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Petrology, phase equilibria modelling, noble gas chronology and thermal constraints of the El Pozo L5 meteorite

Pedro Corona-Chávez[a,*], María del Sol Hernández-Bernal[b], Pietro Vignola[c], Rufino Lozano-Santacruz[d], Juan Julio Morales-Contreras[e], Margarita Reyes-Salas[d], Jesús Solé-Viñas[e], José F. Molina[f]

[a] Universidad Michoacana de San Nicolás de Hidalgo, Instituto de Investigaciones en Ciencias de la Tierra, Edificio U, Ciudad Universitaria, Morelia, 58020, Mexico
[b] Universidad Nacional Autónoma de México, Escuela Nacional de Estudios Superiores, Unidad Morelia, 58190, Mexico
[c] Consiglio Nazionale delle Ricerche (CNR) – Istituto per la dinamica dei processi ambientali, via Botticelli 23, 20133 Milan, Italy
[d] Universidad Nacional Autónoma de México, Instituto de Geología, Circuito interior Ciudad Universitaria, 04510, Mexico
[e] Universidad Nacional Autónoma de México, Instituto de Geofísica, Unidad Morelia, 58190, Mexico
[f] Departamento de Mineralogía y Petrología, Universidad de Granada, Spain

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ABSTRACT

We present the results of physical properties, petrography, bulk chemistry, mineral compositions, phase relations modelling and Noble gases study of the meteorite El Pozo. The petrography and mineral compositions indicate that the meteorite is an L5 chondrite with a low shock stage of S2-S3. Heterogenous weathering was preferentially along shock structures. Thermobarometric calculations indicate thermal equilibrium conditions between 768 °C and 925 °C at ∼4 to 6 kb, which are substantially consistent with the petrological metamorphism type 5. A pseudosection phase diagram is relatively consistent with the mineral assemblage observed and PT conditions calculated. Temperature vs. fO_2 diagram shows that plagioclase compositional stability is very sensitive to Tschermack substitution in orthopyroxene, clinopyroxene and X_{An} plagioclase during the high temperature metamorphic process. Based on noble gases He, Ne, Ar and K contents a cosmogenic exposure age CRE of 1.9 Myr was calculated. The ^{21}Ne would be totally cosmogenic, with no primordial Ne. The $^{21}Ne/^{22}Ne$ value (0.97) is higher than solar value. According to the cosmogenic Ne content, we argue that El Pozo chondrite originally had a pre-atmospheric mass of 9–10 kg, which would have been produced by a later collision after the recognized collision of the L-chondrite parent body ∼470 Ma ago.

1. Introduction

Metamorphic or equilibrated chondrites (e.g. petrologic type 4–6), provide understanding about size and heating events acquired during accretional, collisional and fragmental processes (Grossman and Brearley, 2005; Huss et al., 2006). Although the degree of metamorphism of chondrites groups is commonly referred to reliable classification of petrologic types (Van Schmus and Wood, 1967), many textural and mineral reaction details are not well understood (Dunn et al., 2010). Ordinary chondrites show a vast variety of bulk chemistry that can lead to significant differences during the multiple metamorphic reaction series. Consequently, detailed textural and metamorphic phase equilibria modelling studies of natural ordinary chondrites could provide new insights about reaction of solids metamorphic chondrites (Johnson et al., 2016).

Two pieces totalling 460 g of the El Pozo meteorite were found in the Chihuahua State, Mexico (Grossman, 2000). Based on the preliminary mineralogy: olivine $Fa_{23.6}$ and pyroxene $Fs_{22.2}$ (Sánchez–Rubio and Reyes–Salas *in* Grossman 2000; Sánchez-Rubio et al., 2001), El Pozo meteorite is considered to be an ordinary chondrite belonging to the L group and petrologic type 5. Hernández-Bernal and Solé (2010) reported a whole rock K–Ar age of 3103 ± 16 Ma. A comparative Raman (RMP), infrared (IR) and X-ray diffraction (XRD) study identified a common mineral assemblage of ordinary chondrite (Ostrooumov and Hernández-Bernal, 2011). However, petrography, modal abundances of minerals and bulk chemistry in the El Pozo chondrite are not yet described.

In this work, we provide the first physical, chemical, petrological

* Corresponding author.
E-mail addresses: pcorona@umich.mx (P. Corona-Chávez), msol_hernandez@enesmorelia.unam.mx (M.d.S. Hernández-Bernal), pietroevignola@gmail.com (P. Vignola), rufino@unam.mx (R. Lozano-Santacruz), moralesjuanjulio@gmail.com (J.J. Morales-Contreras), adelars@unam.mx (M. Reyes-Salas), jsole@unam.mx (J. Solé-Viñas), jfmolina@ugr.es (J.F. Molina).

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and isotopic study of the El Pozo meteorite (See Appendix A for supplementary material, and Analytical Methods in Sm.1). Based on bulk and mineral chemistry, conventional thermobarometry and phase diagram technique we discuss the relationships between chondrule textures and P-T phase conditions of metamorphic reactions during thermal processes of the El Pozo chondrite. Finally, considering the ^{21}Ne and ^{3}He isotopic contents we discuss the implications of early irradiation cosmic rays on the El Pozo-asteroid before entering the Earth's orbit.

2. Results

2.1. Physical description and petrography

The El Pozo meteorite is black to dark brown with reddish haloes of oxidation distributed preferentially along shock structures. Specific bulk density value is $G = 3.441\ g/cm^3$. The apparent porosity is 10.674% and the magnetic susceptibility obtained was $\chi = 58158.1 \times 10\text{–}8\ m^3/kg$. (See detail in Sm.2).

The study of the polished thin section under the polarising microscope reveals a chondritic texture with heterogeneously sized components showing a chaotic arrangement (Fig. 1). However, the overall look of the texture is dominated by irregular and relatively sub-parallel veins and sometimes broken chondrules originated by shock events, which are closely associated with a weathering reddish to ochre coloured appearance in plane polarised light, consisting of hydroxides and clay minerals. The modal abundances of the chondritic components determined from the El Pozo thick section by point counting (Tables Table 1and Sm.3), show that wholly preserved chondrules, chondrule fragments and/or relic chondrules that make up from 30 to 45% of the whole area as well as > 10.5% of scattered opaque minerals are set in a medium-grained inequigranular matrix composed mainly of olivine (50–300 μm) and to a lesser extent of orthopyroxene (~150 μm). (Fig. Sm.4).

Chondrules are mainly FeO-rich type and vary from relatively spherical to ellipsoidal shapes, with diameters ranging from 0.2 mm to 1 mm; however, there are some of ≥2 mm and up to 4 mm. Chondrules with igneous and accretionary rims are tightly welded with an aggregate of olivine crystals in the matrix because of metamorphic reactions at high temperatures. Considering petrographic and microprobe data, chondrules show a wide textural range (Tables Table 1; Sm.5; Sm.6): the olivine ± pyroxene porphyritic type (PO ± POP) and granular olivine (GO) constitute ~73% vol, while the non-porphyritic type: barred olivine (BO) > radial pyroxene (RP) types and > cryptocrystalline (C) constitute the ~27% vol. Scattered droplet and metal-sulphide chondrules ~1%, were also observed. On the other hand, opaque minerals are measuring between 0.2 mm up to 2 mm in diameter and, based on the image analysis (Sm.3), specific modal abundances from the large 10.5% vol. are: 25.7% alloys NiFe (kamacite/taenite), 32.5% troilite and 41.8% hydroxides.

2.1.1. Impact deformation

the structure of the El Pozo meteorite shows evident features of impact deformation characterized by an irregular network of fractures and veins which have fractured all the primary components. Olivine and orthopyroxene show undulate light extinction, planar and irregular secondary fractures. The appearance of the veins is dark brown and has been filled by troilite, but currently shows a partial or total weathering substitution composed by ferrous hydroxide and clays. We suggest an S2-S3 or very weakly shocked degree in terms of Stöffler et al. (1991).

2.1.2. Weathering

From the petrographical mapping (Fig. 1), it is observed that the weathering process on the sample has not been homogeneous. The main area (≤65%) is relatively well preserved and shows matrix and chondrules with relatively clear contours, opaque minerals and veins are not or are moderately altered. The remaining area (≥ 35%) is indeed irregularly distributed and is relatively subparallel to the fractures and the impact veins. In these areas, a moderate to complete oxidation of metal occurred and there are only relict structures of some primary components. On the scale of Wlotzka (1993), W2 and W3 levels could be considered respectively for the different weathering areas of the El

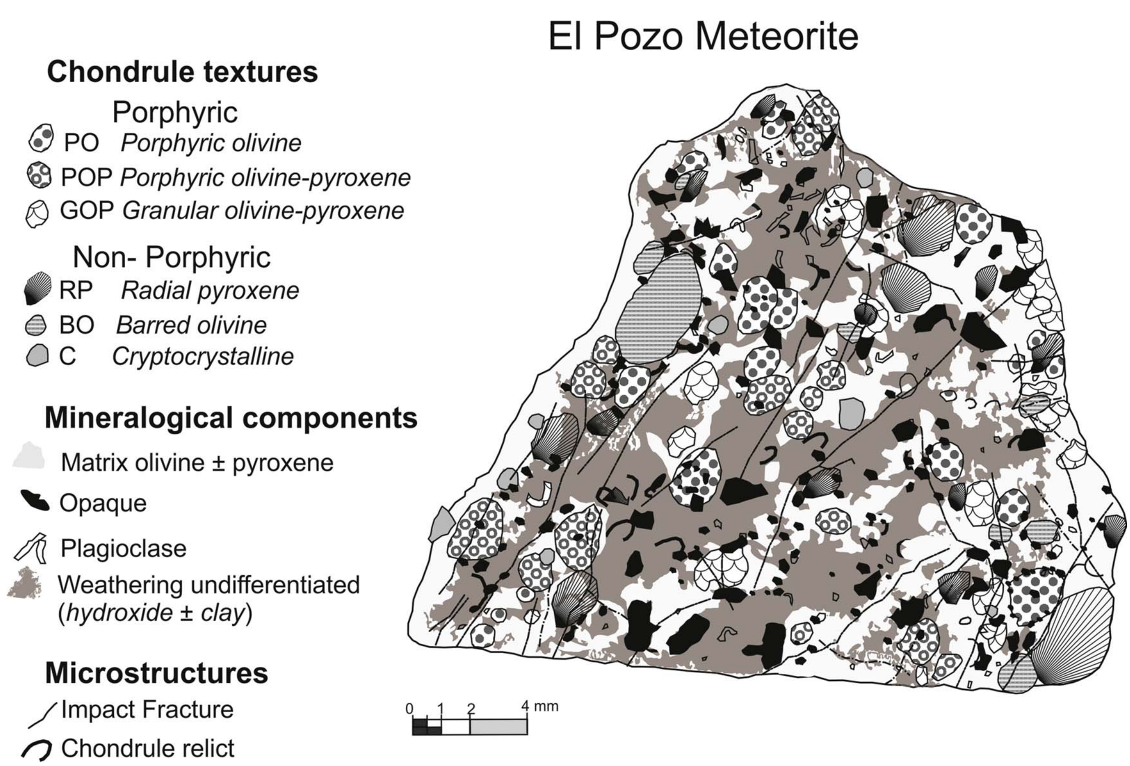

Fig. 1. Petrographical mapping of the El Pozo meteorite, showing the distribution and diversity of chondrules and other components.