

Hydrocarbons in Fluid Inclusions from Native Gold, Pyrite, and Quartz of the Sovetskoe Deposit (Yenisei Ridge, Russia) According to Pyrolysis-Free Gas Chromatography–Mass Spectrometry Data

T.A. Bul'bak^{a, ✉}, A.A. Tomilenko^a, N.A. Gibsher^a, A.M. Sazonov^b, E.O. Shaparenko^a,
M.A. Ryabukha^a, M.O. Khomenko^a, S.A. Sil'yanov^b, N.A. Nekrasova^b

^a V.S. Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences,
pr. Akademika Koptyuga 3, Novosibirsk, 630090, Russia

^b Institute of Mining, Geology and Geotechnology of Siberian Federal University, pr. Svobodnyi 79, Krasnoyarsk, 660041, Russia

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Abstract—The first results on the composition of fluids from native gold and associated pyrite and quartz have been obtained. Despite the small amount of analytical data, these results are of scientific and practical interest. The identified geochemical criteria can be used for the assessment of gold ore shoots and the substantiation of prospecting in the region. The one-act shock-destructive extraction of volatiles from fluid inclusions and their pyrolysis-free gas chromatography–mass spectrometry analysis made it possible to determine the composition of fluids in native gold and in associated pyrite and quartz. Based on these data, we have first shown that fluids in native gold, pyrite, and quartz are a mineral-forming multicomponent system. In addition to water and carbon dioxide, the studied fluid inclusions contain representatives of at least 11 homologous series of organic compounds, including oxygen-free aliphatic and cyclic hydrocarbons (paraffins, olefins, cyclic alkanes and alkenes, arenes, and polycyclic aromatic hydrocarbons), oxygenated hydrocarbons (alcohols, esters, furans, aldehydes, ketones, and carboxylic acids), and nitrogenated, sulfonated, halogenated, and siliconorganic compounds. The portion of hydrocarbons together with S–N–Cl–F–Si compounds reaches 52.0 rel.% in fluid inclusions from native gold, 10.1 rel.% in fluid inclusions from pyrite, and 18.0 rel.% in fluid inclusions from quartz. Gold-transporting gas fluids have reducing properties. Pyrite and quartz contain oxidized water–carbon dioxide fluids with low contents of hydrocarbons and nitrogen–halogenated compounds.

Keywords: gold; fluids; hydrocarbons; gas chromatography–mass spectrometry analysis; Yenisei Ridge; Sovetskoe deposit

INTRODUCTION

There are several dozen gold-bearing minerals currently known in nature (Petrovskaya 1973, 1993; Spiridonov, 2010) and a number of artificially synthesized organo-gold compounds (Paddefet, 1982; Elschenbroich, 2006; Akhmadullina et al., 2012). Among all this variety of gold-bearing minerals, native gold from the mineral deposits is of industrial value. Native gold contains relics of ore-forming medium in the form of fluid inclusions, the study of which can help to reconstruct the composition of volatiles, the fluid regime of generation processes and origin of its natural concentrations. The first data on fluid inclusions were obtained using the decrepitation and gas chromatography methods. The chronological order of publications on fluid inclusions in native gold shows that the first of these appeared at the beginning of the last century, when in 1922 S.F. Zhemchuzhnyi observed the formation of bubbles on the polished

surface of gold nuggets during the process of quenching (Zhemchuzhnyi, 1922). Later, swelling bubbles on natural native gold samples were described in (Nikolaeva, 1954; Gapon, 1962; Babkin and Kuklin, 1966; Petrovskaya et al., 1971; Moiseenko, 1977; Neronskii and Levitskii, 1988). On heating, gases are released from these bubbles and they were called gas inclusions. The data in (Novgorogova, 1983) show that the distribution of these vacuoles in gold is uneven and their sizes vary in a wide range (from a few micrometers to 1–1.5 mm). The shapes of decrepitated inclusions vary from spherical, polyhedral (type of negative crystals), angular or complicated sinuous contours with uneven, frequently thinly stepped sculpture of walls. Gas pressure in the gas inclusions of gold particles from the Lena region placers, according to P.V. Babkin and A.P. Kuklin, was 530–850 atm (Babkin and Kuklin, 1966).

The data of the decrepitation method indicate that gas from native gold released in the temperature range of 180–570°C (Moiseenko, 1977; Kokin, 1981; Neronskii et al., 1982; Neronskii and Levitskii, 1988; Ostapenko et al., 1988; Ostapenko, 1989; Eirish et al., 2002). Visual observations of

✉ Corresponding author.

E-mail address: taras@igm.nsc.ru (T.A. Bul'bak)

decrepitation of fluid inclusions in gold showed (Neronskii et al., 1982; Levitskii et al., 1984) the highest decrepitation temperatures in the central part of large gold grains compared to the periphery, which indirectly suggests that their crystallization required a long and wide temperature range.

Observations of decrepitated vacuoles of fluid inclusions in native gold showed that solid precipitations are concentrated on their walls and around them (Petrovskaya, 1973; Moiseenko, 1977; Semenko, 1986). Solid phases were found by Babkin and Kuklin (1966) only in one in a hundred of decrepitated gas inclusion cavities in gold particles from the Lena placers. The walls of the cavity were covered with clusters of tiny (0.3 mm) white needle-like crystals containing phosphorus according to spectral analysis. Most likely, solid phases in the decrepitated vacuoles were previously in a dissolved state, the evidence of which comes from the substance splashed on the surface of gold particles in the form of tiny coatings around decrepitated inclusions. The methods of scanning electron microscopy and X-ray microanalysis qualitatively indicate that Mg, Na, K, Ca, Cl, S and other elements are permanently concentrated near decrepitated vacuoles and on their walls (Moiseenko, 1977). Sulfur compounds Ca and Mg were found in the central parts of gold dendritoids from the deposits of the Far East (Petrovskaya et al., 1975). The authors assume that the sulfur compounds are precipitates that released during decrepitation of vacuoles.

Gas chromatography data show that the gas compound of fluid inclusions consists of H_2O , CO_2 , CH_4 , and N_2 (Moiseenko, 1977; Tomilenko and Gibsher, 2001; Tomilenko et al., 2010). When analyzing volatile components, fluid inclusions were decrepitated either mechanically or by pyrolysis – by heating the sample to decrepitation temperature. Each of these procedures has advantages and drawbacks, which were thoroughly analyzed in (Mironova, 2010). Therefore, in Mironova's opinion, there is no exact answer to the question, which method is the best for decrepitating fluid inclusions.

Earlier, the composition of fluid conserved in gold was inferred from indirect evidence, which led to a conclusion that gold was transported by “dry gas-condensate reduced fluids, likely of hydrogen-hydrocarbon composition” (Nikolaeva, 1954; Ryabchikov and Novgorodova, 1981; Novgorodova, 1983).

The complexity and difficulty of fluid study resulted from the absence of special procedures and highly sensitive equipment, owing to which the works in this direction were relatively slow and publications on this problem were limited. Our procedure combines a one-act shock-destructive method for extracting volatile components from fluid inclusions in native gold, pyrite, quartz and their pyrolysis-free gas chromatography-mass spectrometry analysis (GC-MS). Without aiming at the analysis of the chemical composition of native gold from the Sovetskoe deposit in the Yenisei gold-ore province, which were discussed in detail in (Petrovskaya, 1973, 1993), we will focus on fluids in native gold and associated pyrite and quartz. The main goal of the work

is to determine the composition of fluids conserved as fluid inclusions in native gold, quartz and pyrite.

MATERIAL AND RESEARCH METHODS

The composition of fluid inclusions in native gold and its main carriers – pyrite and quartz – was analyzed in the samples from the Sovetskoe quartz-gold deposits occurring in the northern part of the Vostochnyi gold-bearing belt of the Yenisei Ridge. The geology and structure of the Sovetskoe deposit is studied well and was reported in many publications. The deposit area is made up of carbonate-argillaceous, quartz-Chlorite-sericite and quartz-muscovite-biotite shales of the upper Proterozoic (Bogdanovich, 1962, 1964). The deposit is confined to the tectonic zone of crush and occurs in the northwestern wing of a large syncline complicated by numerous small folds and tectonic disturbances such as reverse and reverse-shift faults (Bogdanovich, 1962, 1964; Simkin, 1997). The ore-bearing zone of the deposit is a thick (more than 1000 m) band of rocks intensely schistose and broken by numerous faults. A specific feature of the deposit is that mineralization in it doesn't occur in the form of separated and more or less continuous veins, but it forms series of converging, merging and re-branching veins, veinlets and complex deposits concentrated into persistent vein zones. A series of quartz-vein zones of various gold contents was identified within the deposit. The thickness of vein zones ranges from few to 100 m and more. The deposit belongs to a low-sulfide gold-quartz type. Quartz makes up to 97% and more of the vein filling of orebodies. In addition to quartz, nonmetallic minerals are represented by significant amounts of calcite, albite, sericite and chlorite. Ore minerals found at the deposit are pyrrhotite, pyrite, arsenopyrite, gold, sphalerite, chalcopyrite and galena (Petrovskaya, 1956).

The samples were selected from a gold-bearing quartz vein (orebody No. 3, horizon 390, crosscut 86) with visible gold in association with pyrite aggregates. The samples were crushed, scattered on sieves, and pure gold particles, pyrite and quartz grains were picked out under a binocular magnifying glass. When preparing the sample for analysis, no acids, solvents organic substances were used as they could introduce inaccuracies to the initial fluid composition, which was discussed in detail in (Mironova, 2010).

The tested samples of up 0.06 cm^3 in volume were placed using the tweezers into a boat in a special device (Fig. 1, node 4), which was used online in the gas scheme of the chromatograph in front of the analytical column. Before analysis, the samples were heated at 130–160 °C for 13 minutes in the current of helium carrier gas at pressure 45 kPa. The purity of helium was 99.9999%. Analysis of the gas mixture extracted by a single shock destruction of the sample was performed on the gas chromatography – mass spectrometer Focus GC/DSQ II MS (Thermo Scientific, USA). All gas paths, along which the gas mixture moved, including the injector and the tap, node 4 and capillaries, had sulfinert

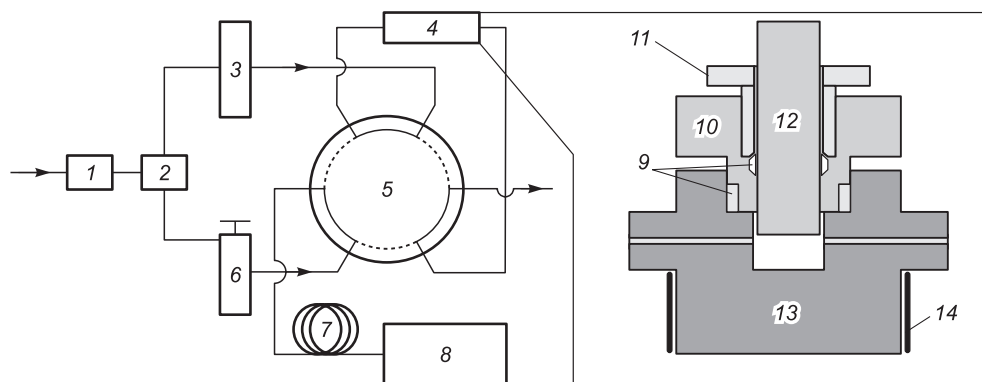


Fig. 1. Schematic diagram of the pneumatic circuit with the main nodes of the used gas chromatograph-mass spectrometer: 1, filter; 2, tee; 3, gas flow regulator; 4, cell for sample destruction; 5–6, port 2-way crane; 6, SSL injector; 7, analytical column; 8, mass selective detector. On the insert, there is a simplified section diagram of 4 nodes: 9, fluoroplastic seals; 10, persistent nut; 11, pressure nut; 12, shockproof stock; 13, housing with a recess for the sample and a through gas path; 14, furnace heater.

coating. The sample was separated into components in the gas chromatograph on a non-polar capillary analytical column Rt-Q-BOND (Restek, USA; immobile phase is 100% divinylbenzene, length is 30 m, internal diameter is 0.32 mm, thickness of the immobile phase is 10 microns) under the following conditions: the mixture without being separated and concentrated, including cryofocussing, was introduced through a six-port two-position thermostatically controlled (270 °C) tap (Valco, USA) into the analytical column. The constant flow rate of He with vacuum compensation was $1.7 \text{ ml} \cdot \text{min}^{-1}$, temperature of the GC-MS connecting line was 300 °C; the column was kept for 2 min at 70 °C, then heated at a rate of $25 \text{ }^\circ\text{C} \cdot \text{min}^{-1}$ to 150°C, and thereafter at a rate of $5 \text{ }^\circ\text{C} \cdot \text{min}^{-1}$ to 290 °C and was kept at this temperature for 100 min. Mass spectra of ionization by electron impact on the full ion current were obtained on a quadruple mass selective detector in a Full Scan mode. Mass spectral conditions: electron energy was 70 eV, emission current was 100 μA , temperature in the ion source was 200 °C, amplifier voltage was 1350 V, polarity of the registered ions was positive, mass scanning range was 5–500 a.m., scanning speed was 1 scan per second. The start of the analysis was synchronized with the moment of destruction of the sample.

In this analytical method the samples were not subjected to pyrolysis, but were only warmed to desorb the surface and transfer water, probably contained in the sample, to a gas phase. Therefore, the gas mixture was analyzed virtually *in situ*, instead of a pyrolysate containing more oxidized compounds (H_2O , CO, CO_2 , etc.) formed due to the reaction between the components of gas mixture and storage surface, compounds in the gas phase and the sample. Before and after “working” analysis, blank online analyses were performed. Previous analysis allowed controlling the release of gases sorbed by the sample surface, including atmospheric components, and to record the blank of the system. Results of the subsequent analysis were used to determine the degree and completeness of elution of heavy hydrocarbons and polycy-

clitic aromatic hydrocarbons (PAHs) from the analytical column when programming the temperature in the chromatograph thermostat. Whenever necessary, the analytical column was thermoconditioned until the required blank was attained.

The GC-MS analysis used for determining the gas phase composition in native gold, pyrite and quartz combines the advantages of two independent quantitative methods for identifying individual compounds in a gas mixture. By dividing the gas mixture into components, chromatography allowed us to determine the specific retention times by the analytical column for each of them. The peak area in the chromatogram is proportional to the concentration of the corresponding substance in the gas mixture. Mass spectrometry provided a set of mass spectra for each compound and information about its ion and diagnostic fragments. Identification of each compound was made by integrating both methods. Interpretation of the obtained GC-MS data with identification of peaks and selection of individual components from overlapping peaks was performed using both the AMDIS (Automated Mass Spectral Deconvolution and Identification System) software version 2.73, and manual mode with background correction for the NIST 2017 and Wiley 11 mass spectrum libraries with the help of the NIST MS Search program version 2.3, the search parameters were standard. The relative concentrations (rel.%) of volatile components in the separated mixture were determined by the normalization method: the sum of the areas of all chromatographic peaks of the analyzed mixture was equal to 100%, and its percentage content in the analyzed mixture was determined from the area of the individual component. The areas of peaks in the chromatogram were determined from the ICIS algorithm using Qual Browser 1.4 SR1 from the Xcalibur software package. The proposed method can be used for detecting trace contents of individual volatile components from dozens of femtograms. The method of pyrolysis-free gas chromatography-mass spectrometry used for determining the gas component of fluid inclusions in minerals is described in detail in

(Tomilenko et al., 2015; Zhimulev et al., 2015; Sokol et al., 2017; Tomilenko et al., 2019).

RESULTS OF RESEARCH

Using the method of pyrolysis-free gas chromatography-mass spectrometry, H₂O, CO₂, a wide range of hydrocarbons and S–N–F–Cl–Si-containing compounds were determined in the composition of volatile extracted from fluid inclusions in native gold, pyrite and quartz. The results are presented graphically on the chromatograms (Figs. 2–4), are listed in Tables 1–3, are summarized in Table 4 and are shown in Figs. 5 and 6, *a–d*. The total list of detected compounds contains from 143 to 211 components (Table 4). The proportion of hydrocarbons with S–N–F–Cl–Si-bearing compounds amounts to 52.0 rel.% in native gold, 10.1 rel.% in pyrite and 18.0 rel.% in quartz. The content of CO₂ in fluid inclusions in gold, pyrite and quartz is 47.7 rel.%, 53.8 rel.%, and 37.3 rel.%, respectively (Figs. 5, 6). Fluid inclusions from native gold contained considerably less water (0.26 rel.%, Table 4), which is 138 times less than in pyrite and 172 times less than in quartz. In fluids extracted from inclusions in native gold, pyrite and quartz, in addition

to water and carbon dioxide, for the first time representatives of no less than 11 homologous series of organic compounds were found, including oxygen-free aliphatic and cyclic hydrocarbons (paraffins, olefins, cyclic alkanes and alkenes, arenes, polycyclic aromatic hydrocarbons – PAHs), oxygen-bearing hydrocarbons (alcohols and esters, furans, aldehydes, ketones, carboxylic acids), nitrogen-, sulfur-, halogen- and silicon-bearing compounds (Tables 1–3; Fig. 6, *a–d*). Nitrogen-containing compounds, the proportion of which ranges from 0.39 to 10.5 rel.% (Tables 1–3), are dominated by molecular nitrogen (N₂). Sulfur-bearing compounds are also constantly present in the fluids from native gold, pyrite and quartz, their contents are 1–2 rel.%, and SO₂ is present in an increased content (Tables 1–3). The proportion of halogen-bearing (F, Cl, Br) compounds in gold fluid inclusions is 0.14 rel.% and by an order of magnitude less than in those from pyrite and quartz (Tables 1–3). Organosilicon compounds have been identified only in the fluids from gold and pyrite fluids, but not from quartz. In the group of paraffins found in the composition of fluids, medium (C₅–C₁₂) hydrocarbons predominate over light (C₁–C₄) hydrocarbons (Fig. 6*b*). This is indicated by the value of the ratio $\Sigma(C_5-C_{12})/\Sigma(C_1-C_4)$, which is 240.25 in gold, 0.40 in pyrite, and 1.32 in quartz (Table 4).

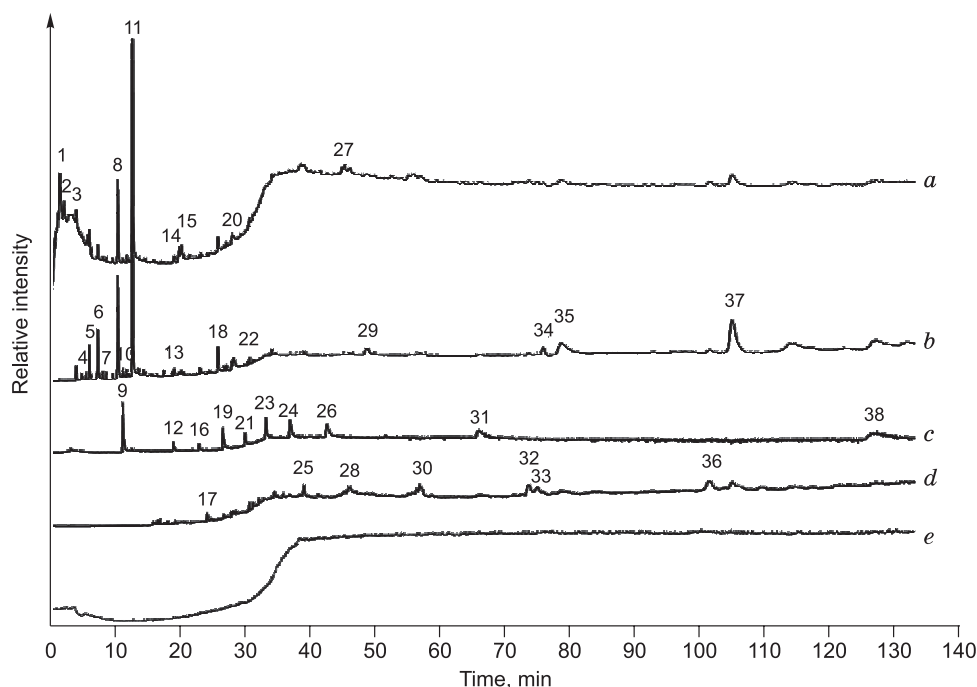


Fig. 2. Results of the GC-MS analysis of volatile components extracted from fluid inclusions in gold from a gold-bearing quartz vein of the Sovetskoye deposit, Yenisei Ridge. Chromatogram (*a*) for total ion current (TIC) and reconstructed ion chromatograms for ion current: *b*, *m/z* (43 + 57 + 71 + 85); *c*, *m/z* 60; *d*, *m/z* (97 + 98); *e*, blank. 1, Carbon dioxide (CO₂); 2, Ethane (C₂H₆); 3, Propane (C₃H₈); 4, Isobutane (C₄H₁₀); 5, Butane (C₄H₁₀); 6, 2-Propanol (C₃H₈O); 7, Pentane (C₅H₁₂); 8, Butanal (C₄H₈O); 9, Acetic acid (C₂H₄O₂); 10, 1-Pentene, 4-methyl- (C₆H₁₂); 11, 1-Butanol (C₄H₁₀O); 12, Butanoic acid (C₄H₈O₂); 13, Hexanal (C₆H₁₂O); 14, Heptane, 3-methylene- (C₈H₁₆); 15, 3-Heptene, 4-methyl- (C₈H₁₆); 16, Pentanoic acid (C₅H₁₀O₂); 17, 1-Nonene (C₉H₁₈); 18, Hexanal, 2-ethyl- (C₈H₁₆O); 19, Hexanoic acid (C₆H₁₂O₂); 20, 1-Hexanol, 2-ethyl- (C₈H₁₈O); 21, Heptanoic acid (C₇H₁₄O₂); 22, Nonanal (C₉H₁₈O); 23, Octanoic acid (C₈H₁₆O₂); 24, Nonanoic acid (C₉H₁₈O₂); 25, Thiophene, 2-hexyl- (C₁₀H₁₆S); 26, Decanoic acid (C₁₀H₂₀O₂); 27, 1,13-Tetradecadiene (C₁₄H₂₆); 28, n-Tetradecane (C₁₄H₃₀); 29, Tetradecane, 3-methyl- (C₁₅H₃₂); 30, 1-Undecanethiol (C₁₁H₂₄S); 31, Dodecanoic acid (C₁₂H₂₄O₂); 32, Tetradecanal (C₁₄H₂₈O); 33, 1-Hexadecene (C₁₆H₃₂); 34, Hexadecane (C₁₆H₃₄); 35, Hexadecane, 3-methyl- (C₁₇H₃₆); 36, 1-Heptadecene (C₁₇H₃₄); 37, Heptadecane (C₁₇H₃₆); 38, Tetradecanoic acid (C₁₄H₂₈O₂).

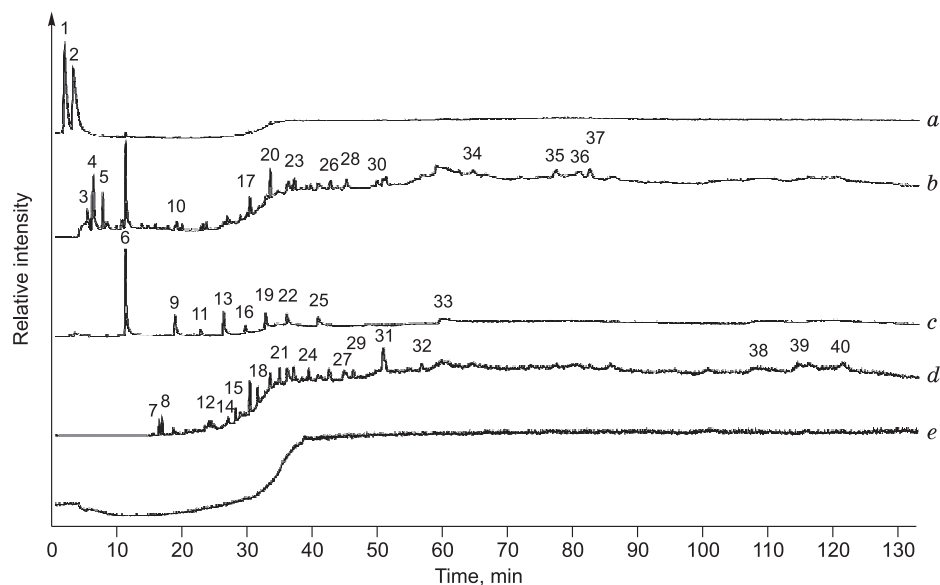


Fig. 3. Results of the GC-MS analysis of volatile components extracted from fluid inclusions in quartz from a gold-bearing quartz vein of the Sovetskoye deposit, Yenisei Ridge. Chromatogram (a) for total ion current (TIC) and reconstructed ion chromatograms for ion current: b, m/z (43 + 57 + 71 + 85); c, m/z 60; d, m/z (97 + 98); e, blank. 1, Carbon dioxide (CO_2); 2, Water (H_2O); 3, Acetaldehyde ($\text{C}_2\text{H}_4\text{O}$); 4, Propane, 2-methyl- (C_4H_{10}); 5, 2-Propanone ($\text{C}_3\text{H}_6\text{O}$); 6, Acetic acid ($\text{C}_2\text{H}_4\text{O}_2$); 7, Thiophene, 2-methyl- ($\text{C}_5\text{H}_6\text{S}$); 8, Thiophene, 3-methyl- ($\text{C}_5\text{H}_6\text{S}$); 9, Butanoic acid ($\text{C}_4\text{H}_8\text{O}_2$); 10, Hexanal ($\text{C}_6\text{H}_{12}\text{O}$); 11, Pentanoic acid ($\text{C}_5\text{H}_{10}\text{O}_2$); 12, Thiophene, 2-propyl- ($\text{C}_7\text{H}_{10}\text{S}$); 13, Hexanoic acid ($\text{C}_6\text{H}_{12}\text{O}_2$); 14, Thiophene, 2-(1,1-dimethylethyl)- ($\text{C}_8\text{H}_{12}\text{S}$); 15, Thiophene, 2-butyl- ($\text{C}_8\text{H}_{12}\text{S}$); 16, Heptanoic acid ($\text{C}_7\text{H}_{14}\text{O}_2$); 17, Nonanal ($\text{C}_9\text{H}_{18}\text{O}$); 18, Thiophene, 2-pentyl- ($\text{C}_9\text{H}_{14}\text{S}$); 19, Octanoic acid ($\text{C}_8\text{H}_{16}\text{O}_2$); 20, Decanal ($\text{C}_{10}\text{H}_{20}\text{O}$); 21, Thiophene, 2-hexyl- ($\text{C}_{10}\text{H}_{16}\text{S}$); 22, Nonanoic acid ($\text{C}_9\text{H}_{18}\text{O}_2$); 23, Tridecane ($\text{C}_{13}\text{H}_{28}$); 24, Thiophene, 3-heptyl- ($\text{C}_{11}\text{H}_{18}\text{S}$); 25, Decanoic acid ($\text{C}_{10}\text{H}_{20}\text{O}_2$); 26, Dodecanal ($\text{C}_{12}\text{H}_{24}\text{O}$); 27, 1-Tetradecane ($\text{C}_{14}\text{H}_{30}$); 28, Tetradecane ($\text{C}_{14}\text{H}_{30}$); 29, Thiophene, 2-octyl- ($\text{C}_{12}\text{H}_{20}\text{S}$); 30, 2-Tridecanone ($\text{C}_{13}\text{H}_{26}\text{O}$); 31, 1-Pentadecene ($\text{C}_{15}\text{H}_{30}$); 32, Thiophene, 2-nonyl- ($\text{C}_{13}\text{H}_{22}\text{S}$); 33, Dodecanoic acid ($\text{C}_{12}\text{H}_{24}\text{O}_2$); 34, Tetradecanal ($\text{C}_{14}\text{H}_{28}\text{O}$); 35, 2-Pentadecanone ($\text{C}_{15}\text{H}_{30}\text{O}$); 36, Pentadecanal ($\text{C}_{15}\text{H}_{30}\text{O}$); 37, Heptadecane ($\text{C}_{17}\text{H}_{36}$); 38, Resorcinol, 5-pentyl- (1,3-Benzenediol, 5-pentyl-) ($\text{C}_{11}\text{H}_{16}\text{O}_2$); 39, Resorcinol, 2-hexyl- ($\text{C}_{12}\text{H}_{18}\text{O}_2$); 40, Resorcinol, 4-hexyl- ($\text{C}_{12}\text{H}_{18}\text{O}_2$).

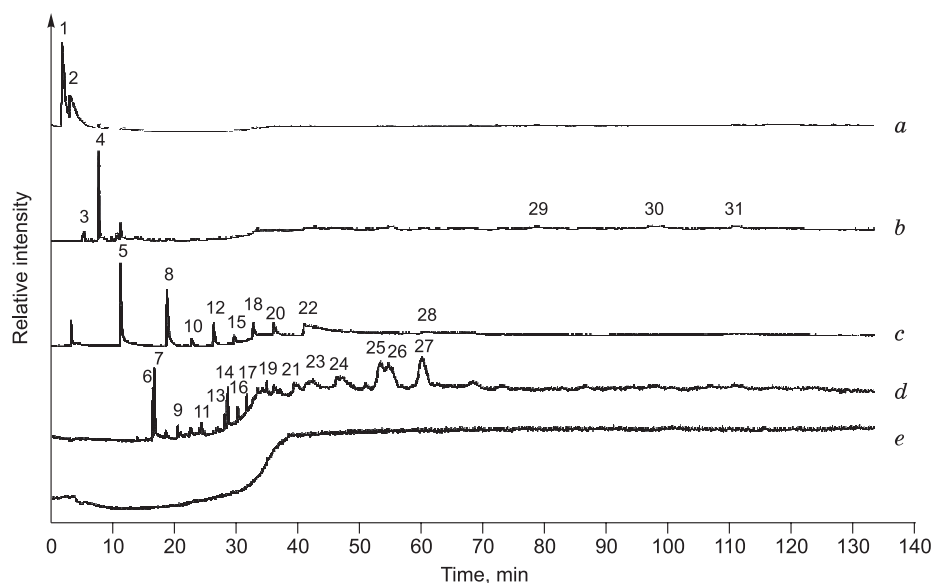


Fig. 4. Results of the GC-MS analysis of volatile components extracted from fluid inclusions in pyrite from a gold-bearing quartz vein of the Sovetskoye deposit, Yenisei Ridge. Chromatogram (a) for total ion current (TIC) and reconstructed ion chromatograms for ion current: b, m/z (43 + 57 + 71 + 85); c, m/z 60; d, m/z (97 + 98); e, blank. 1, Carbon dioxide (CO_2); 2, Water (H_2O); 3, Acetaldehyde ($\text{C}_2\text{H}_4\text{O}$); 4, 2-Propanone ($\text{C}_3\text{H}_6\text{O}$); 5, Formic acid (CH_2O_2); 6, Thiophene, 2-methyl- ($\text{C}_5\text{H}_6\text{S}$); 7, Thiophene, 3-methyl- ($\text{C}_5\text{H}_6\text{S}$); 8, Butanoic acid ($\text{C}_4\text{H}_8\text{O}_2$); 9, Thiophene, 2-ethyl- ($\text{C}_6\text{H}_8\text{S}$); 10, Pentanoic acid ($\text{C}_5\text{H}_{10}\text{O}_2$); 11, Thiophene, 2-propyl- ($\text{C}_7\text{H}_{10}\text{S}$); 12, Hexanoic acid ($\text{C}_6\text{H}_{12}\text{O}_2$); 13, Thiophene, 2-butyl- ($\text{C}_8\text{H}_{12}\text{S}$); 14, Benzene, butyl- ($\text{C}_{10}\text{H}_{14}$); 15, Heptanoic acid ($\text{C}_7\text{H}_{14}\text{O}_2$); 16, Undecane ($\text{C}_{11}\text{H}_{24}$); 17, Thiophene, 2-pentyl- ($\text{C}_9\text{H}_{14}\text{S}$); 18, Octanoic acid ($\text{C}_8\text{H}_{16}\text{O}_2$); 19, Thiophene, 2-hexyl- ($\text{C}_{10}\text{H}_{16}\text{S}$); 20, Nonanoic acid ($\text{C}_9\text{H}_{18}\text{O}_2$); 21, Thiophene, 3-heptyl- ($\text{C}_{11}\text{H}_{18}\text{S}$); 22, Decanoic acid ($\text{C}_{10}\text{H}_{20}\text{O}_2$); 23, Dodecanal ($\text{C}_{12}\text{H}_{24}\text{O}$); 24, Thiophene, 2-octyl- ($\text{C}_{12}\text{H}_{20}\text{S}$); 25, Benzoic acid, hexyl ester ($\text{C}_{13}\text{H}_{18}\text{O}_2$); 26, Tetradecane, 2,6,10-trimethyl- ($\text{C}_{17}\text{H}_{36}$); 27, Benzoic acid, hept-3-yl ester ($\text{C}_{14}\text{H}_{20}\text{O}_2$); 28, Dodecanoic acid ($\text{C}_{12}\text{H}_{24}\text{O}_2$); 29, 2-Pentadecanone ($\text{C}_{15}\text{H}_{30}\text{O}$); 30, Heptadecane, 8-methyl ($\text{C}_{18}\text{H}_{38}$); 31, Heptadecane, 4-methyl ($\text{C}_{18}\text{H}_{38}$).

Table 1. The results of the GC-MS analysis of gas-phase products extracted during shock destruction of native gold, Sovetskoye deposit, Yenisei Ridge

Formula	Name	¹ CAS/(NIST)	² MW	Gold	
				³ RT, min	⁴ A, %
Aliphatic hydrocarbons					
<i>Paraffins</i>					
C ₄ H ₁₀	<i>n</i> -Butane	106-97-8	58	6.454	0.004
C ₆ H ₁₄	<i>n</i> -Hexane	110-54-3	86	12.404	0.038
C ₇ H ₁₆	<i>n</i> -Heptane	142-82-5	100	16.594	0.058
C ₈ H ₁₆	3-Methyleneheptane	1632-16-2	112	20.106	0.405
C ₈ H ₁₈	<i>n</i> -Octane	111-65-9	114	20.778	0.241
C ₉ H ₂₀	<i>n</i> -Nonane	111-84-2	128	24.722	0.067
C ₁₁ H ₂₄	<i>n</i> -Undecane	1120-21-4	156	31.722	0.044
C ₁₂ H ₂₆	<i>n</i> -Dodecane	112-40-3	170	35.015	0.108
C ₁₃ H ₂₈	<i>n</i> -Tridecane	629-50-5	184	39.554	0.043
C ₁₄ H ₃₀	<i>n</i> -Tetradecane	629-59-4	198	46.778	0.023
C ₁₅ H ₃₂	<i>n</i> -Pentadecane	629-62-9	212	58.627	0.039
C ₁₇ H ₃₆	<i>n</i> -Heptadecane	629-78-7	240	104.710	0.754
<i>Olefins</i>					
C ₃ H ₆	1-Propene	115-07-1	42	4.070	0.002
C ₄ H ₈	2-Methyl-1-propene	115-11-7	56	6.022	0.009
C ₄ H ₈	(E)-2-Butene	624-64-6	56	6.251	0.002
C ₄ H ₈	2-Butene	107-01-7	56	6.369	0.002
C ₆ H ₁₂	1-Hexene	592-41-6	84	12.057	0.064
C ₇ H ₁₄	(E)-4-Methyl-2-hexene	3683-22-5	98	15.847	0.048
C ₇ H ₁₄	2-Methyl-1-hexene	6094-02-6	98	16.178	0.101
C ₇ H ₁₄	1-Heptene	592-76-7	98	16.452	0.070
C ₈ H ₁₆	3,4-Dimethyl-3-hexene	30951-95-2	112	19.946	0.180
C ₈ H ₁₆	4-Methyl-3-heptene	4485-16-9	112	20.275	0.242
C ₈ H ₁₆	1-Octene	111-66-0	112	20.418	0.161
C ₈ H ₁₆	(Z)-3-Octene	14850-22-7	112	20.505	0.280
C ₈ H ₁₆	(Z)-2-Octene	7642-04-8	112	20.631	0.091
C ₉ H ₁₈	1-Nonene	124-11-8	126	24.409	0.093
C ₁₀ H ₂₀	1-Decene	872-05-9	140	28.086	0.070
C ₁₁ H ₂₂	1-Undecene	821-95-4	154	31.491	0.072
C ₁₂ H ₂₄	1-Dodecene	112-41-4	168	34.759	0.154
C ₁₃ H ₂₆	1-Tridecene	2437-56-1	182	39.200	0.191
C ₁₄ H ₂₈	1-Tetradecene	1120-36-1	196	46.051	0.142
C ₁₅ H ₃₀	1-Pentadecene	13360-61-7	210	57.723	0.077
Cyclic hydrocarbons					
<i>Cycloalkanes (naphthenes) and cycloalkenes</i>					
C ₆ H ₁₀	3,3-Dimethyl-cyclobutene	16327-38-1	82	13.132	0.114
C ₁₀ H ₁₆	α -Pinene	80-56-8	136	26.143	0.081
<i>Arenes</i>					
C ₆ H ₆	Benzene	71-43-2	78	12.768	0.133
C ₇ H ₈	Toluene	108-88-3	92	17.366	0.071
C ₈ H ₉ F	<i>p</i> -Fluoroethylbenzene	459-47-2	124	21.234	0.095
C ₈ H ₁₀	Ethylbenzene	100-41-4	106	21.703	0.096
C ₈ H ₁₀	<i>p</i> -Xylene	106-42-3	106	21.768	0.155
C ₈ H ₁₀	<i>o</i> -Xylene	95-47-6	106	22.037	0.160
C ₈ H ₁₀	<i>m</i> -Xylene	108-38-3	106	22.184	0.106
C ₈ H ₈	Styrene	100-42-5	104	22.370	0.168
C ₁₀ H ₁₂	1-Methyl-4-(1-methylethenyl)-benzene	1195-32-0	132	29.211	0.056
C ₁₁ H ₁₆	Pentylbenzene	538-68-1	148	32.642	0.021
C ₁₂ H ₁₈	Hexylbenzene	1077-16-3	162	36.345	0.057
C ₁₃ H ₂₀	Heptylbenzene	1078-71-3	176	41.678	0.242

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Table 1 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Gold	
				³ RT, min	⁴ A, %
Heterocyclic compounds					
Furans					
C ₅ H ₆ O	2-Methylfuran	534-22-5	82	14.362	0.002
C ₆ H ₈ O	2-Ethylfuran	3208-16-0	96	16.422	0.003
C ₇ H ₁₀ O	2-Propylfuran	4229-91-8	110	18.481	0.003
C ₈ H ₁₂ O	2-Butylfuran	4466-24-4	124	22.769	0.012
C ₉ H ₁₄ O	2-Pentylfuran	3777-69-3	138	26.645	0.029
C ₁₁ H ₁₈ O	2-Heptylfuran	3777-71-7	166	33.567	0.013
C ₁₂ H ₂₀ O	2-Octylfuran	4179-38-8	180	37.742	0.006
C ₁₃ H ₂₂ O	2-Nonylfuran	x	194	43.575	0.016
Oxygenated hydrocarbons					
<i>Alcohols, ethers and esters</i>					
C ₂ H ₆ O	Ethanol	64-17-5	46	6.467	0.007
C ₄ H ₁₀ O	1-Butanol	71-36-3	74	13.059	0.039
C ₆ H ₆ O	Phenol	108-95-2	94	24.896	0.263
C ₇ H ₈ O	Benzenemethanol	100-51-6	108	26.483	0.008
C ₈ H ₁₈ O	2-Ethyl-1-hexanol	104-76-7	130	28.509	0.796
C ₄ H ₆ O ₃	Acetyl ether	108-24-7	102	7.988	0.130
C ₅ H ₈ O ₂	Methyl methacrylate	80-62-6	100	14.701	0.137
C ₅ H ₈ O	3,4-Dihydro-2H-pyran	110-87-2	84	16.941	0.061
C ₄ H ₆ O ₂	Butyrolactone	96-48-0	86	20.761	0.004
C ₇ H ₁₄ O ₂	Methyl ester 4-methyl-pentanoic acid	2412-80-8	130	23.758	0.041
C ₇ H ₁₂ O ₂	γ-Heptalactone	105-21-5	128	34.781	0.016
C ₈ H ₁₄ O ₂	γ-Octalactone	104-50-7	142	39.562	0.018
C ₁₃ H ₂₈ O	1-Methoxy-dodecane	3482-63-1	200	47.741	1.182
C ₁₂ H ₁₄ O ₄	Diethyl Phthalate	84-66-2	222	63.281	16.700
C ₁₄ H ₁₈ O ₄	Dipropyl Phthalate	131-16-8	250	122.295	0.197
<i>Aldehydes</i>					
C ₂ H ₄ O	Acetaldehyde	75-07-0	44	5.201	0.051
C ₄ H ₆ O	2-Methyl-2-propenal	78-85-3	70	9.635	0.130
C ₄ H ₈ O	<i>n</i> -Butanal	123-72-8	72	10.633	0.145
C ₅ H ₁₀ O	3-methylbutanal	590-86-3	86	13.787	0.070
C ₅ H ₁₀ O	<i>n</i> -Pentanal	110-62-3	86	14.856	0.187
C ₅ H ₈ O	2-Methyl-2-butenal	1115-11-3	84	17.211	0.006
C ₅ H ₄ O ₂	Furfural	98-01-1	96	17.478	0.039
C ₅ H ₄ O ₂	3-Furaldehyde	498-60-2	96	18.344	0.184
C ₆ H ₁₂ O	<i>n</i> -Hexanal	66-25-1	100	19.290	0.520
C ₇ H ₁₄ O	<i>n</i> -Heptanal	111-71-7	114	23.514	0.437
C ₇ H ₆ O	Benzaldehyde	100-52-7	106	24.257	0.073
C ₈ H ₁₆ O	<i>n</i> -Octanal	124-13-0	128	27.389	0.445
C ₉ H ₁₈ O	<i>n</i> -Nonanal	124-19-6	142	30.946	0.922
C ₁₀ H ₂₀ O	<i>n</i> -Decanal	112-31-2	156	34.283	0.955
C ₁₁ H ₂₂ O	<i>n</i> -Undecanal	112-44-7	170	38.625	0.213
C ₁₂ H ₂₄ O	<i>n</i> -Dodecanal	112-54-9	184	45.249	0.747
C ₁₃ H ₂₆ O	<i>n</i> -Tridecanal	10486-19-8	198	56.869	0.987
C ₁₅ H ₃₀ O	<i>n</i> -Pentadecanal	2765-11-9	226	99.836	0.318
<i>Ketones</i>					
C ₃ H ₆ O	Acetone	67-64-1	58	7.615	0.161
C ₄ H ₆ O	2-Butenone	78-94-4	70	10.291	0.021
C ₄ H ₈ O	2-Butanone	78-93-3	72	10.552	0.080
C ₅ H ₁₀ O	2-Pentanone	107-87-9	86	14.607	0.039

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Table 1 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Gold	
				³ RT, min	⁴ A, %
C ₆ H ₁₂ O	2-Hexanone	591-78-6	100	19.014	0.016
C ₅ H ₄ O ₃	Dihydro-3-methylene-2,5-furandione	2170-03-8	112	22.869	0.130
C ₇ H ₁₄ O	2-Heptanone	110-43-0	114	23.187	0.084
C ₈ H ₁₆ O	6-Methyl-2-heptanone	928-68-7	128	26.061	0.191
C ₈ H ₁₄ O	6-Methyl-5-hepten-2-one	110-93-0	126	26.322	0.207
C ₈ H ₁₄ O	2-Methyl-1-hepten-6-one	10408-15-8	126	26.497	0.109
C ₈ H ₁₆ O	2-Octanone	111-13-7	128	27.076	0.083
C ₉ H ₁₈ O	2-Nonanone	821-55-6	142	30.632	0.076
C ₁₀ H ₂₀ O	2-Decanone	693-54-9	156	33.924	0.134
C ₈ H ₄ O ₃	Phthalic anhydride	85-44-9	148	35.877	0.825
C ₁₁ H ₂₂ O	2-Undecanone	112-12-9	170	38.056	0.269
C ₁₂ H ₂₄ O	2-Dodecanone	6175-49-1	184	44.300	0.056
C ₁₃ H ₂₆ O	2-Tridecanone	593-08-8	198	55.771	0.713
C ₁₅ H ₃₀ O	2-Pentadecanone	2345-28-0	226	95.719	0.270
<i>Carboxylic acids</i>					
C ₂ H ₄ O ₂	Acetic acid	64-19-7	60	11.371	1.026
C ₃ H ₆ O ₂	<i>n</i> -Propanoic acid	79-09-4	74	15.290	0.010
C ₄ H ₈ O ₂	<i>n</i> -Butanoic acid	107-92-6	88	19.126	0.097
C ₅ H ₁₀ O ₂	3-Methylbutanoic acid	503-74-2	102	22.150	0.013
C ₅ H ₁₀ O ₂	<i>n</i> -Pentanoic acid	109-52-4	102	23.104	0.126
C ₆ H ₁₂ O ₂	<i>n</i> -Hexanoic acid	142-62-1	116	26.749	0.264
C ₇ H ₁₄ O ₂	<i>n</i> -Heptanoic acid	111-14-8	130	30.206	0.347
C ₈ H ₁₆ O ₂	<i>n</i> -Octanoic acid	124-07-2	144	33.347	0.393
C ₉ H ₁₈ O ₂	<i>n</i> -Nonanoic acid	112-05-0	158	37.074	0.800
C ₁₀ H ₂₀ O ₂	<i>n</i> -Decanoic acid	334-48-5	172	42.792	1.488
C ₁₁ H ₂₂ O ₂	<i>n</i> -Undecanoic acid	112-37-8	186	51.696	0.028
C ₁₂ H ₂₄ O ₂	<i>n</i> -Dodecanoic acid	143-07-7	200	65.952	0.136
C ₁₃ H ₂₆ O ₂	<i>n</i> -Tridecanoic acid	638-53-9	214	82.927	0.144
C ₁₄ H ₂₈ O ₂	<i>n</i> -Tetradecanoic acid	544-63-8	228	128.071	0.232
Nitrogenated compounds					
N ₂	Nitrogen	7727-37-9	28	1.540	0.925
C ₂ H ₅ NO	Acetamide	60-35-5	59	15.389	0.112
C ₅ H ₅ N	Pyridine	110-86-1	79	15.444	0.008
C ₄ H ₅ NO ₂	Succinimide	123-56-8	99	30.132	0.015
C ₁₀ H ₁₅ N	(-)-Deoxyephedrine	33817-09-3	149	35.227	0.077
C ₁₄ H ₃₀ N ₂ O	N,N-Dimethyl-N'-butyl-N'-heptyl-urea	(439309)	242	110.756	9.387
Sulfonated compounds					
O ₂ S	Sulfur dioxide	7446-09-5	64	4.680	0.629
CS ₂	Carbon disulfide	75-15-0	76	7.958	0.064
C ₂ H ₆ S ₂	Dimethyl disulfide	624-92-0	94	15.526	0.050
C ₅ H ₆ S	2-Methylthiophene	554-14-3	98	16.817	0.059
C ₅ H ₆ S	3-Methylthiophene	616-44-4	98	17.177	0.072
C ₆ H ₈ S	2-Ethylthiophene	872-55-9	112	21.008	0.034
C ₇ H ₁₀ S	2-Propylthiophene	1551-27-5	126	24.966	0.005
C ₇ H ₈ S	4-Methyl-benzenethiol	106-45-6	124	27.708	0.058
C ₈ H ₁₂ S	2-Butylthiophene	1455-20-5	140	28.849	0.011
C ₅ H ₈ O ₂ S	(2-Propenylthio)-acetic acid	20600-63-9	132	29.637	0.028
C ₉ H ₁₄ S	2-Pentylthiophene	4861-58-9	154	32.372	0.020
Organosilicon compounds					
C ₈ H ₁₈ Si ₂	Bis(trimethylsilyl)acetylene	14630-40-1	170	15.255	0.016
C ₄ H ₁₂ Br ₂ Si ₂	1,2-Dibromo-1,1,2,2-tetramethyl-disilane	18209-83-1	274	23.951	0.039

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Table 1 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Gold	
				³ RT, min	⁴ A, %
Inorganic compounds					
<i>Oxides</i>					
H ₂ O	Water	7732-18-5	18	3.162	0.265
CO ₂	Carbon dioxide	124-38-9	44	1.722	47.695
<i>Noble gases</i>					
Ar	Argon	7440-37-1	40	1.616	0.030
Other compounds					
Hg	Mercury	7439-97-6	202	5.260	0.288
CCl ₂ O	Phosgene (=Carbonyl dichloride)	75-44-5	98	5.476	0.002

Note. ¹CAS/(NIST), a unique numerical identifier for chemical compounds listed in the Chemical Abstracts Service registry (<https://www.cas.org>) or NIST number (a unique number given to each spectrum in the NIST archive); ²MW, nominal mass; ³RT, retention time by the analytical column of the individual component of the gas mixture; ⁴A, normalized area, the ratio of the area of the gas mixture component to the summarized area of all components in the chromatogram.

DISCUSSION OF RESULTS

Several models of the formation of the Sovetskoe deposit formation are discussed in the literature (Burak, 1982; Li, 1997; Tomilenko et al., 2010; Kryazhev, 2017). Based on the results of analysis and generalization of isotope-geochemical and thermobarogeochemical data, A.A. Tomilenko et al. (2001, 2006, 2008, 2010) came to the conclusion that the formation of gold mineralization at the Sovetskoye deposit (830–820 and 730 Ma) occurred separately from the regional metamorphism (890–850 Ma) and coincided with the tectonomagmatic activity of the northern part of the Yenisei Ridge (850 to 720 Ma) (Vernikovskiy and Vernikovskaya, 2006). The ore-bearing zones were formed in a wide temperature range with the participation of homogeneous and heterophase crustal hydrothermal solutions, in which the reduced fluids activated in the deep zones of the upper Proterozoic carbon-terrigenous strata played an important

part (Tomilenko et al., 2001; Tomilenko et al., 2010; Kryazhev, 2017).

The data obtained show that the fluids extracted from native gold, pyrite and quartz are a complex multi-component mineral-forming system (Tables 1–3). From 143 to 211 compounds were found in the fluids (Table 4). The fluids contained various hydrocarbons, S–N–F–Cl–Br–Si-containing compounds, carbon dioxide and water (Tables 1–3; Figs. 5, 6). A low water content (0.3 rel.%), found in the fluid inclusions from native gold (Table 1), supports the previously stated assumption that gold was transported by “dry gas-condensate reduced fluids” (Nikolaeva, 1954; Petrovskaya, 1973, 1993; Ryabchikov and Novgorodova, 1981; Novgorodova, 1983; Buslayeva and Novgorodova, 1989). A limited amount of water in the fluid is a necessary condition for the occurrence of reducing conditions in the mineral-forming medium (Yaroshevskii, 2006). The most important parameter of redox conditions for the formation of gold

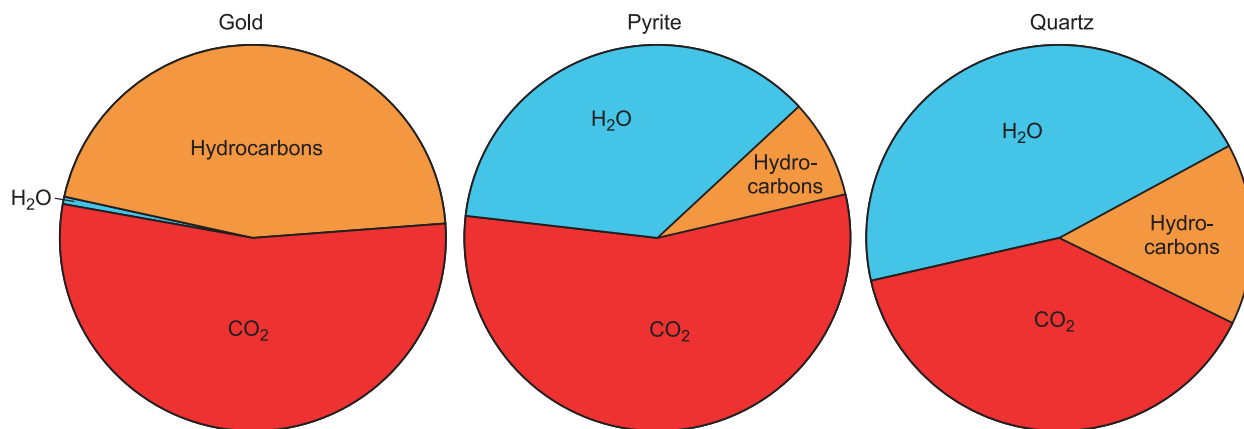


Fig. 5. Relative content of volatile components in gold, quartz and pyrite from the gold-bearing quartz vein of the Sovetskoye gold ore deposit: blue field – water; the red field – carbon dioxide and the light brown field is the sum of aliphatic, cyclic and oxygenated hydrocarbons.

Table 2. Results of the GC-MS analysis of the gas phase extracted during shock destruction of quartz, Sovetskoye deposit, Yenisei Ridge

Formula	Name	¹ CAS/(NIST)	² MW	Quartz	
				³ RT, min	⁴ A, %
Aliphatic hydrocarbons					
<i>Paraffins</i>					
CH ₄	Methane	74-82-8	16	1.70	1.366
C ₂ H ₆	Ethane	74-84-0	30	2.93	0.010
C ₃ H ₈	<i>n</i> -Propane	74-98-6	44	4.15	0.133
C ₄ H ₁₀	2-Methylpropane	75-28-5	58	6.23	0.191
C ₅ H ₁₂	<i>n</i> -Pentane	109-66-0	72	8.51	0.099
C ₆ H ₁₄	<i>n</i> -Hexane	110-54-3	86	11.84	0.039
C ₇ H ₁₆	<i>n</i> -Heptane	142-82-5	100	15.89	0.069
C ₈ H ₁₈	<i>n</i> -Octane	111-65-9	114	19.92	0.029
C ₉ H ₂₀	<i>n</i> -Nonane	111-84-2	128	23.75	0.030
C ₁₀ H ₂₂	<i>n</i> -Decane	124-18-5	142	27.31	0.027
C ₁₁ H ₂₄	<i>n</i> -Undecane	1120-21-4	156	30.59	0.064
C ₁₂ H ₂₆	<i>n</i> -Dodecane	112-40-3	170	33.61	0.330
C ₁₃ H ₂₈	<i>n</i> -Tridecane	629-50-5	184	37.32	0.291
C ₁₄ H ₃₀	<i>n</i> -Tetradecane	629-59-4	198	45.35	0.085
C ₁₅ H ₃₂	<i>n</i> -Pentadecane	629-62-9	212	51.34	0.140
C ₁₇ H ₃₆	2,6,10-Trimethyltetradecane	14905-56-7	240	59.13	0.418
C ₁₆ H ₃₄	<i>n</i> -Hexadecane	544-76-3	226	66.68	0.032
C ₁₇ H ₃₆	<i>n</i> -Heptadecane	629-78-7	240	82.76	0.114
<i>Olefins</i>					
C ₂ H ₄	Ethylene	74-85-1	28	2.17	0.014
C ₂ H ₂	Acetylene	74-86-2	26	2.38	0.120
C ₃ H ₆	1-Propene	115-07-1	42	3.98	0.015
C ₄ H ₈	1-Butene	106-98-9	56	5.63	0.017
C ₄ H ₈	(E)-2-Butene	624-64-6	56	5.90	0.021
C ₄ H ₈	2-Butene	107-01-7	56	6.13	0.010
C ₅ H ₈	Isoprene	78-79-5	68	7.91	0.001
C ₅ H ₁₀	3-Methyl-1-butene	563-45-1	70	8.23	0.014
C ₅ H ₁₀	1-Pentene	109-67-1	70	8.24	0.112
C ₅ H ₈	1,3-Pentadiene	1574-41-0	68	8.48	0.002
C ₅ H ₁₀	(E)-2-Pentene	646-04-8	70	8.56	0.005
C ₅ H ₈	(E)-1,3-Pentadiene	2004-70-8	68	8.69	0.003
C ₅ H ₈	(Z)-1,3-Pentadiene	1574-41-0	68	8.83	<0.001
C ₆ H ₁₂	1-Hexene	592-41-6	84	11.56	0.047
C ₇ H ₁₄	1-Heptene	592-76-7	98	15.52	0.018
C ₈ H ₁₆	(E)-2-Octene	13389-42-9	112	19.60	0.122
C ₉ H ₁₈	1-Nonene	124-11-8	126	23.50	0.013
C ₁₀ H ₂₀	1-Decene	872-05-9	140	27.13	0.015
C ₁₄ H ₂₈	1-Tetradecene	1120-36-1	196	44.85	0.036
C ₁₅ H ₃₀	1-Pentadecene	13360-61-7	210	50.94	0.090
Cyclic hydrocarbons					
<i>Cycloalkanes (naphthenes) and cycloalkenes</i>					
C ₃ H ₁₀	trans-1,2-Dimethylcyclopropane	2402-06-4	70	8.43	0.001
C ₆ H ₁₀	3-Methylcyclopentene	1120-62-3	82	12.69	0.008
<i>Arenes</i>					
C ₆ H ₆	Benzene	71-43-2	78	12.51	0.237
C ₇ H ₈	Toluene	108-88-3	92	16.92	0.193
C ₇ H ₇ F	(Fluoromethyl)benzene	350-50-5	110	20.52	0.002
C ₈ H ₁₀	Ethylbenzene	100-41-4	106	20.97	0.011
C ₈ H ₁₀	<i>p</i> -Xylene	106-42-3	106	21.23	0.103

(continued on next page)

Table 2 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Quartz	
				³ RT, min	⁴ A, %
C ₈ H ₁₀	<i>o</i> -Xylene	95-47-6	106	21.48	0.022
C ₈ H ₁₀	<i>m</i> -Xylene	108-38-3	106	21.87	0.019
C ₈ H ₈	Styrene	100-42-5	104	21.97	0.006
C ₉ H ₁₂	Propylbenzene	103-65-1	120	24.76	0.011
C ₁₀ H ₁₄	<i>p</i> -Cymene	99-87-6	134	27.54	0.006
C ₁₀ H ₁₄	Butylbenzene	104-51-8	134	28.48	0.025
C ₈ H ₉ Cl	1-(Chloromethyl)-4-methylbenzene	104-82-5	140	31.69	0.002
C ₁₁ H ₁₆	Pentylbenzene	538-68-1	148	31.82	0.054
C ₈ H ₉ Cl	1-(Chloromethyl)-3-methylbenzene	620-19-9	140	32.54	0.004
C ₈ H ₉ Cl	1-(Chloromethyl)-2-methylbenzene	552-45-4	140	32.79	0.003
C ₁₂ H ₁₈	Hexylbenzene	1077-16-3	162	35.15	0.069
C ₁₃ H ₂₀	Heptylbenzene	1078-71-3	176	39.75	0.038
C ₁₄ H ₂₂	Octylbenzene	2189-60-8	190	46.61	0.073
C ₁₅ H ₂₄	Nonylbenzene	1081-77-2	204	57.37	0.079
<i>Polycyclic aromatic hydrocarbons (PAH)</i>					
C ₁₀ H ₈	Naphthalene	91-20-3	128	32.19	0.008
C ₁₁ H ₁₀	1-Methylnaphthalene	90-12-0	142	35.92	0.006
C ₁₁ H ₁₀	2-Methylnaphthalene	91-57-6	142	36.42	0.007
C ₁₄ H ₁₀	Phenanthrene	85-01-8	178	86.68	0.005
Oxygenated hydrocarbons					
<i>Alcohols</i>					
CH ₄ O	Methanol	67-56-1	32	4.10	0.203
C ₂ H ₆ O	Ethanol	64-17-5	46	6.51	0.050
C ₄ H ₁₀ O	1-Butanol	71-36-3	74	12.61	0.008
C ₆ H ₆ O	Phenol	108-95-2	94	24.81	0.018
C ₇ H ₈ O	<i>o</i> -Cresol	95-48-7	108	27.61	0.005
C ₇ H ₈ O	<i>p</i> -Cresol	106-44-5	108	28.59	0.009
C ₁₁ H ₁₆ O ₂	4-Pentylresorcinol	533-24-4	180	101.15	0.008
C ₁₁ H ₁₆ O ₂	5-Pentylresorcinol	500-66-3	180	108.96	0.025
C ₁₂ H ₁₈ O ₂	2-Hexylresorcinol	x	194	114.75	0.048
C ₁₂ H ₁₈ O ₂	4-Hexylresorcinol	136-77-6	194	121.66	0.041
C ₁₂ H ₁₈ O ₂	5-Hexylresorcinol	x	194	126.81	0.008
C ₁₃ H ₂₀ O ₂	4-Heptylresorcinol	x	208	130.12	0.024
<i>Ethers and esters</i>					
C ₅ H ₈ O	3,4-Dihydropyran	110-87-2	84	13.54	0.003
C ₅ H ₈ O ₂	Methyl methacrylate	80-62-6	100	14.47	0.081
C ₅ H ₈ O	3,4-Dihydro-2H-pyran	110-87-2	84	17.14	0.008
C ₄ H ₆ O ₂	Butyrolactone	96-48-0	86	21.43	0.096
C ₆ H ₁₀ O ₂	γ -Hexalactone	695-06-7	114	27.84	0.005
C ₇ H ₁₂ O ₂	γ -Heptalactone	105-21-5	128	31.37	0.008
C ₉ H ₁₀ O	1-Ethenyl-4-methoxybenzene	637-69-4	134	31.52	0.009
C ₈ H ₁₄ O ₂	γ -Octalactone	104-50-7	142	34.72	0.006
C ₉ H ₁₆ O ₂	γ -Nonalactone	104-61-0	156	39.15	0.018
C ₁₀ H ₁₈ O ₂	γ -Decalactone	706-14-9	170	45.76	0.014
C ₁₃ H ₁₈ O ₂	Acetate 2-tert-butyl-4-methylphenol	6950-09-0	206	48.29	0.005
C ₁₀ H ₁₂ O ₃	Methyl 4-methoxy-3-methylbenzoate	(378753)	180	50.81	0.033
C ₁₂ H ₁₆ O ₂	Methyl ester 4-butylbenzoic acid	20651-69-8	192	56.89	0.003
C ₁₂ H ₂₂ O ₂	γ -Dodecalactone	2305-05-7	198	72.09	0.014
C ₁₄ H ₁₈ O ₄	Diisopropyl phthalate	605-45-8	250	72.97	0.013
<i>Aldehydes</i>					
C ₂ H ₄ O	Acetaldehyde	75-07-0	44	5.38	2.097

(continued on next page)

Table 2 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Quartz	
				³ RT, min	⁴ A, %
C ₃ H ₄ O	2-Propenal	107-02-8	56	7.43	0.011
C ₃ H ₆ O	<i>n</i> -Propanal	123-38-6	58	7.58	0.013
C ₄ H ₆ O	2-Methyl-2-propenal	78-85-3	70	9.83	0.020
C ₄ H ₈ O	2-Methylpropanal	78-84-2	72	9.84	0.027
C ₄ H ₈ O	<i>n</i> -Butanal	123-72-8	72	10.62	0.166
C ₄ H ₆ O	(Z)-2-Butenal	15798-64-8	70	12.39	0.004
C ₅ H ₁₀ O	3-Methylbutanal	590-86-3	86	13.79	0.082
C ₅ H ₁₀ O	<i>n</i> -Pentanal	110-62-3	86	14.82	0.125
C ₅ H ₄ O ₂	2-Furaldehyde	98-01-1	96	17.72	0.003
C ₅ H ₄ O ₂	3-Furaldehyde	498-60-2	96	18.65	0.077
C ₆ H ₁₂ O	<i>n</i> -Hexanal	66-25-1	100	19.12	0.201
C ₇ H ₁₄ O	<i>n</i> -Heptanal	111-71-7	114	23.20	0.026
C ₆ H ₆ O ₂	5-Methyl-2-furancarboxaldehyde	620-02-0	110	23.70	0.017
C ₇ H ₆ O	Benzaldehyde	100-52-7	106	24.33	0.246
C ₈ H ₁₆ O	2-Ethylhexanal	123-05-7	128	25.58	0.012
C ₈ H ₁₆ O	<i>n</i> -Octanal	124-13-0	128	26.93	0.029
C ₆ H ₄ O ₃	2,5-Furandicarboxaldehyde	823-82-5	124	28.26	0.125
C ₉ H ₁₈ O	<i>n</i> -Nonanal	124-19-6	142	30.36	0.090
C ₁₀ H ₂₀ O	<i>n</i> -Decanal	112-31-2	156	33.49	0.467
C ₁₁ H ₂₂ O	<i>n</i> -Undecanal	112-44-7	170	37.10	0.248
C ₁₂ H ₂₀ O	5,9-Dimethyl-4,8-decadienal	762-26-5	180	38.05	0.024
C ₁₂ H ₂₄ O	<i>n</i> -Dodecanal	112-54-9	184	42.78	0.084
C ₁₄ H ₂₈ O	<i>n</i> -Tetradecanal	124-25-4	212	64.78	0.088
C ₁₅ H ₃₀ O	<i>n</i> -Pentadecanal	2765-11-9	226	81.20	0.117
Ketones					
C ₃ H ₆ O	2-Propanone	67-64-1	58	7.81	0.146
C ₄ H ₆ O ₂	2,3-Butanedione	431-03-8	86	10.72	0.002
C ₄ H ₈ O	2-Butanone	78-93-3	72	10.87	0.104
C ₅ H ₁₀ O	2-Pentanone	107-87-9	86	14.59	0.010
C ₅ H ₈ O	Cyclopentanone	120-92-3	84	17.49	0.004
C ₆ H ₁₂ O	2-Hexanone	591-78-6	100	18.87	0.017
C ₇ H ₁₄ O	2-Heptanone	110-43-0	114	22.93	0.021
C ₅ H ₄ O ₃	3-Methyl-2,5-furandione	616-02-4	112	23.55	0.223
C ₈ H ₁₆ O	2-Octanone	111-13-7	128	26.63	0.019
C ₉ H ₁₈ O	2-Nonanone	821-55-6	142	30.04	0.040
C ₉ H ₁₀ O	1-(2-Methylphenyl)ethanone	577-16-2	134	31.67	0.007
C ₉ H ₁₀ O	1-(3-Methylphenyl)ethanone	585-74-0	134	31.84	0.024
C ₉ H ₁₀ O	1-(4-Methylphenyl)ethanone	122-00-9	134	32.24	0.014
C ₁₀ H ₂₀ O	2-Decanone	693-54-9	156	33.16	0.220
C ₈ H ₄ O ₃	1,3-Isobenzofurandione	85-44-9	148	36.50	0.158
C ₁₁ H ₂₂ O	2-Undecanone	53452-70-3	170	36.79	0.212
C ₁₂ H ₂₄ O	2-Dodecanone	6175-49-1	184	41.78	0.029
C ₁₃ H ₂₆ O	2-Tridecanone	593-08-8	198	50.02	0.104
C ₁₄ H ₂₈ O	2-Tetradecanone	2345-27-9	212	62.63	0.042
C ₁₅ H ₃₀ O	2-Pentadecanone	2345-28-0	226	77.58	0.111
Carboxylic acids					
CH ₂ O ₂	Formic acid	64-18-6	46	10.28	0.086
C ₂ H ₄ O ₂	Acetic acid	64-19-7	60	11.22	0.892
C ₃ H ₆ O ₂	<i>n</i> -Propanoic acid	79-09-4	74	15.14	0.012
C ₄ H ₈ O ₂	<i>n</i> -Butanoic acid	107-92-6	88	18.83	0.233
C ₅ H ₁₀ O ₂	3-Methylbutanoic acid	503-74-2	102	21.80	0.006

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Table 2 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Quartz	
				³ RT, min	⁴ A, %
C ₅ H ₁₀ O ₂	<i>n</i> -Pentanoic acid	109-52-4	102	22.80	0.220
C ₆ H ₁₂ O ₂	<i>n</i> -Hexanoic acid	142-62-1	116	26.33	0.008
C ₇ H ₁₄ O ₂	<i>n</i> -Heptanoic acid	111-14-8	130	29.66	0.025
C ₈ H ₁₆ O ₂	<i>n</i> -Octanoic acid	124-07-2	144	32.74	0.356
C ₉ H ₁₈ O ₂	4-Methyloctanoic acid	54947-74-9	158	34.62	0.020
C ₉ H ₁₈ O ₂	<i>n</i> -Nonanoic acid	112-05-0	158	36.09	0.681
C ₁₀ H ₂₀ O ₂	<i>n</i> -Decanoic acid	334-48-5	172	40.88	0.080
C ₁₁ H ₂₂ O ₂	<i>n</i> -Undecanoic acid	112-37-8	186	48.78	0.036
C ₁₂ H ₂₄ O ₂	2-Methylundecanoic acid	24323-25-9	200	54.94	0.050
C ₁₂ H ₂₄ O ₂	<i>n</i> -Dodecanoic acid	143-07-7	200	60.02	0.160
C ₁₄ H ₂₈ O ₂	<i>n</i> -Tetradecanoic acid	544-63-8	228	108.43	0.096
C ₁₅ H ₃₀ O ₂	3-Methyltetradecanoic acid	x	242	119.93	0.148
Heterocyclic compounds					
<i>Dioxanes</i>					
C ₄ H ₈ O ₂	1,4-Dioxane	123-91-1	88	13.81	<0.001
<i>Furans</i>					
C ₄ H ₄ O	Furan	110-00-9	68	8.48	0.001
C ₅ H ₆ O	2-Methylfuran	534-22-5	82	10.24	0.004
C ₅ H ₆ O	3-Methylfuran	930-27-8	82	10.51	0.001
C ₆ H ₈ O	2-Ethylfuran	3208-16-0	96	12.71	0.002
C ₆ H ₈ O	3-Ethylfuran	x	96	13.96	0.001
C ₆ H ₈ O	2,5-Dimethylfuran	625-86-5	96	14.01	0.001
C ₆ H ₈ O	2,3-Dimethylfuran	(458499)	96	14.44	0.001
C ₆ H ₈ O	2,4-Dimethylfuran	3710-43-8	96	15.35	<0.001
C ₆ H ₈ O	3,4-Dimethylfuran	(458504)	96	15.87	<0.001
C ₇ H ₁₀ O	2-Propylfuran	4229-91-8	110	18.67	0.004
C ₈ H ₁₂ O	2-Butylfuran	4466-24-4	124	22.13	0.002
C ₉ H ₁₄ O	2-Pentylfuran	3777-69-3	138	25.91	0.008
C ₁₀ H ₁₆ O	2-Hexylfuran	3777-70-6	152	29.43	0.003
C ₁₁ H ₁₈ O	2-Heptylfuran	3777-71-7	166	32.64	0.003
C ₁₂ H ₂₀ O	2-Octylfuran	4179-38-8	180	36.04	0.004
Nitrogenated compounds					
N ₂	Nitrogen	7727-37-9	28	1.60	0.694
H ₃ N	Ammonia	7664-41-7	17	3.00	0.006
CHNO	Hydrogen isocyanate	75-13-8	43	6.31	0.456
C ₂ H ₃ N	Acetonitrile	75-05-8	41	7.04	0.065
C ₃ H ₅ N	Propargylamine	2450-71-7	55	9.64	0.002
C ₄ H ₅ N	Pyrrole	109-97-7	67	14.65	0.006
C ₅ H ₅ N	Pyridine	110-86-1	79	16.25	0.005
C ₃ H ₅ NO ₂	2-Oxopropanamide	x	87	17.82	0.021
C ₆ H ₉ N	2,3-Dimethyl-1H-pyrrole	600-28-2	95	18.77	0.002
C ₆ H ₇ N	2-Methylpyridine	109-06-8	93	19.40	0.002
C ₆ H ₁₃ NO	1-Methyl-3-piperidinol	3554-74-3	115	25.85	0.017
C ₇ H ₁₁ N	1,2,5-Trimethylpyrrole	930-87-0	109	26.11	0.006
C ₈ H ₁₅ N	Octanenitrile	124-12-9	125	28.91	0.154
C ₄ H ₅ NO ₂	Succinimide	123-56-8	99	29.24	0.128
C ₉ H ₈ ClNO ₄	(2-Chloro-5-nitrophenyl)methyl ester acetic acid	303965-18-6	229	93.25	0.012
Sulfonated compounds					
H ₂ S	Hydrogen sulfide	7783-06-4	34	2.83	0.042
COS	Carbonyl sulfide	463-58-1	60	3.40	0.042
O ₂ S	Sulfur dioxide	7446-09-5	64	4.85	1.163

(continued on next page)

Table 2 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Quartz	
				³ RT, min	⁴ A, %
CH ₄ S	Methanethiol	74-93-1	48	5.55	0.018
C ₂ H ₆ S	Dimethyl sulfide	75-18-3	62	7.68	0.003
CS ₂	Carbon disulfide	75-15-0	76	7.84	0.083
C ₃ H ₈ S	Propyl mercaptan	107-03-9	76	10.92	0.003
C ₄ H ₄ S	Thiophene	110-02-1	84	12.26	0.007
C ₂ H ₆ S ₂	Dimethyl disulfide	624-92-0	94	15.35	0.002
C ₃ H ₆ S	2-Methylthiophene	554-14-3	98	16.47	0.005
C ₃ H ₆ S	3-Methylthiophene	616-44-4	98	16.82	0.006
C ₆ H ₈ S	2-Ethylthiophene	872-55-9	112	20.55	0.002
C ₇ H ₁₀ S	2-Propylthiophene	1551-27-5	126	24.13	0.005
C ₇ H ₁₀ S	3-Propylthiophene	x	126	24.40	0.004
C ₃ H ₄ OS	3-Thiophenecarboxaldehyde	498-62-4	112	25.21	0.008
C ₈ H ₁₂ S	2-(1,1-Dimethylethyl)-thiophene	1689-78-7	140	26.96	0.008
C ₈ H ₁₂ S	2-Butylthiophene	1455-20-5	140	28.21	0.007
C ₆ H ₆ OS	5-Methyl-2-thiophenecarboxaldehyde	13679-70-4	126	29.53	0.009
C ₈ H ₇ F ₃ S	2-(Trifluoromethyl)benzyl mercaptan	26039-98-5	192	29.71	0.002
C ₉ H ₁₄ S	2-Pentylthiophene	4861-58-9	154	31.61	0.009
C ₁₀ H ₁₆ S	2-Hexylthiophene	18794-77-9	168	34.94	0.015
C ₁₁ H ₁₈ S	3-Heptylthiophene	x	182	39.47	0.007
C ₁₁ H ₁₈ S	2-Heptylthiophene	18794-78-0	182	39.70	0.003
C ₁₂ H ₂₀ S	2-Octylthiophene	880-36-4	196	46.23	0.010
C ₁₃ H ₂₂ S	2-Nonylthiophene	57754-07-1	210	56.94	0.022
Inorganic compounds					
<i>Oxides</i>					
CO ₂	Carbon dioxide	124-38-9	44	1.88	37.312
H ₂ O	Water	7732-18-5	18	3.10	44.676
<i>Noble gases</i>					
Ar	Argon	7440-37-1	40	1.58	0.011

deposits is the CO₂/hydrocarbons value. A low value of this ratio is the evidence of reducing conditions of the mineral-forming environment (Robert and Kelly, 1987; Bortnikov et al., 1996; Jia and Kerrich, 2000; Ronde et al., 2000; Eirish et al., 2002; Kryazhev, 2002; Safonov and Prokofiev, 2006). For fluids from native gold from the Sovetskoye deposit, the value of CO₂/hydrocarbons is 1.2, 5.2 in pyrite and 2.1 in quartz (Table 4), which shows a more reduced fluid in gold than in pyrite and quartz.

The role of reduced fluids in the formation of gold deposits is complex and still remains debatable. However, the revealed facts must be taken into account in further research on gold deposits, since they are directly related to the solution of genetic and forecasting-metallogenic problems. Gold was transferred in the form of organoelement compounds (OEC) (Slobodskoi, 1981; Novgorodova, 1983; Buslayeva and Novgorodova, 1989). However, these compounds in the ore process are extremely unstable, which leads to their decomposition (Mathez et al., 1984; Schoell, 1988; Buslayeva and Novgorodova, 1989, 1992; Schwander et al., 2013). In our opinion, OEC decompose to crystallize gold, and its hydrocarbon-transporters are partially preserved in fluid in-

clusions. Gold is part of a number of organic compounds, in which gold with the oxidation degree Au^I and Au^{III} forms complex compounds containing such elements as C, O, H, S, N, Cl, F (Paddefet, 1982; Elschenbroich, 2011; Akhmadullina et al., 2012). These elements were found in the fluids preserved in studied native gold (Tables 1–3). Analysis of the literature cited in (Novgorodova, 1983) and (Buslayeva and Novgorodova, 1989) showed that under reducing conditions the most likely form of migration is carbonyl halides for Au, tetraalkylsilanes, alkides, alkylsilanes, alkyl halides for Si, and alkyl compounds and alkylhalogenides for Sb and As. Recovered fluids can accumulate and transport significant amounts of native elements, including gold (Gizé and Macdonald, 1993). Based on the experiments, it was shown that gold is transported by hydrocarbons, i.e., hydrocarbons act as an ore fluid (Williams-Jones et al., 2009; Migdisov et al., 2017).

The compounds found in the fluids of native gold play an important role in the transport of ore substance. Let us discuss only some of them. Carbon dioxide is constantly present in the fluids (Tables 1–3) and, according to (Gizé and Macdonald, 1993; Gizé, 1999), transports hydrocarbons, whereas

Table 3. Results of the GC-MS analysis of the gas phase extracted during shock destruction of pyrite, Sovetskoye deposit, Yenisei Ridge

Formula	Name	¹ CAS/(NIST)	² MW	Pyrite	
				³ RT, min	⁴ A, %
Aliphatic hydrocarbons					
<i>Paraffins</i>					
CH ₄	Methane	74-82-8	16	1.72	0.060
C ₂ H ₆	Ethane	74-84-0	30	2.83	0.004
C ₃ H ₈	<i>n</i> -Propane	74-98-6	44	4.10	0.004
C ₄ H ₁₀	2-Methylpropane	75-28-5	58	6.23	0.007
C ₅ H ₁₂	<i>n</i> -Pentane	109-66-0	72	8.49	0.001
C ₆ H ₁₄	<i>n</i> -Hexane	110-54-3	86	11.87	0.005
C ₇ H ₁₆	<i>n</i> -Heptane	142-82-5	100	15.84	0.007
C ₈ H ₁₆	3-Methyleneheptane	1632-16-2	112	19.32	0.024
C ₈ H ₁₈	<i>n</i> -Octane	111-65-9	114	19.90	0.013
C ₉ H ₂₀	<i>n</i> -Nonane	111-84-2	128	23.76	0.016
C ₁₀ H ₂₂	<i>n</i> -Decane	124-18-5	142	27.31	0.009
C ₁₁ H ₂₄	<i>n</i> -Undecane	1120-21-4	156	30.59	0.014
C ₁₂ H ₂₆	<i>n</i> -Dodecane	112-40-3	170	33.61	0.010
C ₁₃ H ₂₈	<i>n</i> -Tridecane	629-50-5	184	37.34	0.020
C ₁₄ H ₃₀	<i>n</i> -Tetradecane	629-59-4	198	43.88	0.005
C ₁₅ H ₃₂	<i>n</i> -Pentadecane	629-62-9	212	51.34	0.016
C ₁₇ H ₃₆	2,6,10-Trimethyltetradecane	14905-56-7	240	55.17	0.190
C ₁₆ H ₃₄	<i>n</i> -Hexadecane	544-76-3	226	64.98	0.039
C ₁₇ H ₃₆	<i>n</i> -Heptadecane	629-78-7	240	86.98	0.100
C ₁₈ H ₃₈	8-Methylheptadecane	13287-23-5	254	97.70	0.362
C ₁₈ H ₃₈	4-Methylheptadecane	26429-11-8	254	111.16	0.180
<i>Halogenated paraffins</i>					
C ₄ H ₉ Cl	1-Chlorobutane	109-69-3	92	12.42	0.003
<i>Olefins</i>					
C ₂ H ₄	Ethylene	74-85-1	28	2.17	0.004
C ₂ H ₂	Acetylene	74-86-2	26	2.38	0.018
C ₃ H ₆	1-Propene	115-07-1	42	3.93	0.004
C ₄ H ₈	1-Butene	106-98-9	56	5.76	0.006
C ₄ H ₈	(E)-2-Butene	624-64-6	56	5.90	0.013
C ₄ H ₈	2-Butene	107-01-7	56	6.13	0.010
C ₅ H ₁₀	3-Methyl-1-butene	563-45-1	70	8.21	0.004
C ₅ H ₈	1,3-Pentadiene	1574-41-0	68	8.46	0.001
C ₅ H ₁₀	(E)-2-Pentene	646-04-8	70	8.58	0.002
C ₅ H ₈	(E)-1,3-Pentadiene	2004-70-8	68	8.69	0.001
C ₆ H ₁₂	1-Hexene	592-41-6	84	11.54	0.002
C ₇ H ₁₄	1-Heptene	592-76-7	98	15.50	0.003
C ₈ H ₁₆	(Z)-4-Octene	7642-15-1	112	19.62	0.004
C ₉ H ₁₈	1-Nonene	124-11-8	126	23.51	0.005
C ₁₀ H ₂₀	1-Decene	872-05-9	140	27.11	0.003
C ₁₄ H ₂₈	1-Tetradecene	1120-36-1	196	43.46	0.011
C ₁₅ H ₃₀	1-Pentadecene	13360-61-7	210	50.99	0.008
C ₁₆ H ₃₂	1-Hexadecene	629-73-2	224	63.88	0.012
Cyclic hydrocarbons					
<i>Cycloalkanes (naphthenes) and cycloalkenes</i>					
C ₃ H ₁₀	trans-1,2-Dimethylcyclopropane	2402-06-4	70	8.44	0.001
C ₆ H ₁₀	3-Methylcyclopentene	1120-62-3	82	12.69	0.001
<i>Arenes</i>					
C ₆ H ₆	Benzene	71-43-2	78	12.51	0.071

(continued on next page)

Table 3 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Pyrite	
				³ RT, min	⁴ A, %
C ₇ H ₈	Toluene	108-88-3	92	16.95	0.027
C ₈ H ₁₀	Ethylbenzene	100-41-4	106	20.97	0.005
C ₈ H ₁₀	<i>p</i> -Xylene	106-42-3	106	21.23	0.041
C ₈ H ₁₀	<i>o</i> -Xylene	95-47-6	106	21.57	0.005
C ₈ H ₁₀	<i>m</i> -Xylene	108-38-3	106	21.87	0.010
C ₈ H ₈	Styrene	100-42-5	104	21.98	0.001
C ₉ H ₁₂	Propylbenzene	103-65-1	120	24.78	0.007
C ₁₀ H ₁₄	<i>p</i> -Cymene	99-87-6	134	27.56	0.005
C ₁₀ H ₁₄	Butylbenzene	104-51-8	134	28.51	0.011
C ₈ H ₉ Cl	1-(Chloromethyl)-4-methylbenzene	104-82-5	140	31.76	0.002
C ₁₁ H ₁₆	Pentylbenzene	538-68-1	148	31.84	0.025
C ₈ H ₉ Cl	1-(Chloromethyl)-3-methylbenzene	620-19-9	140	32.56	0.002
C ₈ H ₉ Cl	1-(Chloromethyl)-2-methylbenzene	552-45-4	140	32.82	0.001
C ₁₂ H ₁₈	Hexylbenzene	1077-16-3	162	35.15	0.020
C ₁₃ H ₂₀	Heptylbenzene	1078-71-3	176	39.72	0.019
C ₁₄ H ₂₂	Octylbenzene	2189-60-8	190	46.68	0.025
C ₁₅ H ₂₄	Nonylbenzene	1081-77-2	204	57.47	0.039
<i>Polycyclic aromatic hydrocarbons (PAH)</i>					
C ₁₀ H ₈	Naphthalene	91-20-3	128	32.22	0.008
C ₁₁ H ₁₀	1-Methylnaphthalene	90-12-0	142	35.99	0.002
C ₁₁ H ₁₀	2-Methylnaphthalene	91-57-6	142	36.42	0.004
C ₁₄ H ₁₀	Phenanthrene	85-01-8	178	87.44	0.001
Oxygenated hydrocarbons					
<i>Alcohols</i>					
CH ₄ O	Methanol	67-56-1	32	4.91	0.224
C ₂ H ₆ O	Ethanol	64-17-5	46	6.65	0.079
C ₄ H ₁₀ O	1-Butanol	71-36-3	74	12.62	0.002
C ₆ H ₆ O	Phenol	108-95-2	94	24.91	0.011
C ₇ H ₈ O	<i>o</i> -Cresol	95-48-7	108	27.53	0.000
C ₇ H ₈ O	<i>p</i> -Cresol	106-44-5	108	28.94	0.003
<i>Ethers and esters</i>					
C ₅ H ₈ O	3,4-Dihydropyran	110-87-2	84	13.54	0.003
C ₅ H ₈ O ₂	Methyl methacrylate	80-62-6	100	14.47	0.035
C ₅ H ₈ O	3,4-Dihydro-2H-pyran	110-87-2	84	17.17	0.006
C ₄ H ₆ O ₂	Butyrolactone	96-48-0	86	21.47	0.009
C ₆ H ₁₀ O ₂	γ -Hexalactone	695-06-7	114	27.88	0.004
C ₇ H ₁₂ O ₂	γ -Heptalactone	105-21-5	128	31.39	0.001
C ₈ H ₁₄ O ₂	γ -Octalactone	104-50-7	142	34.74	0.005
C ₉ H ₁₆ O ₂	γ -Nonalactone	104-61-0	156	39.17	0.003
C ₁₂ H ₁₆ O ₂	Benzoate 3-methyl-1-butanol	94-46-2	192	39.70	0.123
C ₁₂ H ₁₆ O ₂	2-Methylpropionate 3-methylbenzyl alcohol	(447357)	192	42.22	0.008
C ₁₀ H ₁₈ O ₂	γ -Decalactone	706-14-9	170	45.81	0.005
C ₁₂ H ₁₆ O ₂	Pentyl ester benzoic acid	2049-96-9	192	47.21	0.027
C ₁₃ H ₁₈ O ₂	Hexyl ester benzoic acid	6789-88-4	206	53.41	0.290
C ₁₄ H ₂₀ O ₂	Hept-3-yl ester benzoic acid	(368767)	220	60.23	0.159
C ₁₄ H ₂₀ O ₂	Heptyl ester benzoic acid	7155-12-6	220	68.73	0.075
C ₁₂ H ₂₂ O ₂	γ -Dodecalactone	2305-05-7	198	73.22	0.055
C ₁₁ H ₁₂ O ₄	Mono(1-methylethyl) ester 1,2-benzenedicarboxylic acid	35118-50-4	208	78.60	0.708
C ₁₁ H ₈ O ₄	Monoprop-2-ynyl phthalate	6139-61-3	204	96.82	0.018

(continued on next page)

Table 3 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Pyrite	
				³ RT, min	⁴ A, %
C ₁₅ H ₃₀ O ₂	Methyl tetradecanoate	124-10-7	242	107.08	0.066
C ₁₄ H ₁₈ O ₄	Dipropyl phthalate	131-16-8	250	117.22	1.702
<i>Aldehydes</i>					
C ₂ H ₄ O	Acetaldehyde	75-07-0	44	5.36	0.392
C ₃ H ₄ O	2-Propenal	107-02-8	56	7.43	0.005
C ₃ H ₆ O	<i>n</i> -Propanal	123-38-6	58	7.79	0.428
C ₄ H ₆ O	2-Methyl-2-propenal	78-85-3	70	9.83	0.002
C ₄ H ₈ O	2-Methylpropanal	78-84-2	72	9.86	0.003
C ₄ H ₈ O	<i>n</i> -Butanal	123-72-8	72	10.68	0.045
C ₄ H ₆ O	(<i>Z</i>)-2-Butenal	15798-64-8	70	12.39	0.003
C ₅ H ₁₀ O	3-Methylbutanal	590-86-3	86	13.82	0.018
C ₅ H ₁₀ O	<i>n</i> -Pentanal	110-62-3	86	14.79	0.008
C ₅ H ₄ O ₂	2-Furaldehyde	98-01-1	96	17.72	0.003
C ₅ H ₄ O ₂	3-Furaldehyde	498-60-2	96	18.67	0.040
C ₆ H ₁₂ O	<i>n</i> -Hexanal	66-25-1	100	19.12	0.014
C ₇ H ₁₄ O	<i>n</i> -Heptanal	111-71-7	114	23.21	0.007
C ₆ H ₆ O ₂	5-Methyl-2-furancarboxaldehyde	620-02-0	110	23.71	0.010
C ₇ H ₆ O	Benzaldehyde	100-52-7	106	24.35	0.029
C ₈ H ₁₆ O	2-Ethylhexanal	123-05-7	128	25.56	0.015
C ₈ H ₁₆ O	<i>n</i> -Octanal	124-13-0	128	26.94	0.007
C ₆ H ₄ O ₃	2,5-Furandicarboxaldehyde	823-82-5	124	28.31	0.009
C ₉ H ₁₈ O	<i>n</i> -Nonanal	124-19-6	142	30.38	0.013
C ₁₀ H ₂₀ O	<i>n</i> -Decanal	112-31-2	156	33.54	0.014
C ₁₁ H ₂₂ O	<i>n</i> -Undecanal	112-44-7	170	37.17	0.004
C ₁₂ H ₂₄ O	<i>n</i> -Dodecanal	112-54-9	184	42.85	0.039
C ₁₄ H ₂₈ O	<i>n</i> -Tetradecanal	124-25-4	212	62.95	0.026
C ₁₅ H ₃₀ O	<i>n</i> -Pentadecanal	2765-11-9	226	82.96	0.047
<i>Ketones</i>					
C ₃ H ₆ O	2-Propanone	67-64-1	58	7.81	0.469
C ₄ H ₆ O ₂	2,3-Butanedione	431-03-8	86	10.73	0.001
C ₄ H ₈ O	2-Butanone	78-93-3	72	10.86	0.051
C ₅ H ₁₀ O	2-Pentanone	107-87-9	86	14.61	0.013
C ₅ H ₈ O	Cyclopentanone	120-92-3	84	17.50	0.001
C ₆ H ₁₂ O	2-Hexanone	591-78-6	100	18.87	0.013
C ₇ H ₁₄ O	2-Heptanone	110-43-0	114	22.93	0.011
C ₅ H ₄ O ₃	3-Methyl-2,5-furandione	616-02-4	112	23.45	0.008
C ₈ H ₁₆ O	2-Octanone	111-13-7	128	26.65	0.008
C ₉ H ₁₈ O	2-Nonanone	821-55-6	142	30.06	0.011
C ₉ H ₁₀ O	1-(3-Methylphenyl)ethanone	585-74-0	134	31.82	0.015
C ₉ H ₁₀ O	1-(4-Methylphenyl)ethanone	122-00-9	134	32.26	0.007
C ₁₀ H ₂₀ O	2-Decanone	693-54-9	156	33.21	0.007
C ₈ H ₄ O ₃	1,3-Isobenzofurandione	85-44-9	148	36.55	0.053
C ₁₁ H ₂₂ O	2-Undecanone	53452-70-3	170	36.74	0.015
C ₁₂ H ₂₄ O	2-Dodecanone	6175-49-1	184	42.03	0.008
C ₁₃ H ₂₆ O	2-Tridecanone	593-08-8	198	50.09	0.012
C ₁₄ H ₂₈ O	2-Tetradecanone	2345-27-9	212	60.45	0.069
C ₁₅ H ₃₀ O	2-Pentadecanone	2345-28-0	226	78.57	0.201
<i>Carboxylic acids</i>					
CH ₂ O ₂	Formic acid	64-18-6	46	10.31	0.028

(continued on next page)

Table 3 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Pyrite	
				³ RT, min	⁴ A, %
C ₂ H ₄ O ₂	Acetic acid	64-19-7	60	11.28	0.374
C ₃ H ₆ O ₂	<i>n</i> -Propanoic acid	79-09-4	74	15.24	0.004
C ₄ H ₈ O ₂	<i>n</i> -Butanoic acid	107-92-6	88	18.82	0.072
C ₅ H ₁₀ O ₂	3-Methylbutanoic acid	503-74-2	102	21.80	0.004
C ₅ H ₁₀ O ₂	<i>n</i> -Pentanoic acid	109-52-4	102	22.82	0.011
C ₆ H ₁₂ O ₂	<i>n</i> -Hexanoic acid	142-62-1	116	26.38	0.024
C ₇ H ₁₄ O ₂	<i>n</i> -Heptanoic acid	111-14-8	130	29.74	0.010
C ₈ H ₁₆ O ₂	<i>n</i> -Octanoic acid	124-07-2	144	32.86	0.021
C ₉ H ₁₈ O ₂	<i>n</i> -Nonanoic acid	112-05-0	158	36.15	0.020
C ₁₀ H ₂₀ O ₂	<i>n</i> -Decanoic acid	334-48-5	172	41.07	0.116
C ₁₁ H ₂₂ O ₂	<i>n</i> -Undecanoic acid	112-37-8	186	48.76	0.004
C ₁₂ H ₂₄ O ₂	<i>n</i> -Dodecanoic acid	143-07-7	200	61.07	0.025
C ₁₃ H ₂₆ O ₂	3-Methyldodecanoic acid	x	214	67.43	0.015
C ₁₄ H ₂₈ O ₂	<i>n</i> -Tetradecanoic acid	544-63-8	228	110.29	0.044
Heterocyclic compounds					
<i>Dioxanes</i>					
C ₄ H ₈ O ₂	1,4-Dioxane	123-91-1	88	13.81	0.001
<i>Furans</i>					
C ₄ H ₄ O	Furan	110-00-9	68	7.26	0.012
C ₅ H ₆ O	2-Methylfuran	534-22-5	82	10.26	0.017
C ₅ H ₆ O	3-Methylfuran	930-27-8	82	10.56	0.002
C ₆ H ₈ O	2-Ethylfuran	3208-16-0	96	12.71	0.001
C ₆ H ₈ O	3-Ethylfuran	x	96	14.02	0.003
C ₆ H ₈ O	2,5-Dimethylfuran	625-86-5	96	14.02	0.011
C ₆ H ₈ O	2,3-Dimethylfuran	(458499)	96	14.44	<0.001
C ₆ H ₈ O	2,4-Dimethylfuran	3710-43-8	96	15.34	<0.001
C ₇ H ₁₀ O	2-Propylfuran	4229-91-8	110	18.69	0.002
C ₈ H ₁₂ O	2-Butylfuran	4466-24-4	124	22.13	0.001
C ₉ H ₁₄ O	2-Pentylfuran	3777-69-3	138	25.93	0.002
C ₁₀ H ₁₆ O	2-Hexylfuran	3777-70-6	152	29.41	0.001
C ₁₁ H ₁₈ O	2-Heptylfuran	3777-71-7	166	32.64	0.001
C ₁₂ H ₂₀ O	2-Octylfuran	4179-38-8	180	36.14	0.001
Nitrogenated compounds					
N ₂	Nitrogen	7727-37-9	28	1.63	0.212
H ₃ N	Ammonia	7664-41-7	17	2.93	0.075
C ₂ H ₃ N	Acetonitrile	75-05-8	41	7.03	0.064
C ₃ H ₅ N	Propargylamine	2450-71-7	55	9.64	0.001
C ₄ H ₅ N	Pyrrrole	109-97-7	67	14.67	0.006
C ₅ H ₅ N	Pyridine	110-86-1	79	16.32	0.004
C ₃ H ₅ NO ₂	2-Oxopropanamide	x	87	17.84	0.008
C ₆ H ₉ N	2,3-Dimethyl-1H-pyrrole	600-28-2	95	18.75	0.001
C ₆ H ₇ N	2-Methylpyridine	109-06-8	93	19.42	0.001
C ₆ H ₁₃ NO	1-Methyl-3-piperidinol	3554-74-3	115	25.83	0.007
C ₇ H ₁₁ N	1,2,5-Trimethylpyrrole	930-87-0	109	26.10	0.001
C ₈ H ₁₅ N	Octanenitrile	124-12-9	125	29.49	0.002
C ₄ H ₅ NO ₂	Succinimide	123-56-8	99	29.34	0.006
C ₉ H ₈ ClNO ₄	(2-Chloro-5-nitrophenyl)methyl ester acetic acid	303965-18-6	229	93.71	0.003
Sulfonated compounds					
H ₂ S	Hydrogen sulfide	7783-06-4	34	2.81	0.128

(continued on next page)

Table 3 (continued)

Formula	Name	¹ CAS/(NIST)	² MW	Pyrite	
				³ RT, min	⁴ A, %
COS	Carbonyl sulfide	463-58-1	60	3.36	0.029
O ₂ S	Sulfur dioxide	7446-09-5	64	5.03	1.084
CH ₄ S	Methanethiol	74-93-1	48	5.51	0.024
CS ₂	Carbon disulfide	75-15-0	76	7.83	0.178
C ₃ H ₈ S	Propyl mercaptan	107-03-9	76	10.96	0.001
C ₄ H ₄ S	Thiophene	110-02-1	84	12.29	0.012
C ₂ H ₆ S ₂	Dimethyl disulfide	624-92-0	94	15.35	0.001
C ₅ H ₆ S	2-Methylthiophene	554-14-3	98	16.47	0.009
C ₅ H ₆ S	3-Methylthiophene	616-44-4	98	16.82	0.016
C ₆ H ₈ S	2-Ethylthiophene	872-55-9	112	20.57	0.003
C ₆ H ₈ S	3-Ethylthiophene	1795-01-3	112	20.97	0.002
C ₇ H ₁₀ S	2-Propylthiophene	1551-27-5	126	24.15	0.001
C ₇ H ₁₀ S	3-Propylthiophene	x	126	24.43	0.003
C ₇ H ₄ OS	3-Thiophenecarboxaldehyde	498-62-4	112	25.23	0.002
C ₈ H ₁₂ S	2-(1,1-Dimethylethyl)-thiophene	1689-78-7	140	26.94	0.003
C ₈ H ₁₂ S	2,5-Diethylthiophene	5069-23-8	140	27.98	0.003
C ₈ H ₁₂ S	2-Butylthiophene	1455-20-5	140	28.23	0.004
C ₆ H ₆ OS	5-Methyl-2-thiophenecarboxaldehyde	13679-70-4	126	29.54	0.002
C ₉ H ₁₄ S	2-Pentylthiophene	4861-58-9	154	31.64	0.006
C ₁₀ H ₁₆ S	2-Hexylthiophene	18794-77-9	168	34.97	0.004
C ₁₁ H ₁₈ S	3-Heptylthiophene	x	182	39.50	0.009
C ₁₁ H ₁₈ S	2-Heptylthiophene	18794-78-0	182	39.90	0.012
C ₁₂ H ₂₀ S	2-Octylthiophene	880-36-4	196	46.40	0.015
Inorganic compounds					
<i>Oxides</i>					
CO ₂	Carbon dioxide	124-38-9	44	1.90	53.880
H ₂ O	Water	7732-18-5	18	3.08	35.997
<i>Noble gases</i>					
Ar	Argon	7440-37-1	40	1.62	0.011
<i>Others</i>					
CCl ₂ O	Carbonyl dichloride	75-44-5	98	4.95	0.014
Hg	Mercury	7439-97-6	202	5.38	0.024
F ₄ Si	Silicon tetrafluoride	7783-61-1	104	14.26	0.001

water fluids are depleted of these compounds. In the depths of the Earth's crust, the components of the fluid, including CO₂, occur in a supercritical state (Savage et al., 1995; Gorbatiy and Bondarenko, 2007; Letnikov et al., 2018). A supercritical fluid is an intermediate state between liquid and gas and has a unique reactivity in the transfer and deposition of ore substance (Letnikov et al., 2018). According to (Taylor and Miller, 2010), SO₂ has the same properties, but with an increase in the proportion of water in the fluid the dissolving power of these compounds decreases. Among the sulfur-containing compounds in the fluids from native gold, pyrite and quartz, SO₂ is predominant (Tables 1–3).

Molecular nitrogen and nitrogen-bearing compounds are constantly present in native gold, pyrite and quartz fluids (Tables 1–3). Nitrogen, as well as sulfur and halogens, can

participate in the formation of complexes as compounds Au(CN)₂⁻; (Au(SCN))⁻; (Au(S₂O₃)⁻³); (Au(HS₂)⁻); AuCl₄⁻; KAuCl₄ (Marchuk, 2008; Williams-Jones et al., 2009; Bondar et al., 2010; Lyakhov and Pavlun', 2013).

Carboxylic acids present in the fluids (Table 4) also play a positive role in the formation of complexes, resulting in Organometallic anionic complexes, i.e., they are potentially capable of transporting gold. In addition, carboxylic acids increase the porosity of host rocks, which contributes to the migration of Organometallic complexes (Greenwood et al., 2013).

Fluids preserved in native gold can be classified as gaseous according to their aggregate state. This is first of all, inferred from their low water content and the presence of hydrocarbons (Tables 1–3), most of which are volatile com-

Table 4. Composition (rel.%) of volatiles extracted by single mechanical shock destruction of the minerals from the gold-bearing quartz vein of the Sovetskoye deposit, Yenisei Ridge

Name	MW	Gold	Quartz	Pyrite
Aliphatic hydrocarbons:				
Paraffins (CH ₄ –C ₁₈ H ₃₈)	16–254	1.82	3.47	1.09
Olefins (C ₂ H ₄ –C ₁₆ H ₃₂)	28–224	2.05	0.68	0.11
Cyclic hydrocarbons:				
Cycloalkanes (naphthenes) (C ₅ H ₁₀ –C ₆ H ₁₀)	70–82	0.20	0.01	0.01
Arenes (C ₆ H ₆ –C ₁₅ H ₂₄)	78–204	1.36	0.96	0.32
Polycyclic aromatic hydrocarbons (C ₁₀ H ₈ –C ₁₄ H ₁₀)	128–178	–	0.03	0.02
Oxygenated hydrocarbons:				
Alcohols, Esters and ethers (CH ₄ O–C ₁₄ H ₁₈ O ₄)	32–250	19.6	0.76	3.70
Aldehydes (C ₂ H ₄ O–C ₁₅ H ₃₀ O)	44–226	6.43	4.40	1.18
Ketones (C ₃ H ₆ O–C ₁₅ H ₃₀ O)	58–226	3.47	1.51	0.97
Carboxylic acids (CH ₂ O ₂ –C ₁₅ H ₃₀ O ₂)	46–242	5.10	3.11	0.77
Heterocyclic compounds:				
Dioxanes (C ₄ H ₈ O ₂)	88	–	0.01	0.01
Furans (ethers) (C ₄ H ₄ O–C ₁₂ H ₂₀ O)	68–180	0.07	0.04	0.05
Nitrogenated compounds (N ₂ –C ₉ H ₈ ClNO ₄)				
Sulfonated compounds (H ₂ S–C ₁₃ H ₂₂ S)	34–210	1.0	1.49	1.55
CO ₂	44	47.8	37.3	53.9
H ₂ O	18	0.30	44.65	35.9
Carbonyl dichloride (CCl ₂ O)	98	0.01	–	0.01
Mercury (Hg)	202	0.29	–	0.02
The number of identified components				
CO ₂ /(H ₂ O+CO ₂)	–	0.9	0.5	0.6
CO ₂ /hydrocarbons	–	1.2	2.1	5.2
Σ(C ₅ –C ₁₂)/Σ(C ₁ –C ₄)	–	240.25	0.40	1.32

Note. The relative concentrations (rel.%) of volatile components in the studied mixture were obtained by normalizing areas of individual chromatographic peaks to the total area of all peaks.

pounds (Buslayeva and Novgorodova, 1992). In endogenous processes, volatile components of fluids have high mobility and play an important role in the transport of metals, including gold (Archibald et al., 2001; Williams-Jones and Heinrich, 2005; Malyshev, 2008). The idea that gases can play an important part in the transport of metals was initially suggested on the basis of theoretical research (Krauskopf, 1957). Then the discovery of appreciable quantities of gold in gas inclusions in the gold deposits of Argentina and Indonesia led the authors (Ulrich et al., 1999) to the conclusion that gaseous fluids play a significant role in the transport of gold.

CONCLUSIONS

The composition of the fluid from inclusions in native gold, pyrite, and quartz from the Sovetskoe deposit was studied using pyrolysis-free gas chromatography-mass spectrometry with shock destruction of the sample. The results show that the fluid contained in the inclusions from native gold differs in quantitative and species composition from the fluids in inclusions from pyrite and quartz. The solutions of fluid inclusions in pyrite and quartz are, on the whole, similar in the species composition of substances, but differ in their quantitative ratio.

1. Fluids from inclusions in native gold deposits have a minimum water content (~0.3 rel.%) and elevated, up to ~47.7 rel.%, CO₂. These fluids also have maximum contents of nitrogen-bearing compounds (~10.5 rel.%), halogen-bearing compounds (~0.14 rel.%), olefins (~2.1 rel.%), cyclic alkanes (~0.2 rel.%), arenes (~1.4 rel.%); alcohols and esters (~19.6 rel.%), aldehydes (~6.4 rel.%), ketones (~3.5 rel.%), carboxylic acids (~5.1 rel.%), and mercury (~0.3 rel.%). A distinctive feature of this fluid is also the presence of organosilicon compounds (up to ~0.06 rel.% in total), which are absent in the inclusions in quartz.

2. Among the fluid inclusions preserved in pyrite, there is a fluid with a higher water content (H₂O up to ~36.0 rel.%), containing the maximum amount of carbon dioxide (~53.9 rel.%) and sulfur-bearing compounds (~1.6 rel.%). The fluid from inclusions in pyrite is characterized by increased contents (relative to quartz) of alcohols and esters (~3.6 rel.%) and the presence of halogen-bearing paraffins (~0.003 rel.%), which were not found in gold and quartz samples.

3. The fluid trapped in inclusions in quartz is the richest in water (~44.5 rel.%) and contains a minimum amount of carbon dioxide (~37.3 rel.%). The fluid has a maximum paraffin content (~3.5 rel.%). Relative to the pyrite sample, the fluid

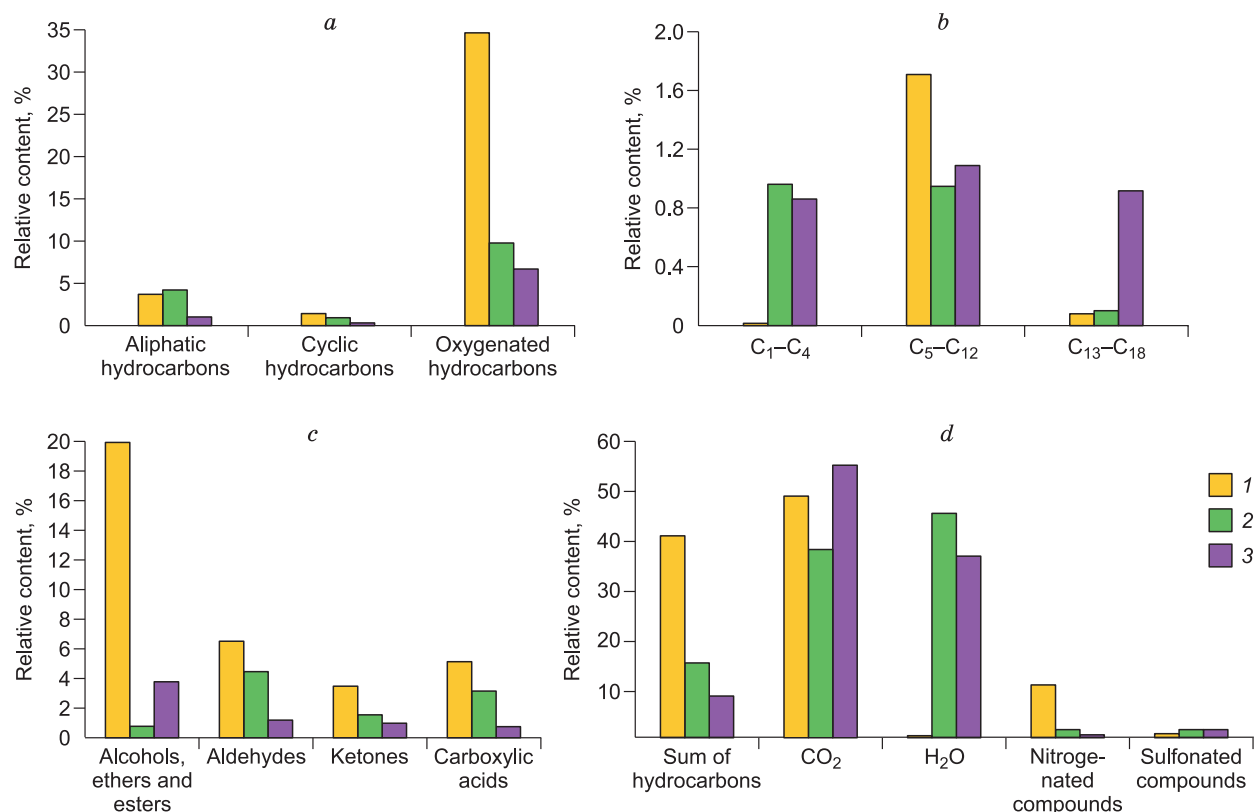


Fig. 6. The relative content of volatile components in gold, quartz and pyrite from the gold-bearing quartz vein of the Sovetskoe gold ore deposit: *a*, Aliphatic, cyclic and oxygenated hydrocarbons; *b*, “light” (C₁-C₄), “medium” (C₅-C₁₂) and “heavy” (C₁₃-C₁₈) paraffins; *c*, alcohols, esters and ethers, aldehydes, ketones and carboxylic acids; *d*, the sum of hydrocarbons, carbon dioxide, water, and nitrogenated and sulfonated compounds.

is enriched with olefins (~0.6 el.%); arenes (~1.0 rel.%); aldehydes (~4.4 rel.%); ketones (~1.5 rel.%); carboxylic acids (~3.1 rel.%) and nitrogen-bearing compounds (~1.6 rel.%).

4. A distinctive feature of fluids from inclusions in pyrite and quartz is the presence of polycyclic aromatic hydrocarbons at the level of 0.0*n* rel.% and dioxanes at 0.00*n* rel.% not found in the gold sample.

5. The main feature of the ore-bearing fluid in the formation of the Sovetskoye gold deposit is the active participation of hydrocarbons, including high-molecular ones, in the transport of gold. Identification of such fluids using the thermobarogeochemical and chromatography-mass spectrometric mapping of quartz-vein zones is one of the most promising ways to forecast a gold-ore object in them.

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REFERENCES

- Akhmadullina, N.S., Churakov, A.V., Retivov, V.M., Sandu, R.A., Shishilov, O.N., 2012. Gold(III) chloride and acetate complexes with bipyridine and phenanthroline. *Russ. J. Coord. Chem.* 38 (9), 589–595.
- Archibald, S.M., Migdisov, A.A., Williams-Jones, A.E., 2001. The stability of Au-chloride complexes in water vapor at elevated temperatures and pressure. *Geochim. Cosmochim. Acta* 65 (23), 4413–4423.
- Babkin, P.V., Kuklin, A.P., 1966. To the question of gas bubbles in native gold, in: *Genetic Features and General Patterns of Development of the Gold Mineralization of the Far East* [in Russian]. Nauka, Moscow, 196–200.
- Bogdanovich, V.A., 1962. New data on the structure of the Sovetskoye gold ore deposit. *Geologiya i Geofizika* 7, 87–96.
- Bogdanovich, V.A., 1964. On structural control of gold mineralization of the Sovetskoye deposit *Geologiya i Geofizika* 12, 72–81.
- Bondar, R.A., Naumko, I.M., Lyubchak, A.V., Khokha, Yu.V., 2010. On the question of the forms of transfer of precious and rare-metal metals to the ore deposition zones of gold deposits, in: *Native Gold, Typomorphism of Mineral Associations, Conditions for the Formation of Deposits, Tasks of Applied Research* [in Russian]. IGEM RAS, Moscow, Vol. 1, pp. 76–78.
- Bortnikov, N.S., Razdolina, N.V., Prokof'ev, V.Yu., 1996. Origin of the Charmitan gold-quartz deposit (Uzbekistan). *Geol. Ore Deposits* 38 (3), 208–226.
- Burak, V.N., 1982. *Metamorphism and Ore Formation* [in Russian]. Nedra, Moscow.
- Buslaeva, E.Yu., Novgorodova, M.I., 1989. *Organic-Element Compounds in the Context of Ore Migration* [in Russian]. Nauka, Moscow.
- Buslaeva, E.Yu., Novgorodova, M.I., 1992. *Organic-Element Compounds in Endogenous Ores* [in Russian]. Nauka, Moscow.
- Eirish, L.V., 2002. *Gold Metallogeny of Priamurye (Amur region)* [in Russian]. Dal'nauka, Vladivostok.

- Elschenbroich, C., 2006. *Organometallics* 3. Edition. Wiley-VCH, Weinheim.
- Gapon, A.E., 1962. Some data on gas and liquid inclusions in native gold, in: *Notes of the East-Siberian Branch of the All-Union Mineralogical Community* [in Russian]. Issue 4, pp. 192–196.
- Gizé, A.F., 1999. Organic alteration in hydrothermal sulfide ore deposits. *Econ. Geol.* 94, 967–980.
- Gizé, A.F., Macdonald, R., 1993. Generation of compositionally atypical hydrocarbons in CO₂-rich geologic environment. *Geology* 21, 129–132.
- Gorbatyi, Yu.E., Bondarenko, G.V., 2007. Water in the supercritical state. *Sverkhkriticheskie fluyidy: Teoriya i Praktika*, No. 2 (2), 5–19.
- Greenwood, P.F., Brocks, J.J., Grice, K., Schwark, L., Dick, J.M., Evans, K.A., 2013. Organic geochemistry and mineralogy. 1. Characterization of organic matter associated with metal deposits. *Ore Geol. Rev.* 50, 1–27.
- Jia, Y., Kerrich, R., 2000. A fluid inclusion study of Au-bearing quartz vein systems in the Central and North Deborah deposits of the Bendigo gold field, Central Victoria, Australia. *Econ. Geol.* 95, 467–494.
- Kokin, A.V., 1981. Thermobarometry of native gold and its mineral associates from deposits in South-East Yakutia. *Soviet Geology and Geophysics (Geologiya i Geofizika)* 5, 74–79.
- Krauskopf, K.B., 1957. Separation of manganese from iron in sedimentary processes. *Geochim. Cosmochim. Acta* 12, 61–84.
- Kryazhev, S.G., 2002. *Isotope-Geochemical Regime of the Formation of the Gold Ore Deposit Muruntau* [in Russian]. TsNIGRI, Moscow.
- Kryazhev, S.G., 2017. *Genetic Models and Criteria for Prediction of Gold Deposits in Carbon-Terrigenous Complexes*. DSci. Thesis [in Russian]. TsNIGRI, Moscow.
- Letnikov, F.A., Shumilova, T.G., Medvedev, V.Ya., Ivanova, L.A., 2018. Transport and crystallization of noble platinum in supercritical C–O–H fluid. *Dokl. Earth Sci.* 479 (2), 460–462.
- Levitskii, Yu.T., Neronskii, G.I., Skabelkin, A.V., Pantaev, A.D., 1984. Visual and photographic determination of the decrepitation temperature, in: *Thermobarogeochemistry of Endogenous Processes* [in Russian]. DVNZ AN SSSR, Blagoveshchensk, pp. 149–150.
- Li, L.V., 1997. Precambrian gold mineralization in the Yenisei Ridge, in: *Geology and Mineral Deposits of Central Siberia* [in Russian]. KNIIGiMS, Krasnoyarsk, pp. 184–248.
- Lyakhov, Yu.V., Pavlun, N.N., 2013. Some geological and geochemical features of gold mineralization in metamorphic and magmatic hydrothermal systems, in: *Metallogenic Processes: from Genetic Theories to Prediction and Discovery of New Ore Provinces and Deposits* [in Russian]. IGEM, Moscow, p. 144.
- Malyshev, A.I., 2008. Gas diffusion in the evolution of magmatic systems. *Dokl. Earth Sci.* 422 (1), 1113–1115.
- Marchuk, M.V., 2008. *Transport of Major Elements and Metals in Reduced Fluids: An Experimental Study*. PhD Thesis [in Russian]. IZK SO RAN, Irkutsk.
- Mathez, E.A., Dietrich, V.J., Irving, A.J., 1984. The geochemistry of carbon in mantle peridotites. *Geochim. Cosmochim. Acta* 48, 1849–1859.
- Migdisov, A.A., Guo, X., Xu, H., Williams-Jones, A.E., Sun, C.J., Vasyukova, O., Sugiyama, I., Fuchs, S., Pearce, K., Roback, R., 2017. Hydrocarbons as ore fluids. *Geochim. Persp. Lett.* 5, 47–52.
- Mironova, O.F., 2010. Volatile components of natural fluids: Evidence from inclusions in minerals: Methods and results. *Geochim. Int.* 48 (1), 83–90.
- Moiseenko, V.G., 1977. *Geochemistry and mineralogy of gold ore regions of the Far East* [in Russian]. Nedra, Moscow.
- Neronskii, G.I., Levitskii, Yu.T., 1988. Gas-liquid inclusions in native gold and their structural position, in: *Mineral-Forming Fluids and Ore Genesis* [in Russian]. Naukova Dumka, Kiev, pp. 137–140.
- Neronskii, G.I., Levitskii, Yu.T., Ostapenko, N.S., Belousov, V.I., 1982. On the issue of thermal vacuum gold decrepitation, in: *Thermobarogeochemistry in Geology* [in Russian]. DVNZ AN SSSR, Vladivostok, pp. 165–170.
- Nikolaeva, L.A., 1954. Gas inclusions in native gold. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshestva* [in Russian]. Part 83, Vol. 4, pp. 404–402.
- Novgorodova, M.I., 1983. *Native Metals in Hydrothermal Ores* [in Russian]. Nauka, Moscow.
- Ostapenko, N.S., 1989. On the temperatures of decrepitation and the composition of gas-liquid inclusions in native gold, in: *Geology, Mineralogy, and Geochemistry of Noble Metals* [in Russian]. DVNZ AN SSSR, Vladivostok, pp. 69–77.
- Ostapenko, N.S., Levitsky, Yu.T., Shakhrai, S.A., 1988. On the assessment of the temperature of mineral decompitation by thermobarograms, in: *Mineral-Forming Fluids and Ore Genesis* [in Russian]. Naukova Dumka, Kiev, pp. 229–237.
- Paddefet, R., 1982. *Chemistry of Gold* [in Russian]. Mir, Moscow.
- Petrovskaya, N.V., 1956. Some features of intra-ore metamorphism of gold-quartz formations on the example of deposits of the Yenisei Ridge, in: *Trans. of the Institute "NIGRIZOLOTO"* [in Russian]. Issue 21, pp. 3–45.
- Petrovskaya, N.V., 1973. *Native Gold* [in Russian]. Nauka, Moscow.
- Petrovskaya, N.V., 1993. *Gold Nuggets* [in Russian]. Nauka, Moscow.
- Petrovskaya, N.V., Elinson, M.M., Nikolaeva, L.A., 1971. Composition and conditions for the formation of gas inclusions in native gold. In: *Proc. Int. Geochem. Congress. Hydrothermal processes* [in Russian]. Izd-vo AN SSSR, Moscow, Vol. 2, pp. 441–451.
- Petrovskaya, N.V., Novgorodova, M.I., Tsepin, A.I., 1975. On the chemical composition of relicts of a mineral-forming environment in native gold. *Geologiya Rudnykh Mestorozhdenii*, No. 5, pp. 53–61.
- Robert, F., Kelly, W.C., 1987. Ore-forming fluids in Archean gold-bearing quartz veins at the Sigma Mine, Abitibi green-stone belt, Quebec, Canada. *Econ. Geol.* 82, 1464–1482.
- Ronde, C.E.J., Faure, K., Bray, C.J., Whitford, D., 2000. Round Hill shear zone-hosted gold deposit, Macraes Flat, Otago, New Zealand: evidence of a magmatic ore fluid. *Econ. Geol.* 95, 1025–1048.
- Ryabchikov, I.L., Novgorodova, M.I., 1981. Reconstituted fluids in hydrothermal ore formation. *Dokl. Akad. Nauk USSR* 258 (6), 1453–1456.
- Safonov, Yu.G., Prokof'ev, V.Yu., 2006. Gold-bearing reefs of the Witwatersrand basin: a model of syndeformation hydrothermal formation. *Geol. Ore Deposits* 48 (6), 415–447.
- Savage, P.E., Gopalan, S., Mizan, T.I., Martino, C.J., Brock, E.E., 1995. Reactions at supercritical conditions: applications and fundamentals. *AIChE J.* 41 (7), 1723–1778.
- Schoell, M., 1988. Multiple origins of methane in the Earth. *Chem. Geol.* 71, 1–10.
- Schwandne, F.M., Seward, T.M., Gizé, A.P., Hall, K., Dietrich, V.J., 2013. Halocarbons and other trace heteroatomic organic compounds in volcanic gases from Volcano (Aeolian islands, Italy). *Geochim. Cosmochim. Acta* 101, 191–221.
- Semenko, V.A., 1986. New data on the composition of gas-liquid inclusions in native gold, in: *Thermobarogeochemistry of endogenous processes* [in Russian]. DVNZ AN SSSR, Vladivostok, pp. 108–110.
- Simkin, G.S., 1997. The geological position and prospects of the Sovetskoye gold deposit. *Rudy i Metally*, No. 2, 57–72.
- Slobodskoi, R.M., 1981. *Organoelement Compounds in Magmatic and Ore-Forming Processes* [in Russian]. Nauka, Novosibirsk.
- Sokol, A.G., Palyanov, Y.N., Tomilenko, A.A., Bul'bak T.A., Palyanova G.A., 2017. Carbon and nitrogen speciation in nitrogen-rich CO–H–N fluids at 5.5–7.8 GPa. *Earth Planet. Sci. Lett.* 460, 234–243.
- Spiridonov, E.M., 2010. A review of gold mineralogy in the leading types of Au mineralization, in: *Proc. All-Russ. (with Int. Part.) Sci. Conf. "Gold of the Kola Peninsula and adjacent regions"* [in Russian]. Izd. K&M, Apatity, pp. 143–171.

- Taylor, L., Miller, L., 2011. Supercritical fluid chromatography with packed columns. *Sverkhkriticheskie Fluidy. Teoriya i Praktika* 6 (1), 69–83.
- Tomilenko, A.A., Gibsher, N.A., 2001. Peculiarities of fluid composition in the mineralized and barren zones of the Sovetskoe quartz-gold deposit, Yenisei mountain range based on fluid inclusion study. *Geochem. Int.* 39 (2), 142–152.
- Tomilenko, A.A., Gibsher, N.A., Travin, A.V., 2006. $^{40}\text{Ar}/^{39}\text{Ar}$ age of sericites from gold-bearing and barren quartz-vein zones of the Sovetskoye deposit, Yenisei Ridge, Russia, in: *Isotopic Dating of the Processes of Ore Formation, Magmatism, Sedimentation and Metamorphism* [in Russian]. GEOS, Moscow, Vol. 2, pp. 345–349.
- Tomilenko, A.A., Gibsher, N.A., Koz'menko, O.A., Palesskii, S.V., Nikolaeva, I.V., 2008. Lanthanides in fluid inclusions, quartz, and greenschists from auriferous and barren quartz-vein zones of the Sovetskoe quartz-gold deposit, Yenisei Range, Russia. *Geochem. Int.* 46 (4), 402–408.
- Tomilenko, A.A., Gibsher, N.A., Dublaynsky, Y.V., Dallai, I., 2010. Geochemical and isotopic properties of fluid from gold-bearing and barren quartz veins of the Sovetskoye deposit (Siberia, Russia). *Econ. Geol.* 105 (2), 375–394.
- Tomilenko, A.A., Chepurov, A.I., Sonin, V.M., Bul'bak, T.A., Zhimulev, E.I., Chepurov, A.A., Timina, T.Yu., Pokhilenko, N.P., 2015. The synthesis of methane and heavier hydrocarbons in the system graphite-iron-serpentine at 2 and 4 GPa and 1200 °C. *High Temperature–High Pressure* 44 (6), 451–465.
- Tomilenko, A., Sonin, V., Bul'bak, T., Chepurov, A., 2019. Composition of volatile components in the polycrystalline CVD diamond (by coupled gas chromatographic–mass spectrometric analysis). *Carbon Lett.* 29, 327–336.
- Ulrich, T., Günther, D., Heinrich, C.A., 1999. Gold concentrations of magmatic brines and the metal budget of porphyry copper deposits. *Nature* 399, 676–679.
- Vernikovskiy, V.A., Vernikovskaya, A.E., 2006. Tectonics and evolution of granitoid magmatism in the Yenisei Ridge. *Russian Geology and Geophysics (Geologiya i Geofizika)* 47 (1), 32–50 (35–52).
- Williams-Jones, A.E., Bowell, R.J., Migdisov, A.A., 2009. Gold in solution. *Element* 5, 281–287.
- Williams-Jones, A.E., Heinrich, C.A., 2005. Vapor transport of metals and the formation of magmatic-hydrothermal ore deposits. *Econ. Geol.* 100, 1287–1312.
- Yaroshevskii, A.A., 2006. Possible geochemical conditions of local reducing environments in the Earth's crust and upper mantle. *Geochem. Int.* 44 (3), 308–309.
- Zhemchuzhnyi, S.F., 1922. Physico-chemical study of gold nuggets in connection with the question of their genesis, in: *Izvestiya Instituta Fiziko-Khimicheskogo Analiza* [in Russian]. Vol. 2, Issue 1, pp. 5–28.
- Zhimulev, E.I., Sonin, V.M., Bul'bak, T.A., Chepurov, A.I., Tomilenko, A.A., Pokhilenko, N.P., 2015. Volatile compounds of sulfur in the Fe–C–S system at 5.3 GPa and 1300 °C. *Dokl. Earth Sci.* 462 (1), 527–532.

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