IN SITU MULTIPHASE LA-ICP-MS U-Pb GEOCHRONOLOGY OF TERRESTRIAL IMPACT STRUCTURES. M. McGregor1, C. R. M. McFarlane1, J. G. Spray1. 1 Planetary and Space Science Centre, University of New Brunswick, Fredericton, NB E3B 5A3, Canada (m.mcgregor@unb.ca) 2 Department of Physical Sciences, MacEwan University, 10700 - 104 Ave, Edmonton, AB, T5J 4S2, Canada, 3 Department of Earth Sciences, University of New Brunswick, Fredericton, NB E3B 5A3, Canada.

Introduction:
Geochronological studies of terrestrial impact structures are crucial for understanding the role of meteorite bombardment on Earth, with accurate and precise impact ages enabling correlation of impact events with environmental change and evolutionary processes. While high precision ages are attainable from minerals crystallized within impact melt sheets (e.g., Manicouagan, Canada [1, 2]), coherent melt sheets are not always developed, such as in smaller complex craters (<15 km) or craters formed in targets dominated by a significant sedimentary component. In these cases, the impact component is only present as crater-fill, existing as fragments within impact-melt bearing breccias or as a melt-matrix within clast-laden rocks. These impactites are typically challenging to date, as newly formed (impact-generated) minerals are typically not developed. Rather, they occur as inherited mineral clasts within the melt-clast volume which may experience variable to incomplete isotopic resetting.

In this contribution, we outline a dating approach that allows ages to be obtained from inherited (relic) phases incorporated within impact melt-bearing rocks. The application of in situ laser ablation ICP-MS U-Pb geochronology, combined with detailed petrographic analysis of individual grains, not only yields reliable impact and basement ages, but also provides insights into the mechanisms responsible for variable isotopic resetting. Using this approach, we discuss the results of performing multiphase U-Pb geochronology on apatite, titanite and zircon from three impact structures within the Canadian Shield: Lac La Moine, Nicholson Lake and Steen River.

Multiphase U-Pb geochronology: Lac La Moine. Lac La Moine is a small (~8 km) complex crater situated within northeastern Quebec [3]. Formed in crystalline basement of the De Pas Suite, and a very minor sedimentary component [3], the structure represents one of the few terrestrial impact structures developed entirely within plutonic granitoids. A total of 97 apatite grains (109 analyses), 82 titanites (97 analyses) and 66 zircons (118 analyses) were selected from 7 thin sections of clast-laden melts and impact melt-bearing breccias. Apatite yields a younger, lower intercept discordia age of 453 ± 5 Ma (MSWD = 1.2), and an older discordia array with a lower intercept age of 1708 ± 10 Ma (MSWD = 1.4). Similar to apatite, titanite yields two discordia arrays, with the youngest having a lower intercept age of 444 ± 15 Ma (MSWD = 2.2), which is within error of apatite, and an older array with an intercept age of 1844 ± 24 Ma (MSWD = 1.6). Similar to titanite, zircon yields an upper intercept age of 1810 ± 13 Ma (MSWD = 2.6) and a lower intercept of 433 ± 21 Ma (MSWD = 2.6), which is within error of both phases. However, due to recent Pb-loss and common Pb contamination associated with the process of metamictization and granularization [3], a lower intercept age of 433 ± 21 Ma is considered the best estimate minimum age, and is the least precise of all three phases. The oldest age obtain from titanite (1844 ± 24 Ma) and zircon (1810 ± 13 Ma) are consistent with the crystallization age of the De Pas Suite granitoids [5], while the oldest age recorded by apatite (1708 ± 10 Ma) corresponds to later metamorphic overprinting [5]. An impact age of 453 ± 5 Ma from apatite, which we argue is the most precise and reliable of all three phases, places the Lac La Moine impact event in the Middle-to-Late Ordovician, joining a cluster of more than 12 terrestrial impact structure potentially formed during the L-chondrite parent body breakup event.

Nicholson Lake. Nicholson Lake is a small complex crater (~13 km) formed in Archean and Proterozoic crystalline target rocks, over lain by a thin veneer of fossiliferous limestone [4]. A total of 57 apatite grains (84 analyses) and 52 zircons (90 analyses) were analyzed in situ within 7 thin sections of clast-laden impact melt and impact melt-bearing breccias from the Nicholson Lake impact structure. Comparable to results from Lac La Moine, apatite records two well defined discordia arrays that define ages for both the impact event and regional tectono-metamorphic events in the underlying target lithologies. The youngest array yields a precise lower intercept age of 384 ± 5 Ma (MSWD = 0.87), which corresponds to the impact event, and an older array with a maximum age lower intercept of ~1740 Ma, within error of the basement Nueltin Suite [6]. Similarly, zircon yields two distinct discordia arrays, both of which intersect at 384 ± 8 Ma (MSWD = 1.2). The oldest discordia has a maximum age upper intercept of 2679 ± 14 Ma and a younger discordia array which intersects at ~1740 Ma, recording the same Nueltin age as apatite [6].
Steen River. The Steen River impact structure, located in northwest Alberta, Canada is a buried complex crater with an apparent rim diameter of ~25 km [7]. It formed within mixed crystalline-sedimentary target rocks of the Western Canada Sedimentary Basin (WCSB), with the target component dominated by ~1.2 km Devonian shales, carbonates and evaporites [8, 9]. A total of 84 apatite grains, 38 titanites and 49 zircons from impact-melt bearing breccias were selected for U-Pb dating. Apatite gives a lower intercept age of 138 ± 7 Ma (MSWD 2.1) and zircon yields an impact age of 120 ± 14 Ma (MSWD = 1.5), within error of apatite. The youngest age obtained from titanite is 162 ± 2 Ma (MSWD = 2.0). Being ~30 Ma older than co-existing apatite and zircon, titanite is considered partially reset and is the least reliable of all three phases. In terms of basement ages, zircon yields an upper intercept age of 1882 ± 11 Ma (MSWD = 1.5), titanite gives a concordia age of 1898 ± 6 Ma (MSWD = 1.1), while a single concordant point from apatite gives a $^{206}\text{Pb} / ^{238}\text{U}$ ages of 1914 ± 39 Ma. The oldest ages from all three phases are within error of the underlying Hottah Terrane [10].

Discussion and Implications: The dating technique outlined here provides the first high precision age constraints for Nicholson Lake, Lac La Moine and Steen River. We discuss the mechanisms responsible for isotopic resetting in all three phases (i.e., melt proximity, nature of clastic matrix, and shock microstructures). Moreover, we demonstrate a cautionary tale for zircon, and argue that apatite is the more robust impact chronometer when dating impact melt-bearing breccias. Furthermore, by comparing the U-Pb results from each structure, we demonstrate that the nature of target lithologies (i.e., crystalline verses mixed crystalline-sedimentary) has a significant affect on the extent of isotopic resetting in apatite and titanite. We argue that by using a multiphase approach it is possible to discriminate ‘true’ impact ages by ensuring that all phases are within error and that the most accurate age is used as the age of formation.