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Enigmatic organosiliceous rocks in the 2000 Ma petrified oil field in Russian Fennoscandia

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The c. 2000 Ma, 900 m-thick, Zaonezhskaja Formation in the Onega basin, Russian Fennoscandia, contains one of the greatest accumulations of organic matter (OM) in the Early Precambrian. It also represents a unique preservation of a supergiant petrified oil field. Zaonezhskaja Formation rocks are greenschist-facies volcaniclastic greywackes (distal turbidites), dolostone and limestones, mafic tuffs and lavas intruded by numerous mafic sills. Several sedimentary beds are enriched in OM with the overall content of total organic carbon (TOC) ranging from 0.1 to 16 wt.% whereas d13C varies between -44 and -17 per mil(V-PDB). The formation contains plentiful evidence of generation and migration of oil (now petrified) as well as oil traps. Results of geophysical surveys combined with drillcore data, including results recently obtained within the framework of the Fennoscandian Arctic Russia – Drilling Early Earth Project (FAR-DEEP), revealed numerous bodies of organosiliceous rocks (OSR) containing mainly silica (c. 57 wt.% SiO_2), organic carbon (up to 40 wt.%), Al_2O_3 (c. 5 wt.%), S (c. 2 wt.%), and minor K, Mg, Fe, Ca and Ti. d13C of the OSR ranges between -40 and -20 per mil. The OSR form crudely stratified beds, cupola-like bodies or veins. The cupola-like bodies show cross-cutting (intrusive) contacts with the host turbiditic greywackes, reach thicknesses of 120 m with a lateral extent of several hundreds of metres. Veins are a few tens of centimetres thick. The OSR show close spatial association with gabbro sills. Although different fabrics have been recognised in the OSR, syngenetic macro- and microbreccias per se are the most common rock types. Fragments of different sedimentary rocks, as well as those with alternating C-rich and C-poor concentric lamina are present. The latter suggests precipitation from hydrothermal fluids. The nature of the OSR remains enigmatic. Several models have been advanced for explanation of origin of the OSR. However, neither of them could explain the source, and joint transport of two major components, namely silica and OM. We propose a model involving a hydrothermal system initiated by heat produced during the emplacement of numerous mafic intrusive bodies. Such heat may have created the necessary temperature gradient for earlier oil generation, thermal oil to gas cracking, and initiation of shallow-seated, sub-surface, hydrothermal circulation. The proposed result would have been the mingling of silica leached from mafic rocks with hydrocarbon, and gas (primarily CO_2, CH_4) extracted from the host sedimentary rocks. Such a gas-rich C-Si-H_2O substance would have migrated into permeable beds. A high sedimentation rate, as expected in many turbiditic depositional environments, would have produced a high lithostatic pressure on to unlithified beds during the course of the basin subsidence. This would have forced gas-rich C-Si-H_2O fluids that moved either laterally along permeable beds or vertically along zones of weakness. In the first case, sediments 'impregnated' with gas-rich C-Si-H_2O fluids would have formed stratigraphic beds of OSR, whereas in the second case the result would been crosscutting veins. Beds may retain some primary layering, whereas veins do not. If veins reached the seafloor, the sediment – C-Si-H_2O mush would have extruded in the form of a mud volcano / hydrothermal mound, and thus formed a cupola-like morphology. During the course of compression, the sediment – C-Si-H_2O mush might have experienced several stages of partial lithification, as well as fluidisation processes leading to the formation of several generations of micro- and macro-brecciated rocks. The large d13C range of reduced carbon in the OSR suggests a complex maturation process of the biogenic OM. Further detailed microstructural, geochemical, isotopic and biomarker studies are planned for distinguishing between biological and abiological processes involved in the formation of the enigmatic OSR.