The Ina "D-Caldera" Potentially Contains Evidence for Liquid Water in the Moon

Abstract: That temperature and pressure regions within the Moon exist that should favor the existence of liquid water is a simple matter of logic. Somewhere between the frozen regolith and the hot core, there must exist a zone where liquid water is able to exist. The only questions are whether there is enough juvenile water within the Moon's mantle to form liquid water, and if so, whether the liquid zone extends close enough to the surface to where evidence for the existence of liquid water could be found practically. In this regard, note that the unusual shape and extreme youth of the Ina "D-Caldera"—first discovered during the Apollo missions—indicate that it was formed neither from impact cratering nor volcanic eruption. Moreover, the Ina feature is far from unique: over 20 other "meniscus hollows"—so-called due to characteristic convex upward humps—have been identified on the Moon, and similar features have been found on Mercury. Our current best guess is that these hollows were caused by episodic buildups of high pressure volatiles followed by explosive outgassing. Shultz et al. (2006) suggest that CO_2 and H_2O are likely culprits. In addition, it has been widely suggested that outgassing of juvenile water is at least partially responsible for the buildup of water ice in permanently shaded regions of the Moon. However, it is difficult to see how either CO_2 or H_2O alone could cause explosive events. In the case of CO_2, in the absence of some sort of caprock, there would be no way for pressure to buildup: for example, Frisillo et al. (1974) estimate that a concentration of argon atoms would diffuse through 30 feet of regolith in a single day. In the case of H_2O, it would also be difficult to form high pressures, though for different reasons: as juvenile water vapor released from mantle moved upward, before it reached the surface it would pass through a zone where it would exist as liquid, and then reach as layer where it would freeze solid, suspending any further movement. Simple calculations demonstrate that the liquid/frozen boundary should be several kilometers below the surface of the Moon. Note, however, that meniscus hollows are nearly always associated with volcanic features and graben-like structures. Ina itself is located squarely atop a 15-km diameter volcanic shield. Such volcanic shields are likely locations of potential hotspots. Furthermore, the grabens indicate deep faulting and fracturing that would serve the dual function of facilitating the flow of volatiles while inhibiting the flow of heat, thus allowing higher temperatures to build up closer to the lunar surface. In addition, regolith is an excellent insulator, so that regions with thick regolith should also allow higher temperatures—in this regard note that the regolith around Ina is deeper than average. Thus, it is conceivable that temperatures and pressures favoring liquid water could have extended to the base of the regolith at Ina. There liquid water would freeze, and the frozen regolith would form an effective cap rock blocking the flow of volatiles. Nevertheless, it is difficult to see how water alone would have enough energy to cause the "D-caldera" to form. It is highly unlikely that temperatures high enough to form steam could occur, and in any case, hot water would melt the frozen regolith cap rock, allowing any vapor to diffuse through the regolith. In addition, if the liquid water were exposed to the vacuum, it would flash into vapor, but the rapid expansion would cause much of the vapor to form ice crystals—as is commonly observed during everyday urine dumps in crewed spacecraft—thus absorbing much energy. However, we propose here the hypothesis that CO_2 and H_2O could work synergistically: liquid water trapped beneath a frozen regolith cap rock could entrain massive amounts of dissolved CO_2 gas, similar to the situation known to exist in Lake Manoun and other so-called "exploding lakes". There deep layers in the lake absorb large amounts of dissolved CO_2: when the lakes turn over, a catastrophic release of the dissolved CO_2 occurs, similar to opening a shaken up can of soda. Thus, it is possible that an impact could cause the catastrophic release of CO_2 and H_2O at Ina. The resulting explosion would release pressure on adjacent zones causing a cascading chain reaction that can explain the characteristic humpy morphology of meniscus hollows. The astrobiological and ISRU significance of liquid water at low-latitude, near-side locations is obvious.