EPSC Abstracts
Vol. 12, EPSC2018-1175-1, 2018
European Planetary Science Congress 2018

Post Impact Hydrothermal Activity. Thermodynamic Simulations on the Chicxulub Crater & Habitability Assessment.

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Abstract

Large asteroid and comet impacts on terrestrial planets and moons deliver vast amounts of heat that drive hydrothermal activity. Such hydrothermal processes subsequently raise probabilities for life evolution beneath planetary surfaces in the Solar System. We use the Chicxulub crater setting to model the thermodynamic evolution of the impact induced hydrothermal system. Data from the recent M0077A borehole samples of the IODP 364 Expedition and other seismic, magnetic and gravity surveys constrain our model inputs. As the impact induced central melt sheet gradually cools and crystallizes, it allows fluids to flow through it. Rock permeability is the determining factor of fluid circulation and lifetimes of hydrothermal systems. According to the assumed permeability, we found that the hydrothermal upwellings at Chicxulub were active for more than 2 Myr. Furthermore, the distributions of temperature and water mass flux along the Chicxulub crater and its annular trough allow us to proceed with the thermodynamic modelling of the geochemical reaction paths and to investigate potential energy metabolism pathways. Through this model, we assess habitability at the Chicxulub crater by (hyper) thermophiles / thermoacidophiles for the period of the impact-induced hydrothermal activity. As a result, we favor the application of the suggested model to habitability scenarios of fresh impact craters in the Solar System.

1. Introduction

Large impacts into planetary crusts, like the one that formed the Chicxulub crater, deliver vast amount of energy, some of which is converted into heat. Sufficient heat is deposited by the shock wave to induce phase changes, melting and vaporization of target rocks. As a consequence, such impacts can produce even km3 of liquid melt that take a long time to cool. The impact induced melt pools in the topographically lowest regions of the crater basin, forming a melt sheet. The final heat source is the central uplift, or material that has been uplifted from warmer regions of the crust during the crater formation process. The importance of the melt sheet and the central uplift, relative to shock emplaced heat, increases with crater diameter [6]. If water or ice is present in the crust, the resulting temperature increase provides a thermal driver for the circulation of water and the emission of steam, initiating a hydrothermal system [3].

Studies of terrestrial craters reveal three important features of impact-generated hydrothermal systems:

1. The volume affected by hydrothermal activity extends laterally across the entire diameter of a crater (more than 200 km in the Chicxulub Crater) and to depths of several kilometers [7].

2. Impact induced hydrothermal systems have the capacity to significantly redistribute chemical elements and create chemical gradients throughout equally large volumes of the Earth’s crust.

3. In these systems we observe the same biogeochemical features as in volcanically driven hydrothermal systems and hence, may have influenced the biological evolution of Earth [3].

1.1 Sub-section: Modelling the Impact Induced Hydrothermal Activity at the Chicxulub Crater

The Chicxulub crater has been extensively studied through seismic, magnetic and gravity surveys, more significantly through several drilling expeditions for research or industrial purposes. Especially, borehole data and previously collected samples of the Chicxulub Scientific Drilling Project and the most recent joint IODP/ICDP 364 Expedition allow us to construct an enhanced numerical model of the post impact generated hydrothermal activity. Modelling the post impact water and heat flow at Chicxulub crater required formulation of the numerical code HYDROTHERM, which is a three dimensional finite difference model developed by the U.S. Geological Survey. It is mainly used to simulate water and heat transport in a porous medium [4] and has been previously applied to hydrothermal systems of volcanic origin [5] and hydrothermal systems at several Martian impact craters [2], [8] and impact craters on Earth eg. Sudbury impact [1] and Chicxulub [3].

2. Preliminary Results

Subsequently, after setting the boundary conditions, model inputs and physical parameters, according to [3], feasibility tests via HYDROTHERM simulations took place and are presented as follows. Our simulations (Figures 1 and 2) are in compliance with previous results presented in [3] and prove that we can rely on this model. After constructing the 3D physical model of the temperature, pressure and water mass flux distributions versus time for the Chicxulub crater, a homogenous data catalogue of the physical properties of the simulated hydrothermal system is produced. These data are used anew to provide geochemical reaction paths and to investigate the metabolic energy potential across the entire diameter of the crater and its annular trough.

3. Figures

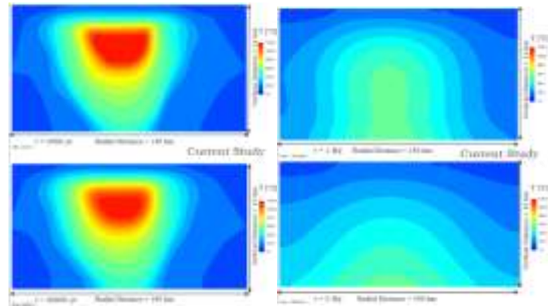

Figure 1: Temperature distributions at the Chicxulub Crater (2000yr, 20.000yr, 1My and 2My after the impact). Red colours represent isotherms of T > 1200°C, yellow of T = 800°C, dark blue of T = 50°C.

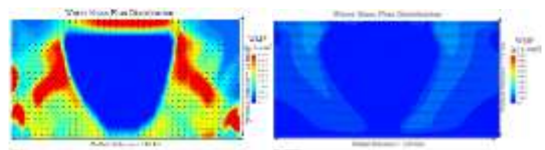

Figure 2: Water Mass Flux distributions at the Chicxulub Crater (2000yr and 2My after the impact). Red colours represent Water Mass Flux WMF > 7.0E-6 kg/s×m2, dark blue of WMF < 0.5E-6 kg/s×m2.

4. Summary and Conclusions

The cutting edge of this research work is to simulate via deterministic modelling the thermodynamics, lifetimes and mechanics of impact induced hydrothermal systems and essentially, to provide geochemical constraints and suggest potential energy metabolism pathways. Several studies provide models of impact induced hydrothermal systems on Earth [1], [3] and on Mars [2], [8] focusing on the lifetimes of such systems, the temperature and water/vapor mass flux distributions. Nevertheless, the geochemical constraints and the biological potential of impact induced hydrothermal systems still remain unknown. Through this study, we use data deriving from our constructed 3D thermodynamic model of the impact induced hydrothermal system at Chicxulub to examine the geochemical reaction paths that took place. These geochemical constraints should also explain the mineralogical distribution and hydrothermal alteration observed at samples of the Chicxulub crater. We continue by exploring specific regions of the simulated hydrothermal setting of the

Chicxulub crater, where the thermodynamic conditions (temperature, pressure) and water flows would allow (hyper) thermophilic life to thrive. Consequently, we use the physical conditions and geochemical compositions of these areas of particular interest to define the metabolic energy potential therein. Hence, through modelling the thermodynamics and the biogeochemical reaction paths of the impact induced hydrothermal system at the Chicxulub crater, we expect to shed new light on the metabolic energy potential and the astrobiological implications of fresh impact craters in the Solar System.

References

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