

PETROLOGY AND GEOCHEMISTRY OF ERG CHECH 002, THE OLDEST ANDESITE IN THE SOLAR SYSTEM. A. Yamaguchi¹, J.A. Barrat², M. Chaussidon³, P. Beck⁴, J. Villeneuve⁵, D.J. Byrne⁵, M.W. Broadley⁵, B. Marty⁵, ¹National Institute of Polar Research, Tokyo, 190-8518, Japan (yamaguch@nipr.ac.jp), ²Univ Brest, Institut Universitaire Européen de la Mer (IUEM), UMR 6539, Place Nicolas, Copernic, F-29280 Plouzané, France, ³Université de Paris, Institut de physique du globe de Paris, CNRS, F-75005 Paris, ⁴Université Grenoble Alpes, CNRS, Institut de Planetologie et d'Astrophysique de Grenoble (IPAG), Saint-Martin d'Herès, France, ⁵Université de Lorraine, CNRS, CRPG, F-54000 Nancy, France.

Introduction: The nature of the early volcanism on planetesimals and protoplanets has not been well understood because of the scarcity of the samples available to our study. Melting of chondritic precursors would have produced silica-rich (andesitic) melts, as shown experimentally [1]. However, such andesitic meteorites (or clasts in breccias) are not common in the meteorite collection [2]. Here, we report the petrology and geochemistry of a recently-found andesitic meteorite, Erg Chech 002 (EC 002), focusing on its crystallization and thermal history. EC 002 is, to date, the oldest differentiated achondrite with a Al-Mg crystallization age of 4565.0 Myr [3]. Thus, the study of EC 002 provides us with the unique opportunity to study the nature of the earliest volcanism in the Solar System.

Results and Discussion: We examined polished thick and thin sections (~1.5 cm² each) of EC 002 using an FE-SEM, an EPMA, and a Raman spectrometer. EC 002 is an unbrecciated greenish rock with a medium-grained groundmass (ca. 1-1.5 mm) with 8 vol% pores (Fig. 1). Its texture suggests a crystallization within a thick flow or in a shallow intrusion. It consists of 45 vol% of lath-shaped albitic plagioclases containing thin lamellae of K-feldspar, 38 vol% of anhedral pyroxene (ca. 0.6 x 3.7 mm), 5 vol% interstitial silica minerals (cristobalite and tridymite (PO), with no quartz), and minor spinel, ilmenite, Ca-phosphate, troilite and FeNi metal. The samples we have examined are rather fresh, with only a few rust patches produced by the alteration of troilite and metal, and some carbonate fillings in the fractures, which are typical of Saharan finds. Pyroxenes are partly equilibrated and consist of relict augite with fine, closely spaced (~1 μm thick) exsolution lamellae of low-Ca pyroxene, or relict low-Ca pyroxene with fine exsolution lamellae of augite. In addition, EC 002 also contains angular to rounded pyroxene or olivine xenocrysts, irregularly dispersed in the groundmass (Fig. 1), and reaching several centimeters (<9 cm, [4]). EC 002 is slightly shocked. Plagioclase and pyroxene show only moderate mottled extinction. Some plagioclase grains have fine polysynthetic twinning. Fractures in these minerals are not prominent. The shock stage is M-S2 [5].

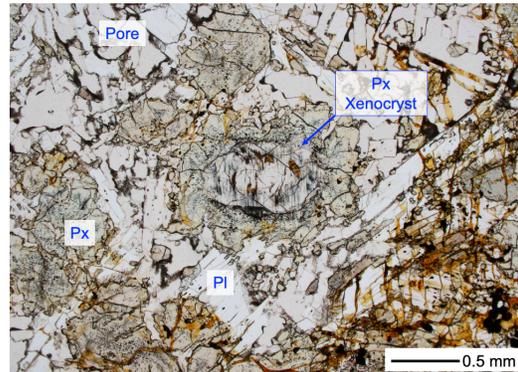


Fig. 1. Photomicrograph of EC 002. Note the pyroxene xenocryst in the groundmass in the center. Px: pyroxene; Pl: plagioclase

Pyroxene compositions are presented in Fig. 2. Bulk groundmass pyroxene compositions are generally augitic ($Wo_{27.7-33.0}En_{36.9-38.5}$). Some crystals exhibit remnant zoning from core to rim ($Wo_{22.9}En_{39.4}$ to $Wo_{35.2}En_{36.3}$). The crystals are partly equilibrated and are a mixture of augite ($Wo_{38.7-40.9}En_{39.5-41.5}$) and fine exsolutions of low-Ca pyroxene ($Wo_{2.4-4.3}En_{47.1-49.4}$). Plagioclase are albitic ($Or_{2.0-7.1}Ab_{75.8-87.4}$) and contains lamellae of K-rich feldspar ($Or_{84.0-84.4}Ab_{11.3-11.6}$). Groundmass spinel compositions are $Usp_{18.2-56.5}Sp_{2.6-6.2}$ and $Mg\# = 3.51-5.83$. Silica phases contain detectable amounts of Al, Fe, Ca and alkalis.

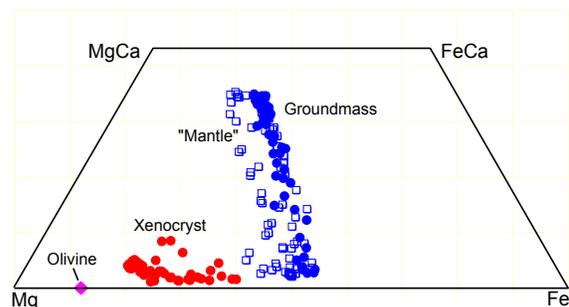


Fig. 2. Pyroxene and olivine megacryst compositions. Groundmass pyroxenes are low-Ca pyroxene and augite. The intermediate Wo contents are due to incomplete spatial resolutions of electron microprobe.

We determined bulk compositions of a 1 g sample devoid of apparent xenocrystals, representative of the groundmass, and therefore very close to the melt from which EC 002 crystallized. With 58 wt% SiO₂ and 4.54 wt% of Na₂O+K₂O, it is andesitic using the IUGS criteria (Fig. 3). EC 002 is quite rich in MgO and FeO. Its CIPW norm shows some normative quartz (2.5 wt%), indicating a rock slightly oversaturated in SiO₂. EC 002 is very poor in P (216 µg/g), Ni (18.5 µg/g), Co (5.85 µg/g), Pb (90 ng/g), Ga (2.6 µg/g), and Zn (0.44 µg/g). EC 002 displays some excesses in Ba, Sr and U, which are usual for Saharan finds. Other incompatible trace element abundances (e.g., REE, Th) are low and of the order of 5 or 6 times the chondritic reference. The CI-normalized trace element pattern of EC 002 is rather flat with no noticeable anomaly, even for HFSE and alkalis. This rock is only slightly light REE depleted (La_n/Sm_n = 0.94) with a small positive Eu anomaly (Eu/Eu* = 1.05). Moreover, it displays the same Tm negative anomaly (Tm/Tm* = 0.973) as achondrites and inner Solar System planetary bodies (typically ≈ 0.975, [6]). The chemical composition of EC 002 is very different from that of other andesitic achondrites (Fig. 3). The smoothness of its trace element pattern, parallel to that of non-carbonaceous chondrites even for alkalis, also distinguishes it from the other known achondritic lavas.

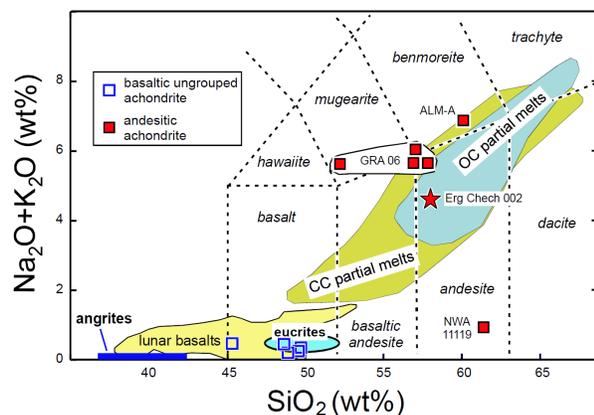


Fig. 3. Plot of total alkalis vs. silica content showing the compositions EC 002, the other achondritic lavas, and the experimental melts obtained by [1].

We estimated the thermal history of EC 002 from our petrologic and geochemical data. Experimental data allow a precise evaluation of the temperature at which the magma formed (Fig. 3). The MgO concentration of EC 002 compared with the experimental data [1], makes it possible to estimate the melting temperature at $1224 \pm 20^\circ\text{C}$. This high temperature is consistent with crystallization temperatures estimated from the bulk compositions of Ca-rich pyroxene [7] in the range of

1149-1229 °C (average = 1186 °C (SD = 25°C), slightly lower due to post-crystallization equilibration during cooling). The final equilibration temperature, about 957 °C, is estimated from the highest Ca in pyroxene. The cooling of the rock was fast enough to preserve remnant zoning in groundmass pyroxene and the compositions of the core of the small xenocrysts. Using the zoning profile of Mg# across the small xenocryst exposed in our sections, and the diffusion coefficient from [8], the cooling rate is estimated to be ~5°C/yr between 1200 and 1000°C, a value consistent with a thick lava flow or a shallow intrusion. Important additional constraints are brought by silica polymorphs. Only cristobalite and tridymite (PO) were detected in EC 002, and quartz is totally lacking. As experimentally shown for eucrites [9,10], cristobalite crystallized at high temperatures. Subsequently, it partially transformed to tridymite above ~900 °C. Since cristobalite easily transforms to quartz, the lack of quartz indicates a very fast cooling rate below 900 °C (>0.1-1 °C/day), consistent with the lack of monoclinic tridymite [10]. The most likely explanation for this change in cooling rate is an impact that would have excavated, or more likely ejected, the rock from its parent body, in agreement with the evidence for shock metamorphism. The cooling history of this meteorite, therefore, appears to be short, since it would have cooled for only a few decades before it was probably ejected. Assuming the diffusion coefficient of Mg in plagioclase, a spherical plagioclase 100 µm in diameter will reset the Al-Mg age at 1000°C for 0.4 year completely and for 0.1 years for significantly [11]. Thus, it is certain that the second cooling event record the Al-Mg age.

References: [1] Collinet M. and Grove T. (2020) *Geochim. Cosmochim. Acta* 214, 73-85. [2] Bischoff A. et al. (2014) *PNAS* 111, 12689-12692. [3] Chaussidon M. et al. (2021) *LPSC* 52, this volume. [4] Meteoritical bulletin database. [5] Stöffler D. et al. (2018) *Meteoritics & Planet. Sci.*, 53, 5-49. [6] Barrat J.A. et al. (2016) *Geochim. Cosmochim. Acta* 176, 1-17. [7] Nakamura Y. et al. (2017) *Meteoritics & Planet. Sci.*, 52, 511-521. [8] Ganguly J. and Tazzoli V. (1994) *Am. Mineral.* 79, 930-937. [9] Yamaguchi A. et al. (2013) *Earth Planet. Sci. Lett.* 368, 101-109. [10] Ono H. (2020) PhD. thesis, Univ. of Tokyo. [11] Van Orman J.A. et al. (2014) *Earth Planet. Sci. Lett.* 385, 79-88.