FIRST $^{40}Ar/^{39}Ar$ AGE OF THE LONAR CRATER: A ~0.65 MA IMPACT EVENT?.

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Summary: We obtained a statistically robust global $^{40}Ar/^{39}Ar$ isochron age at 656 ± 81 ka (MSWD = 1.29; P =0.12) including 45 heating steps based on a combination of five concordant plateau/isochron ages from four samples. This age strongly contrasts with the previous age estimate at ~52 ka.

Fig. 1: Google Earth® satellite view of the Lonar crater.

Introduction: The Lonar crater is a 1.8-km diameter, Quaternary age crater (Fig.1) located on the ~65 Ma old Deccan basaltic traps, in Maharashtra, India [1]. This crater has been intensely studied over the last few years as it is one of the very few craters on Earth emplaced directly on basaltic lava-flows (~400 m thick at the impact site). As such, Lonar represents a good analogue for impacts occurring on terrestrial-like bodies covered with primitive igneous rocks, such as Mars or the moon. Here, we present the first detailed $^{40}Ar/^{39}Ar$ study of Lonar impact melt rock.

Previous Geochronology: The emplacement age proposed for the Lonar crater is currently 52 ± 6 ka, based on thermoluminescence analyses [2]. However, fission track, thermoluminescence, and radiocarbon dating yielded a wide range of dates ranging from ~15 to ~62 ka (see compilation and discussion in [3]), thus illustrating the complexity of the dating of the Lonar impact crater. For instance, radiocarbon dating of Lonar lake sediments yielded ages ranging from ~15 to 30 ka, but this range likely represents minimum ages due to carbon contamination [2]. More recent fission track data yielded a reset age at 15 ± 13 ka, most likely indicating the age of younger thermal event [3].

Very few of the well-constrained and reliable ages of any Earth impact structures is currently based on methods other than $^{40}Ar/^{39}Ar$ and U/Pb isotopic dating and in very few cases, relative stratigraphy [e.g. 4; 5]. Among these three approaches, only the $^{40}Ar/^{39}Ar$ method is applicable to the Lonar basaltic melt rocks as stratigraphic constraints are poor and no U-rich minerals are present. To test the proposed Lonar age at ~52 ka, we undertook $^{40}Ar/^{39}Ar$ analysis on several melt rock samples from the Lonar crater.

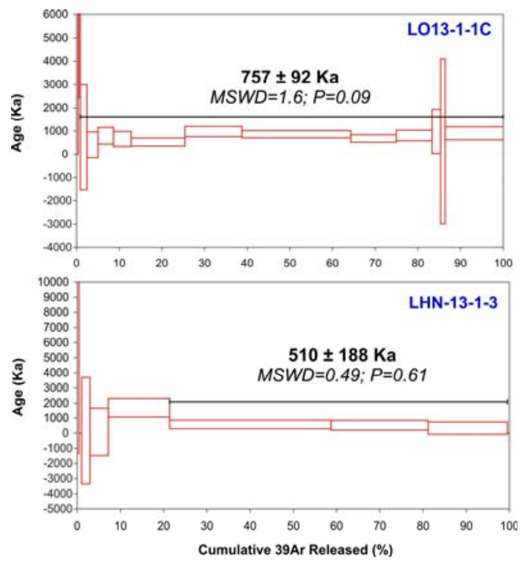

Fig. 2: Age spectra of a selected Lonar impact crater melt rocks.

$^{40}Ar/^{39}Ar$ Systematics: Four samples (LO-13-1-1, LO-13-1-3, LO-10-5 and LHN-05-65) were selected for $^{40}Ar/^{39}Ar$ analyses. ~50 mg of grains from each sample was carefully hand-picked using a stereomicroscope and step-heated using a resistance furnace. Sample LO-13-1-1 was run a second time using a Nd-YAG laser. Ar analyses were carried out at the Western Australian Argon Isotope Facility using a MAP 215-50 mass spectrometer. The five analyses yield four, unequally precise, plateau ages ranging from 510 ± 188 ka to 1035 ± 516 ka (Fig. 2) and five inverse isochrons with $^{40}Ar/^{36}Ar$ trapped ratios varying from 298 ± 6 to 310 ± 10. As all trapped ratios are within error of each other and because inherited $^{40}Ar^*$ can be present in impact melt rock and bias its age determination [6], we combined all the results in a single inverse isochron. We obtain a concordant inverse isochron age at 656 ± 81 ka (MSWD = 1.29; P =0.12) that included 45 steps, with a trapped $^{40}Ar/^{36}Ar$ ratio of 300 ± 3 and a reasonable spreading factor [5] of ~ 30% (Fig. 3).

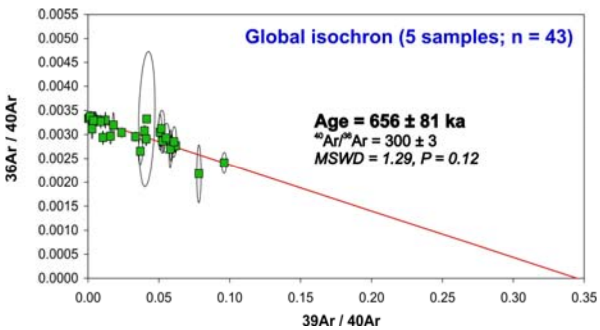

Fig. 3: Inverse isochron diagram of all five step-heating experiments (n=45 steps) combined in a single calculation. The age given by the isochron (green symbols and red line) is the proposed age of the Lonar impact .

The supra-atmospheric $^{40}Ar/^{36}Ar$ trapped ratio and the variance between the total fusion and isochron apparent ages indicate the presence of <<1% of inherited $^{40}Ar^*$ in the melt rock. The relative difference between the ages of the target rock and the impact event would make the apparent age of Lonar relatively sensitive to inherited $^{40}Ar^*$ [6]. However, the slight amount of inherited $^{40}Ar^*$ is homogenously distributed within the melt rock and thus, is fully accounted for in the isochron age calculation.

Due to its low viscosity and low degree of polymerization, a basaltic target rock is more prone to loose most of its inherited $^{40}Ar^*$ and more likely to have a more homogeneous distribution of the residual inherited $^{40}Ar^*$ [6]. This makes basaltic melt rocks relatively easy targets for $^{40}Ar/^{39}Ar$ geochronology.

Lonar crater: 52 or 656 ka? The discrepancy between the thermoluminescence age and the new isotopic $^{40}Ar/^{39}Ar$ age is flagrant. So which one is correct? Basaltic glasses have very low thermal retentivity for fission track and thermoluminescence dating. If one message is clear from the fission track results, it is that the Lonar melt rock has been perturbed by a late thermal event(s) that partially reset and erased fission tracks in the glass. The direct consequence is an apparent age younger than the impact age [3]. This thermal event is more than likely to have affected the electron charge traps used during thermoluminescence dating as well, and thus, to have produced a younger apparent age using the later method. ^{40}Ar is resistant to minor thermal event and, according to the flat shape of the step-heating age spectrum (i.e. it does not present a ^{40}Ar volume diffusion loss profile; Fig. 2), the $^{40}Ar/^{39}Ar$ systematics of the Lonar melt rocks have not been affected by any post-impact thermal event. On the other hand, examples such as tektites from the Tswaing Crater in Africa urge caution about dating very young impact craters with the $^{40}Ar/^{39}Ar$ technique due to the malicious effect of inherited $^{40}Ar^*$ [6]. However, in the Tswaing case, no valid isochron were obtained. This case differs from the Lonar data where several concordant isochrons have been obtained indicating that the distribution of inherited $^{40}Ar^*$ within the melt rock is homogenous at the multi-sample level. For these reasons, we tend to favor the isotopic age obtained in this study as the best estimate for the emplacement age of the Lonar crater (Fig. 3). Finally, an age significantly older than ~50 ka is compatible with a more degraded state of preservation of the Lonar crater compared to e.g., the ~50 ka Meteor crater [7].

Due to the significant discrepancy between the thermoluminescence and $^{40}Ar/^{39}Ar$ results, another batch of samples has been irradiated and is being readied for $^{40}Ar/^{39}Ar$ analysis. The new batch of analyses will be presented along with the present results. Future desirable developments will consist of analyzing spherules from the Lonar crater. The spherules are more likely to be entirely degassed from their inherited ^{40}Ar and $^{40}Ar/^{39}Ar$ investigation of these objects will present and interesting comparison with the melt rock data.

Conclusions: We propose a new impact age at 656 ± 81 ka for the Lonar crater. This age is based on $^{40}Ar/^{39}Ar$ analyses of several samples combined in a statistically robust global inverse isochron (MSWD = 1.29; P =0.12). This age is in accordance with the preservation state of the crater.

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