Geothermometry on ureilites; implications for diamond formation

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Introduction

Ureilites are coarse-grained ultramafic rocks that make up the second largest group of achondrites. They show characteristics of highly fractionated igneous rocks such as their mineralogy (primarily olivine and pigeonite) and texture. However, they also show signs of primitive characteristics like a relatively high carbon content, found as graphite and diamond, and a heterogenous oxygen isotopic composition. The existence of diamonds begs the question of what conditions were needed for the formation of this mineral. Did they crystalize under high-pressure conditions, or were they formed as a result of an impact? The crystallization temperature can help to answer this question. The following samples were used for all measurements: Dhofar 2116, Dhofar 2117 and Dhofar 2118, all of which were found in Oman in 2018.

Fig. 1. Overview of sample Dhofar 2116

Methods used include reflected light and transmitted light microscopy, Raman spectroscopy, SEM, XRD and LA-ICP-MS.

Diamond petrography

The platy texture of the diamond follows the shape of the graphite plates.

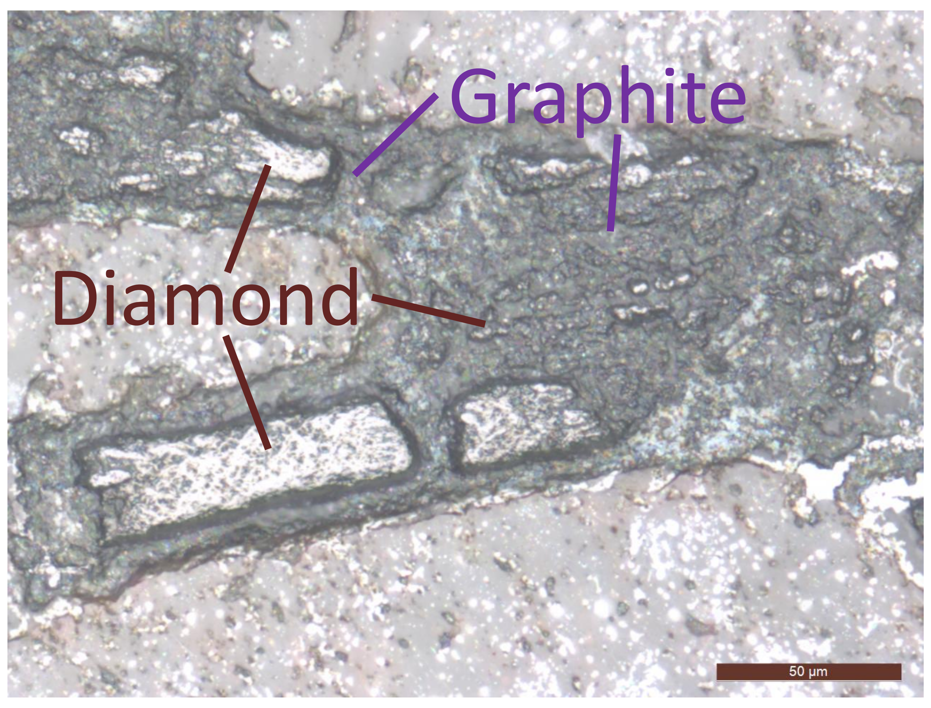

Fig. 4. Diamond in graphite

Chemistry

The REE and trace element pattern of both olivine and pigeonite (shown below) show they formed from a depleted source material. The trace elements also show that the minerals are in equilibrium.

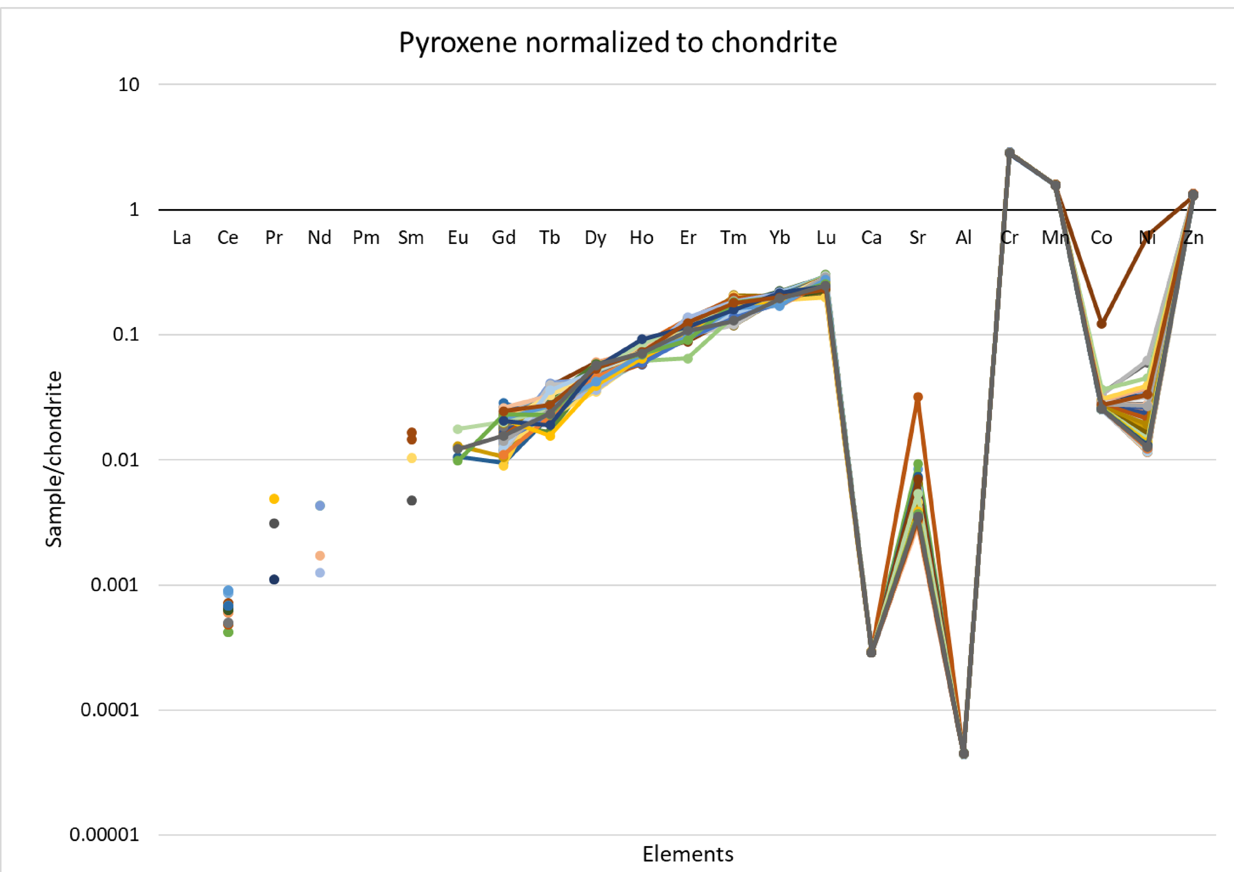

Fig 5. Elemental composition of pyroxene normalized to chondrite

Microscopic analysis

The samples contain olivine, minor pigeonite and small carbon aggregates. The olivine contains small metal blebs that are largely oxidized due to terrestrial weathering. With XRD analysis it was determined that the carbon phases consists of about 70% diamond and 30% graphite; both are microcrystalline. The samples are also weakly shocked and moderately weathered as most iron is oxidized, though the silicates are unaffected.

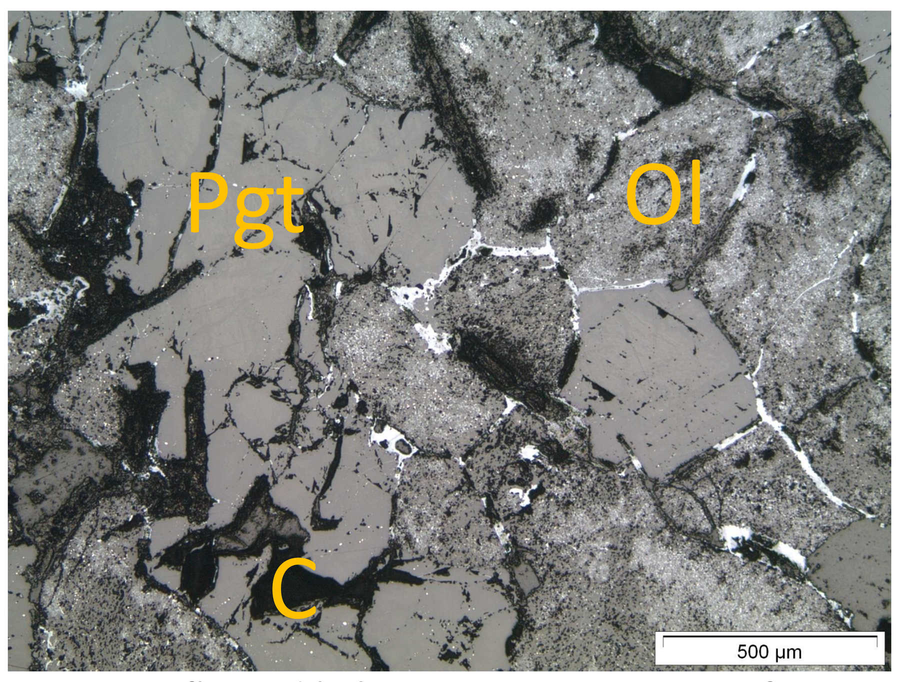

Fig. 2. Reflected light microscopy image of sample Dhofar 2117

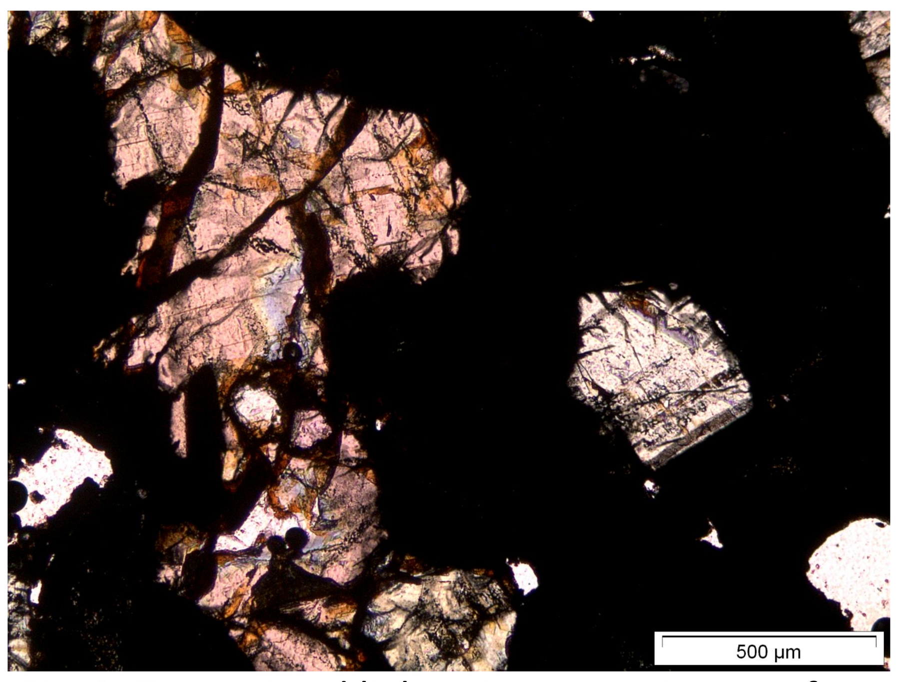

Fig. 3. Transmitted light microscopy image of sample Dhofar 2117

Pyroxene thermometry

This thermometer uses the experimentally determined Ca-Mg-Fe pyroxene phase relation at 800-1200 °C and calculated phase equilibria for the diopside-enstatite and hedenbergite-ferrosilite joint to construct a graphical two-pyroxene thermometer. The Ca-Mg-Fe composition of the pigeonite shows a crystallizations temperature of above 1200 °C. The measurements were done using LA-ICP-MS.

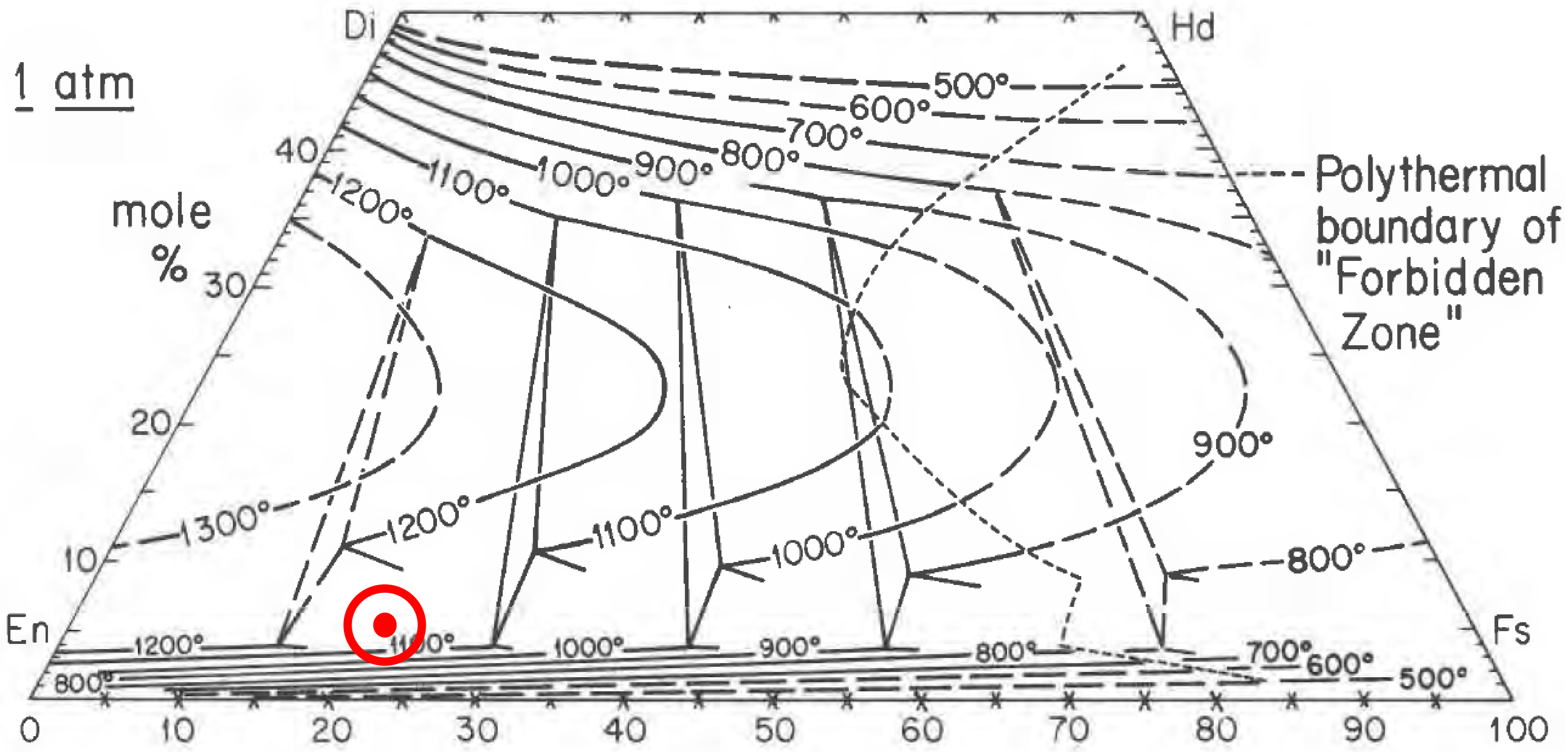

Fig 6. Pyroxene thermometer, modified after (Linsaley, 1983)

Thermometry based on the partitioning of Cr between olivine and low-Ca pyroxene

Batch melting experiments on chondrites show a decrease of the compatibility of Cr in olivine and low-Ca pyroxene with increasing temperature. This thermometer is specifically designed for ureilites and is used to estimate the temperature of equilibration. Using the measured Cr composition of the olivine and coexisting pigeonite yields a temperature of 1249 ± 4 °C.

Summary.

Understanding ureilites has been a challenge for a long time. But the petrography of diamonds combined with the estimated equilibration temperatures indicate that the diamond is not a primary phase but formed most likely later through shock metamorphism of graphite flakes.

References.

Linsaley, D.H., 1983, Pyroxene thermometryl: American Mineralogist, v. 68, p. 477–493.

Collinet, M., and Grove, T.L., 2020, Incremental melting in the ureilite parent body: Initial composition, melting temperatures, and melt compositions: Meteoritics and Planetary Science, v. 55, p. 832–856, doi:10.1111/maps.13471.

Moshinsky, M., 1959, Ureilites: A critical review, Nucl. Phys., v. 13, p. 104–116.