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Insight into the Post-Impact Hydrothermal System at the Chicxulub Impact Structure, Mexico

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Summary

The 66-million-year-old Chicxulub impact structure was formed by the hypervelocity impact of an asteroid into the Yucatán peninsula[1,4]. Hypervelocity impacts generate hydrothermal circulation systems in the resulting craters and create long-term thermal anomalies in near-surface areas of the crust[2]. Drill cores have sampled preserved impactites from the Chicxulub crater with the most recent core, M0077A, intersecting the peak ring. Analysis of the mineralogy, composition, and occurrence of secondary minerals in the core may be used to understand conditions in the post-impact hydrothermal environment. In this study, the secondary minerals within ten thin sections and five polished offcut tiles from drill core M0077A were investigated. The thin sections were sampled from ~750-1300 metres below sea floor (mbsf), while the tiles were constrained to a depth of ~1250-1330 mbsf. Identified secondary minerals include andradite-grossular garnet assemblages, anhydrite, Fe-oxides, calcite, Mg-Fe-Al-rich clay group minerals, sulfides, Ca-sulphates, titanite, albite, fluorite, epidote, quartz, and halite. These minerals occur as vein- and vug-filling assemblages in the shocked granite and suevite breccia. The andradite-grossular garnet assemblages are of particular interest as they suggest that high-temperatures (300-400 C°) dominated the early stages of the post-impact hydrothermal system[4]. Secondary minerals anhydrite, titanite, epidote, and Fe-oxides support the temperature range indicated by the garnets, but do not constrain the temperature as tightly. The temperature range indicated by the garnets is sufficiently hot for the hydrothermal system to persist for at least two million years, based on previous numerical modeling[1,3]. Calcite, Mg-Fe-Al-rich clay group minerals, sulfides, and halite formed as the hydrothermal system cooled. The secondary minerals identified attest to the depth and range of thermal and chemical modification that occurred in the Earth's crust due to impact events, both immediately after and in the ensuing millions of years.

Methods

Samples were analyzed using transmitted and reflected light microscopy with a petrographic microscope to characterize texture. Back-scattered electron (BSE) and secondary electron (SE) images of the thin sections and tiles were obtained using a scanning electron microscope (SEM) equipped with a high resolution dual detector energy dispersive X-ray (EDX) spectroscopy system (University of Alberta). BSE and SE images were acquired using an accelerating voltage of 15 kV. The resultant BSE and SE images of the samples were used to characterize microtextures, while the EDX spectrometer was used in spot analyses of specific minerals and maps of larger assemblages. The abundances of eight major and minor elements of the identified hydrothermal garnets were quantified on an electron microprobe analyzer (EMPA) (University of Alberta). Raman spectra collected in the backscattered direction were obtained from point measurements of various minerals to provide final confirmation of identity using a Bruker SENTERRA instrument (MacEwan University). A 532 nm laser was focused on the sample surface to yield a spot size of ~100 micrometers. Multiple exposures were acquired and stacked to achieve the final spectrum. Backgrounds were graphically reduced using commercial software.

Results and Conclusions

The characterized samples consist of impact melt bearing polymict breccias, termed suevite, and shocked but intact granite basement rocks. Secondary minerals observed in the two types of rock are similar, though particulars of occurrence, habit, and size differ. The secondary minerals identified in the shocked granite include apatite, Fe-oxides, Fe-Mg-Al-rich clay group minerals, albite, quartz, calcite, andradite, Fe-sulfides, fluorite, titanite, and epidote. The secondary minerals are mainly constrained to cataclastic zones which intersect shocked grains of quartz and feldspar. Secondary minerals observed in the suevite include inclusion-bearing calcium-rich garnets, epidote, titanite, Fe-oxides, halite, Mg-Fe-Al-rich clay group minerals, Fe-sulfides, albite, apatite, and quartz. In the suevite breccias, secondary minerals are mainly found in association with vugs and veins in the porous matrix. Hydrothermal garnets are of particular interest as only sparse grains of Ti-rich calcic garnets have previously only been reported from a single core penetrating Chicxulub impactites[4]. The hydrothermal garnets that we have documented in the granitoid samples are rare, small (~10 µm), and are associated with veins of calcite. In suevite samples deeper in the core, the hydrothermal garnets are abundant, occur lining the margins of vugs and veins, and are ~20-40 µm in size. The presence of hydrothermal garnets constrains the post-impact temperature to 300-400 C^{o} at the peak ring[4]. This temperature range is sufficiently hot for the lifespan of the hydrothermal system to span at least two million years, tightening previous estimates of 1.5-2.3 million years[1,3]. The chemical composition of the large majority of hydrothermal garnets in M0077A is $Ca_3Fe_2SiO_{12}$, identifying them as andradite, the iron-rich end member in the andradite-grossular solid solution series. Zoned garnets with grossular rims are observed within suevite samples, as are ~10 µm grossular grains, but both are less typical. The consistent chemical formula of the garnets indicates that they formed during a single precipitation event, with a stable, alkaline (6.5-8 ph) fluid[3]. Inclusions are also found within the garnets, though many have been plucked out by the polishing process. Inclusions are confirmed through Raman spectroscopy to be two distinct types: calcite and anhydrite. The presence of calcite inclusions in the garnets, calcite veins in granite samples, Mg-Fe-Al-rich clay group minerals, and halite is indicative of lower (<300 C^{o}) temperature alteration, and represents the evolution of the hydrothermal system as it cooled[2]. The secondary minerals provide evidence for an extensive, spatially and temporally complex hydrothermal system. Information gleaned from the minerals at the peak ring will be used to refine previously developed numerical models of the post-impact hydrothermal system.

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