ORIGIN OF HIGH AND LOW WATER SIGNATURES ON THE MOON. P.H. Schultz[1], S. Li[2], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook St., Box 1846, Providence, RI, 02912 (peter_schultz@brown.edu), [2]Hawai'i Institute of Geophysics and Planetology, University of Hawaii.

Introduction: Early studies [1] and lunar missions (e.g., [2]) indicated that H (perhaps as OH or H_2O) might be sequestered at low temperatures under shadows at the lunar poles. Later missions made the surprising discovery that OH or H_2O occurs across all latitudes and varies with lunation and latitude dependent [3-5]. The Moon-Mineralogy-Mapper (M^3) mission allowed detailed mapping of concentrated OH-bearing materials across the Moon [6,7]. The global OH distribution is commonly attributed to solar-wind implantation and exchanges with SiO_2 with rare concentrations in central peaks or OH-bearing volcanic glasses [e.g., 6]. More detailed examination, however, reveals that these initial observations and interpretations were incomplete [8].

Background: High-resolution OH maps in [9] reveal that many craters are associated with elevated OH but depend on the impactor and conditions of impact [8,10]. In particular, impacts occurring on the edge of a larger crater result in a breached transient crater that allows OH-laden vapor and melt to escape and interact with the surface, rather than escaping lunar gravity. This is illustrated by Rutherfurd crater, which formed on the rim/wall of the much larger crater Clavius and distributed OH-bearing melt and deposits [10]. Impact breccias and melts are able to trap water as demonstrated in terrestrial impact melts [11] and experiments [12]. In contrast, both recent impacts and swirls are surrounded by low OH (<10 ppm) [8]. OH-depleted zones around craters can be attributed to ejecta scouring, whereas the absence around swirls has been attributed to the stand-off of the solar wind [9]. Nevertheless certain oblique impact craters (or breached-rim) craters exhibit not only the low-OH zone but also high-OH ejecta and melt [10].

OH Highs and Lows: A portion of the global distribution of OH from the lunar equator to high latitudes is shown in **Fig. 1**. Poleward from about ±40°-45°, OH levels exceed about 150 ppm. A background level of ~50-100 ppm characterizes lower levels but drops to near zero in certain areas around small, fresh craters (<20 km), large Copernican-age impacts, and secondary craters and rays [10]. For example, the crater Jackson (**Fig. 1**) exhibits a broad low-OH oval extending downrange but high levels (>100 ppm) within the zone of avoidance uprange. The low-OH oval is not just associated with crater rays or secondaries; rather, it covers both rays and inter-ray areas. However, small patches of elevated OH also correlate with clusters of small primary craters, melt ponds [e.g., 10] and certain secondary craters or scour zones as illustrated by Tycho (**Fig. 2**) as well as other craters such as Giordano Bruno and Jackson. "Restoring" OH-depleted crater haloes between 45° and 65° must take time (100 Ma) due to the large number of examples.

Craters, Swirls and Topographic Effects: The impact forming the crater Mandel'shtam-F (17 km diameter) first made struck the top of a 500 m scarp. This geometry resulted in a breach of the eastern rim and wall of the transient crater, thereby allowing impact melt to escape to the east (**Fig. 3**), along with darker rays and ejecta scouring. Along these rays, swirls closely correlate with the crests of subdued crater rims and walls. Farther to the east, a diffuse high-albedo patch directly correlates with OH levels over 100 ppm. Although the swirl also correlates with a magnetic anomaly, the issue is whether the swirl developed because of the anomaly or the process of swirl formation also generated this anomaly. Consequently, Mandel'shtam-F illustrates the direct connection between an impact, swirl, topography, magnetic field, OH depletion, and OH concentration. Such connections are not unique. In many locations on the Moon, bright swirls occur along the crests of crater rims (e.g., Firsov swirls) or rays crossing massifs (e.g., Jackson). High-resolution images reveal that such rays are expressed as anastomosing and lineated textures.
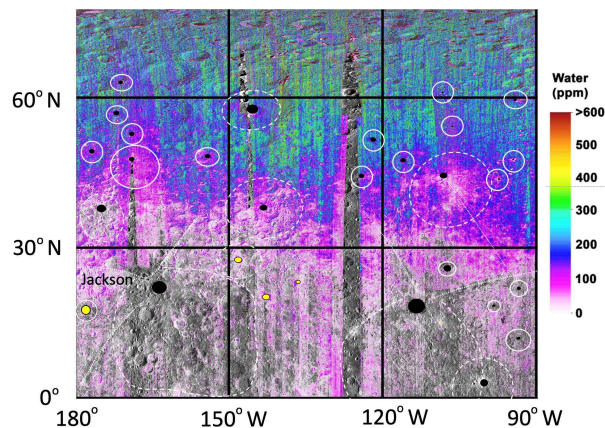
Discussion: These observations raise several questions. If a local magnetic field is responsible for standing off the solar wind (and low OH) in swirls, then what prevents replenishing the much larger OH-depleted halo around the swirls? How can swirls (bright and dark) develop on top of the very young Giordano Bruno impact yet solar-wind bombardment was insufficient to restore OH-depleted zones around older craters? What accounts for the unusual photometric properties of bright swirls relative to surrounding surfaces [13-15], an observation that requires processing affecting the regolith at mm scales and unaffected by solar wind stand-off?

Conclusions: Low-latitude OH is characterized not by where it is but where it isn't. This background 50-100 ppm level of OH must have multiple origins: (a) delivery by episodic water-rich impactors trapped in impact melt, breccias, and regolith mixing; (b) solar-wind implantation; (c) processes related to agglutinate formation; and (d) recycled OH-trapped breccias but released through gradual breakdown through impact gardening. Oblique impacts and breached-rim craters

reveal the contributions from water-rich impactors (asteroids and comets) trapped in their impact melt and pockets of ejecta. Nevertheless, the expanding vapor plume and micro-scale ejecta also erase the OH background over broad areas.

Although the migration of volatiles to high-latitude traps should be a mixture of all components, the low-latitude background OH must reflect accumulation from episodic collisions by water-rich impactors pre-dating 1 Ga in order to account for maintaining OH-depleted areas around certain Copernican-age craters. The removal of OH in such areas resulted from micro-scouring by expanding impact vapor and ejecta, especially oblique impacts and breached-rim craters. Consequently, the OH-depleted areas around swirls is not unique and may be related to a similar process, especially since some swirls appear to be related to secondary ejecta. Specifically, cometary collisions will generate ionized vapor and ejecta that envelopes a planetary surface [16], perhaps even generating magnetic fields trapped in the regolith [13]. Alternatively, swirl patterns develop as charged ejecta [17] electrostatically separate as they interact with as pre-existing magnetic field.

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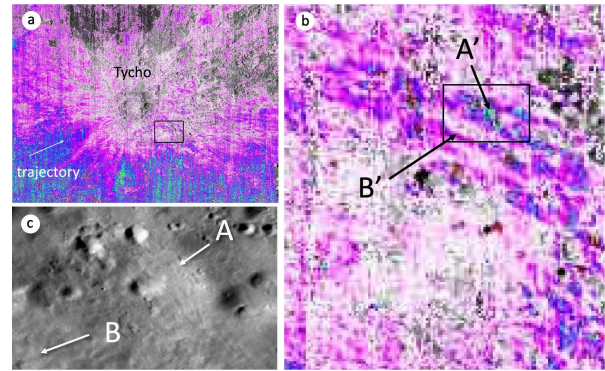
Fig. 2. Ejecta from Tycho (**2a**) have erased background levels OH (50-100 ppm) over broad area downrange to (NE) while preserving them uprange (SW). Certain crater rays (A and B) in **2b** and **2c**), however, have levels >300 ppm, most likely due to OH-impactor components trapped in breccias.
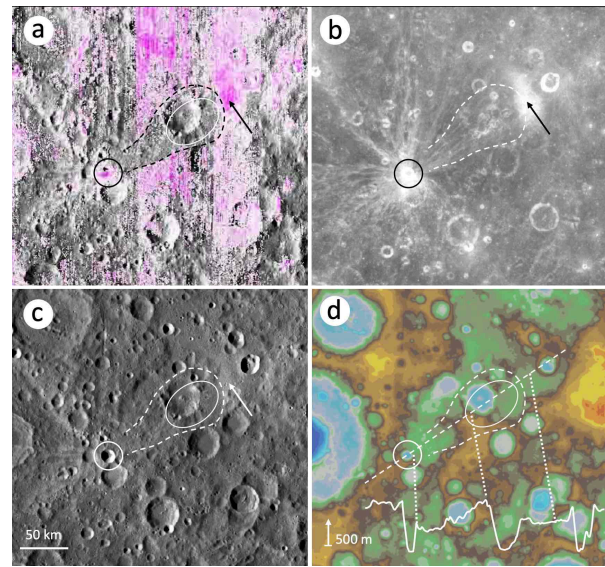
Fig. 3. The NE rim of Mandel'shtam-F is breached as the result of impacting the rim of a crater of a larger crater. A lobe of low OH extends to NE (**3a**) corresponding to faint crater rays (**3b**). Farther downrange, a bright, diffuse area (arrow, **3a-3c**) correlates with ~100 ppm OH, in contrast with bright the effects of ejecta. Swirls occur in between and correspond to the crests of pre-existing craters (**3c** and **3d**). Its rays extend across old craters


Fig. 1. Recent craters (black) have surrounding zones of reduced OH levels < 25 ppm (white). Oblique impacts result in large offset OH deficits (white dashes) and rays (white dotted lines) downrange but high OH uprange. In contrast, some craters exhibit 100 ppm OH (yellow).