**The formation of early andesitic magmas triggered by hybrid accretion.** P.F. Zhang[1], Z.L. Jin[1*], M. Wiedenbeck[2], S. Glynn[3], F. Coufignal[2]. [1]State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Macao, China. [2]GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam 14473, Germany. [3]School of Geosciences, University of the Witwatersrand, PVT Bag 3, Wits, Johannesburg 2050, South Africa*zljin@must.edu.mo

**Introduction:** Several recently discovered ancient trachyandesitic or andesitic achondrites, i.e., Graves Nunatakes 06128 and 06129, ALM-A, and NWA 11119, have revealed a potentially widespread existence of intermediate crust at the early stage of planetary growth [1-3]. In contrast to the terrestrial andesites that formed in tectonically active regions and via long-term magmatic evolution, these extraterrestrial andesitic rocks commonly formed within the first few million years after the formation of CAIs. Questions regarding the petrogenesis and scarceness of these ancient extraterrestrial andesites have been raised and remain debated.

Recently, the andesitic achondrite Erg Chech 002 (EC 002) has been shown to be the oldest fragment of an igneous crust [4]. Distinct from the previously reported (trachy)andesitic meteorites, EC002 is composed of andesitic groundmass and disequilibrium orthopyroxene (Opx) xenocrysts (Fig. 1). Currently, the parent body of EC002 and its evolutional history are still unclear to us. Although several isotope systematics have been employed to constrain the age of EC002 meteorite [4-7], no consistency has been reached.

To better understand the genesis of early andesitic rocks and resolve the intriguing chronological issue, we conducted detailed chemical and isotopic analysis on the minerals in EC002 meteorites. Our results uncover a distinct evolutional story of its parent body.

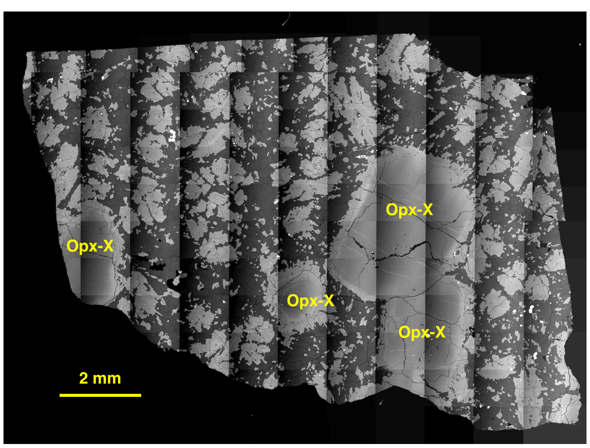


*Fig. 1 Overview SEM image of the studied EC002 fragment. Opx-X denotes the Opx xenocrysts.*

**Sample:** Our EC002 chip contains several large euhedral Opx xenocrysts (22 vol%), medium-grained groundmass (77 vol%), and pores (<1 vol%, Fig.1). The mineralogy of the groundmass is similar to the previously reported ones, which consists of lath-shaped plagioclase, anhedral clinopyroxene (Cpx), Opx, silica phases, and chromites. Fine-grained rims surrounding the Opx xenocrysts have been recognized, which are composed of thin exsolution lamellae of Opx and clinopyroxene (Cpx) minerals. In addition, we identify three generations of chromites. The first-generation chromites are micron-sized grains hosted in the Opx xenocryst. The second-and third-generation ones occur in the groundmass, where the second-generation chromites surround the grain of the xenocrysts, and the third-generation minerals formed interstitial to the groundmass minerals.

The sample was first observed under the scanning electron microscope (SEM). Then the chemical compositions of representative minerals were obtained by wavelength-dispersive X-ray spectrometry (WDX) at Macau University of Science and Technology. *In-situ* oxygen isotopic ratios of 30 Opx and Cpx grains including xenocrysts and minerals in the rims and groundmass were obtained by Cameca IMS 1280HR at GeoForschung Zentrum, Potsdam, Germany.

**Analytical results:** The chemical compositions of the pyroxene and plagioclase minerals are similar to the previously reported ones. Here we specifically report the chemical compositions of the chromite minerals and *in-situ* oxygen isotope of pyroxene mineral.

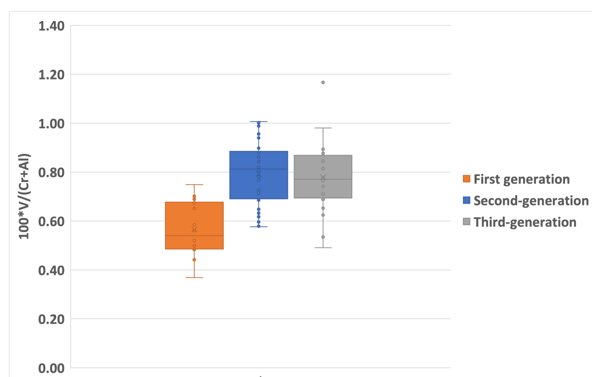


*Fig. 2 Box plots of 100*V/(Cr+Al) of three generations of chromites*

*Chemical compositions of chromites*. The first-generation chromites hosted in the Opx xenocryst contain the highest $Cr_2O_3$ contents of 58.85–63.85 wt.%. The average $Cr_2O_3$ components in the second- and third-generation chromites are 50.70 wt.% and

42.24 wt.% respectively. The Cr# [atomic 100*Cr/(Cr+Al)] of all generations of chromites are indistinguishly scattered in a range of 78–95, whereas the Fe# [atomic 100*Fe/(Fe+Mg)] values of the first-generation chromite (77 on average) are lower than those of the second- (90 on average) and third-generations (96 on average). 100*V/(Cr+Al) ratios (0.49–1.17) of the late two generations are identical and both higher than those of the first-generation ones (0.37–0.75) (Fig. 2).

*In-situ oxygen isotopic signatures.* $\delta^{18}O$ and $\delta^{17}O$ values of Opx xenocrysts and pyroxene minerals in rims and groundmass were obtained by normalizing their $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios to that of Standard Mean Ocean Water. The Opx xenocrysts have the heaviest oxygen signatures ($\delta^{18}O$ = 2.79–3.66 ‰). $\delta^{18}O$ values of the pyroxene minerals (Opx+Cpx) from the rims around the xenocrysts and groundmass ($\delta^{18}O$ = 1.79–3.02 ‰) are lower than those of the Opx xenocrysts. The $\Delta^{17}O$ [$1000*\ln(1+\delta^{17}O/1000)-0.5247*1000*\ln(1+\delta^{18}O/1000)$] values of all types of minerals are indistinguishable within errors (Fig. 3).

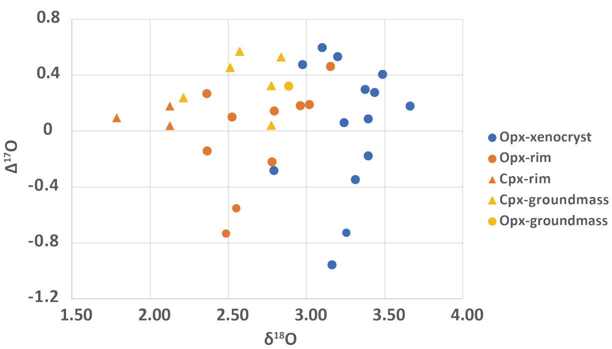


*Fig. 3 $\Delta^{17}O$ vs. $\delta^{18}O$ plots of pyroxene minerals*

**Discussion:** V/(Cr+Al) atomic ratio of chromite mineral can act as an indicator of the redox of the magma [9]. As shown in Fig.2, chromites captured in the Opx xenocryst have lower V/(Cr+Al) ratios, indicating that the primary magma where the xenocrysts crystallized were more oxidized than the groundmass magma. Besides, the normalized $\delta^{18}O$ values of the xenocrysts are ~0.5‰ higher than those of the groundmass pyroxenes. After considering the different temperatures of crystallization, we estimate that the $\delta^{18}O$ of the primary magma of the xenocrysts was ~0.3‰ higher than the groundmass magma. Generally, in a common parent body, a more evolved magma should have exhibited heavier $^{18}O$ signatures, as the mafic minerals such as olivine and pyroxene tend to contain more $^{16}O$ atoms [9]. Thus, compared to the magma source of the Opx xenocryst, the source of the groundmass magma should have been modified. Given the growing history of the parent body, we speculate that the modification of the magma source was caused by accreting external materials that were more reduced and $^{18}O$ depleted. Accordingly, a likely candidate for these materials is the CR group materials.

One of the previous studies [4] proposed that the primary magma of the andesitic groundmass could be derived by 15-25 % partial melting of OC materials. However, our in-situ oxygen isotopes indicate a distinct inner solar system source from the OC parent bodies. Besides, the addition of CR materials can also bring sufficient volatiles, e.g., $H_2O$ to the original parent body. The addition of the volatiles could have lowered the liquidus of the primary materials and led to the generation of andesitic magmas, similar to the common cases on our Earth [e.g., 10]. More importantly, the incorporation of CR materials to an inner solar system parent body represents a mixing process of materials from the inner and outer regions of the solar system, which therefore accounts for the distinct reflectance spectrum of the EC002 meteorite.

Another implication we get lies in the chronological study. Based on our results, we emphasize that utilizing the bulk isotopic systematics to date EC002 meteorite is inappropriate, as the xenocrysts and groundmass are from distinct sources. Besides, one has to be careful when dating using the groundmass materials, because the source of groundmass was hybrid materials from both the inner and outer regions of the early solar system.

Last, we briefly summarize the peculiar evolutional history of the EC002 parent body. Prior to the derivation of the andesitic magma, basaltic magmas where opx mineral cumulates were developed should have been generated. As the parent body grew, volatile-rich materials have been accreted and partially altered the parent body. Subsequently, andesitic magmas were formed via the partial melting of these altered materials. In this process, previous mineral cumulates (e.g., Opx) were captured and preserved in the EC002 rocks.

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**References:** [1] Day, et al. (2009) *Nature* 457, 179–182 (2009). [2] Bischoff et al. (2014) *PNAS* 111, 12689–12692 (2014). [3] Srinivasan et al. (2018) *Nat Commun* 9, 3036 (2018). [4] Barrat et al. (2021) *PNAS*, 118. [5] Zhu et al. [2022] *MNRASL* 515, L39–L44. [6] Fang et al. (2022) PNAS 119. [7] Anand et al. (2022) *MPS* 57, 2003–2016. [8] Papike et al. (2004) *AM*, 89 1557–1560. [9] Bindemann (2008) *RiMG,* 69, 445-478. [10] Campbell & Taylor (1983) *GRL* 10, 1061–1064.