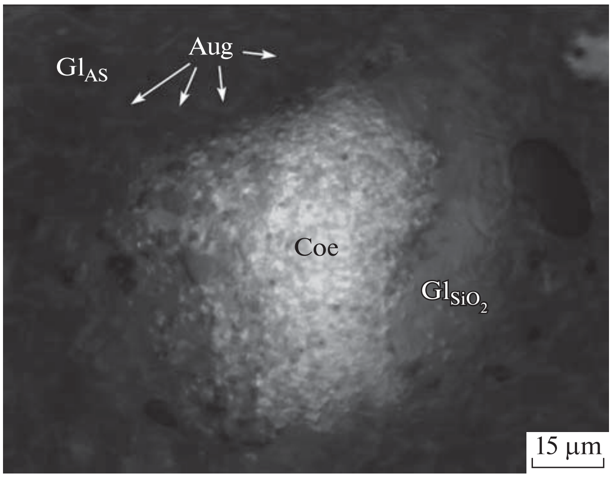

Fig. 1. Coesite in glass segregation of silicate composition surrounded by aluminosilicate glass with augite microcrystals. Polished section, image in reflected light, parallel nicols. Coe, coesite; Gl$_{SiO_2}$, silicate glass; Gl$_{AS}$, aluminosilicate glass; Aug, augite.

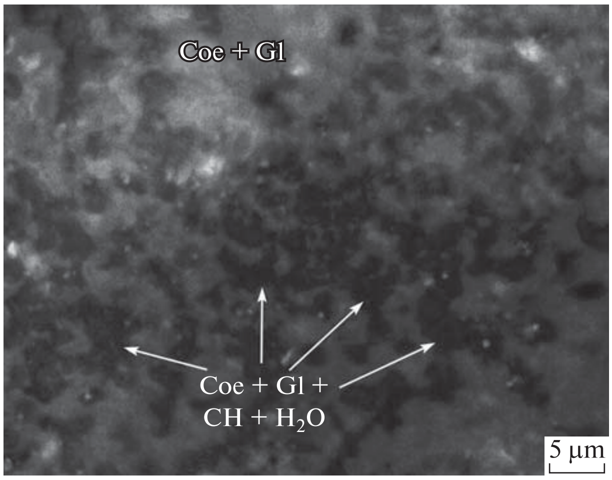

Fig. 2. Texture of ultrahigh-pressure silicate melt liquation in the components. Polished section, image in reflected light, parallel nicols. Coe, coesite; Gl$_{SiO_2}$, silicate glass; CH, relics of hydrocarbons; H_2O, water.

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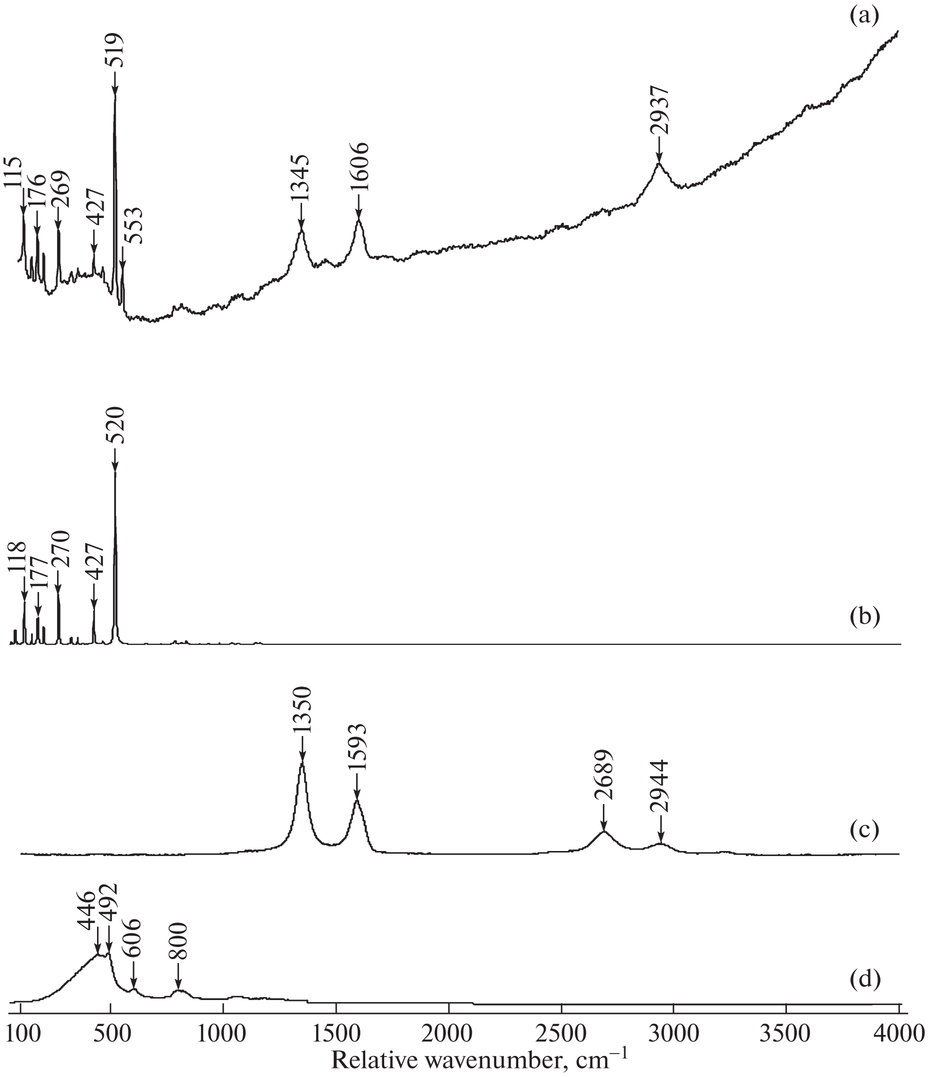

Fig. 3. Raman spectra. (a) Silicate glass with coesite, carbon matter, and relics of hydrocarbons (the band at 553 cm^{-1} corresponds to the presence of finely scattered polishing abrasive Cr_2O_3); (b–d) standard spectra of coesite, RRUFF database (b), glassy carbon, SU-2000, Novocherkassk factory (c), and quartz glass, RRUFF database (d). The spectra were obtained on a LabRam HR800 Raman spectrometer (Horiba, Yvon Jobin) at an axitation radiation of 514 nm, power of 12 mW, and magnification of ×100.

solutions to geological problems and for modeling of the processes of astrobleme formation [10, 11], as well as for understanding of general regularities in the formation of noncrystalline substances under extreme conditions and their stability.

Because of this, we studied the discovered ultrahigh-pressure glasses from the Kara astrobleme (Pai-Khoi) at the micro- and nanolevel. As a result, we obtained the first data on the probability of ultrahigh-pressure liquation in an impact melt and on its influence on the sequence of the formation of solid phases with decreasing temperature.

Diaplect glasses (deformational, unmelted) with coesite were previously described on the territory of the Kara astrobleme [6]; according to the current ideas on the formation of impactites [10], they were formed at a pressure of ~30–40 GPa and a temperature of ~2300°C. Previously [5] variegated impact glasses presumably formed at different temperatures were described, but detailed study of them was not performed until now.

As a result of our research, we discovered and studied ultrahigh-pressure impact glasses of the melted type with coesite among impactites of the Kara astrobleme by a wide complex of methods. According to our data, these glasses also contain small impact apocoal diamonds and other carbon phases previously described in impactites of the Kara astrobleme [13, 14]. Newly formed apocarbon diamonds including paramorphs after organic residues [14] in this association with silica polymorphs provide evidence for the formation of ultrahigh-pressure silicate impact glasses of the Kara astrobleme at 60–80 GPa and 2300–2500°C, which allows us to identify the range of temperatures and pressures of the formation of consolidated material of an astrobleme more appropriately.

It was established in the study of the discovered ultrahigh-pressure high-temperature melted glasses of the Kara astrobleme that most of the glasses had an aluminosilicate composition of a significantly albite type with quenched inclusions of silicate drops with a size of tens microns, partially recrystallized into coesite (Fig. 1), which form isolated crystalline aggregates, as well as a liquation texture of the mirmecitic type with silicate glass (Fig. 2) containing dispersed carbon (D = 1347 cm^{-1}, G = 1606 cm^{-1}) and relics of hydrocarbons registered spectroscopically by a wide band with a maximum at 2937 cm^{-1} (Fig. 3). As a whole, the observed relationships between the components of ultrahigh-pressure glass correspond to the signs of the liquation process considered in [15].

The presence of molecular water (up to a few wt %) is an important peculiarity of the silicate and aluminosilicate glasses considered. Water is uniquely detected by the data of gas chromatography and thermal analysis and is often observed in Raman spectra as a wide structureless band at ~3600 cm^{-1}. According to thermal studies and step analysis of fluid inclusions by the method of gas chromatography, water is released within the whole temperature range during heating from 100 to 1000°C, which may result from rapid water conservation upon solidification of the impact melt including that in nanopores with an average diameter of ~12 nm; according to our measurements, their total volume is 1.8×10^{-2} cm^3/g. We do not rule out the possibility of some decrease in the temperature of solidification and viscosity of the impact melt due to the presence of high contents of water in it, as in the case of magmatic melts.

We registered partial crystallization of the impact melt with the formation of high-temperature pyroxene (augite) as regularly distributed microcrystals in an amorphous glass matrix (Fig. 2). It is surprising that water captured in ultrahigh-pressure glasses did not have a significant impact on secondary alterations of the aluminosilicate component of glasses. The presence of secondary minerals usually formed after aluminosilicates of feldspar composition was not registered by X-ray diffraction, or by microprobe analysis or spectroscopic studies.

One more specific component in high-pressure glasses, although with a less significant content, but of high genetic significance, is the ore component represented by consolidated globules of pyrite distributed "in accordance" with the fluidal structure of glass and as liquation textures in aluminosilicate glass (Fig. 4). The morphology of pyrite particles shows that the sulfide melt did not crystallize before consolidation of the aluminosilicate matrix of high-pressure glass.

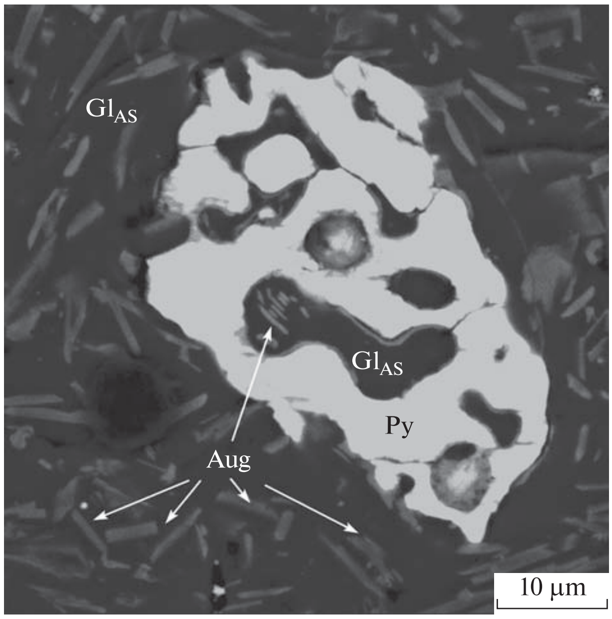

Fig. 4. BSE image of the liquation texture of sulfide and aluminosilicate melts. Polished section. Gl_{AS}, aluminosilicate glass; Aug, augite; Py, pyrite.

As a whole, the data obtained on the structural–material composition, morphological patterns, and spatial relationships between constituents of glasses from the Kara astrobleme allow us to postulate that, despite the short-term course of an impact event, ultrahigh-pressure impact melts are characterized by complex liquation processes with separation of the bisilicate, aluminosilicate, and ore components. Ultrahigh-pressure melted glasses from the Kara astrobleme show the following sequence of the formation of solid phases with decreasing temperature of the impact melt: (1) coesite; (2) silicate glass; (3) augite; (4) aluminosilicate glass of albite composition; (5) pyrite.

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