

THE VIABILITY OF APATITE AS AN IMPACT CHRONOMETER: THE MANICOUAGAN IMPACT STRUCTURE AS A CHRONOLOGIC STANDARD. M. McGregor^{1,2}, C. R. M. McFarlane² and J. G. Spray^{1,2},

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Introduction: Precise and accurate ages are critical for improving the impact record on Earth and other heavily cratered planetary bodies, such as the Mercury, Mars and Mars. Of the ~200 known impact craters on Earth [1], <10% (~21) have accurate and precise ages (e.g., Sudbury, Manicouagan and Vredefort). Unfortunately, only a limited number of craters on Earth remain well preserved, well exposed and unaffected by post-impact tectonics. For example, the ~85 km rim diameter Manicouagan impact structure of Quebec, Canada, is one of most intact, well-exposed and undeformed craters on Earth [3]. The extensive sample collections available from drill cores, and the well constrained impact age of Manicouagan offers the unique potential to develop and test dating techniques on a variety of impactites and radiogenic minerals.

Here we use in situ LA-ICP-MS U-Pb geochronology on co-existing zircons and apatite from various depths within the impact melt sheet (up to 1.4 km thick) to test the viability of apatite as a new impact chronometer for accurately resolving impact ages.

Geologic Background and Previous Ages: The Manicouagan impact structure, located in Québec, Canada, is situated within the eastern Grenville Province of the Canadian Shield. With a rim-to-rim diameter of ~85 km, the Manicouagan impact structure is the sixth largest, and best preserved of the exposed impact craters on Earth [1] and the second known to have a differentiated impact melt sheet [2]. The target is composed of crystalline metamorphic and igneous rocks of the ~1 Ga Precambrian Grenville Province. This was overlain by Ordovician carbonates at the time of impact, which in turn would have locally draped the Mesoproterozoic Manicouagan Imbricate Zone (MIZ), the Hart Juane Terrane, and the underlying Archean Gagnon Terrane [3]. Various geochronologic studies on Manicouagan have been undertaken over the past 50 years, including fission track dating, K-Ar, Rb-Sr, (U-Th)/He, U-Pb and Ar-Ar (e.g., [4]). All isotopic systems used provide similar impact ages, and as a result, the crater has a precise and accurate impact melt sheet crystallization age of ~215 Ma, with a precision better than $\pm 2\%$.

Methods: In situ U-Pb geochronology of apatite and zircon was conducted using a 193 nm Excimer laser ablation system coupled to an Agilent 7700x quadrupole ICP-MS. Target selections were guided by combined BSE and μ -XRF elemental maps. Apatite analy-

sis were run with a 60 μ m spot size, laser energy of 6 J/cm², a repetition rate of 3 Hz, and 30 s background time. Measurements were externally calibrated using the matrix-matched MAD apatite as the primary standard [5], while accuracy was checked using in-house apatite from Phalaborwa, South Africa (2048 ± 16 Ma; MSWD = 1.2). Data reduction was performed using the VizualAge_UcomPbine data reduction scheme in Iolite [6]. An initial common Pb (^{204}Pb) value of 0.941 ± 0.002 , previously obtained from Pb-Pb isotope analysis of feldspars within the same samples [2], was used as an estimate for initial common Pb.

Results: A total of 11 thin sections were selected from both the undifferentiated (U-IMS) and differentiated (D-IMS) regions of the Manicouagan impact melt sheet. Apatite and zircon occur as accessory phases within the impact melt sheet. Zircon (ZrSiO_4) is a minor accessory phase within samples from both the U-IMS and D-IMS, occurring as anhedral or elongated prisms which typically exhibit oscillatory or patchy magmatic zoning, with darker domains containing trace amounts hafnium (Fig. 1).

Analysis of 28 zircons gives a lower intercept age of 213.9 ± 1.5 Ma (MSWD = 1.4) (Fig. 1), with a weighted average $^{206}\text{Pb}/^{238}\text{U}$ age of 213.7 ± 3.8 Ma.

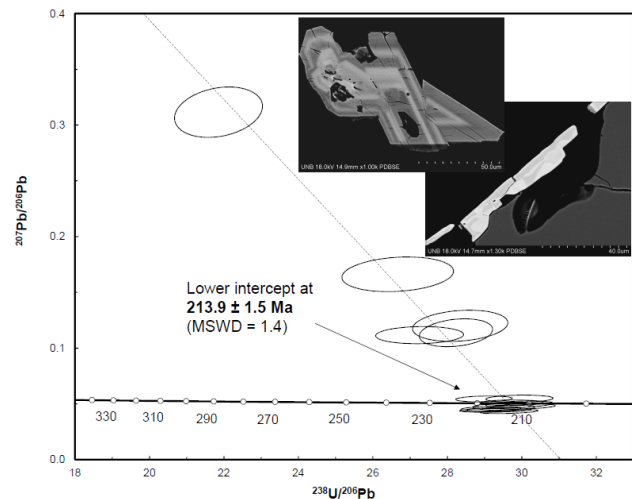


Fig. 1. Zircon U-Pb data plotted on an inverse Concordia diagram with a lower intercept age of 213.9 ± 1.5 Ma. Image inserts are representative grains showing both oscillatory (top) and patchy (bottom) magmatic zoning.

Apatite occurs as both large prismatic to acicular apatite laths within mesostatis regions of impact melt

(Fig. 2). Due to the low U concentration of apatite (1.84ppm), a total of 200 apatite grains were selected for U-Pb analysis in order to obtain high-U bearing grains. When plotted on an inverse concordia and anchored using an initial $^{207}\text{Pb}/^{206}\text{Pb}$ value of 0.941 ± 0.0022 , apatite yields a lower intercept age of 213 ± 11 Ma (MSWD = 0.39) (Fig. 2). This age is indistinguishable from that obtained from zircon (Fig. 1), although with a higher error due to low U concentrations.

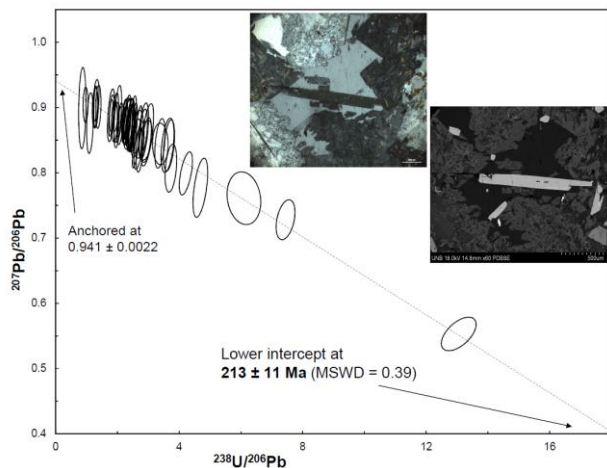


Fig. 2. Apatite U-Pb data plotted on inverse concordia diagram. Regression is anchored at an initial Pb value of 0.941 ± 0.0022 . Lower intercept age of 213 ± 11 Ma (MSWD = 0.39). Image inserts are representative XPL (top) and BSE (bottom) of apatite within mesostasis regions of impact melt sheet.

Discussion and Conclusions:

Viability of apatite as an impact chronometer

U-Pb dating of zircon and apatite from the Manicouagan impact melt sheets yield dates that are similar to those obtained from earlier studies. Further, the age obtained from apatite is indistinguishable from that of zircon, demonstrating the viability of apatite as a U-Pb impact chronometer. The well-defined impact age makes Manicouagan a chronometric standard. In addition, the excellent preservation of the impact melt sheet and extensive samples collected by drilling, makes the Manicouagan impact structure a perfect site for determining the viability of apatite and future minerals as a potential U-Pb impact chronometers.

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