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TITRE du SUJET : Les intrusions magmatiques planétaires, théorie, modélisation, caractérisation

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Développement du Sujet :

Introduction

Volcanism is a key process to study the structure, evolution and habitability of terrestrial planets. Volcanism leads to resurfacing and to the formation of characteristic objects that can be observed. It is closely related to, and thus informs on the differentiation, evolution and thermal state of planets. The style and importance of volcanism also depends on the nature and abundance of volatile elements in magmas, volatiles which are of crucial importance for the planet's habitability.

Intrusive volcanism is a hidden, but potentially important process in terms of volume. On Earth, most of the magmas are emplaced in the form of intrusions (sills, laccoliths) in the sub-surface and geological and geophysical data allow detailed studies of these structures (Michaut and Jaupart, 2006, 2009). However, evidences of intrusions are rare on the other terrestrial planets. They include surface deformation such as low-slope domes within lunar mare basalts and within the Northern plains of Mars Mars (Wöhler et al, 2009, Rampey et al, 2007) or floor-fractured craters on the Moon, Mars, Venus, and recently on Mercury (Schultz, 1976, Head et al, 2009). The volume and shape of of these potential intrusions could be constrained by the surface topography. But such observations must be linked to physical model for the intrusion dynamics in order to constrain magma physical properties, injection rate or to obtain information in the geological history of these structures.

A physical model for the spreading of a magmatic intrusions below an elastic plate has been proposed by Chloé Michaut (JGR 2011) and tested on terrestrial laccoliths : the observed and modeled morphologies are in good agreement. In this project, we propose to complex the theory and to compare the model results with available data and observations on terrestrial as well as potential lunar and martian intrusions.

II- Floor-fractured craters

Floor-fractured craters are numerous on the Moon, and observed on Mars, Venus and Mercury. They seem to record an endogenous process of floor uplift that could be due to a central magmatic intrusion below the crater floor (this type of craters are observed in particular around sites showing intense magmatic activities). We propose to model the flow of magma below a crust of variable topography. The comparison of the modeled morphology for the flow to the potential intrusion geometry, deduced from the difference between the topography of modified craters and non-modified craters the same sizes, will provide constraints on injection rate and magma physical properties. The crater topography will be taken from the new topographic LOLA data, from the LRO mission, launched in 2009, for the lunar craters and the MOLA topographic data, for the martian craters. Most of the previous studies on these types of craters relied on images and morphometric analyses (Wichman and Schultz, 1995). We will also verify the compatibility of local gravity signals above crater sites with the presence of a magmatic intrusion at depth. Until now, the resolution of the gravity database from previous missions were not sufficient given the typical crater size (30-200 km). However, the GRAIL mission, launched in 2011, will provide gravity data (in 2012) whose resolution (<10mGal) should be enough to provide information on the crustal structure over a lateral scale of the order of several tens to a few hundred of kilometers.

III- Thermal evolution of intrusions, comparison of intrusive domes on Earth, Mars and the Moon.

From one planet to the other the dominant cooling process in the intrusion can be different. On the Moon, were water is absent, cooling is purely conductive on the intrusion walls. On Earth (and maybe on Mars), water circulation and hydrothermalism allow for a more efficient cooling of the intrusions. In consequences, terrestrial intrusions should be relatively shorter than on the Moon. On the Moon indeed, low-slope domes seem relatively larger than terrestrial laccoliths, and this, even considering physical factors influencing the intrusion spreading other than cooling (gravity and viscosity differences in particular).

Until now, only the dynamics of an isothermal intrusion, with a constant viscosity, has been developed. But, with time, the intrusion cools, its temperature decreases and its viscosity increases. This effect should play on the intrusion shape and final dimensions. We want to incorporate effect due to the cooling of the intrusions and study its influence on the final size and shape of intrusions. The model will be tested on the Moon and the Earth. By comparing the geometry and topography of lunar and martian domes and their terrestrial analogs (laccoliths), to the models results, we will bring constraints on the time necessary for intrusion emplacement, their physical properties, as well as on the dominant cooling process of these intrusions, in their respective environments. In particular, do we have to invoke a large part of cooling due to the circulation of fluids on Mars and the Earth to explain the radius and shapes of observed intrusions?

IV- Thermal evolution of the Moon and Mars

Finally, we want to replace the obtained results and observations, i.e. the presence or absence of intrusions, their physical characteristics, and the geological characteristics of their environments, in a more global context of the planet thermal evolution.

On the Moon, a phase of intense volcanism has lead to the formation of Mare basalts, and ceased 3 Ga ago. A fundamental question is then if the duration of this intense volcanism (3.9-3.1 Ga) was controlled by the presence of magma at depth or by its ability to reach the surface. The contraction due to cooling of the Moon, may have generated constraints that could have prevented the magma to reach the surface (Solomon, 1977). The evidence of intrusive volcanism seem all restricted to the lunar mare; the domes deform the Mare, they provide thus crucial information on the characteristics of the magmatic phase that followed the mare basalt.

On Mars, evidences for intrusions are rare and seems limited to recent volcanism. In this case, we will have to look for other indications of intrusion to understand their occurrence in time, in relation with the thermal and magmatic evolution of the planet in agreement with chemical and mineralogical data (Baratoux et al., 2011,Poulet et al., 2009).

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