MULTI-STAGE DIFFERENTIATION HISTORY OF ANDESITIC ACHONDRITE ERG CHECH 002

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Introduction: The majority of achondrites in current collections are either close to chondritic or basaltic in nature, and Si-rich evolved achondrites are rare. With the discovery of the paired andesitic achondrites Graves Nunataks (GRA) 06128 and GRA 06129, the paradigm of dominantly basaltic magmatism on asteroids has shifted [1], revealing the role of partial melting processes that could produce these compositions [2-4]. Subsequently, materials such as those with trachyandesite compositions in Almahata Sitta [5], as well as in Northwest Africa (NWA) 11119 [6] have been recognized, illustrating the likelihood of widespread felsic volcanism on asteroids. Unlike felsic igneous rocks on Earth, which are typically the result of melting of mafic rocks, all of the known felsic achondrite meteorites are thought to be the result of low-degree melting of chondrite-like precursor lithologies [1-6], with no intermediate formation of a mafic precursor.

In May 2020, a large strewn field of an unusual meteorite was discovered in the Erg Chech region of southern Algeria. The meteorite that formed the strewn field, designated Erg Chech 002, totaled ~31 kg in mass. Pieces of Erg Chech 002 have since been sold to private collectors and commercial meteorite dealers. Here we present the first extensive geochemical characterization of Erg Chech 002, showing that it is a new felsic achondrite, with a distinct petrogenesis from previous andesite achondrites.

Methods: A 1.687 g slice of Erg Chech 002 was obtained by one of us (KGG-V) from Michael Farmer. Approximately 2/3^{rds} of the slice was broken off and powdered for whole-rock analyses. The remaining fragments were made into a polished thin section (**Fig. 1**). Element maps of this section as well as spot analyses were done using the electron microprobe at the University of Nevada, Las Vegas, while trace element analyses of major phases will be performed at the *Scripps Isotope Geochemistry Laboratory* (*SIGL*) by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Bulk major and trace element analyses were performed by ICP-MS at the *SIGL*. Highly siderophile element (HSE; Re, Pd, Pt, Ru, Ir, Os) abundances and Os isotopic systematics were performed by isotope dilution TIMS and ICP-MS with Carius tube digestion at the *SIGL* using established methods [7].

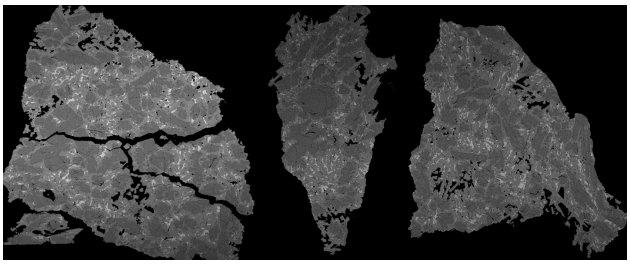

Figure 1: *Semi-quantitative Si map of the Erg Chech 002 thin section, showing dark grey pyroxenes, light grey plagioclase, bright Si phase,, and black oxide, sulfide and metal grains. Grains are ~1.5 cm in greatest dimension.*

Results: Erg Chech 002 consists of ~62 modal % large (>1 mm) acicular to blocky zoned pyroxene crystals with homogeneous augite cores (average $En_{39}Fs_{29}Wo_{32}$), in addition to two large enstatite grains ($En_{60}Fs_{37}Wo_3$) in the thin-section studied. These are set in a groundmass of sodic plagioclase (33 modal %; ~$Ab_{85}An_{11}Or_4$) and a high Si phase (5 modal %; ~94% SiO_2), with accessory chromite, ilmenite, iron metal and sulfide (**Fig. 1**). The bulk sample can be classified as andesitic in composition with 60 wt.% SiO_2, 4.6 wt.% Na_2O+K_2O, 11.3 wt.% FeO, 9.3 wt.% Al_2O_3, 8.2 wt% CaO and a high Cr content (3980 ppm). Erg Chech 002 is relatively depleted in light rare earth elements (REE), has a more modest positive Eu anomaly (1.24) and flat heavy REE pattern when compared with other 'andesitic' achondrites (**Fig. 2**).

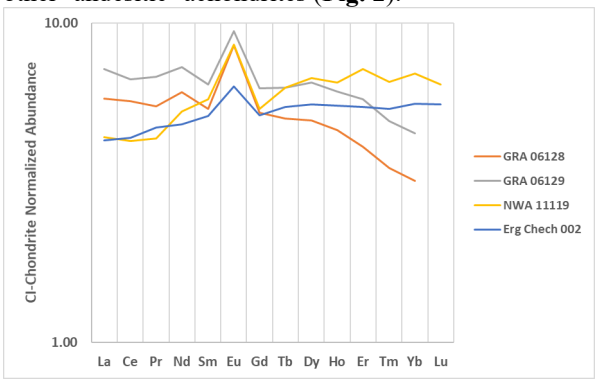

Figure 2: *Chondrite normalized REE abundances of Si-rich achondrites and new meteorite Erg Chech 002. Note the greater Eu anomalies in other felsic meteorites compared to Erg Chech 002. Additional data from [1] and [6].*

The HSE abundances of bulk Erg Chech 002 are remarkable relative to other andesite achondrites analyzed to date, showing very low abundances similar to the estimated terrestrial upper continental crust composition (**Fig. 3**). In particular, Erg Chech 002 exhibits strong fractionations within and between the incompatible HSE (Re, Pt and Pd) and the compatible HSE (Os, Ir and Ru). The sample has a super-chondritic measured $^{187}Os/^{188}Os$ ratio of 0.1502 ± 0.0018. Prior work has demonstrated Erg Chech 002 to have relatively low $\delta^{18}O$ (3.5 ±0.4‰), with $\Delta^{17}O$ (-0.126 ±0.025‰; n = 7, 2 St. Dev [7]) similar to howardite-eucrite-diogenite (HED) meteorites. The oxygen isotope composition indicates that it is highly unlikely for Erg Chech 002 to have derived from a known large planetary body (Earth, Mars, Moon), and instead has an asteroidal heritage.

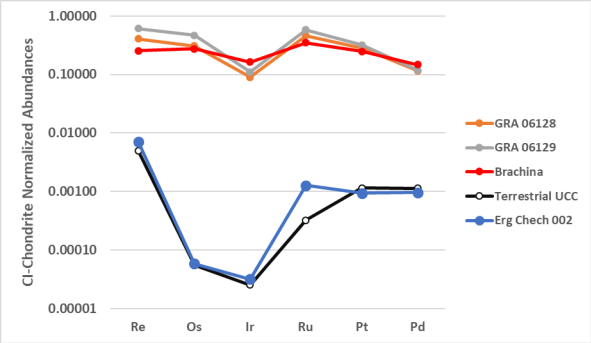

Figure 3: *Chondrite normalized HSE abundances of achondrites and UCC. Data from [1] and [8].*

Discussion: Erg Chech 002 joins GRA 06128/9, NWA 11119 and components in other achondrites as felsic material from an asteroidal body. However, Erg Chech 002 does not appear to share a parent body with any of these prior felsic achondrites based on O isotopes. Using the terrestrial classification system, Erg Chech 002 is classified as a high-Mg andesite, distinct from other evolved achondrites, which are trachyandesites and andesites. Another unusual aspect of Erg Chech 002 is its strongly depleted Al_2O_3 composition relative to other evolved achondrites, which is also reflected in its lower proportion of feldspar. Unlike GRA 06128/9, Erg Chech 002 contains silica as a major phase, and lacks any olivine. The REE pattern (**Fig. 3**) also shows a smaller positive Eu anomaly than the other andesitic meteorites, indicating that it inherited only a small proportion of plagioclase. The LREE depletion over HREE is shared with NWA 11119, indicating either fractionation of a LREE-rich phase, such as apatite or a previously depleted protolith.

The mineralogy of Erg Chech 002 is dominated by pyroxene, which is similar in composition to that found in GRA06128/9 but is notably more Fe-rich than the augite in NWA 11119. Plagioclase is very Na-rich similar to those in GRA06128/9 but distinct from NWA 11119 plagioclase. The presence of metal grains indicates a low oxygen fugacity close to the iron-wüstite (IW) buffer. Perhaps most notable is the presence of two large pyroxene grains showing zoning from enstatite ($En_{60}Fs_{37}Wo_3$) to augite ($En_{37}Fs_{28}Wo_{36}$) similar in composition to non-zoned pyroxenes. These two grains are possibly xenocrysts or antecrysts, that were subsequently rimmed by equilibrium pyroxene compositions. Aside from these two grains, pyroxene compositions are uniform, indicating that Erg Chech 002 likely represents close to an *in situ* crystallized melt and not a cumulate, as indicated by its modest Eu anomaly.

The low and non-chondritic HSE pattern **(Fig. 3**) is remarkable, not only for being similar to that of the terrestrial upper continental crust, but the implications for the process of Erg Chech 002's formation. Meteorites GRA 06128/9 have relatively high HSE contents consistent with partial melting of a chondritic precursor. In contrast, Erg Chech 002 requires a two stage melting process of initial silicate differentiation and metal-silicate equilibrium followed by re-melting of the crust. Such processes are known to have occurred in some strongly differentiated planetesimals, such as Vesta, restricting the number of likely parent bodies. Erg Chech 002 therefore indicates that secondary melting processes can act on small planetesimals, suggesting felsic volcanism exists on all rocky bodies for which there are samples (Earth, Moon, Mars, asteroids). Although Erg Chech 002 has not yet been dated, it is likely ancient (> 4 Ga), similar to other achondrites. The only chronological information currently available is that, assuming a chondritic initial composition, the Re-Os isotope systematics of the bulk sample suggests recent disturbance (~30 Ma).

If Erg Chech 002 is indeed related to the HED, it could represent re-melting of basaltic precursors. Vesta, the parental asteroid to the HED, segregated a metal core, explaining the low HSE abundances and oxygen fugacity required to explain the composition of Erg Chech 002. Further petrological and isotopic constraints are forthcoming.

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References: [1] Day J. M. D. et al. (2009) *Nature, 457,* 179-182 [2] Gardner-Vandy, K.G. et al. (2013) *GCA* 122, 36-57; [3] Usui, T. et al. (2015) *MaPS* 50, 759-781; [4] Collinet, M., Grove, T.L. (2020) *GCA* 277, 334-357; [5] Bischoff, A. et al. (2014) PNAS, 111, 12689-12692; [6] Srinivasan P. et al. (2018) *Nat Comm, 9,* 3036 [7] *Met. Bull., 109* (2020); [8] Peucker-Ehrenbrink B. and Jahn B. (2001) *G³, 2*, 1525-2027