THE "SWARM" - A PECULIAR CRATER CHAIN ON VESTA.

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Introduction: NASA's Dawn spacecraft arrived at asteroid 4Vesta on July 16, 2011, and spent 141 days (between Dec. 13, 2011 and Apr. 30, 2012) in the Low Altitude Mapping Orbit (LAMO), during which the Framing Camera 2 (FC2) obtained 10251 images with an average spatial resolution of 20m per pixel.

The surface of Vesta displays a diverse geological structure – numerous impact craters of all sizes, extended ejecta blankets, a large trough system around the equator, and large impact basins [1]. We used the entire data set obtained in LAMO to search for crater chains (Catenae) – defined by the IAU as *a line of craters along the surface of an astronomical body*.

Crater Chains in The Solar System: Crater chains are a common feature in the solar system. The current IAU nomenclature list includes 62 named Catenae, on 9 solar system bodies. They are a subgroup of the larger family of lineament features, and cover a large range of sizes - from a few kilometers to almost 1000 km in length. The current literature identifies few mechanisms for their formation.

Exogenous processes include primary, and secondary impact cratering, while *endogenous* processes involve the collapse of fine surface regolith into subsurface faults or fractures, forming a line of collapse pits known as pit crater chains.

Exogenous case 1 - Primary Impact Craters: A long-standing mystery from the first flybys of the two Voyager spacecraft in the late 1970's was the discovery of crater chains, on Callisto and Ganymede. These impressive straight chains are composed of between 4 to 25 craters, and are up to 620 km long. They were initially thought to be secondary craters produced by projectiles from a larger primary craters, which were never found. Inspired by the observation in 1993 of comet Shoemaker-Levy 9, which split into a line of about 20 fragments as it swept past Jupiter, Melosh & Schenk [2] suggested that the impact of a previously split comet might have been responsible for some of the catenae on Callisto and Ganymede. Modeling of tidal disruption by the Earth and Moon of ''rubble-pile'' bodies by Bottke et al. [3] suggest that the Earth has disrupted enough objects over the last 3.8 billion years to account for one or two lunar crater chains.

Exogenous Case 2 - Secondary Impact Craters. In order to classify a crater chain as a product of an aligned "projectile train" of secondaries, it is essential to identify the source impact crater. Early Lunar images from the Apollo missions revealed numerous lines or chains of craters which have been classified into two groups: volcanic crater chains (endogenous), and secondary impact crater chains extending radially from large craters (such as Copernicus, Kepler, and Aristarchus) formed by ballistic ejecta. The Stevenson crater on Mercury (imaged by MESSENGER) presents very distinct lines of secondary crater chains crisscrossing its floor (in an X-shape), the result of impacting ejecta from two primary craters which are outside the field of view. Secondary crater chains are also found on Mars, and most icy satellites.

Exogenous Case 3 - *Phobos* The origin of the grooves of Phobos has been debated since they were first discovered. Recently, it has been suggested that they result from material ejected from large impacts on Mars. The orientation of each family of grooves allows the inertial direction of arrival of the ejecta at Phobos to be determined. [4][5].

Endogenous Case 1- Pit Crater Chains. Pit craters are circular to elliptical depressions found in alignments (chains), which in many cases coalesce into linear troughs. They are common on the surface of Earth and Mars and also have been observed on Venus, the Moon, Phobos, Eros, Enceladus, and Europa. Pit craters lack the features that are usually associated with impact craters: an elevated rim, ejecta deposits, or melt. It is generally agreed that the pits are formed by collapse into a subsurface fracture [6,7,8] . Very few endogenic geologic processes operate on such a wide variety of planetary bodies with various lithologies and geologic histories. The identification of pit chains on wide range of bodies - from small asteroids to icy moons to large terrestrial planets - raises important questions regarding both the potential geologic formation mechanisms and near-surface regolith and crust properties of solid bodies in the solar system [e.g. 6,7,8].

Endogenous Case 2 - Lava Channels. Crater chains frequently occur on the flanks of shallow shield volcanoes, the bases of which have a very large diameter. When a lava flow cools and solidifies on its surface, its interior remains liquid and continues to flow as if inside a pipe, creating a subterranean cavity. Once the volcanic activity ceases, a tunnel or drained lava tube can be left behind underground. Over time, separate sections along the rocky roof of the tube collapse, leaving circular depressions on the surface. Such lava tubes have been observed and studied on Earth, Mars and the Moon [9,10].

Crater Chains on Vesta: We searched the entire LAMO imaging dataset for crater chains. More than 300 surface features were identified as crater chains, the great majority of which are oriented in the east - west direction (parallel to the equator). Based on their morphology the chains were divided into subgroups: (a) Single crater chains associated with other linear geological features (lineaments) e.g. trenches, grooves, or troughs. (b) Single crater chains not associated with other linear geological features. (c) Families or groups of crater chains in complex spatial configuration – either few short segments along a general lineament, and/or next to each other in close parallel lines. (d) The swarm - an elongated aggregation of numerous small craters aligned as a wide band - not a single chain.

The Swarm - A unique crater Chain on Vesta: An elongated concentration of small craters (Fig. 1a) is located in the Pinaria quadrangle Av-11, centered at 21.8E and 26.7S. There is no clear association of the craters to other lineation features, and it is not a collection of single chains. The craters are symmetrically distributed on both sides of the main linear axis of the aggregate, with decreasing crater density as function of the distance away from the central symmetry axis. Crater counting in three sub-regions of the chain (Fig. 1b), including more than 1600 craters, suggest a very distinct group of small craters with a peak size at a diameter of 105m and FWHM of 85m (Fig. 1c). We suggest that this swarm is a very enigmatic crater chain of unique morphology. The following formation scenarios are possible: 1) collapse pits, 2) secondaries from an unknown primary crater, 3) impact of a small fragmented rubble pile satellite, and 4) impact of fragments of an ancient disc. More detailed 3D modeling is required to constrain the origin of the Swarm.

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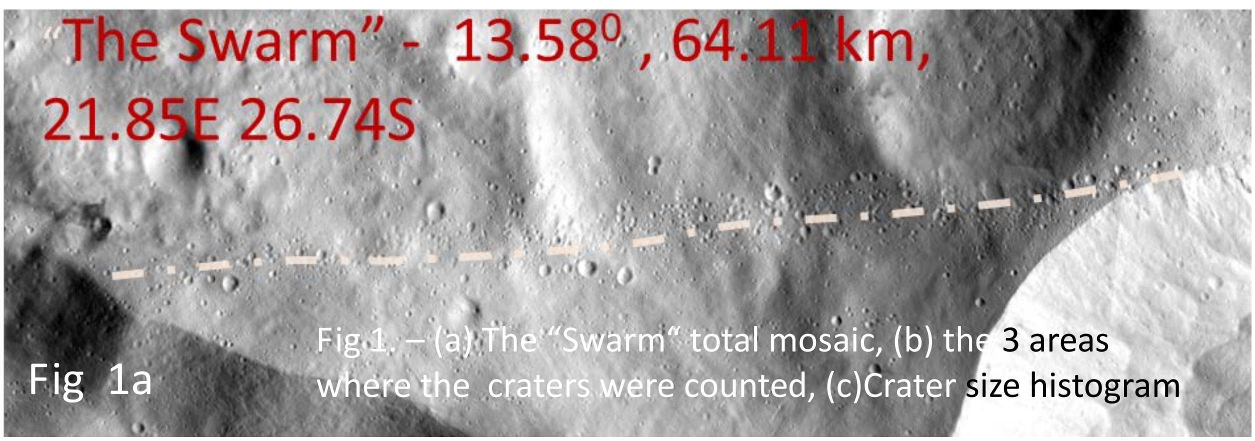

Fig.1. – (a) The "Swarm" total mosaic, (b) the 3 areas where the craters were counted, (c)Crater size histogram