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EVALUATION OF THE POSSIBLE FORMATION OF A HYDROTHERMAL SYSTEM IN THE NOACHIAN IN HELLAS CRATER, MARS, FROM THE STUDY OF ITS MINERAL AND GEOLOGICAL ENVIRONMENT

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RESUMEN

En este trabajo se realizó un estudio del contexto geológico y mineralógico de la región de Hellas, mediante el análisis de mapas de unidades geológicas, redes hídricas y distribución de minerales hidratados, utilizando el programa JMARS. El propósito de este trabajo fue evaluar la posible formación de un sistema hidrotermal en el Noeico, asociado al impacto que produjo la cuenca Hellas. También se estimó el volumen de fundidos de impacto producido por la colisión. La estimación del volumen de fundidos de impacto en Hellas, dió valores entre 3.83×10^7 km^3 y 3.52×10^8 km^3. Este volumen es importante para tener una idea de cuánto tardó en enfriarse dicho fundido, lo que se asocia al tiempo de vida del sistema hidrotermal.

ABSTRACT

In this work, a study of the geological and mineralogical context around the Hellas region was carried out through the analysis of maps of geological units, water networks and distribution of hydrated minerals, using the JMARS program. The purpose of this work was to evaluate the possible formation of an hydrothermal system in the Noachian, associated to the impact that produced Hellas basin. The volume of impact melt produced by the collision was also estimated. The volume of impact melt estimated at Hellas gave values between 3.83×10^7 km^3 and 3.52×10^8 km^3. This volume is important to get an idea of how long it took for the melt to cool, which is associated with the lifetime of the hydrothermal system.

Key Words: planets and satellites: general

1. INTRODUCTION

The formation of impact craters or basins, generated by the hypervelocity collision of an asteroid or cometary nucleus with planetary surfaces, can cause various scenarios of geological and astrobiological interest, including the formation of hydrothermal systems. A hydrothermal system has three components: a heat source, water or ice on the site and permeable and/or fractured rock environment. In particular, in impact-induced hydrothermal systems, the heat source is associated with the impact melts caused by the high pressures and temperatures resulting from the transfer of energy from the projectile to the target.

The existence of hydrothermal systems on Earth, associated with impact craters, is evident through the study of mineral deposits in several impact structures, among which are Chicxulub, Sudbury and Haughton (Kirsime & Osinski 2013). Hydrothermal systems in these impact structures have been estimated to last between 10^4 and 10^6 years (Daubar & Kring 2001). Furthermore, hydrothermal systems may have played a very important role in the origin and evolution of early life on Earth and maybe on other planets.

The Hellas impact basin on Mars, 2,300 km in diameter, is the largest and best-preserved structure in the southern region of the planet. This was formed in the Noachian period, between 4.1 and 3.7 Ga (Carr & Head 2010). It presents interesting features, both geological and mineralogical, that suggest the possible formation of a hydrothermal system associated with the basin.

The objectives in this work were to identify the mineral and geological context of the Hellas impact basin to evaluate the possible formation of a hydrothermal system in the Noachian associated with the basin, as well as to calculate the amount of melt produced by the Hellas formation and to compare the amount of melts to the melt volume in Chicxulub and Sudbury basins.

2. METHODOLOGY

2.1. *Obtaining information through JMARS*

The JMARS program was used to obtain the maps. This is a geospatial information system (GIS)

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that provides tools to visualize and analyze multiple independent data related to planet Mars (physical, geological, geomorphological, etc.), with the aim of superimposing, reprojecting and combining the data easily. Maps can be global, regional or local (Weiss et al. 2005).

Four maps were made for the geological and mineralogical study in the Hellas basin and its surroundings. The first three maps were of geological units of the Noachian, Hesperian and Amazonian regions showing the distribution of hydrated minerals, and the fourth map was of the distribution of water networks with hydrated minerals in the Hellas region.

2.2. *Melt volume estimation*

The estimation of the volume of impact melts is related to the cooling time of a hydrothermal system: the more melt there is, the longer time of cooling, and therefore the hydrothermal system will be active for longer. In this work, the impact melt volume of the Chicxulub and Sudbury terrestrial basins, and the Hellas and Argyre martian basins, was estimated. Both of these equations consider the sine of the impact angle and the specific internal energy of the target at shock pressure that results in melting (that depends on the target material); the difference is that one of these equations is also a function of the projectile diameter and the speed of impact, while the other one depends on the gravitational acceleration of the planetary body and the size of the transient crater. Both equations are consistent in the sense that they give similar results.

3. RESULTS

The maps made of the Hellas region, using JMARS data, are shown in Figure 1. In Figure 1.A it is observed that the hydrated minerals are located to the north of the basin, within units of the early and middle Noachian , these units are the oldest and the most cratered. Figures 1.B and 1.C show that there is a lower presence of hydrated minerals within the Hesperian and Amazonian geological units. Fig. 1.D shows the distribution of the water networks to the north and south of the basin, which indicates a possible interaction of impact melts with water in these areas. The results obtained from these maps agree with a work of Ehlmann and Edwards (2014). They find a greater presence of hydrated minerals on Noachian units. This finding is significant because these minerals were observed in large outcrops on the southern highlands and in small places where the Noachian crust is exposed. It is worth mentioning that these places are related to large impact basins

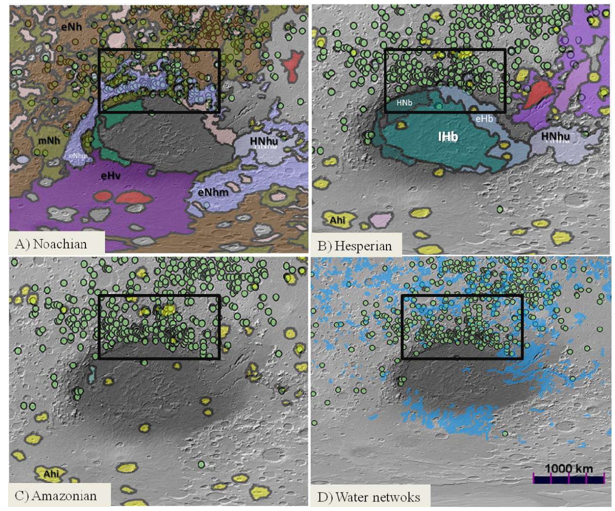

Fig. 1. Maps of the Hellas region. The green dots show the location of the hydrated minerals. (A) Noachian geological units (eNh in brown color; eNhm in lilac color; mNh in dark green color). (B) Hesperian geological units (AHi in yellow; Ihb in turquoise; eHv in purple).
(C) Amazonian geological units (AHi in yellow color).
(D) Water networks (in blue). The northern region of the basin (black box) has the highest concentration of hydrated minerals.

TABLE 1

VOLUMES OF MELT CALCULATED FOR DIFFERENT MARTIAN AND TERRESTRIAL BASINS.

Basin	Projectile diameter (km)	Velocity (km/s)	Transient crater diameter (km)	Melt volume (km^3)	Average (km^3)
Sudbury	14	17	91.88	8.52×10^3	8.29×10^3
				8.05×10^3	
		20	98.69	1.12×10^4	1.09×10^4
				1.05×10^4	
Chicxulub	10	17	70.67	3.10×10^3	3.02×10^3
				2.93×10^3	
		20	75.91	4.09×10^3	3.97×10^3
				3.85×10^3	
	15	17	96.97	1.04×10^4	1.02×10^4
				9.90×10^3	
		20	104.15	1.38×10^4	1.34×10^4
				1.30×10^4	
Argyre	360	9.6	1114.04	5.48×10^7	5.35×10^7
				5.23×10^7	
		10	1134.23	5.87×10^7	5.74×10^7
				5.60×10^7	
Hellas	322	9.6	1021.20	3.92×10^7	3.83×10^7
				3.74×10^7	
		10	1039.71	4.20×10^7	4.10×10^7
				4.01×10^7	
	659	9.6	1785.32	3.36×10^8	3.28×10^8
				3.21×10^8	
		10	1817.68	3.60×10^8	3.52×10^8
				3.44×10^8	

formed during early Mars. eNh, eNhm and mNh units are associated with cratered terrains. These sites are areas that show the oldest crust of Mars, basalt in composition. Basalt rocks contain minerals such as pyroxenes and olivines wich have Mg, Fe, and Al ions, which, when hydrated, favor the formation of phyllosilicates such as smectites and chlorites. The formation of these last two minerals also suggests that the temperature of the heat source that formed them was greater than 100 C and probably greater than 350 C. Likewise, other minerals have been detected in several impact craters, the presence of prehnite, illite, muscovite, serpentine, silica, opaline, analcime, and also sulphides and carbonates have been detected. The existence of these minerals is associated with alteration processes at high temperatures (>400 C).

The formation of phyllosilicates on Mars, belonging to smectites group such as nontronite, saponite, vermiculite and hectorite, occurs in hydrothermal environments inside the crust and it needs the presence of hot fluids underground. The exposition of these minerals on the surface of Mars could be due to erosion and asteroid impacts that permit to see the deeper crust (Reyes, 2019). Based on this, we could say that phyllosilicates are associated to sites that had hydrothermal activity after the formation of impact basins.

Table 1 shows the results obtained when calculating the melt volume for the Chicxulub, Sudbury, Argyre and Hellas impact basins. In the calculations, two impact speeds were considered for both planets and the gravitational acceleration of 9.8 m $/s^2$ for Earth and 3.7 m/s^2 for Mars.The fifth column of the Table 1 shows the melt volume that results from consider the two equations proposed by Abramov et al. (2012), for each velocity on the third column. The sixth column shows the average of the contiguous values in the fifth column.

4. CONCLUSIONS

With the geological, mineralogical and hydrological information of the Hellas region obtained from the JMARS maps, it was observed that the northern rim of the Hellas basin presents the necessary conditions to form a hydrothermal system associated to Hellas impact melts. This means that hydrothermal systems could be active during the early and middle Noachian.

The present work is the first to estimate the volume of impact melts in the Hellas basin from the equations proposed by Abramov et al. (2012). To validate these equations, the volume of the melts at Chicxulub and Sudbury was first estimated, and the results were compared with estimates from geophysical measurements that we found in the literature. As both results were similar, this allowed us to say that the melt volumes for Hellas and Argyre obtained through the equations of Abramov et al. (2012), provide a reasonable estimate, then it is concluded that the melt volume in Hellas could be between 3.83×10^7 km^3 and 3.52×10^8 km^3, i.e. the melt volume at Hellas is 4 orders of magnitude greater than the melt volumes at Chicxulub and Sudbury.

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