CRYOVOLCANISM IN CONCEPT AND REALITY

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Introduction: Planetary volcanism is considered by R. Lopes as a conduit-fed eruption whereby a magma, defined specifically for each body based on meltable substances, is erupted onto a planetary surface. The term "cryovolcanism" has roots meaning "icy cold doctrine of Vulcan." The etymology and meaning of that and related terms is better understood when parsed from traditional geological terms. Thus, cryovolcanism is the eruption and flow of icy-cold aqueous or non-polar molecular solutions or partly crystallized slurries, perhaps containing gas bubbles, derived by partial melting of icy materials. Cryoclastic (adjective) is an icy cold parallel of pyroclastic; cryomagma (noun) is an icy cold magma—water based, or not; and cryo-igneous (adj.) is a cold parallel of igneous. These cryo terms pertain to melting and solid-liquid phase separation, ascent, and eruption of liquids on icy planets, moons, comets, and asteroids.

Cryovolcanism in concept: The concept of cryovolcanism is that icy satellites are heated and ices melt, thus generating a liquid phase, which then erupts. Hypothetically, cryovolcanoes, cryolava flows, and cryoclastic ash sheets can form. Cryomagmatism also can form cryo-igneous dikes, sills, and batholiths.

Studies of cryovolcanism employ three methodologies: laboratory measurement of cryomagma properties and simple deductions about cryovolcanism on icy bodies; the theoretical geophysics of melt formation, phase separation, ascent, and eruption; and the identification of landforms possibly formed by cryovolcanism. Some researchers have emphasized physico-chemical parallels expected between the cryomagmatic processes and landforms and those of silicate magmatic processes and landforms. Cryovolcanism is primarily a concept for extraterrestrial icy worlds involving different classes of substances than what pertain to well-studied cases of magmatism and volcanism on rocky worlds, e.g., Earth, Moon, Venus, and Mars. However, the physics and products of cryovolcanism and cryomagmatism are not alien; they draw directly from basic physics and Earth's igneous processes and landforms.

Two requirements for cryovolcanism, and for volcanism in general, is that there must be enough heat to partially melt interior substances, and buoyancy must be able to drive liquid phase separation, ascension, and eruption. Melting can occur, but if the liquid is denser than the solid, then the liquid might sink and form an ice-crusted ocean. In H_2O-dominated systems, pure liquid water is denser than ice I, thereby preventing cryovolcanism. Freezing-point depressants, e.g., ammonia, methanol or salts, can aid melting on low-energy budgets, but the resulting liquids mainly are still denser than ice I. Hence, a dissolved and exsolvable gas component may be needed to drive aqueous cryovolcanic eruptions—a direct parallel with most types of silicate volcanism. Most icy satellite sources of cryomagmas are not pure ice; many mineralogical constituents may melt and partition into eutectic aqueous liquids. These constituents commonly might include both freezing point depressants and nonpolar or weakly polar gases. Ammonia-water solutions are a favored candidate cryolava for Saturnian satellites, whereas various salt-water brines might make sense for asteroids and Jovian moons. I will discuss the physico-chemical properties of candidate cryolavas and what the properties may mean for processes and landforms.

Cryovolcanism in reality (and not):

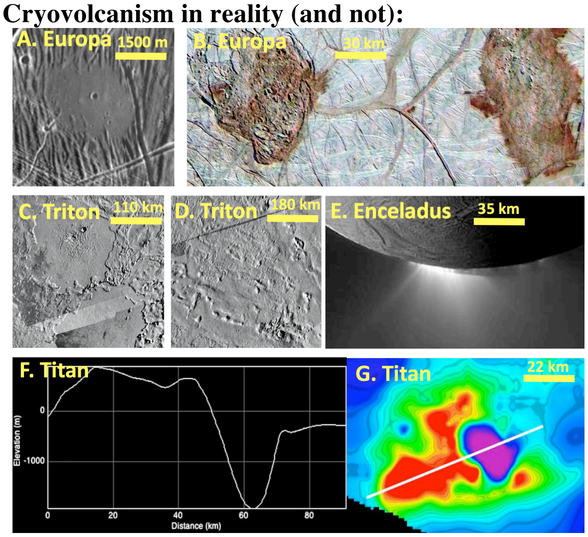

Fig. 1: Possible cryovolcanism.

Voyager images of Ganymede showed what appeared to be flooded grooved tectonic terrain and cryovolcanic collapse. Galileo observations offered less support for that interpretation, and expected widespread cryovolcanic plains on Europa turned out to be absent, but limited spectacular cases of cryovolcanic extrusions and cryolava plains were found on Europa in Galileo images. Enceladus has the most compelling cases for cryovolcanism, where Voyager 2-era suggestions of cryoclastic volcanism were spectacularly confirmed by multiple Cassini instruments showing active plume erupting through tectonic rifts. Other cases of cryovolcanism are suggested for other worlds, notably from Voyager 2 images of Triton and Cassini radar scenes of Titan. However, good cases of ice-crusted satellite oceans exceed the number of satellites with compelling cases of cryovolcanism. A child's knowledge of ice applies… normal ice floats on water.