EARLY BASALTIC VOLCANISM AND LATE HEAVY BOMBARDMENT ON VESTA: U-Pb AGES OF SMALL ZIRCONS AND PHOSPHATES IN EUCRITES.

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Introduction: There are very few published studies on meteoritic U-Pb chronology of zircons [e.g., 1,2,3], plus a few more unpublished conference abstracts over the last two decades. Part of the reason is that zircons found in meteorites are typically small and far too rare compared to terrestrial rocks. Such constraint has limited previous studies to a few fortunate cases of large zircon grains available for detailed investigation. The full potential to apply the conventional U-Pb and Pb-Pb chronometry to U-rich minerals to constrain the crystallization ages of the earliest stages of the Solar System magmatism as well as late impact events and thermal metamorphism on the parent body of meteorites is yet to be unleashed. We have developed a technique using Cameca IMS-1280 ion microprobe to date zircon grains <5 micron (see Fig. 1), as well as apatite grains.

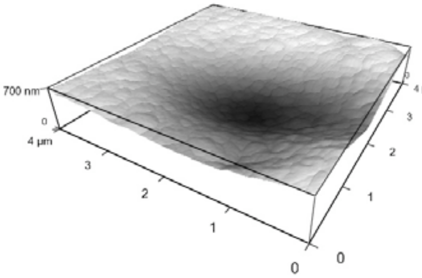

Fig. 1. Atomic Force Microscopy of a eucrite zircon grain (ion probe spot of ~2 µm size and ~500 nm deep is shown).

Experiment: In-situ isotopic analysis of U-Pb was performed on a large radius magnetic sector multi-collector Cameca IMS-1280 ion microprobe at the Institute of Geology and Geophysics, Chinese Academy of Sciences in Beijing. The procedures for Pb isotopic analysis of small zircons are described in Zhou et al. [4] and references therein. The experimental procedure for apatite followed that of Sano et al. [5]. NW-1 apatite (1160Ma) was used as a standard, which comes from the same complex of Prairie Lake as that of Sano et al. apatite standard (PRAP).

Results: The results for zircon in Cachari and Béréba are illustrated in Fig. 2 and 3 with conventional concordia diagram, and the apatite in Béréba is also presented in Fig. 4. Three data point for Cachari zircon plot on the concordia (Fig. 2) and five data point for Béréba zircon are slight discordance (Fig. 3). Three data point for apatite in Béréba also give a concordia age (Fig. 4). There was no significant Pb-loss from the zircons and apatite at non-zero time.

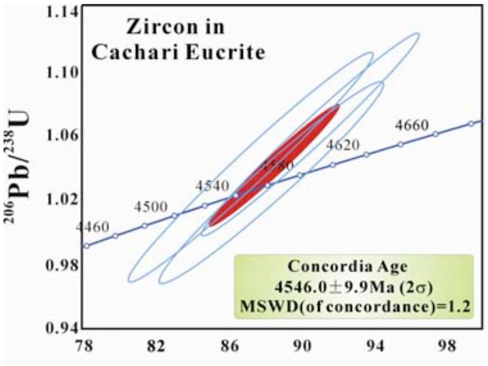

Fig. 2. U-Pb concordia age of 4546.0±9.9 Ma is determined in Cachari zircon (4x5 μm^2). A weighted average of $^{207}Pb/^{206}Pb$ age is 4549±13 Ma [4].

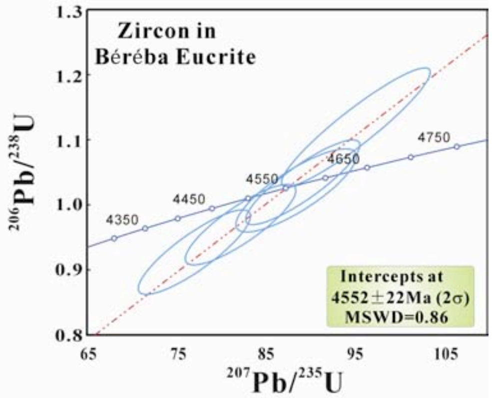

Fig. 3. U-Pb concordia diagram for zircon in Béréba eucrite. The chord intercepts the concordia at 4552 ± 22 Ma.

Discussion: The first goal of our studies is to refine the peak of basaltic volcanism on Vesta. The target materials we chose to work on are those tiny zircon grains found in eucrites. Eucrites, a subgroup of basaltic achondrites, represent the remnants of the earliest magmatic stage of the Solar System formation, possibly on the asteroid 4 Vesta. The age of the igneous event that generated basaltic eucrite is of primary importance, since this information can be used to constrain the evolutionary history, including melting and differentiation processes of the parent body. Consistent with the unique property of zircon known to be resistant to resetting of U-Pb isotopic systematics at high temperatures, we conclude that the Cachari and Béréba eucrite zircons from our result record peak basaltic volcanism at ~4550Ma on Vesta.

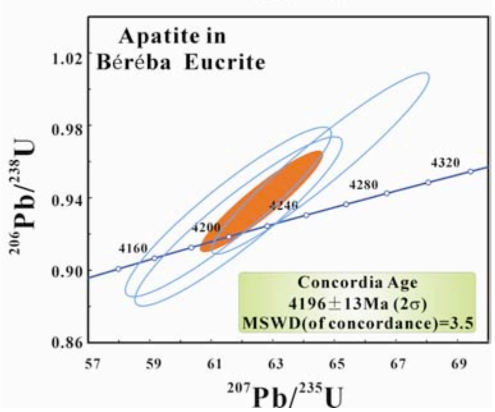

Fig. 4. U-Pb concordia age of 4196±13 Ma is determined inBéréba apatite (10x20 μm^2).

A second goal of the project is to investigate if the Late Heavy Bombardment (LHB) at ~3.9 Ga uncovered from the Apollo lunar sample returns [6] is representing a solar system wide LHB. Our approach is to establish and extend such record on Vesta. It is unlikely that LHB would be limited to the Moon only. On Earth, the active plate tectonic and recycling engine effectively erased all the Hadean rock records older than 3.9 Ga, thus it is very difficult to establish the LHB events on our home planet, although the Earth has a much larger geometrical cross section than the Moon to intercept the late stage of planetesimal accretion. We thus resort to meteoritic records for additional evidence in the other part of the Solar System. If the impact melt zircon or secondary phosphate minerals in eucrites reveal a ~3.9-4.1 Ga event, we may build an increasingly strong case that the LHB affected asteroid belts, thus enabling isotopic age constraints linked to solar system dynamics, such as angular momentum transfer associated with moving outer giant planets orbit resulting in influx of minor bodies such as comet and asteroid inward [7], which were the ultimate source of LHB projectile materials. Compilation of impact ages of howardites-eucrites-diogenites (HEDs) shows a clear peak at around 4.1 Ga (Fig. 5) on Vesta. It suggests that a large-scale LHB also exists on the HED parent bodied during the same time period. The apatite age from Béréba eucrite may represent the beginning of the LHB on asteroid belts. The Bererba apatite age is in line with evidence suggesting the LHB possibly started near 4.1 Ga. For example, Ar-Ar shock degassing ages of H chondrites, eucrites, and ureilites are limited between 4.1-4.4 Ga but are common between 3.3-4.1 Ga [9,11]. The impact events could provide heat source for the metamorphism to form secondary phosphates in Béréba. This age is also within the range of cataclysmic bombardment on the Moon (3.7-4.1 Ga) [7,8]. Similarly strong LHB case for Mars is shown in Fig. 6. The new age of Martian meteorite AL84001 is 4.1 Ga [12], and this time also represents when the shergottites had their source region disturbed [13]. Finally, Bottke et al., at this meeting, shows off a new model of the LHB that indicates most Nectarian and Imbrian-era basins formed on the Moon between 3.7-4.1 Ga [14].

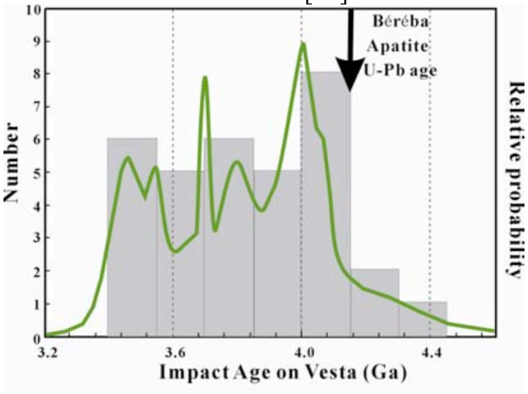

Fig. 5. Compilation of impact ages in HED achondrties of Vesta origin [9]. Bérérba apatie age (4196±13 Ma) marks the beginning of LHB on Vesta.

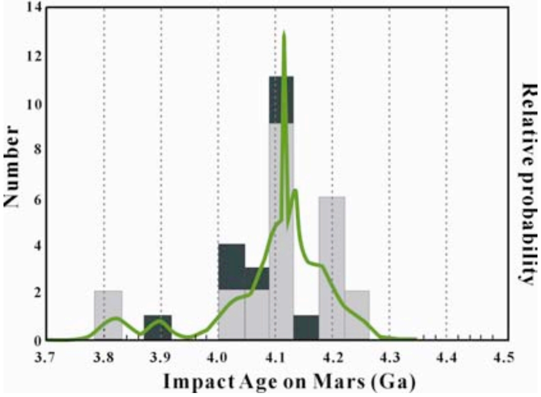

Fig. 6. Impact basin ages of Mars are shown in grey rectangular bars [10]. Black squares are ALH 84001 ages [12]. Consistent with Béréba apatite age of 4196±13 Ma, the 4.2Ga peak on Mars is very pronounced.

References: [1] Ireland T. R. and Wlotzka F. (1992) *EPSL*, 109, 1-10. [2] Ireland T. R. and Bukovanska M. (2003) *GCA*, 67, 4849-4856. [3] Misawa K. et al. (2003) *GCA*, 69, 5847-5861. [4] Zhou Q. et al. *GCA* submitted. [5] Sano Y.J. et al. (1999) *Chem. Geol.* 153, 249-258. [6] Tera F. et al. (1974) *EPSL*, 22, 1-21. [7] Gomes R.et al. (2005) *Nature*, 435, 466-469. [8] Norman M.D. et al. (2006) *GCA*, 70, 6032-6049. [9] Bogard D. (1995) *Meteorit.*, 30, 244-268. [10] Frey H. (2008) *GRL*, 35, L13203. [11] Swindle et al. (2009) MAPS 44, 747. [12] Lapen T. J. et al. (2010) *Science,* 328, 347-351. [13] Bouvier et al. (2008) EPSL 266 105. [14] Bottke et al. this meeting.