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GEOCHEMISTRY

Phytofulgurites: A New Type of Geological Formations

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Lightning strikes to dry dielectric rocks result in local evaporation and melting of mineral matter and formation of fulgurites, which are peculiar geological formations [1–3] consisting of glass, relicts of host rocks, and newly formed (hereafter, neogenic) mineral matter. They form under conditions of local ultrahigh-speed (hundredths to thousandths of a second) impact of ultrahigh temperatures (up to 25 000 K) and pressures (>250 kbar) caused by tremendous atmospheric electric discharge up to 80 Kl (current strength up to 200 kA) on mineral matter that is accompanied by light, X-ray, gamma, and other types of radiation [4].

Until recently, fulgurites were divided into two types depending on the target rocks. *Clastofulgurites* (aleuritic or psammitic) form after various coherent sediments, whereas *petrofulgurites* result from a lightning strike on the exposed surface of bedrocks. We present *phytofulgurites*, a new type of fulgurites that originate from a lightning strike on a haycock.

Material for the study was provided by O.A. Erilova from the Podvolok Settlement (Chita district of the eponymous region), an owner of a burnt haycock, who observed, together with other neighbors, the lightning strike and incineration of the haycock at the opposite northwestern end of the settlement one August evening in 2002. The next morning, her son E.V. Erilov examined the fire area and found a shining dark blue to black cake-shaped body with felty structure 15×6 cm in size and up to 1 cm thick. The total weight of the body was estimated at 70–90 g. The haycock was approximately 2 m in diameter. Fragments of the cake-shaped body provided by O.A. Erilova for examination were 4.6×0.3 and 1×0.3 in size.

The examined body is not an ash product of hay combustion, but consists of solid hydrocarbon material close to anthraxolite (natural bitumen). Therefore, taking into account its origin related to atmogenic electric discharge, we have every reason to classify this unusual rock with fulgurites and consider it as phytofulgurites, a new type of fulgurites.

Phytofulgurite represents a felty reticular–porous aggregate of united fibrous, botryoidal, and drop-shaped spherical structures with distinct near-parallel orientation of fibers probably inheriting the position of mummified grass stems (Fig. 1a).

Dominant fibers and similar structures vary from fractions of a millimeter to 30 mm in length and from 0.05 to 2 mm in thickness. Their cross sections are round, elliptic, and mostly isometric irregular. The surface is usually uneven, tuberous, vesicular, and wrinkled. Fibers are variable in thickness (usually with outgrowths and offshoots) and are sometimes icicle- or drop-shaped (Figs. 1b, 1c). Commonly, they have spherical structures ranging from regular globules to botryoidal aggregates and hemispheres at the surface of fibers and solid phytofulgurites. The globules and other spherical structures are from 10 μm to 1 mm across. They also contain peculiar hollow thin-walled globules (100–200 μm), which resemble beads in fibers (Fig. 1d).

The fulgurite aggregates are dark blue to black in color. Their surface is smooth and shining with a distinct glassy luster. They have a conchoidal uneven fracture. Under the microscope, the material is opaque. In thin chips, the material is transparent, pinkish brown to brown, and isotropic. Its density measured by the method of liquid displacement in a microcapillar tube is 1.36 ± 0.06 g/cm^3 (N.I. Bryanchaninova, analyst).

Fulgurite material is amorphous in X-ray rays. Their diffractograms demonstrate diffuse halos in the $\theta = 8$–$18.5°$ region with a maximum at 11.6° ($d = 3.33$ Å) and in the $\theta = 3.5$–$6°$ region with a maximum at 4.73° ($d = 9.31$ Å), indicating its multiphase composition and the presence of at least three phases: polynaphthene (14%), graphite-type (68%), and hydrocarbon (18%). The diffractograms also show separate lines indicating the presence of accessory quartz, including a variety with $d = 4.04$ Å.

According to incomplete element analysis, the organic matter in fulgurites has the following composition (%): C = 64.20; H = 2.37; N = 4.72; S = 0.43; total 71.72. Such a composition corresponds to a complex

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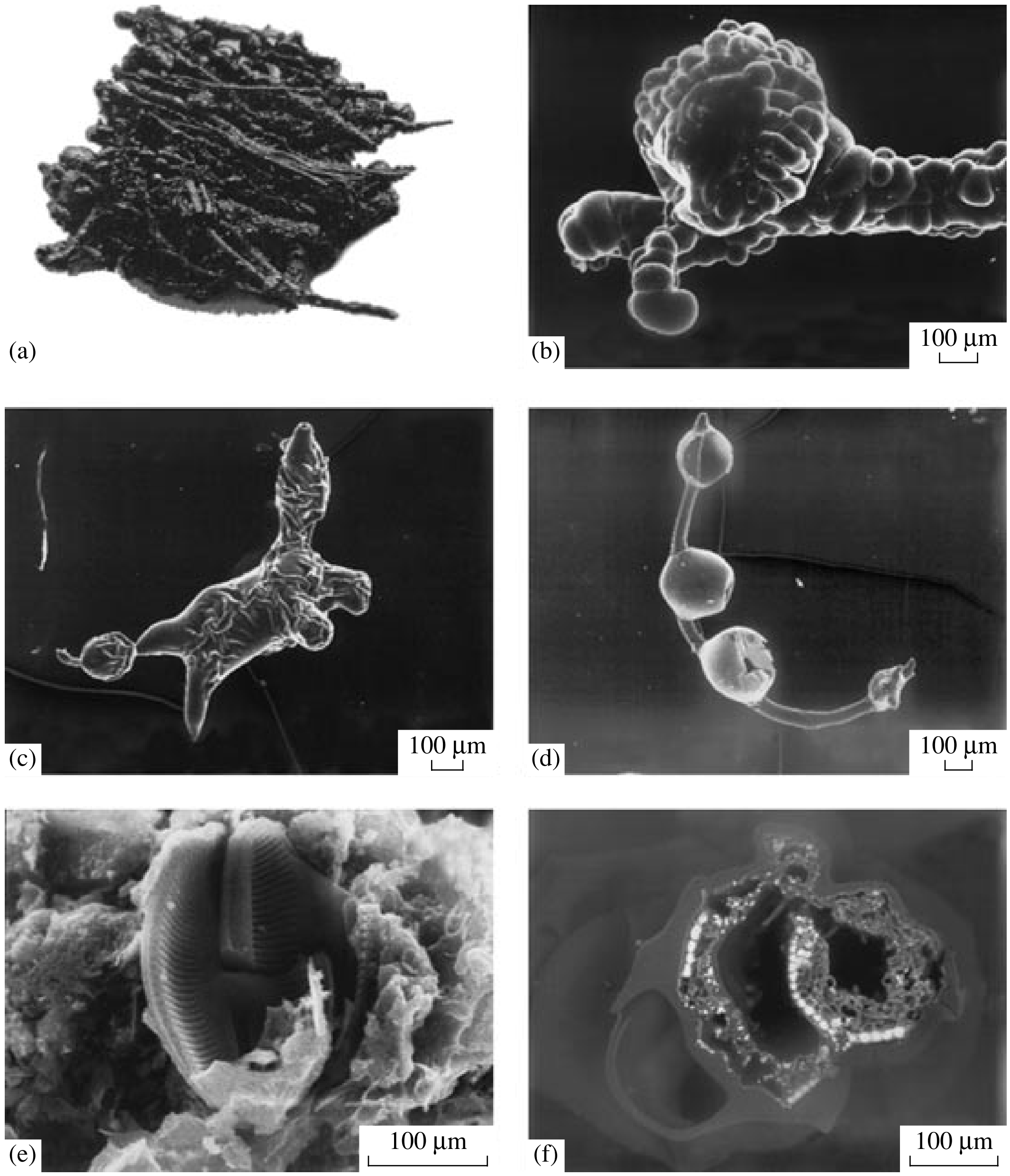

Fig. 1. Fragment of phytofulgurite and enclosed inclusions. (a–f) See explanations in text. (a) magn. 5 (reprod. 3/4).

hydrocarbon polymer $C_{411}H_{182}N_{26}S$. Oxygen and mineral impurities constitute the remaining 28.28%. Judging from the intensities of C and O lines in the energy spectrum, the oxygen content can be estimated as 2–3%. According to approximate quantitative spectral and X-ray fluorescence analyses, the contents of Si, Ca, Mg, and Mn are ~1% or more, while the contents of Fe, Ti, Al, and Sr make up only 0.*n*% or less. In addition to these accessory elements, analysis with a Link energy spectrometer revealed K, P, Cu, Zn, Pb, and Co in microinclusions of neogenic mineral phases. The integral content of accessory elements is at least 25%.

The $\delta^{13}C/^{12}C$ value measured at the Institute of Mineralogy, Ural Division, Russian Academy of Sciences (S.A. Sadikov, analyst) using a Delfo^{plus} Advantage mass spectrometer (Termo Finnigan Company) is 27.80‰ (average of three samples, standard deviation 0.06), which indicates the biogenic nature of carbon, as was expected. It is within the value range corresponding to terrestrial vegetation.

In the course of phytofulgurite matter heating up to 1000°C, water, carbon dioxide, and the main hydrocarbon components (CH_4, C_2H_4, C_2H_6, C_3H_6, C_3H_8, and others) were released at the first temperature stage (20–600°C). Dehydrogenation occurred largely at the high-temperature stage (800–1000°C). N_2 and CO were removed during the entire heating interval with the maximum at the temperature stage of 600–800°C.

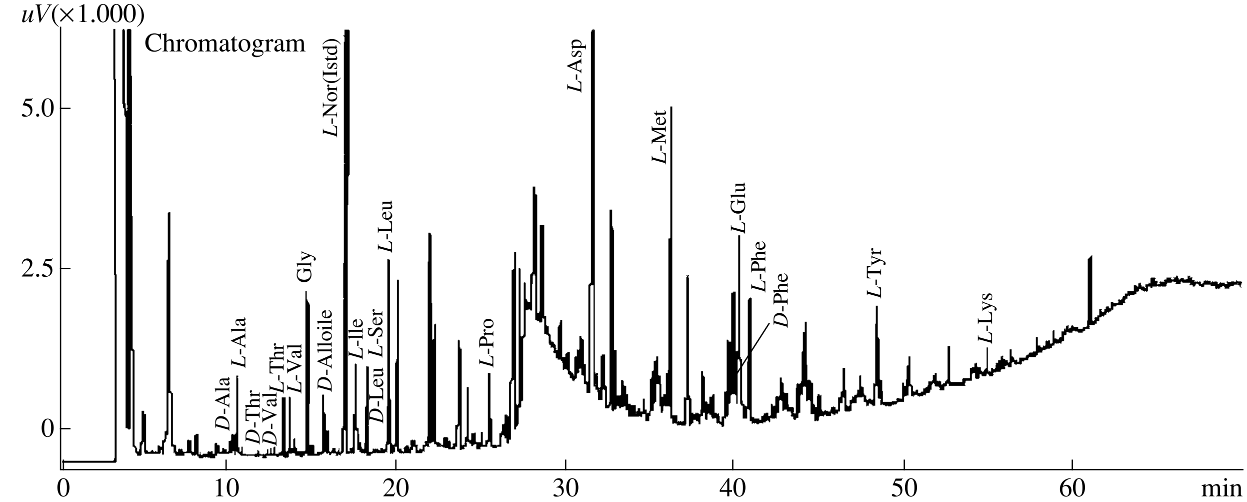

Fig. 2. Amino acid spectrum in fulgurite.

The chromatographic and mass-spectrographic analysis of products of phytofulgurite matter pyrolysis revealed no analytically significant quantities of low-molecular hydrocarbon or heteroatomic compounds. The phytofulgurite matter has a highly condensed aromatic texture and is characterized by insignificant content of peripheral alkyl and heterogeneous groups eliminated under conditions of dry (400°C) pyrolysis. The aromatic specifics of phytofulgurite is determined by its origin, when the basic substance was represented by humus organic matter with a substantially aromatic hydrocarbon framework.

As is known [5, 6], solid natural hydrocarbons contain practically all the so-called albuminous amino acids both inherited from primary oils, which are characteristic of naphtides, and neogenic ones resulting from the thermo- and radiosynthesis in naphtoids. Our studies revealed the presence of diverse amino acids in the examined phytofulgurite material (Fig. 2). It appeared that their total content (2.36 mg/g) is almost maximal for all the natural bitumens (an order of magnitude higher as compared with the background value). It should be noted that practically all amino acids are largely represented by *L*-modification (95%). Moreover, the latter is also dominant in other naphtoids (in naphtides, 85%). Because amino acids in phytofulgurite are abiogenic products of pyro- and thermosynthesis, the fact mentioned above is inconsistent with the accepted idea of the exclusively biogenic nature of *L*-modification amino acids and limits substantially their use as biomarkers. Our experimental studies with irradiation of solid bitumen revealed a phenomenon of radiosynthesis of amino acids with formation of largely their *L*-modifications, as in thermosynthesis [7].

The carbonaceous substance of phytofulgurite hosts numerous relict and the predominant neogenic mineral inclusions (total content 10–15 vol %). Only fossilized, relatively well-preserved diatoms can be attributed to relicts (Fig. 1e). They consist of silica (SiO_2 60–72%) and Al_2O_3 (8–23%) with an admixture of K, Mg, Ca, S, P, Fe, Ti, and Mn. Most common are silica inclusions (Fig. 1f) represented by aggregates of rounded structures (from 10*n* to 100*n* μm across) frequently with twisting boundaries. The silica inclusions vary in composition from pure SiO_2 to silica with an admixture of P, S, K, Ca, Cu, and Zn. Walls of some caverns are covered by parallel columnar aggregates of prismatic Ca–Mg carbonate crystals, as well as by druses of fibrous K–Ca–Mg sulfate crystals with an admixture of P, Pb, and Zn. Isometric metallic inclusions (1–5 μm) composed of Pb (54–77%), Cu (10–19%), and Zn (7–9%) are also common. They are monomineral formations corresponding to Cu–Zn lead or Pb brass. There are also inclusions containing Bi_2O_3 and Nb_2O_5 (up to 80 and 13%, respectively).

According to the above-mentioned data on the composition, physical, textural, spectroscopic, and thermal properties, phytofulgurite represents a complex hydrocarbon polymer with oxygen and other heteroatomic (N, S) groups of a high carbonization degree. Thus, it corresponds to natural medium anthraxolite, which is similar to oil coke or natural bitumen coke related to the contact-metamorphic alteration of naphtoids [8].

Carbonization is a process of pyrolitic transformation of solid and liquid hydrocarbons under temperatures of 900–1050°C without air access, which results in distillation of volatile components, formation of a solid hydrocarbon residue due to polycondensation and strong compaction of high-molecular compounds, and their carbonization and deoxidation. Precisely these processes are responsible for the formation of the examined phytofulgurite. This scenario had, however, specific features: high-energy electric discharge that resulted in both evaporation of volatile components of grass and its partial atomization, ultrahigh-speed pyrosynthesis of a solid residue, and accompanied diverse radiation.

The instant carbonization and similar rapid release of volatile components hampered their migration from aggregates and provided conservation in numerous pores and hollow spherical structures. Ultrahigh temperatures were most likely the triggering mechanism of amino acid synthesis, although a substantial role could belong to X-ray (with an energy of approximately 250 keV) and, particularly, gamma (energy 10 MeV) radiation. Let us remember that radiosynthesis of amino acids was realized in our experiments under gamma radiation of ^{60}Co with an energy of 1.25 MeV, while it occurred at 5–6 MeV in a nuclear reactor [7].

The occurrence of carbonate and sulfate crystals and druses in pores and caverns of phytofulgurite implies a short-term postimpact stage in mineral formation related to crystallization of mineral matter from hydrothermal or liquid–vapor fluids. As is known, postimpact hydrothermal activity related to the separation of fluids from glassy melts is also characteristic of impactites resulting from falls of extraterrestrial bodies [9].

Thus, the powerful atmospheric electric discharge on the haycock provoked ultrahigh-speed (almost instant) transformation of high plant material, i.e., organic matter of *humus* origin, into *pyrobitumen* (naphtoid) corresponding to medium anthraxolite. It means that the multistage and long-term (in natural environments) process was realized almost instantly. Despite some specifics of phytofulgurite formation, this process demonstrates all the features and consequences of the thermal-metamorphic succession of geological bitumen formation.

The obtained data are of substantial interest for the study of regularities in hydrocarbon structuring, formation of prebiological structures, and the origin and evolution of life. It should be noted that this discovery offers potential technological opportunities for elaboration of new electric-discharge methods for obtaining hydrocarbons from plant material and domestic wastes using the mechanism of phytofulgurite formation in natural environments as a methodical basis.

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