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Published in:
Impacts and their Role in the Evolution of Life

Publication date:
2019

Document Version:
Final published version

Citation for published version (APA):
Feignon, J-G., Ferrière, L., & Koeberl, C. (2019). Petrography, shock metamorphism, and geochemistry of the main lithologies from the Chicxulub impact structure peak-ring IODP-ICDP Expedition 364 drill core. In *Impacts and their Role in the Evolution of Life: Schedule and Abstracts* (pp. 44-45)

Petrography, shock metamorphism, and geochemistry of the main lithologies from the Chicxulub impact structure peak-ring IODP-ICDP Expedition 364 drill core

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From April to May 2016, IODP-ICDP Expedition 364 drilled the peak-ring of the ~200-km diameter Chicxulub impact structure (Yucatán peninsula, Mexico) and recovered a continuous 829 m core [1]. This provides a unique opportunity to investigate the nature, properties, and composition of the peak-ring rocks and the mechanism of their formation. The core can be divided into three main units, from top to bottom: (1) post-impact Paleogene, carbonate-rich sedimentary rocks (from 505.7 to 617.3 mbsf [meters below sea floor]); (2) the 'upper peak-ring' section, consisting mainly of suevite and an impact melt rock layer at its base (from 617.3 to 747.0 mbsf); and (3) the 'lower peak-ring' section consisting predominantly of granitoid cross-cut by different types of pre-impact volcanic dikes and intercalations of impact melt-bearing rocks units (from 747.0 to 1334.7 mbsf).

Our study is restricted to the upper and lower peak-ring sections. We report here on our petrographic and whole-rock geochemical analyses of a total of 116 samples. Sr-Nd isotope data for 12 granites are also presented and discussed. Optical microscopy and a JEOL JSM-6610 SEM (at the Natural History Museum Vienna (NHMV), on a selection of thin sections) were used for the petrographic investigations. The Universal stage (U-stage) was used to investigate shock features in quartz grains (from granite samples), and shock pressures were estimated. The geochemistry of the different lithologies was investigated at the University of Vienna, using XRF and instrumental neutron activation analysis (INAA). Strontium and Nd isotopic compositions and concentrations (via isotope dilution) were obtained by thermal ionization mass spectrometry (TIMS).

The 'upper peak-ring' section can be divided into two subunits: a ~100 m suevite unit overlaying a ~25 m impact melt rock unit. The suevite is made up of angular to sub-rounded clasts in a grey micritic carbonate matrix with some opaque minerals in the upper part and a brownish carbonate matrix on the lower part. The clast size increases with depth, from < 1 cm at 620 mbsf to ~10 cm at 710-720 mbsf. The suevite is relatively well sorted in the upper part but poorly sorted in the lower part. It contains shocked and unshocked rock (and mineral) clasts of various lithologies, including impact melt rock fragments (green to dark in color), brown "glassy" fragments (some strongly altered), limestone, carbonate, granitoid, gneiss, and even some fossils. Quartz grains are shocked, showing a number of sets of planar fractures (PFs) and decorated planar deformation features (PDFs), and some are toasted. Ballen silica is also present. The suevite has a relatively low SiO_2 content, ranging from 35.0 to 50.0 wt.%, whereas it is relatively enriched in CaO, ranging from 16.3 to 23.0 wt.%, due to the carbonate matrix. The impact melt rock is generally clast poor, and is characterized locally by intermingling of two distinct melts with flow texture. The first one characterized by green color, generally altered and enriched in CaO (> 12.0 wt.%), whereas the second melt is black to grey in color, with small (<0.5 cm) undigested lithic clasts, mainly igneous lithologies and mineral grains (quartz, plagioclase, and calcite). Interestingly no sedimentary clasts were seen. The composition of this melt is more silicic (SiO_2 content ranging from 57.6 to 60.5 wt.%). At the base of the 'upper peak-ring' section, only the black impact melt rock is present, representing an about 9 m thick unit on top of the granitoid of the ‘lower peak-ring’ section.

The ‘lower peak-ring’ section consists mainly of a pervasively deformed, locally micro-brecciated (cataclasites) and sheared, coarse-grained leucogranite, with crystals ranging from ~0.5 to 4 cm in size. The mineral assemblage consists mainly of K-feldspar (~25-40%), plagioclase (~25-35%), quartz (~25-35%), and, to a lesser extent, biotite, often chloritized (~1-5%). The main accessory minerals are muscovite, (fluor)apatite, titanite, epidote (piemontite), zircon, (titano)magnetite, and allanite. Other accessory minerals, including monazite, ilmenite, rutile, chalcopyrite, cobaltoan pyrite, stolzite/raspite, galena, uranothorite, and uranothorianite were also detected during our SEM survey. Most of the primary minerals show shock metamorphic features. In the case of quartz, almost all grains are shocked (>99%) and most show a strong undulose extinction; some crystals are toasted and a few show kink bands. PFs are in a few cases visible at the macroscopic scale due to preferential hydrothermal alteration and filling of PFs with calcite; they are mainly oriented parallel to (0001) and $\{10\bar{1}1\}$. Feather features (FFs) and decorated PDFs are abundant. Up to 6 sets of PDFs per grain were observed under the U-stage, with a mean value of ~2.7 sets/grain (average from 12 samples). PDFs are preferentially oriented along the $\{10\bar{1}3\}$ and $\{10\bar{1}4\}$ orientations (i.e., together representing 55 to 82 % of the measured PDFs). Interestingly, PDFs with $\{10\bar{1}2\}$ orientation, which form at somewhat higher shock pressures, are more abundant in the upper part of the basement section, representing on average 10-15 % of the total, and only 1-5 % in the lower part of the section. Shock features were also observed in alkali-feldspar and plagioclase (i.e., PFs filled with opaque minerals and some possible PDFs), titanite, and apatite (with different types of planar microstructures). Biotite, muscovite, and chlorite are generally kinked. Based on our U-stage results, we estimate that the investigated samples were shocked to pressures between 15 and 18 GPa, with little to no attenuation of the shock pressure with increasing depth.

The major element contents of the 41 investigated granite samples range from 66.7 to 77.5 wt.% for SiO_2, from 11.6 to 16.1 wt.% for Al_2O_3, from 3.71 to 5.42 wt.% for Na_2O, and from 2.27 to 5.16 wt.% for K_2O. There is no obvious trend of enrichment/depletion of any specific element with depth. The investigated samples fall within the granite and alkali granite fields in the total alkali vs silica (TAS) diagram. They have I-type and metaluminous affinities. Based on their Nb, Rb, Ta, Y, and Yb contents, our samples mainly fall in the volcanic arc granite field, near the limit with the syn-collision granites, with two samples inside this latter field [2]. Nevertheless, a few samples show distinct La, Ba, Dy, and Yb contents, more consistent with the within-plate granite field, suggesting that there could be at least two different granite generations, as already suggested by [3]. Based on their $^{87}Sr/^{86}Sr$ isotopic compositions, the granites can be divided in two groups, between 0.7080 and 0.7096 and 0.7113 and 0.7137, respectively. Their εNd is relatively low, with values showing a rather narrow interval, between -2.8 and -4.3. Our results argue for a crustal signal with a limited enrichment of the source (i.e., direct melting or crustal assimilation), with these granites being possibly related to the Pan-African granite of the Maya Block forming the main unit of the Northern Yucatán basement [4]. The intercalations of impact melt-bearing lithologies in the ‘lower peak-ring’ section have a more silicic composition than in the upper section, with SiO_2 contents ranging from 55.0 to 60.0 wt.% and a lower CaO content (< 4.0 wt.%). Flow textures and undigested clasts of shocked basement rocks are relatively abundant, suggesting fast quenching during the impact melt emplacement.

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