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Geological exchange processes on Europa and Ganymede: What can we learn from future missions?

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Abstract

The surfaces of Europa and Ganymede each show ample evidence of a dynamic past. Exchange processes on these satellites can be investigated by the Europa Jupiter System Mission (EJSM), an international mission consisting of two primary elements operating in the Jovian system. EJSM consists of the NASA-led Jupiter Europa Orbiter (JEO), and the ESA-led Jupiter Ganymede Orbiter (JGO). Each spacecraft would explore different aspects of the Jupiter system: the JEO element would carry out its primary mission phase in orbit around Europa, while JGO would enter orbit around Ganymede. EJSM has been prioritized by NASA and ESA as the next Flagship mission to the outer solar system, and would launch in or around 2020.

Ganymede

Ganymede's surface is comprised of two geologically distinct terrains [1]. Bright terrain consists of polygonal swaths of smooth- to heavily-faulted relatively clean ice. Dark terrain covers 1/3 of the surface and is dominated by impact craters with a variety of morphologies. Crater densities suggest that the age of dark terrain is ~4 Gyr, while bright terrain may have been emplaced anywhere from ~400 Myr to >4 Gyr ago [2, 3]. The oldest recognizable units of the surface are remnants of vast, multiringed basins termed furrow systems, inferred to be the scars of impacts from a time when Ganymede's lithosphere was relatively thin and mobile. The low albedo of the dark terrain is inferred to be due to the presence of dark, meteoritic (probably silicate) material in the crust [4], some of which has accumulated on the surface as a sublimation lag deposit [5]. The most probable cryovolcanic features identified on Ganymede are 18 or so arcuate depressions, or "paterae", found within the bright terrain, which could represent source vents for icy volcanic flows [6]. The paterae may have formed in association with bright terrain, by the collapse of blocks over partially drained magma chambers in a similar manner to terrestrial calderas. If these are representative of bright terrain cryovolcanism, however, it is not clear why they are only found in some regions, and are not widespread in distribution as is the bright terrain. Bright terrain appears to have formed at the expense of dark terrain and has clearly undergone significant tectonic deformation. Early analyses using Voyager data suggested that the bright terrain represents frozen cryovolcanic deposits that had flooded and filled graben [7]. Galileo imaging instead showed that most of the bright terrain is heavily tectonized even at local scales, leading to the idea of "tectonic resurfacing", in which dark terrain is so heavily tectonized as to be unrecognizable [8], with a corresponding overall brightening of the terrain. The brightening is attributed to the draining down of dark lag deposits into faults and troughs, leaving cleaner, icier surfaces exposed. An alternative formation mechanism for limited swaths of Ganymede's bright terrain suggests that some swath margins could be reconstructed, implying that complete lithospheric separation has occurred [9]. On the basis of topographic modelling, others conclude that the presence of uniformly low-standing smooth terrains, when compared to adjacent, older, highly deformed terrain, suggested that there had been downdropping and flooding of an equipotential surface [10], most simply interpreted within a paradigm of cryovolcanic resurfacing of graben. The proposed models have significantly different implications for surface exchange processes on Ganymede, and the importance of cryovolcanism is uncertain. Key among future

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investigations that would be carried out by the JGO element of the EJSM will be geological and topographic mapping. These techniques would provide valuable global topography and would be able to measure the characteristics of the swaths at a variety of scales. The JEO element of the EJSM would carry out several flybys of Ganymede and would be able to carry out subsurface sounding. Such would be able to determine, for example, whether groove terrain swaths are bounded by graben and are filled with cleaner, icier material than the surrounding dark terrain.

Europa

Europa's young (~60 Ma [2]) icy surface shows ample evidence for exchange processes between the surface and subsurface. Much of Europa's surface has been disrupted into isolated plates of preexisting material with lumpy matrix material between the plates (e.g. [3, 11]). This disrupted terrain may take the form of either large disrupted regions (known as "chaos"), or smaller subcircular to elliptical pits, dark spots, domes and microchaos regions (collectively termed "lenticulae") which are commonly ~10-15 km in diameter. In almost all cases, chaos and lenticulae disrupt other feature types and are at the top of the stratigraphic column. Models for chaos formation generally fall into two end-member categories. One model suggests that chaos forms where Europa's heat flow has been enhanced, and where local melt-through of ocean water to the surface may have occurred [e.g., 12]. An alternate model for chaos formation proposes that ice diapirs have risen buoyantly through the ice shell, breaking or otherwise interacting with the surface [13]. A third model suggests that at least some chaos formed through impacts [14], although it is difficult to reconcile this model with observations of Europa's impact structures, which do not exhibit the characteristics of chaos.

Other features on Europa show clear evidence of surface-subsurface exchange, but have formed further back in Europa's visible past. Bands are swath-like or polygonal features measuring ≤30 kilometers wide and tens of kilometers long [15]. If the dark material comprising some of the bands is removed, their margins fit back together so that the surrounding preexisting lineaments can be reconstructed. Thus the presence of these "pull-apart" bands indicates that complete opening of the lithosphere has occurred, with low albedo material filling in the newly created gap. Further investigation using Galileo data has led to two chief models of band formation, one in which bands form by the opening and closing of a crack, with liquid water filling the gap and freezing [16.], and a second which suggests bands formed in the solid state, and may be more analogous to terrestrial mid-ocean ridges. A third class of features is represented by ridges, which have formed throughout Europa's visible history and may still be forming today [e.g., 11]. Ridges appear to be part of a genetic sequence of different morphological types, ranging from simple troughs, through double ridges, and finally any number of closely spaced ridges, termed "ridge complexes" [11, 18]. The details of how the majority of Europa's ridges are created are still open to debate, but it seems most likely that an element of strike-slip movement along a crack results in the formation of the ridges alongside each ridge [19]. Near-global geological, topographic and subsurface mapping by JEO would help to distinguish among which processes formed each of Europa's feature types. This information can then be extrapolated to other icy satellites.

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