Ph.D. Candidate

Maree McGregor

Graduate Academic Unit

Earth Sciences

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July 28, 2020

10:00 a.m. (Atlantic)

Virtual Defence

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Examining Board:
Dr. Clodualdo Aranas (Mechanical Eng.)
Dr. Anna Ignaszak (Chemistry)
Dr. Allison Enright (Earth Sciences)
Dr. John Spray (Earth Sciences) Supervisor
Dr. Chris McFarlane (Earth Sciences) Co-Supervisor

External Examiner: Dr. Desmond Moser
Dept. of Earth Sciences
Western University

The Oral Examination will be chaired by:
Dr. Kevin Englehart, Associate Dean of Graduate Studies

BIOGRAPHY

Universities attended (with dates & degrees obtained):

2018 – present PhD candidate, University of New Brunswick
2016 – 2018 MSc candidate Earth Sciences, University of New Brunswick (transferred into PhD program May 1, 2018)
2012 – 2015 BSc, Major Geology, James Cook University, Queensland, Australia

Peer-Reviewed Publications:

McGregor M, McFarlane CRM, Spray JG (**2018**) In situ LA-ICP-MS apatite and zircon U–Pb geochronology of the Nicholson Lake impact structure, Canada: Shock and related thermal effects. *Earth Planet. Sci. Lett.* 504: 185–197

McGregor M, McFarlane CRM, Spray JG (**2019**) Multiphase U-Pb geochronology and shock analysis of apatite, titanite, and zircon from the Lac La Moinerie impact structure, Canada. *Contrib. Mineral. Petrol.* 174: 62

McGregor M, Walton EL, McFarlane CRM, Spray JG (**2020a**) Multiphase U-Pb geochronology of sintered breccias from the Steen River impact structure, Canada: Mixed target considerations for a Jurassic-Cretaceous boundary event. *Geochim Cosmochim Acta*. 274:136 – 156.

McGregor M., Dence MR, McFarlane C.RM, Spray JG **(2020b)** U-Pb geochronology of apatite and zircon from the Brent impact structure, Canada: A Late Ordovician Sandbian-Katian boundary event associated with L-chondrite parent body disruption. *Contrib. Mineral. Petrol.* 173:63

Conference Presentations:

McGregor M, McFarlane C. R. M, Spray J.G. (**2019**) In situ Multiphase LA- ICP-MS U-Pb geochronology of terrestrial impact structures Large Meteor. Impacts IV. (*Invited speaker*)

McGregor M, Erickson TM, Spray JG (**2019**) Recrystallization and micro-twinning in apatite and titanite from the Lac La Moinerie impact structure, Canada: Implications for U-Pb impact chronology. Large Meteor. Impacts IV. Abst. #5099

McGregor M, McFarlane C. R. M, Spray J.G. (**2019**) Multiphase U-Pb geochronology and shock analysis of apatite, titanite and zircon from the Lac La Moinerie impact structure, Canada. LPSC 50th Abst #2428.

McGregor M and Spray JG (**2018**) The occurrence of reidite within melt-bearing breccia in the Nicholson Lake impact structure, Canada. SSERVI.

McGregor M, McFarlane C. R. M, Spray J.G. (**2017**) The Nicholson Lake impact structure, Canada: Shock features and age of formation. LPSC XLVIII Abst. #2151.

Conference Posters:

D. A. Kring, L. Angotti , M. Bouchard , B. Byron , N. Chinchalkar , S. De Graaff , T. Déhais , L. Glaspie , J. Hedgepeth , M. Hughes , P. Kaskes , J. MacArthur, **M. McGregor**, C. Ross, K. Stacey, S. Suarez, C. Verhagen, and T. M. Erickson. Traces of fallback breccia on the rim of Barringer Meteorite crater (a.k.a Meteor crater), Arizona. LPSC 50th. Abst #1835.

McGregor M, McFarlane C. R. M, Spray J.G. (**2019**) The viability of apatite as an impact chronometer: The Manicouagan impact structure as a chronologic standard. LPSC 50th. Abst. # 2434.

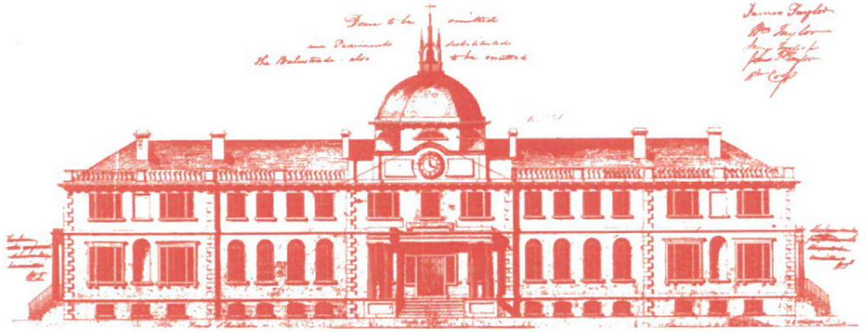
IN SITU MULTIPHASE LA-ICP-MS U-Pb GEOCHRONOLOGY OF TERRESTRIAL IMPACT STRUCTURES

Abstract

In an attempt to improve the chronologic record of impact events on Earth, this dissertation has conducted U-Pb geochronology on shocked and thermally metamorphosed accessory phases (zircon, titanite and apatite) from several terrestrial impact structures using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). All dated phases occur as inherited grains derived from the underlying target lithologies and now occur within impact melt-bearing breccias. This study provides the first application of the apatite U-Pb geochronometer from a terrestrial impact structure, and emphasizes the complexity of dating inherited grains within impact melt-bearing lithologies. Unlike newly-grown (igneous) grains within impact melt sheets, the results presented here highlight the challenges of obtaining precise and accurate impact ages from variably reset grains within complex lithologies. This approach requires an understanding of the relationship between isotopic resetting, the extreme pressure-temperature (*P-T*) conditions and variable temperature-time *(T-t)* histories realized during impact events, impact-induced deformation microstructures, solid-state recrystallization, and pre-impact radiation damage within inherited grains. This dissertation has contributed not only to the chronological record of terrestrial impact events and evaluated their potential influence on Earth's stratigraphic and biological record, but also contributed to the current understanding of U-Pb isotope systematics within multiple U-bearing accessory phases during hypervelocity impact events.

The use of a multiphase in situ LA-ICP-MS U-Pb geochronological approach has permitted an inter-phase assessment on the comparative reliability of zircon, apatite and titanite as impact chronometers, while also providing insights into the U-Pb isotope systematics of these phases under extreme *P-T-t* conditions. The results reveal that isotopic resetting in apatite is thermally induced, inferred to be the result of apatite's lower closure temperature and rapid Pb diffusivities. Consequently, apatite is determined to be more susceptible to isotopic resetting during short-lived temperature excursions compared to zircon and titanite. As such, this study demonstrates that, in the absence of coherent impact melt sheets, apatite is the most viable U-Pb geochronometer for accurately dating terrestrial impact structures. Under the same conditions, zircon and titanite are found to be less reliable impact chronometers. Similar to apatite, isotopic resetting in titanite is primarily thermally induced. However, due to numerous factors including it's higher closure temperatures and slower Pb diffusivities, titanite is prone to incomplete isotopic resetting, and is considered a particularly complex U-Pb impact chronometer. Unlike apatite and titanite, isotopic resetting in zircon is deformation enhanced. In addition to recrystallization-driven Pb loss, the results presented here demonstrate that, for the first time, radiation damage within pre-impact zircons facilitates isotopic resetting. However, metamict zircons are found to be susceptible to recent Pb loss and common Pb contamination, with lower intercept ages typically yielding anomalously young impact ages that are consistently unreliable.

The application of multiphase in situ LA-ICP-MS U-Pb geochronology has provided the first higher precision age constraints for four terrestrial impact structures in Canada: Nicholson Lake (387 ± 5 Ma), Lac La Moinerie (453 ± 5 Ma), Steen River (141 ± 4 Ma) and Brent (452.8 ± 2.7 Ma). Excluding Nicholson Lake, all structures yield ages suggesting possible correlations with known biological extinction events, with Steen River forming at, or close to, the Jurassic-Cretaceous boundary, and both Lac La Moinerie and Brent forming at, or close to, the Sandian-Katian boundary in the Upper Ordovician.



Home of the School of Graduate Studies, Sir Howard Douglas Hall was designed by J.E. Woolford in 1825 and is the oldest university building in Canada still in use.

The University of New Brunswick recognizes that the university sits on traditional Wolastoqey territory. The river that runs right by our university – the St. John River – is also known as Wolastoq, along which live the Wolastoqiyik -- the people of the beautiful and bountiful river.

UNIVERSITY OF NEW BRUNSWICK

SCHOOL OF GRADUATE STUDIES

ORAL EXAMINATION

Maree McGregor

IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY