SAMPLES

EXTENDED ABSTRACTS OF PLANETARY ANALOG RESEARCH

Compressional tectonics in the Alpine Fault, New Zealand: An analog for contractional features on Mercury.

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Introduction: Similar to Earth, Mercury is composed of a core, mantle, and crust. Due to this similarity in internal structure, many earth-like features are found on Mercury's surface. These include: highlands (mountainous regions/elevated plateaus), planitae (plains), valles (valleys), and rupes (steep slopes). Although Mercury is similar to Earth in many ways, it is still different in others. One difference between Earth and Mercury is plate tectonics. Mercury does not have multiple tectonic plates that converge, diverge, or transform one another due to internal heat. Instead, tectonics on Mercury is from global contraction of the planet due to a cooling interior.

Aiming to understand the global contraction of Mercury using a terrestrial analog can be challenging. Although there is no available terrestrial analog for the global contraction of Mercury, there are suitable analogs for the thrust fault features formed as a result of this shortening. Compressional features found in the Alpine Fault in New Zealand can serve as an adequate tool in interpreting the origin of thrust faults found in Mercurian topography.

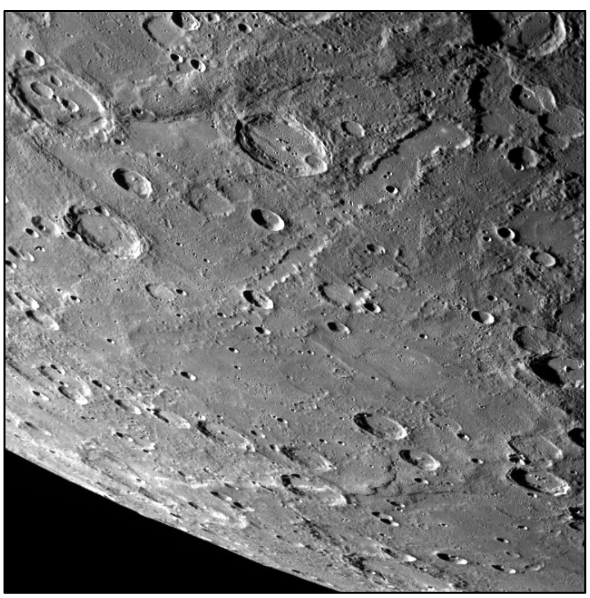

Fig. 1: Image 6776363 from the Wide Angle Camera of the Mercury Dual Imaging System showing scarps in Enterprise Rupes, Mercury. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Thrust faults found on Mercury: Lobate scarps, surface features formed due to thrust faults in rock, have been found to be the prevailing contractional feature found on the surface of Mercury [1, 2, 3,4]. These small scale thrust fault scarps were found in images from the MESSENGER Mission that spanned from 2011-2015 (Fig. 1 and 2). Average relief of thrust faults found on Mercury can range from ~0.06-3 km and lengths of the scarps are found to be <10 km [2, 3].

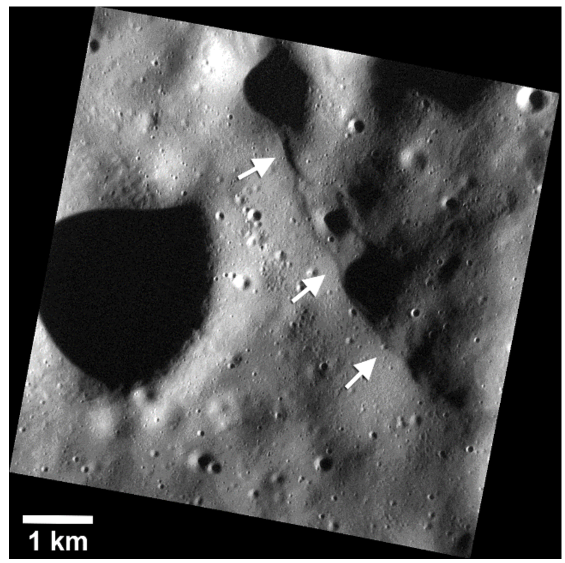

Fig. 2: Image from the Narrow Angle Camera of the Mercury Dual Imaging System showing a <10 km long scarp on the surface of Mercury. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington (no image ID number provided)

Two major topographic units have been identified on Mercury: the smooth northern plains and the intercrater plains [2, 4]. The average dips for the smooth plains and intercrater plains are 35° and 25° [2]. The smooth plains have been characterized by reflecting thin-skinned tectonics found on Earth [2, 4]. This thin-skinned deformation takes place in the upper units of the crust and can be classified as deformation in units due to weak layers just below the surface. In the case of the smooth plains, faulting primarily takes place in the volcanic units and is identified on the surface generally as wrinkle ridges [2].

In contrast, the intercrater plains show signs of a different type of deformation. Distinguishing features such as lobate scarps and high relief ridges are found in the intercrater plains. These features are indicative of thick-skinned deformation in the crust [2]. Rather than deformation taking place solely in upper units, the deformation in this case will continue into basement rock. Thrust faults from both thick- and thin-skinned deformation can be identified on the surface as lobate scarps and wrinkle ridges. The occurrence of these ridges and scarps is notable. Instead of finding individual thrust faults, faults are detected to occur in thrust systems [1,4]. This implies that the faults are structurally linked below the surface [4].

Thrust faults found in New Zealand: The Alpine Fault is located on the west side of New Zealand's South Island (Fig. 3). Many small thrust scarps have been studied to determine displacement of larger faults in the Alpine system. Thrust scarp heights in this area range from <1 m to ~100 m and could measure 230-800 m in length. The total length of the Alpine Fault is ~1600 m. Faults have an average dip of ~50° [5]. The Alpine fault has an average height increase of 11 mm/year [6]. Maximum displacement of faults ranges from 2 to 7 m [5].

Fig. 3: Image of South Island, New Zealand captured by the Moderate Resolution Imaging Spectroradiometer on the Terra satellite. Credit: Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC

Most of this region is covered by a dense forest due to heavy amounts of rainfall. Therefore, rock exposure is limited to rivers and streams that cut through existing rocks [7]. There have been multiple studies measuring strike and dips of structures in different outcrops exposed by water erosion. While observing the different features, the composition of rocks was also noted. Rocks found in the Alpine Fault system include: greywacke, gouge, schist, mylonite, and fluvioglacial gravel [7,6]. Greywacke is a type of sandstone that contains a significant amount of clay. Schist and mylonite are both types of metamorphic rocks that originate from various rocks/minerals that have been exposed to areas of high temperature and pressure. Mylonite is usually an indication of a complex zone. Gouge is a rock formed from tectonic forces. Fluvioglacial gravel is the result of erosion and deposition of rock due to the melting of glaciers or ice sheets.

Discussion: When comparing compressional tectonics, more specifically thrust faults, in the Southern Alps to tectonics on Mercury there are four characteristics to consider: relief, length, dip, and style of deformation. The smooth plains on Mercury show low relief from 0.06-1.7 km. The intercrater plains have a higher relief at 0.09-3 km [2]. Relief of thrust faults in the Alpine Fault, New Zealand range from 0.001-0.1 km [5]. When comparing reliefs, the Alpine Fault correlates more to the smooth plains. Lengths of small scale thrust faults in both the smooth plains and the intercrater plains are < 10 km [2]. The entire Alpine Fault is 1.6 km, but smaller thrust faults range 0.23-0.8 km [5]. The average dip of thrust faults found in the smooth plains, Mercury is 35°. The intercrater plains have a lower dip angle at 25° [2]. Smaller thrust faults in the Alpine Fault average 50° [5]. Dips of thrust faults in the Alpine Fault are more closely related to dips in the smooth plains. Lastly, deformation in the smooth plains is generally thin-skinned and the intercrater plains show thick-skinned [2,4]. The Alpine Fault shows thick-skinned deformation, so in this case will be more like the intercrater plains.

Thrust faults found in the Alpine Fault, New Zealand show similar relief and dip to the smooth plains on Mercury, however, the values for the intercrater plains were not too different. The Alpine Fault also showed the same deformation type as the intercrater plains. An argument could be made that the Alpine Fault is an adequate terrestrial analog to thrust faults in the intercrater plains of Mercury. From this, it can be drawn that similar minerals/rocks would be present in the intercrater plains as in the Alpine Fault. These minerals/rocks could include clay-rich minerals, an abundance of metamorphic rocks, and rocks formed from tectonic forces.

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YELLOWSTONE'S STEAMBOAT GEYSER AS AN ANALOG FOR TIDAL-HEAT DRIVEN CRYOVOLCANISM ON ENCELADUS. A. E. Sharbaugh, Department of Physics, Tennessee Technological University, 1 William L Jones Drive, Cookeville, Tennessee, 38505 (aesharbaug42@students.tntech.edu).

Introduction: Enceladus first received attention from the scientific community in the 1980s when both Voyager 1 and 2 sent back unique photos of Saturn's icy moon. The photos provided copious evidence of a young, geologically active surface. This led to a thorough study of Enceladus by the Cassini spacecraft from 2004 until its retirement in 2017. Cassini carried a total of twelve instruments, including two spectrometers that would return surprising data about the satellite: a liquid ocean lies beneath its icy crust and exhibits some of the most dramatic cryovolcanism observed to date [1]. The moon's cryovolcanic activity is thought to be a product of tidal heating and thermally insulating clathrate hydrates in its subsurface ocean, two processes this volatile mini world demonstrates we have yet to fully ascertain [2].

Tidal heating and cryovolcanism: Enceladus' south pole gives off an unusual thermal signature, showing temperatures up to at least 167K compared to an overall surface temperature of around 72K [1]. According to scientists at NASA's Heliospheric Physics Laboratory, "Data from Cassini's composite infrared spectrometer of Enceladus' south polar terrain indicates that the internal heat-generated power is about 15.8 gigawatts, approximately 2.6 times the power output of all the hot springs in the Yellowstone region, or comparable to 20 coal-fueled power stations" [3]. The theorized rate of core heating due to radioactive decay is too low to explain these temperatures, which leads to tidal heating theory.

Enceladus is a miniature moon compared to other solar system satellites [4], and the only way such a small body might generate enough internal heat to drive active geology is tidal heating, the process by which orbital energy is dissipated as heat in Enceladus' subsurface ocean. This orbital energy comes from a 2:1 mean motion resonance with neighbor satellite Dione [1]. Meanwhile, olivine and H_2O react in hydrothermal vents along the ocean floor, forming methane that then becomes trapped by H_2O molecules in a clathrate hydrate structure [2] (Figure 3). These new molecules act as incredible thermal insulators, allowing pressure and temperature to rise to levels so great that water, methane, and other volatiles erupt from "tiger stripe" fractures along the surface of Enceladus' icy crust. On average, each tiger stripe is 130 km long, 2 km wide, and 500 m deep [1]. The plumes themselves jet material at about 1300 km/h. Particles can reach heights of 30 km above the surface while gases can reach about 80 km [4] (Figures 1 and 2).

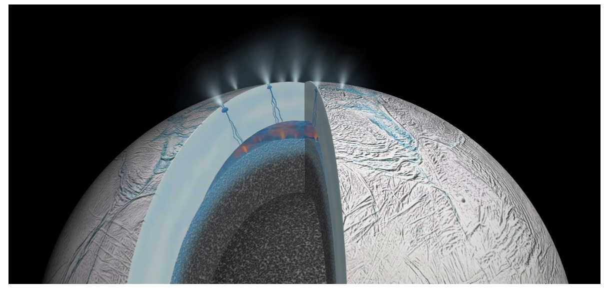

Fig 1: Artist's conception of hydrothermal activity on Enceladus. Credit: JPL/NASA.

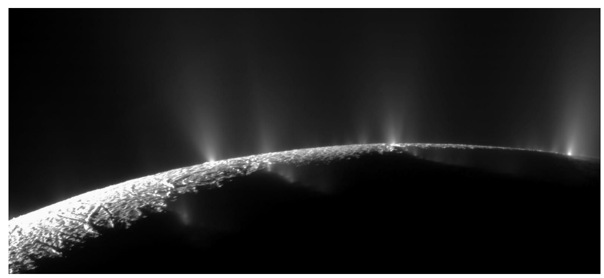

Fig 2: Dramatic plumes close to Enceladus' south pole. A clear curvilinear arrangement of geysers erupting from fractures along the surface can be seen. Image acquired by NASA's Cassini Spacecraft.

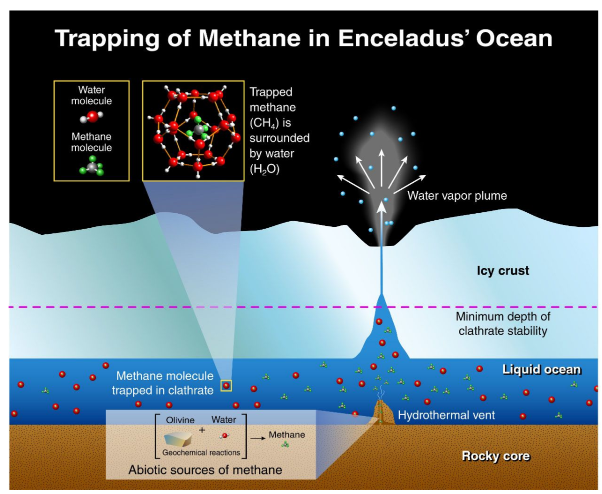

Fig 3: Illustration depicts potential origins of methane found in the cryovolcanic plumes, based on data from the Ion and Neutral Mass Spectrometer on NASA's Cassini mission. Credit: JPL/NASA.

Fig 4: Steamboat Geyser pictured in the steam phase of eruption. Photo credit: Behnaz Hosseini on behalf of USGS, Mar. 16, 2018.

Steamboat Geyser: Geysers on Earth are associated with volcanism because they generally require three geologic conditions of volcanic terrain: magma which lies close to the surface, a plumbing system of fractures and fissures, and underground cavities. As the geyser fills, the water closest to the surface cools and traps the water underneath it in channels so narrow that convective cooling of the reservoir is impossible. This trapped water becomes superheated, meaning it remains liquid as it achieves temperatures well above the standard pressure boiling point. Eventually, temperature wins out and boiling begins, causing some water in the reservoir to shoot upwards and erupt over the surface [5].

Steamboat geyser is located in the Norris Geyser Basin of Yellowstone National Park, Wyoming, USA, and is the largest active geyser on Earth (Figure 4). It is a cone geyser and has two vents located approximately 6 meters apart. The geyser experiences periodic eruption with minor eruptions reaching 3.0 m to 4.6 m above the surface and major eruptions reaching up to 90 m. The composition of ejecta is primarily H_2O and CO_2 with various trace volatiles and metals [6].

Using Steamboat as an Earth analog: The first clear difference between Steamboat and the cryovolcanic plumes observed on Enceladus is the scale of each. This is largely due to the intensity of tidal heating the moon's south pole experiences as well as its weaker gravity. Acceleration due to gravity on Enceladus is a mere 0.11 m/s^2, compared to the Earth's 9.8 m/s^2. Thus, material ejected from Enceladus' surface is able to achieve far greater heights than it would on Earth. Another difference is that the satellite's cryovolcanic activity is not driven by individual, underground networks of tunnels and magma but by the large-scale process of tidal heating.

The two share many characteristics as well. Both operate utilizing a reservoir of liquid water with similar compositions. In addition, each experiences eruptions due to intense pressure and temperature conditions forcing water through narrow passages. This similarity in mechanics is crucial because subsurface features on other bodies cannot be directly observed without some form of lander. Until such a mission comes to pass, Steamboat is an ideal Earth analog for the plumes observed on Enceladus, and studying the geyser may yield new information about the process of cryovolcanism.

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