Recrystallization and Micro-Twinning in Apatite and Titanite from the Lac La Moinerie Impact Structure, Canada: Implications for U-Pb Impact Chronology.

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Introduction: Accessory mineral geochronometers, such as baddeleyite, monazite and zircon are rapidly revealing the complex behavior of the U–Pb system in response to shock metamorphism. However, little is known about the response of apatite and titanite to shock pressures and temperatures. Understanding the development of shock microstructures in these phases is critical for understanding the response of the U–Pb isotope system to hyper-velocity meteorite impact. While both apatite and titanite are widely applied U–Pb geochronometers within the Earth Sciences, their utility for impact chronology has only recently being explored [1, 2, 3]. Furthermore, studies on shock microstructures in apatite and titanite are limited [5, 6, 7]. Here we provide detailed microscopy, BSE imaging and EBSD analysis of shocked apatite and titanite from the Lac La Moinerie impact structure, Canada, to characterize the presence of external and internal shock features.

Geologic Setting and Samples: The Lac La Moinerie (Monastery Lake) impact structure is situated in northeastern Quebec (N57°26', W66°37'). Formed within Paleoproterozoic granitoids of the De Pas Suite. The structure is a small complex crater, with an apparent rim diameter of ~8 km and a ~4-km-diameter central uplift [1]. During reconnaissance field studies a range of impactite lithologies were collected [4], including impact melt-bearing breccias and clast-laden impact melt rocks. We selected apatite and titanite grains that occur as mineral clasts within these samples to document the presence of shock microstructures.

Analytical Techniques: Apatite and titanite grains were characterized using optical microscopy, backscattered electron (BSE) imaging and electron backscattered diffraction (EBSD) mapping. Grain exteriors were imaged in BSE mode using a Hitachi SU-70 field emission scanning electron microscope (FESEM) equipped with a Schottky emitter housed at the University of New Brunswick, Canada. Prior to EBSD analysis, thin sections were further polished using a colloidal silica dispersion. A thin (~5 nm) carbon coat was applied to all slides to mitigate charging. EBSD analyses were conducted on a JEOL JSM-7600F (FESEM) with a Oxford Instruments Symmetry EBSD detector housed at NASA Johnson Space Centre, Houston. All EBSD maps were processed using the Tango and Mambo modules of Oxford Instruments Channel 5.11.

Results: Apatite. We observe a range of shock microstructures in apatite from the Lac La Moinerie impact structure. In addition to planar fractures and microvesicles, we also observed shock-recrystallized apatites. Unlike previous studies [5, 6], individual neoblasts are readily discernable in BSE images (e.g., Fig. 1a, b), highlighting the viability of field emission SEM for identifying recrystallization textures. Recrystallized apatite grains are composed of polycrystalline aggregates of neoblasts, which occur in distinct morphologies, including hexagonal, subrounded, angular/blocky and elongate (e.g., Fig. 1a, b). Unlike previous studies where apatite granules have maximum misorientations of ~15° [5], the apatite neoblasts measured here have relative misorientations of up to ~40° (e.g., Fig. 1c). Additionally, we observe, for the first time, apatite neoblasts which have nucleated in two systematic orientations, with ~30° relative misorientation about the <10-10> principle axis of apatite.

Titanite. We document crystal plastic deformation, polysynthetic micro-twins and recrystallization textures in titanite from Lac La Moinerie. In BSE, micro-twins are discriminated as discrete lines of bright BSE contrast, which terminate along linear to sub-linear arrays of vesicles, and in some grains appear heavily annealed (Fig. 2a). In EBSD, we identify multiple sets of polysynthetic micro-twins with a twin-host disorientation relationship of 74° about <102> (Fig. 2b; T1, T2), similar to micro-twins observed at the Sudbury, Vredefort
and Chixulub impact structures [3, 7]. The micro-

twins with misorientations about <102> occurs as sin-
gle sets, parallel sets or intersecting sets, occasionally 

within single grains. We also observe a new micro-twin 

with a twin-host disorientation relationship of 70° 

about <103>, which occurs within single grains or co-
exists with sets of the 74°<102> twin (e.g., Fig. 2b). 

We also observed evidence of recrystallization in titan-
ite, although the sub-grain domains are less well de-

fined compared to [3]. Where titanite is intergrown 

with rutile, both phases are microcrystalline, similar to 

recrystallized rutile from the Chixulub impact struc-

ture, Mexico [8].

Figures 2. a) Backscattered image of titanite grain showing 
annealed structure and linear-to sub linear arrays of mi-
nces of T1, T2 and T3.

Implications: A range of shock microstructures are 
observed in apatite and titanite from the Lac La Moine-
erie impact structure.

Granular or neoblastic apatite is widespread 
in the studied impact-melt rocks. In contrast to recent 
documentations of granular apatite [5, 6], recrystallized 
apatite observed here is readily observed in BSE and 
individual apatite neoblasts have morphologically dis-
tinct habits (i.e., as hexagonal, subrounded, angular/blocky and elongate crystallites) (Fig. 1a, b). Fur-
thermore, we document two distinct orientations of 
apatite neoblasts observed in a single grain, suggesting 
that recrystallization may be crystallographically con-
rolled.

Titanite grains studied here show evidence for both 
shock-induced deformation (micro-twinning) and dy-
namic recrystallization. Within a single grain, we ob-
erved two differently orientated 74°<102> micro-
twins and a newly identified micro-twin with a twin-
host orientations of 70° about <103>. Where titanite is 
tergrown with rutile (pre-impact), both phases are 
recrystallized (i.e., granular), and in some cases twins 
with the 74°<102> misorientation are partially pre-

The range of microstructures observed in apatite 
and titanite within the impact melt rocks from Lac La Moine-
erie highlights the microstructural complexity of 
shocked apatite and titanite at the sub-micron scale. 
These different microstructure responses may therefore 
varially reset the U–Pb systematics. Thus, given recent 
U–Pb dating of apatite and titanite from terrestrial im-

crater_like structures [1, 2, 3], this study has implications 
for microstructural U–Pb geochronology, whereby discrete 
deformation zones may be targeted for dating.


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