Lunar Domes

Properties and Formation Processes

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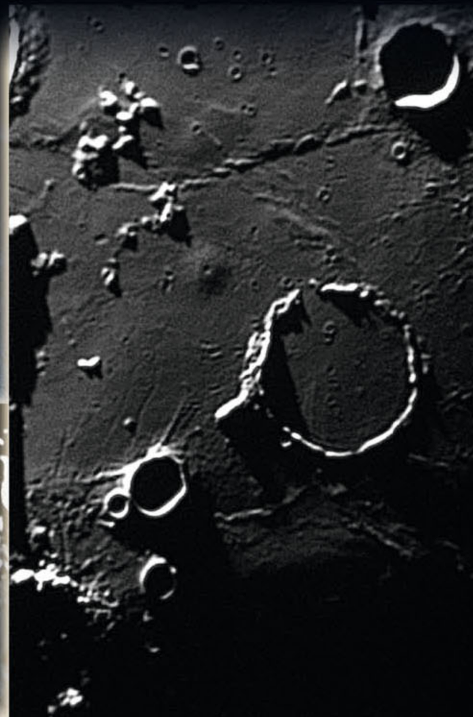

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To all the GLR (Geological Lunar Research Group) friends who have worked with us acquiring images to allow for lunar studies and increase of lunar knowledge.

Preface

During the six successful Apollo missions to the Moon, twelve human beings have walked on its surface. These efforts were accompanied by a variety of robotic spacecraft. Nevertheless, the Moon still has retained many of its secrets.

After the last manned mission, Apollo 17, which took place in 1972, and the unmanned Soviet spacecraft Luna 20–24 launched between 1972 and 1976, the next spacecraft was sent towards the Moon no earlier than 1994: Clementine achieved a nearly global multispectral mapping with imaging sensors in the visible and near-infrared wavelength range. The Clementine mission and a few years later the Lunar Prospector mission in 1998 have stimulated a broad range of scientific activities dealing with the geology and surface composition of the lunar surface. More recently, these efforts were continued by an international "armada" consisting of the European technology demonstrator Smart-1, the Chinese spacecraft Chang'e, the Japanese orbiter Kaguya (SELENE), the Indian spacecraft Chandrayaan-1, and the US-American Lunar Reconnaissance Orbiter (LRO), which provided high-resolution imagery as well as topographic and hyperspectral data of unprecedented quality.

An important domain of lunar research is the field of lunar volcanism. In this context, lunar domes are the result of volcanic processes on the Moon billions of years ago. Lunar domes are low volcanic edifices that are similar to small and low shield volcanoes on the Earth. Most of them are situated in the lunar mare regions, only few are located in the highlands, most of which are steeper than the lunar mare domes. On top of many lunar domes, summit pits can be observed. These are commonly interpreted as having been formed by the eruption of magma from a central vent. The shapes of a relatively small number of exceptionally low lunar domes suggest a formation by subsurface intrusion of a pressurised magmatic body rather than by lava eruption. This scenario is characterised by the intrusion of pressurised magma between layers of rock, the upper one of which is bent upwards to form a dome-like profile on the surface.

Generally spoken, the morphological development of a volcanic edifice is determined by the properties of the dome-forming lava, such as its viscosity, temperature, and chemical composition, as well as the effusion rate and the duration of the effusion process. The magma temperature and composition govern its viscosity and in turn the steepness of the resulting volcanic edifice. Hence, steeper lunar domes were probably formed by more viscous lavas of lower temperature and higher crystalline content than lunar domes with low flank slopes. Accordingly, knowledge about the morphometric properties of lunar domes, especially their diameters, heights, and volumes allows to estimate such magma-specific properties. Recent studies about lunar domes are therefore based on the evaluation of their spectral and morphometric properties, rheologic parameters, and their classification.

This book describes these physical differences between lunar domes of different appearance, examines the factors that may have led to a concentration of domes with certain properties in certain lunar regions, and discusses how the variety of observed properties of lunar domes are related to the characteristics of the dome-forming magma. The presentation partially draws upon various previous publications by the authors.

Notably, the detailed study of lunar domes is only possible based on images of the lunar surface acquired under strongly oblique illumination conditions. The Lunar Orbiter images have hardly been acquired under such illumination, while most images of the Clementine spacecraft were taken at high solar illumination, which is the best configuration for spectral studies. LRO provides coverage of the lunar surface at more or less oblique illumination, but not all known lunar domes are favourably imaged. Most lunar domes are discernible in the topographic maps acquired by the laser altimeters LALT and LOLA on board the Kaguya and LRO spacecraft. Hardly, however, they can be unambiguously identified as lunar domes based on such data alone. As a consequence, ground-based images obtained using telescopes and CCD cameras like those commonly used by well-equipped amateur astronomers are still of great value for the morphologic and morphometric analysis of lunar domes in their geological context.

Accordingly, the main goal of this book is to describe the present knowledge about lunar domes and also to encourage dedicated amateur astronomers who are interested in lunar observations and imaging as well as in the geologic processes that formed the lunar surface. All figures of the book (including the colour versions) are available at Springer ExtraMaterials (http://extras.springer.com/; 978-88-470-2636-0).

The Authors

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Contents

Part I

Lunar Domes Morphometry, Geophysical Modelling and Formation Processes

Volcanism on the Earth and the Moon: Morphometry and Eruption Conditions

1

Abstract

This chapter provides an overview of terrestrial and lunar volcanic processes. The dependence of the shape of a volcanic construct on the physical and chemical properties of the erupting lava is described. Furthermore, an introduction to lunar pyroclastic deposits, lunar cones and effusive lunar domes and their vents as well as an outline of the occurrence of different types of volcanic constructs on the Moon and the corresponding formation mechanisms is given.

1.1 Volcanic Processes and Formation of Volcanic Edifices on the Earth and the Moon

According to the currently most commonly accepted hypothesis, the Earth's Moon was formed by the impact of a protoplanet of about the size of Mars into the proto-Earth (Vaniman et al. 1991). It is assumed that both protoplanets had a core largely consisting of iron and a silicate mantle. According to this model, most of the material ejected during the collision was made up of silicates, which explains the fact that the Moon only has a small metallic core and therefore has a significantly lower average density than the Earth. On the Moon, an outer molten layer of silicate material then formed the so-called "magma ocean" reaching down to a depth of 250–1,000 km, where a differentiation occurred in the form that low-density plagioclase-rich material (which nowadays forms the lunar highlands) rose to the surface while minerals of higher density, e.g. pyroxene, olivine, and ilmenite, formed layers at higher depths. After solidification of the plagioclase-rich upper layer, partial melting of the denser lower layers resulted in the occurrence of extended basaltic volcanism on the Moon (Vaniman et al. 1991).

Fluid material rising up from the interior of a planet is termed "magma" as long as it is located inside the planetary interior and "lava" once it reaches the surface. The so-called "volcanic" or "extrusive" magmatic processes lead to the eruption of lava to the surface, which

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