A novel application of (U-Th)/He geochronology to constrain the age of small, young meteorite impact craters: A case study of the Monturaqui crater, Chile.

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Introduction: Small and young impact structures have been commonly dated by methods such as thermoluminescence, ^{14}C, short-lived extinct radionucleide and cosmogenic techniques. However, (U-Th)/He dating is a low temperature radiometric technique that could potentially bridge the gap between the previously mentioned methods and common geochronological techniques employed on larger impact structures (e.g., U-Pb, Rb-Sr, K-Ar and Ar-Ar) to yield precise impact formation ages. Here we report (U-Th)/He apatite and zircon single crystal ages from the small and young Monturaqui impact structure. The very small size of this crater will act as an ultimate test for the applicability of the low temperature (U-Th)/He technique for dating very small, young impact structures.

Background: The Monturaqui impact crater is located at the southern end of Salar de Atacama in the precordillera of northern Chile (3015 m elevation, 23° 55' 39.28" S, 68° 15' 41.63" W). It is a well-preserved, small simple crater formed in Paleozoic basement granite (441 ± 8 Ma), which is cut by 1-2 m wide mafic dikes and overlain by a thin (~5 m) sheet of Pliocene Tucucaro ignimbrite (3.2 ± 0.3 Ma) [1]. The crater has a sub-circular morphology with preferential NW-SE elongation (370 m E-W, 350 m N-S, 34 m deep) and the crater rim elevation is 10-15 m higher on the southern edge compared to the northern rim [2]. Both granite and ignimbrite are exposed in the walls of the crater, but the rim crest is dominantly draped by an ignimbrite outcrop. It was first proposed as an impact by Sanchez and Cassidy [3], who noted the presence of iron shale, inferred to be altered fragments of the impactor, and impactite described as 'porous cindery aggregates containing fragments of granite and bonded with glass', preferentially deposited on the southern and southeastern crater flanks. The ignimbrite lobes preserve evidence of shock metamorphism at 10-65 GPa and heating to ~1300° C [4]. The impactor is postulated to be a coarse octahedrite of group I based on the composition of Fe-Ni spherules found in the impactite and structure of iron shale fragments [4, 5]. Mathematical modeling suggested an asteroid diameter of ~15 m with a velocity and impact angle of ~18 km/s and 41° [6].

Previous Geochronology of Monturaqui: The initial work on Monturaqui crater assigned an age of Pleistocene to recent based on the apparent disruption of the local Pleistocene drainage patterns [3]. Verdugo and Cartes [7] used thermoluminescence analysis of quartz grains extracted from an impactite to estimate an age of 590 ± 60 (2σ ?) ka. Exposure age dating was undertaken by Valenzuela et al. [8, 9] using terrestrial cosmogenic radionuclides on two suites of materials: quartz mineral separates from granite outcrops within the crater to obtain in situ ages of the crater, and measuring residual activities of iron shale samples to obtain exposure ages of the fragmented impactor. Exposure age data from the granite produced concordant results for ^{10}Be and yielded an age range of 200 to 250 ka, but this is likely to be a minimum age due to subsequent erosion of the crater walls. The iron shale produced a ^{36}Cl and ^{26}Al age of 500-600 ka. Paleomagnetic data from the granite within the crater shows remagnetization at 780 ka, which may be related to the impact [9]. On the basis of these studies, Valenzuela et al. proposed the age of the Monturaqui impact event to have occurred between 500-780 ka [8, 9].

U-Th/He Geochronology: We selected two samples of impactite from the Monturaqui crater, representing different lateral sampling areas from the ejected material. Sample CIUP08099 was from the southeastern flank of the crater, along the inferred impact trajectory, and CIUP08100 was from the crater rim directly to the south (Fig. 1). Impactite fragments ranged in size from 2 mm to 3 cm, and a suite totaling 785 g and 840 grams were selected for mineral separation for each sample, respectively. The samples were crushed, dry and wet sieved, and magnetic separation and heavy liquid separation was undertaken to produce apatite- and zircon-bearing separates.

Zircon and apatite grains were hand picked on the basis of their euhedral habit. ^{4}He was extracted from the single grains by infra-red diode laser heating and measured by an ASI Alphachron at the Noble Gas Geochemistry and Geochronology Laboratories (NG^{3}L) at ASU. The grains were then dissolved and U and Th was measured on a Thermo X-Series quadrupole ICP-MS in the ASU Keck Laboratory. Detailed analytical procedures are discussed in [10]

Results: A total of 10 zircons and 22 apatite grains were analyzed, 5 zircons from each sample and 8 and 14 apatites from CIUP08099 and CIUP08100, respectively. The analyses yielded a total of 10 successful zircon ages, and 12 successful apatite ages. The success rate on the apatite was low, because of undetected inclusions and extremely low He contents in many of the grains. The zircon (U-Th)/He ages range from 0.662 to 197.3 Ma and the apatite (U-Th)/He ages range from 0.616 to 61.5 Ma. These age ranges are illustrated in a probability plot (Fig. 3) showing probability density curves for zircon and apatite ages from both samples from 80 Ma to present.

This age range is interpreted to reflect a set of partially to completely reset (U-Th)/He ages, which yielded 2 reset apatite ages and 1 reset zircon age, which give a mean age of **663 ± 90 ka** (calculated using Isoplot 3.7 [11]). This age appears to fit quite well with the previous age range estimates for the Monturaqui impact crater.

Conclusions: The results of this study show that the (U-Th)/He dating method has the potential to yield accurate ages for even very small impact structures, like Monturaqui: **663 ± 90 ka**. However, many of the grains are only partially reset, requiring analysis of a larger number of grains than is usual to obtain an accurate impact age.

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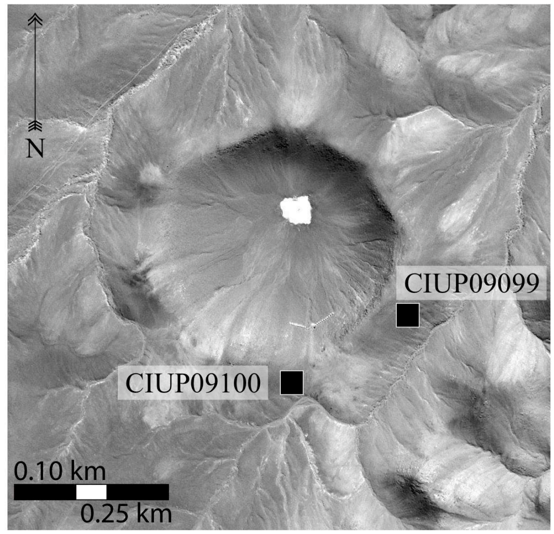

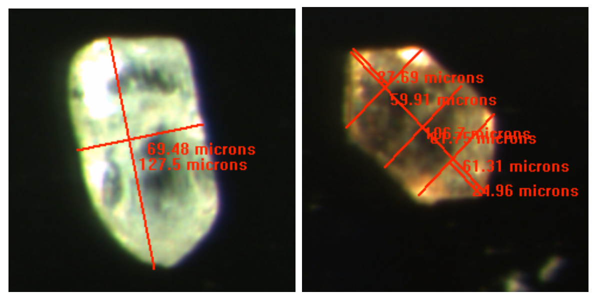

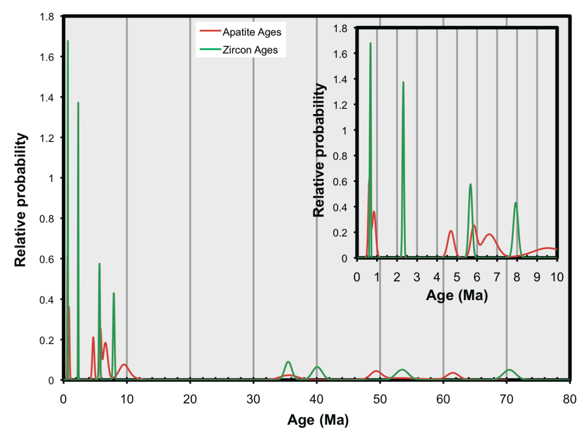

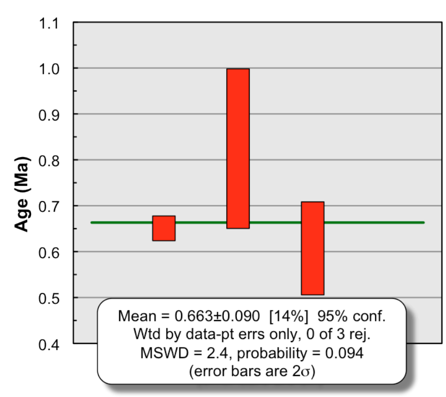

Fig. 1. Satellite image of Monturaqui with sample locations. Fig. 2: Photographs of two of the reset grains, apatite to the left and zircon to the right. Fig. 3: Relative probability curve plot for all (U-Th)/He apatite and zircon ages from both samples, cut off at 80 Ma to show detail. Fig. 4: The average (U-Th)/He age computed for all three reset grains.