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# Petroleum surface oil seeps from Palaeoproterozoic petrified giant oilfield

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Evidence of petroleum generation and migration has been previously reported from rocks dating as early as 3.25 Ga. Micron-size carbonaceous streaks and bitumen micronodules were found in abundance in Archaean rocks across the Pilbara craton in Australia suggesting pervasive petroleum generation and migration. However, none of the Archaean petroleum deposits has been reported to be preserved in quantity due to destructive effects of deformation and thermal obliteration during metamorphism. During the Palaeoproterozoic, unprecedented accumulation of Corg-rich rocks worldwide, known as the 2.0 Ga Shunga Event, occurred during the early stage of progressive oxidation of terrestrial environments, and in the aftermath of the Lomagundi-Jatuli isotopic event, which based on the magnitude and duration of positive d13C was the greatest perturbation of the global carbon cycle in Earth history.

C. 2.0 Ga Zaonezhskaya Formation (ZF) rocks from the Onega Basin in Russian Fennoscandia contain evidence for substantial accumulation and preservation of organic matter (up to 75 wt.-% total organic carbon) with an estimated original petroleum potential comparable to a modern supergiant oilfield. The basin contains a uniquely preserved petrified oilfield including evidence of oil traps and oil migration pathways. Here, we report the discovery of the surface expression of a migration pathway, along which petroleum was flowing from the sub-surface. This surface oil seep, the first occurrence ever reported from the Palaeoproterozoic, appears as originally bitumen clasts redeposited in Palaeoproterozoic lacustrine turbidites of the Kondopozhskaya Formation. The d13Corg of clastic pyrobitumen ranges between -35.4 and -36.0 per mill (n = 14) which is within the range of interbed- and vein-trapped fossil oil (-46 and -24 per mill), suggesting similar source. Biogenic organic matter, whose isotopic composition was modified during thermal maturation, is the likely source for the migrated hydrocarbon. Oil seeps, being a very common attribute of almost every major petroleum-producing province in the world, highlight the scale of oil generation and migration in the Onega Basin.

The large d13C variability in interbed-trapped pyrobitumen and in organic matter (OM) of the ZF can be entirely explained neither by isotopic fractionation during petroleum generation nor by metamorphic processes, thus it might reflect a primary feature. The source material could have had a wide range of compositions that could have reacted in various ways to the subsequent maturation and alteration. We tentatively suggest that small-scale pyrobitumen accumulations may reflect the initial isotope heterogeneity of the source. In contrast, the seeps d13C are homogeneous, thus perhaps reflecting a large-scale migration and accumulation of composite oil produced by mixing and homogenisation of various oil sources. However, the low H/C of OM and pyrobitumens suggests that the source rock's various components with apparent diversity of original d13C have been over-matured. Although these values are compatible with being the source of the seeps, robust source-reservoir correlation cannot be made. In the evolutionary context, it is significant that the 2.0 Ga OM-rich rocks and generation of supergiant oilfields occurred in the aftermath of the Lomagundi-Jatuli isotopic event, and during the course of the early stage of oxidation of the terrestrial atmosphere. Whether enhanced biomass or change in the preservation potential caused such unprecedented OM accumulation and large-scale oil generation remains to be investigated.