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Galilean satellite geology: Outstanding questions

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Abstract

The Galilean satellites comprise a fascinating and diverse array of planetary bodies whose landforms give clues to their histories. Io is the solar system's most volcanically active world, constantly resurfacing itself on human timescales. Europa surface does not reveal its early surface history; the likely presence of an ocean and ongoing tidal stresses result in a youthful surface heavily overprinted by cryovolcanic and tectonic processes. The ice-rich moons Ganymede and Callisto are both believed to have internal oceans, however, these moons have divergent evolutionary histories: Ganymede is strongly differentiated with a history of active tectonics and icy volcanism, while Callisto is weakly differentiated with no signs of internal geological activity. The joint NASA/ESA Europa Jupiter System Mission (EJSM), planned to launch in 2020, will carry a comprehensive set of instruments to investigate these enigmatic worlds.

Introduction

Jupiter's diverse Galilean satellites – three of which are believed to harbor internal oceans – are the key to understanding the habitability of icy worlds. To this end, the Europa Jupiter System Mission (EJSM), an international joint mission under study by NASA and ESA, has the overarching theme to investigate the emergence of habitable worlds around gas [1, 2]. The reference mission architecture consists of the NASA-led Jupiter Europa Orbiter (JEO) and the ESA-led Jupiter Ganymede Orbiter (JGO). JEO and JGO will execute a coordinated exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively. JEO and JGO carry sets of complementary instruments, to monitor dynamic phenomena (such as Io's volcanoes and Jupiter's atmosphere), map the Jovian magnetosphere and its interactions with the Galilean satellites, and characterize water oceans beneath the ice shells of Europa and Ganymede. Here we discuss the major outstanding geological questions for each Galilean moon, and how those could be addressed by the EJSM mission.

Io

Io's high-temperature silicate volcanism leads to massive inflating lava flow fields (Fig, 1); major, explosive, high-temperature outbursts; volcanic plumes; and overturning lava lakes. Io's surface has numerous mountains up to 18 km in height, possibly the result of contraction resulting from gradual subsidence of the lithosphere. Key geological investigations for Io include understanding the eruption mechanisms for Io's lavas and plumes, and their implications for volcanic processes on the early Earth; understanding how volcanism operates in extreme environments; understanding Io's surface chemistry and magma compositions, and what those imply for interior differentiation and contributions to the external environment; and understanding the processes that form Io's mountains.

Figure 1: Lava flows from the Prometheus volcano on Io. The lava flow extends 90 kilometers (54 miles) from the source.

Europa

The "ocean world" Europa is believed to have a relatively thin ice shell above a saltwater ocean in direct contact with its rocky interior. Europa's surface has only a small number of impact craters, and is instead dominated by tectonic features. These include double-crested ridges (Fig. 2), troughs, and bands. Ridges may form when cracks in the shell are reworked by repeated diurnal stressing, while pull-apart bands have formed by complete separation and spreading of the icy lithosphere, in a manner perhaps analogous to terrestrial sea-floor spreading. Europa's global-scale lineament patterns are consistent with long-term stressing by nonsynchronous rotation, amplified by short-term cycling from diurnal orbital flexing. The most recent type of widespread surface deformation comes in the form of chaos terrains, where the surface has been upwarped and broken apart on scales ranging from small domes to large local regions. These features may have formed by laccolith-like intrusion of diapiric ice masses, possibly with some associated partial melting of the ice shell. Key geological investigations for Europa include understanding the three-dimensional character of the icy shell; understanding how surface features such as ridges, bands and chaos form, and whether liquid water is involved; determining whether the ice shell is convecting, and what the surface expression of such activity would be; and determining whether Europa's activity has changed over time, and whether Europa is active today.

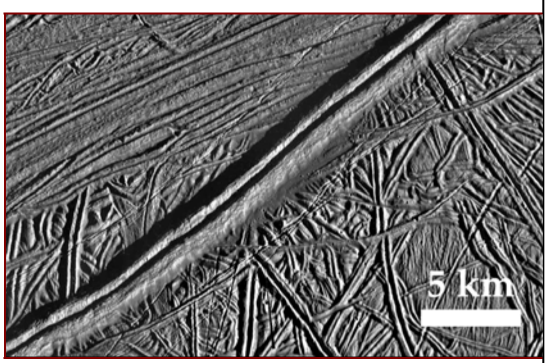

Figure 2: One of Europa's characteristic double ridges, which are found across the entire surface, and throughout Europa's history.

Ganymede

Ganymede's surface can be broadly separated into two geologically distinct terrains: Dark terrain covers 1/3 of the surface and is dominated by impact craters with a variety of morphologies. It is ancient (perhaps essentially primordial), and contains hemisphere-scale sets of concentric troughs termed furrows, probably the remnants of vast multi-ring impact basins, now broken up by subsequent bright terrain tectonism. Bright terrain forms a global network of interconnected icy lanes, separating the dark terrain into polygons. Within the bright terrain is an intricate patchwork of closely spaced parallel ridges and troughs, termed grooves, which morphologically have much in common with terrestrial rift zones. The relative roles of tectonism and icy cryovolcanism in creating bright grooved terrain are an outstanding issue. Key investigations about Ganymede include finding out whether the dark terrain is primordial, and how it compares to Callisto's early history; understanding the relative roles of tectonism and volcanism in shaping bright grooved terrain; determining how old the grooved terrain is, and how long it took to form; and studying what the variety of impact crater morphologies and relaxation states can tell us about the thermal history of Ganymede and the evolution of the Jovian system impactor population.

Callisto

As the outermost large satellite of Jupiter, Callisto is the least affected by tidal heating and the least differentiated, thus offering an "endmember" example of satellite evolution for the Jovian system. Impact features, many of which are vast multi-ringed structures, dominate Callisto's surface. There is no evidence of cryovolcanic resurfacing; the key surface modification process appears to be sublimation degradation. Callisto's landscape at decameter scales, and particularly its lack of small craters, is unique among the Galilean satellites, and might be akin to that of cometary nuclei. Key geological investigations for Callisto include understanding the relationship between Callisto's surface geology and its interior state; understanding what multi-ringed structures imply for the interior; understanding what controls Callisto's crater populations, and what does this tell us about the cratering history of the Galilean satellites.

Summary

There are many unanswered questions about the Galilean satellites, and their surfaces reveal much about their history. The EJSM mission, which would include numerous flybys of all four satellites, and one spacecraft each orbiting Ganymede and Europa, would bring a significant increase in understanding how satellite systems form and evolve.

References

[1] Jupiter Europa Orbiter, JPL Document, D-48297, 2008.

[2] Europa Jupiter System Mission, Joint Summary Report, JPL Document, D-48440, 2008.