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GEOL 286, Week 5 - Lunar Pyroclastic Deposits and Processes

Introduction:

- Regions of low albedo on the Moon were recognized as possible sites of pyroclastic activity ('Dark Mantle Deposits' or DMDs).
- The low albedo material mantles underlying terrain, supporting a pyroclastic origin.
- A pyroclastic origin is also supported by returned Apollo samples from the Taurus-Littrow DMD.
- The mode of origin for these deposits was not initially understood (fire fountaining, association with effusive flows?), which is further complicated by the lack of visible source vents.
- The pyroclastic deposits are thought to represent some of the most primitive materials on the lunar surface.
- The DMDs are split up into two groups: large, regional deposits, of which there are 11, and smaller, localized deposits, of which there may be hundreds (Gaddis et al., 1985).

Vent and Deposit Morphology:

- General characteristics of the DMDs include (Gaddis et al., 1985; Weitz et al., 1998; Head et al., 2002):
  - Low albedo deposits.
  - Deposits that mantle the underlying terrain.
  - Diffuse boundaries of the deposits.
  - Deposits are associated with, and often buried by, mare-filled impact basins.
  - Deposits are on the order of 10's of meters thick.
  - With a few exceptions, there is no visible source vent.
  - Deposits have varying areal extent, from 80 km^2 (localized DMDs) to 37,000 km^2 (regional DMDs).

Spectral Character of Deposits:

- The deposits have very weak to non-existent radar backscatter, from Earth based telescopic observations (Gaddis et al., 1985).
  - This is thought to be due to a lack of scattering from the smooth pyroclastic deposit.
- Earth based telescopic observations suggest the near-infrared signatures of many of the deposits have low reflectance and a broad absorption at 1μm (Gaddis et al., 1985) (**Attached Figure 1**).
  - This absorption is caused by a crystal field transition of Fe^{2+} in volcanic glasses, and is distinguished from olivine based on the low reflectance of the deposits.
- Detailed analysis of Clementine data showed that the relative proportions of glass:crystallized beads can be determined from reflectance spectra (Weitz et al., 1998).

- In contrast to the glass spectra discussed above, crystallized bead spectra are dominated by an absorption centered at ~0.6µm.
    - This absorption is due to an Fe-Ti charge transfer in ilmenite.
    - This absorption results in a featureless spectrum at the spectral resolution of Clementine data.
- Using the Clementine spectral signatures of seven regional DMDs, Weitz et al. (1998) estimate a range of glass:crystallized bead ratios (**Attached Figure 2**), which relates to the rate of cooling (i.e. sites with higher proportions of glass had higher rates of cooling).

Returned Lunar Samples:

- Returned samples from Apollo 15 (very low- to low-Ti green glasses) and Apollo 17 (high-Ti orange glass and crystallized black beads) are interpreted as pyroclastic beads.

Apollo 17 Drill Core (Weitz et al., 1999):

- There are three main types of volcanic beads:
    - Orange glasses.
    - Brown glasses, which are the devitrified equivalents of the orange glasses, and are found primarily on the rims of orange glasses.
    - Crystallized black beads, which are the crystallized equivalents of the orange glasses.
- The orange glasses are compositionally homogenous throughout the core, which suggests a single eruptive event.
- Glass inclusions contain ~600 ppm S, and 50 ppm Cl, but no H_2O is detected.
- The 68 cm deep drill core from the rim of Shorty crater grades from 24% crystallized beads at top of core to 98% crystallized beads at depth, although this stratigraphy is inverted.
- This transition can be explained by a decrease in exsolved gas content with time, leading to an increased optical density, and thus longer cooling times.

Volatile Contents of Volcanic Glasses (Saal et al., 2008; Hauri et al., 2011):

- Volatile contents of the Apollo 15 and Apollo 17 lunar glasses were measured using improved analytical techniques by Saal et al. (2008).
- These results show a clear trend of decreasing volatile contents towards glass bead rims, indicative of degassing.
- Numerical models suggest an initial water content of 745 ppm H_2O, with a minimum estimate of 260 ppm.
- Following these analyses, Hauri et al. (2011) analyzed the volatile contents of lunar volcanic glass inclusions, which should not have been affected by degassing.
- These results show the glasses have water contents of 615-1400 ppm, and correlated high values of other volatile elements (F, S and Cl).
- These values are very similar to primitive terrestrial MORBs, indicating that at least portions of the lunar mantle contain similar amounts of volatiles as the Earth's upper mantle (**Attached Figure 3**).

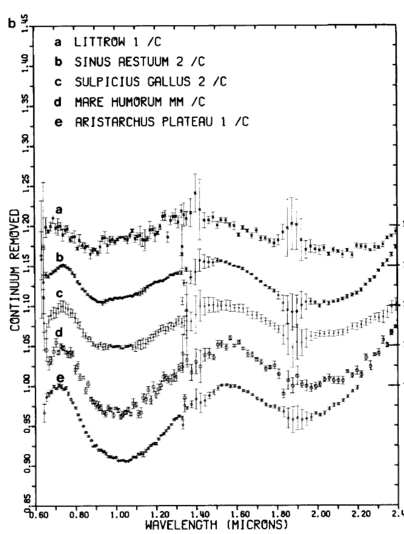
Models for Emplacement:

- There are three primary models for emplacement of the DMD's (Head and Wilson, 1979) (**Attached Figure 4**):
    - Strombolian eruptions.
    - Continuous eruption of basaltic liquid, either with or without gas (i.e. Hawaiian fire fountain eruptions).
    - Vulcanian eruptions.
- Vulcanian style eruptions are favored for the Alphonsus DMDs and the Orientale DMD (Head and Wilson, 1979; Head et al., 2002), while Hawaiian style fire fountain eruptions are favored for the formation of the other regional DMDs (Weitz et al., 1998; Head et al., 2002).

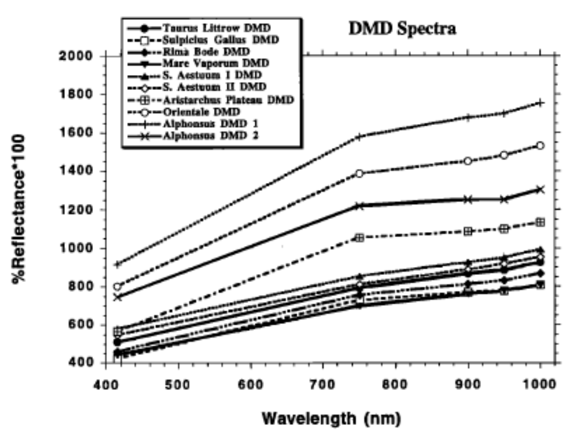
Discussion Questions:

- Are the regional and localized deposits fundamentally different, or the same process operating on different scales?
- Is the association with mare-filled impact basins genetic or coincidental?
- How do the results of Weitz et al. (1998) change if the crystallized beads are not spectrally dominated by ilmenite?
- How does space weathering affect the spectral signature of the DMDs? The 'glassiest' deposits appear to also have the highest albedo.
- Which model for formation do people prefer? Vulcanian vs. Hawaiian Fire Fountain? Can both have occurred?
- How do the results of Saal et al. (2008) and Hauri et al. (2011) change the models for emplacement of the pyroclastic deposits?

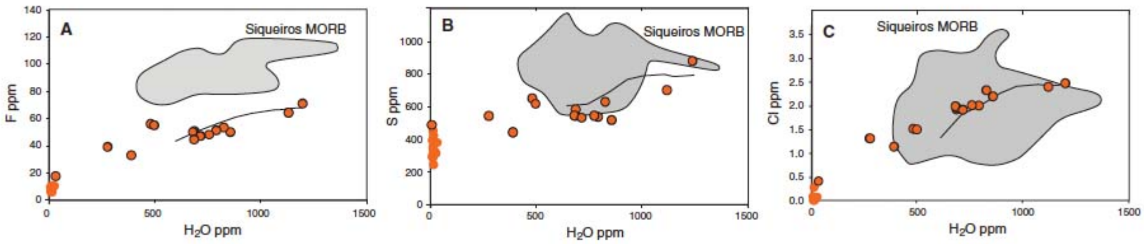
Figures:



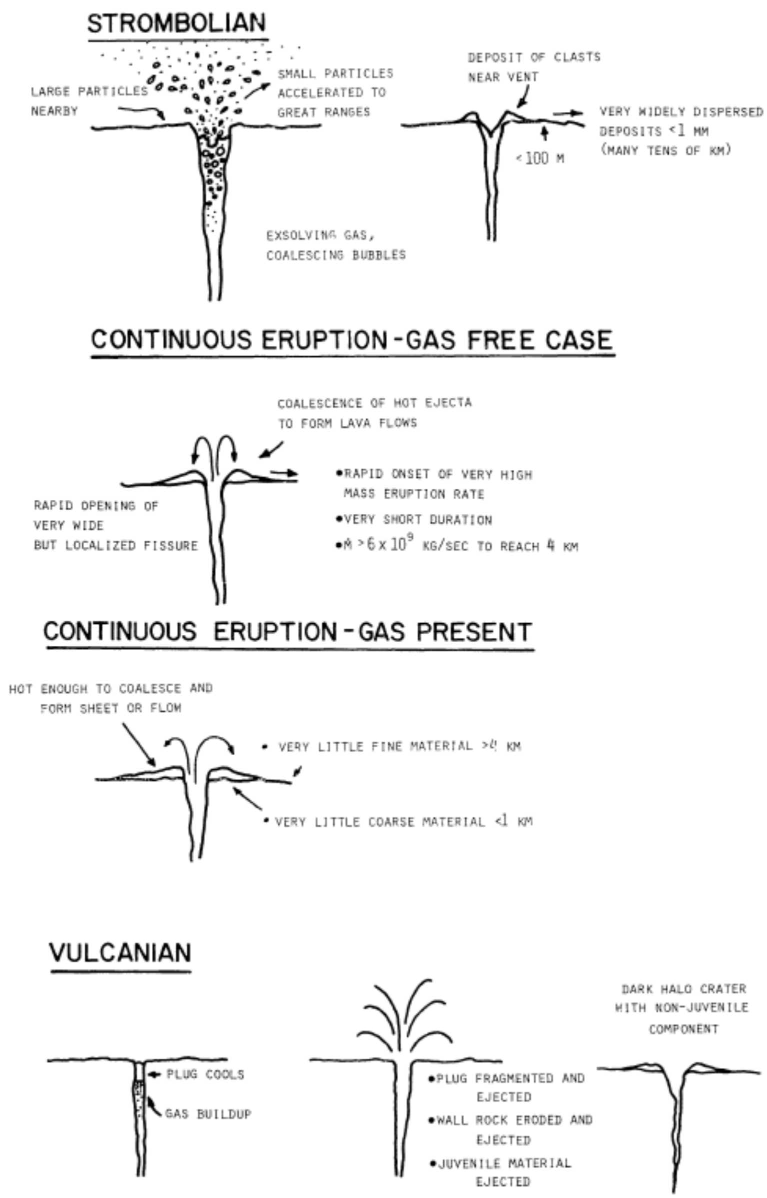
Attached Figure 1: Figure 4B of Gaddis et al. (1985).



Attached Figure 2: Figure 21 of Weitz et al. (1998).



Attached Figure 3: Figure 3 of Hauri et al. (2011).



Attached Figure 4: Figure 9 of Head and Wilson (1979).