Volcanic Features and Processes

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General Overview and Outline:
Overview:

Lunar volcanism is a fundamental process in the geological and thermal evolution of the Moon. Early studies have used geological, petrological, and remote sensing data to define and characterize deposits and features associated with lunar volcanism (e.g., Head, 1976), and to model the generation, ascent and eruption of lunar magma (e.g., Wilson and Head, 1981). Remote sensing data have been used to define and characterize geological units of volcanic origin (e.g., Head et al., 1978; Pieters, 1978), to link these units to samples returned from Apollo and Luna missions, and to assess the role of volcanism in lunar thermal history (e.g., Solomon and Head, 1980). The advent of Galileo and Clementine remote sensing data permitted more extensive definition and characterization of units, and impact crater size-frequency distribution (CSFD) analyses provided an important assessment of the chronology of emplacement (e.g., Hiesinger et al., 2002, 2003; Wagner et al., 2002). Improved data (e.g., spatial and spectral resolution and coverage) permitted further documentation of the characteristics of lunar volcanic features and deposits (e.g., Greeley et al., 1993; Weitz et al., 1998; Weitz and Head, 1999; Heather et al., 2003) and the implications for the generation, ascent and eruption of magma (e.g., Head and Wilson, 1992; Wilson and Head, 2003).

A plateau was reached in 2006 with the synthesis and publication of *New Views of the Moon*, a compendium of the geology (Hiesinger and Head, 2006), remote sensing (Lucey et al., 2006), petrology (Shearer et al., 2006), chronology (Stoffler et al., 2006) and thermal evolution (Wieczorek at al., 2006) of the Moon and, implicitly and explicitly, the role of volcanism.

In the decade since this time, a flood of new data has been acquired and continues to be acquired for the Moon. Missions such as Lunar Reconnaissance Orbiter, Chandrayan-1, SELENE-Kaguya, Chang'e 1-3, LADEE, LCROSS and GRAIL have provided views of the Moon and its environment in unprecedented detail. Much of this new information has significant implications for the characterization and understanding of lunar volcanism. From these missions, extremely high resolution image data have revealed the characteristics and distribution of volcanic features and structures (sinuous rilles, cones, domes, flow fronts, vents, pits, etc.) and permitted improved and more extensive chronology from CSFD analyses. Spectral data have revealed the mineralogy of volcanic features, and gravity data have provided new insight into the thickness and physical properties of the lunar anorthositic crust that mantle-derived melts must transect.

These new data have permitted a host of analyses in the last decade that have changed our view of lunar volcanism and the processes of magma generation, ascent and eruption. We now have an improved understanding of the array of volcanic features and provinces: irregular mare

patches, IMPs, interpreted as very recent volcanism (Braden et al., 2014); floor-fractured craters and evidence for shallow intrusions and eruptions (Jozwiak et al., 2012, 2015); the global distribution and characteristics of sinuous rilles (Hurwitz et al., 2013); new definitions of shield volcanoes (Spudis et al., 2013); improved understanding of pyroclastic deposits(Gaddis et al., 2003); improved definition and documentation of cryptomaria (Whitten et al., 2015a,b); documentation of silicic domes and pyroclastic deposits (Glotch et al., 2011; Jolliff et al., 2011); improved understanding of the cones, domes and flows in volcanic complexes (Stopar et al., 2015; Besse et al., 2011; Bugiolacchi and Guest, 2008; Campbell et al., 2009; Lawrence et al., 2013); and many other features. New data have permitted improved chronology for lunar volcanic deposits on the lunar nearside and farside (e.g., Hiesinger et al., 2011; Whitten et al., 2011; Paskart et al., 2015; Morota et al., 2009) adding constraints on the geological and thermal evolution of the Moon. Finally, these new data have permitted the reassessment of the generation, ascent and eruption of magma on the Moon (Wilson and Head, 2016; Head and Wilson, 2016a, b).

Thus, *New Views of the Moon 2* provides a unique opportunity to synthesize the important developments of the last decade in our understanding of lunar volcanism and its implications for lunar petrology and the thermal evolution of the Moon. Equally importantly, it is essential that we not only outline the current state of knowledge, but also identify the set of outstanding questions that will help us improve our current understanding in the coming decades. In the future exploration of the Moon, where do we need to go and what do we need to do to address these most critical questions? How can this information inform the design of new instruments and spacecraft and the architecture of new lunar exploration strategies? What are the roles for robotic orbiters, landers, rovers, and sample return missions? What are the roles for human exploration and human-robotic partnerships? How can humans contribute from lunar orbit or cis-lunar space?

Basic Background and Goals for the Lunar Volcanism Chapter:

-Orientation of the approach is:

1) Geological (What volcanic deposits do we observe on the Moon, what are their characteristics and associated features, and what is their chronology?).
2) Process (How did magma get there, andwhat are the implications for its generation, ascent and eruption?).
3) What are the implications of the observed volcanic deposits for the geological, petrological and thermal evolution of the Moon?

Relationships to other chapters:

1) We use use remote sensing data to summarize and characterize volcanic deposits, but leave the important details of the remote sensing data to other chapters.
2) We summarize the geological setting, characteristics and chronology of lunar volcanic deposits, and provide an assessment of the physical volcanology (the generation ascent and eruption), as an aid in interpreting the petrogenesis of volcanic rocks.
3) We provide a summary of the implications and constraints of lunar volcanic deposits and their chronology as input into the thermal and geological history of the Moon.

The Outline:

I. Background and history of lunar volcanism studies. Brief, referring to the existing literature. Similar to the *Overview* section above.

II. Characteristics and distribution of lunar volcanic deposits:
A) Unit definition and characterization.
B) Mineralogy, chronology and distribution of mare volcanic deposits, including cryptomaria and irregular mare patches (IMPs).
C) Mineralogy, chronology and distribution of non-mare (silicic) volcanic deposits.

II. Characteristics and distribution of lunar volcanic features:
A) Lava flows and compound flow fields.
B) Dark Mantle Deposits.
C) Pit craters and crater chains.
D) Cones.
E) Sinuous rilles.
F) Linear rilles with associated volcanism.
G) Domes: Small shield volcanoes.
H) Viscous domes and related non-mare volcanic deposits.
I) Large shield volcanoes.
J) Volcanic complexes (Marius Hills, Rumker Hills, Aristarchus, Prinz-Harbinger, etc.).
K) Floor-fractured craters.
L) Irregular Mare Patches (IMPs).

III. A synthesis of the history of lunar volcanism (space and time):

IV. A synthesis of the generation, ascent and eruption of magma on the Moon:

V. A synthesis of the implications of the lunar volcanic record for the geological, petrological and thermal evolution of the Moon

VI. Outstanding Questions and future research and exploration strategies.

-Figures, tables and references.
-Appendix: Catalog of downloadable global unit and feature data sets in ArcGIS shapefile format.

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