Red/Orange Volcanic Ash Deposits on the Lunar Surface Documented in Color-Balanced Apollo 17 Hasselblad Orbital Photographs Compared with Apollo Panoramic, Metric Mapping, and Lunar Reconnaissance Orbiter Photos

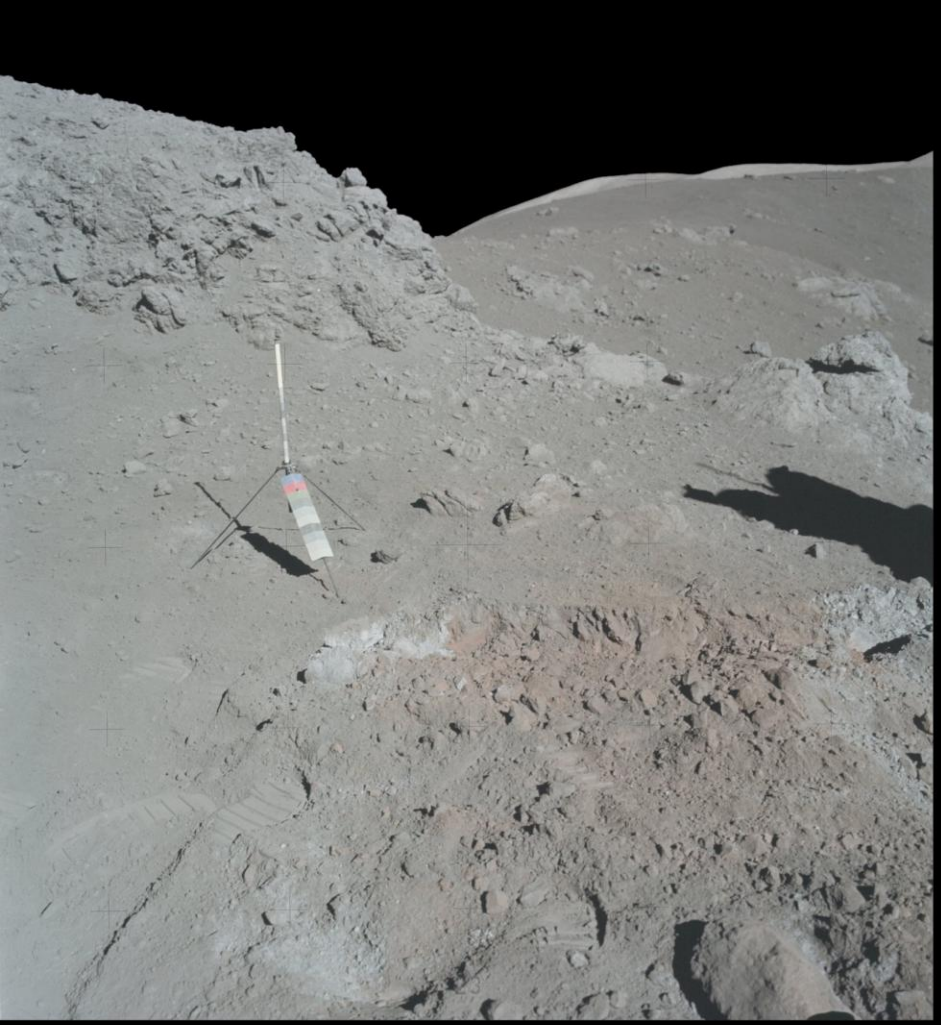
- Ronald A. Wells, *Tranquillity Enterprises, s.p.*, Abingdon, VA
- Noah E. Petro, *Goddard Space Flight Center*, Greenbelt, MD
- Harrison H. Schmitt, P.O. Box 90730, Albuquerque, NM

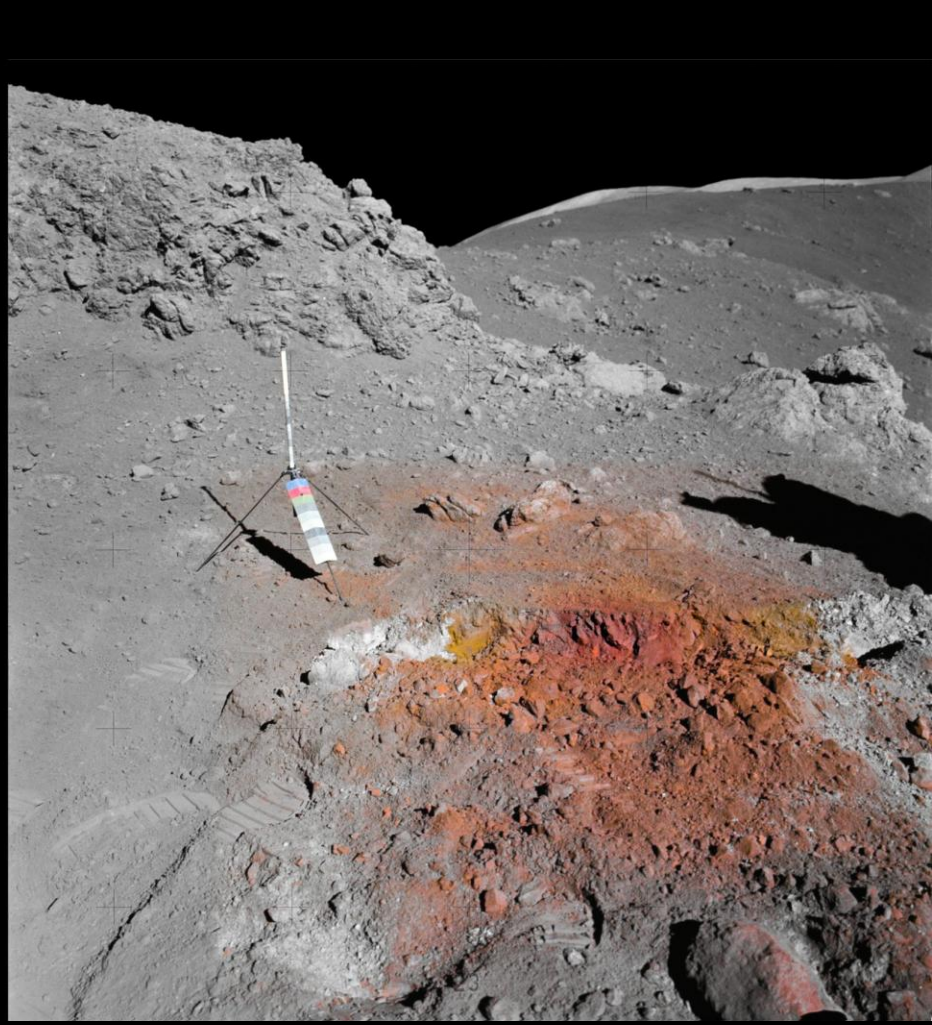
Slide # 1

My co-authors, Jack Schmitt and Noah Petro, send their regrets at not being able to attend this year's meeting. They both made prior commitments before the 2019 GSA conference dates had been set.

At last year's meeting in Indianapolis, I spoke about the bright orange, red and yellow colors in the trench that Jack Schmitt dug on the rim of Shorty Crater at Station 4, as well as the green soil in photos from Apollo 15. I want to extend that discussion here to colors of surface features photographed from orbit after Jack and Gene returned to the Command Module.

In fact, the goal of this talk is to demonstrate that colored, volatile, volcanic pyroclastic ash distributions on the lunar surface are more prevalent than previously considered.

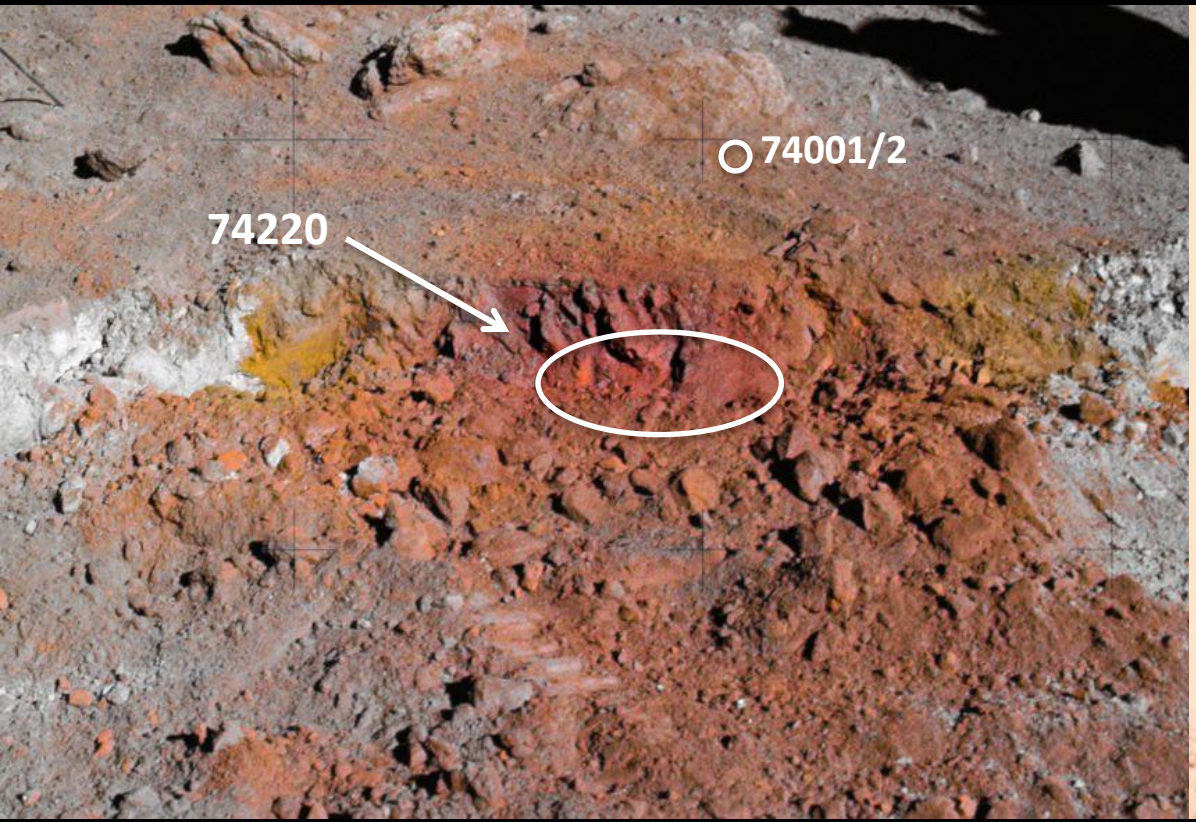


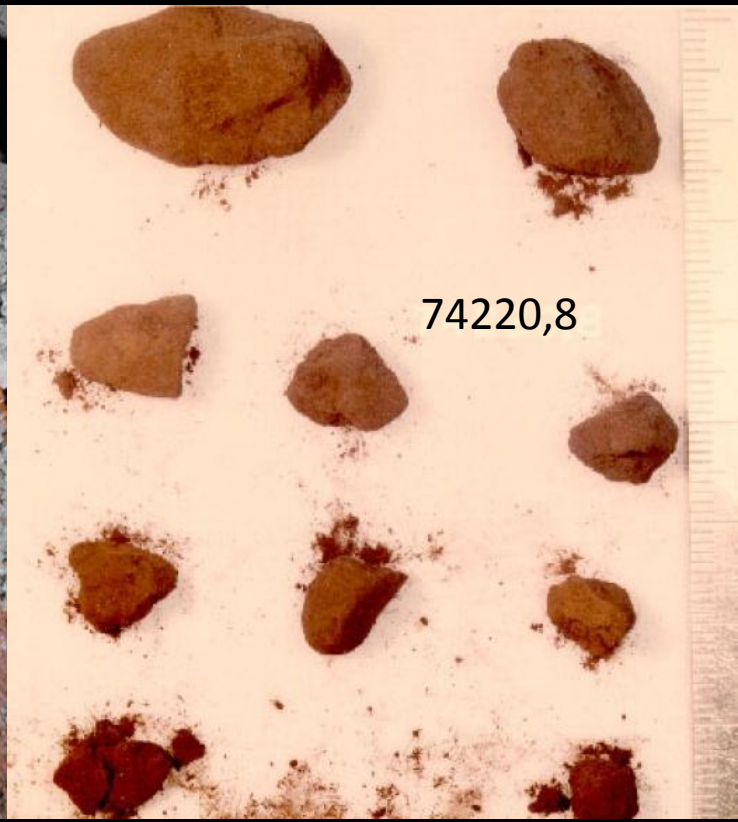


Slide # 2

For those who missed the discussion last year, let me recap it briefly (presentation can be downloaded from: https://gsa.confex.com/2018AM/webprogram/Paper317759.html).

The left photo (AS17-137-20990) is the original raw scan of the Apollo 17 prime film made in ca. 2004 at JSC. Contemporary prints after the mission in the 70s were similarly poor renditions of what Schmitt saw and described *in situ*. Working with him last year, and using the software programs Adobe Lightroom and Corel Photo-Paint, the image was contrast-balanced, and then by using the 3 color channels, red, orange, and yellow and adjusting their intensities, it was possible to match what he had observed. The right photo (AS17-137-20990_cw8) was approved by him after 8 iterations or adjustments of the balancing process. (*left*: NASA photo. *right*: Derivative copyright © 2018 by Tranquillity Enterprises, s.p. Courtesy of Tranquillity Enterprises, s.p.)


74001/2
74220

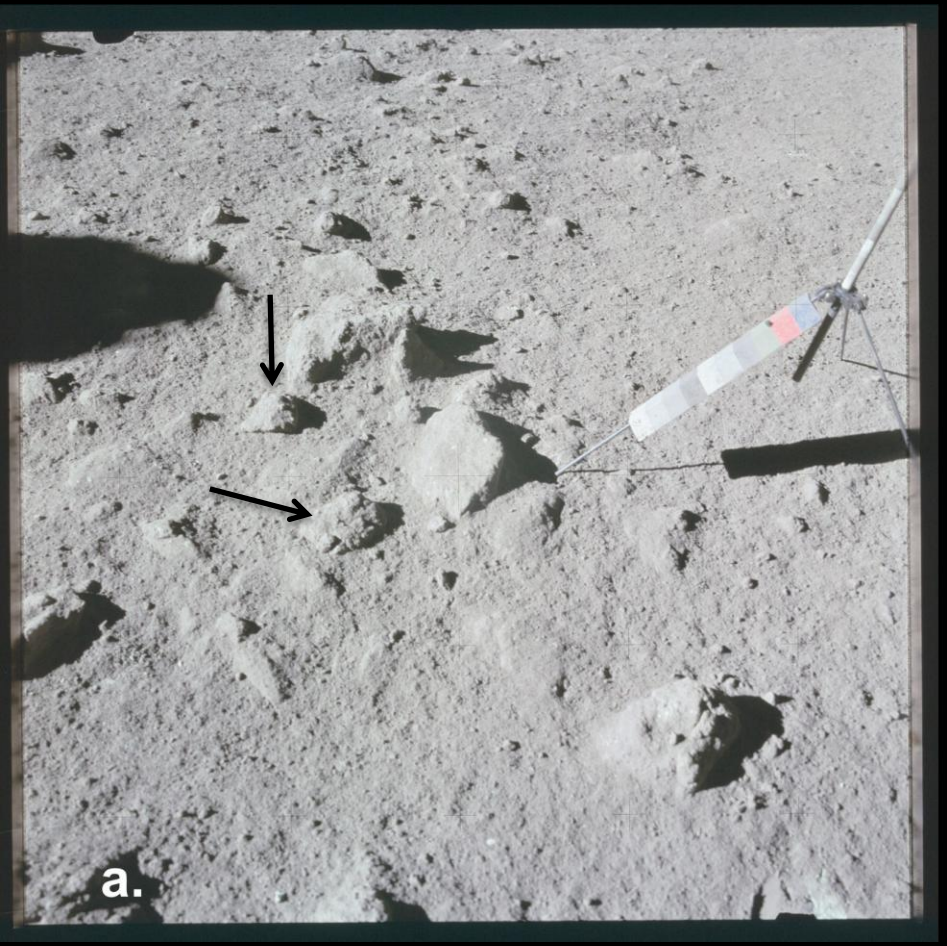

74220,8

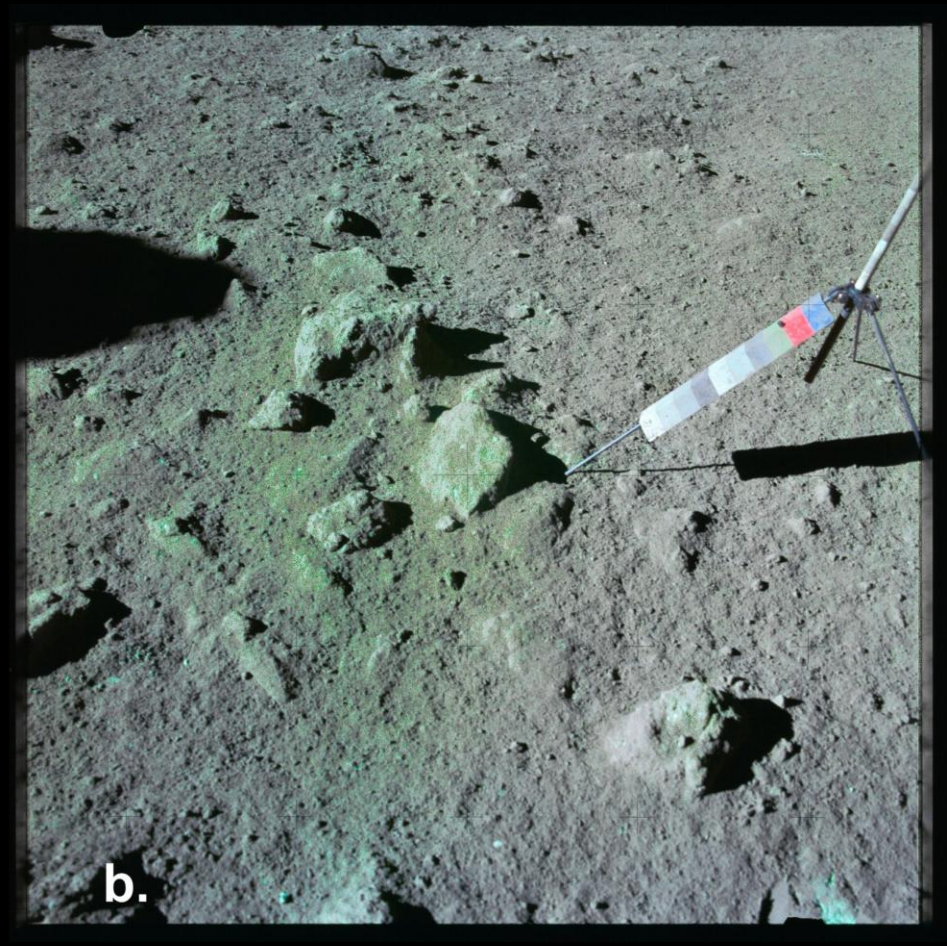
Slide # 3

The clods at right were scooped up from the lower central red area of the trench, sample 74220, as shown in the trench enlargement at left. They are a dark red-to-red in color and 4 of them are brownish. The small circle in the left panel marks the location of the double core sample 74001/2. I have a slide of the glass beads from this sample to show in a moment. (*right*: NASA photo S75-34259)

Slide #4

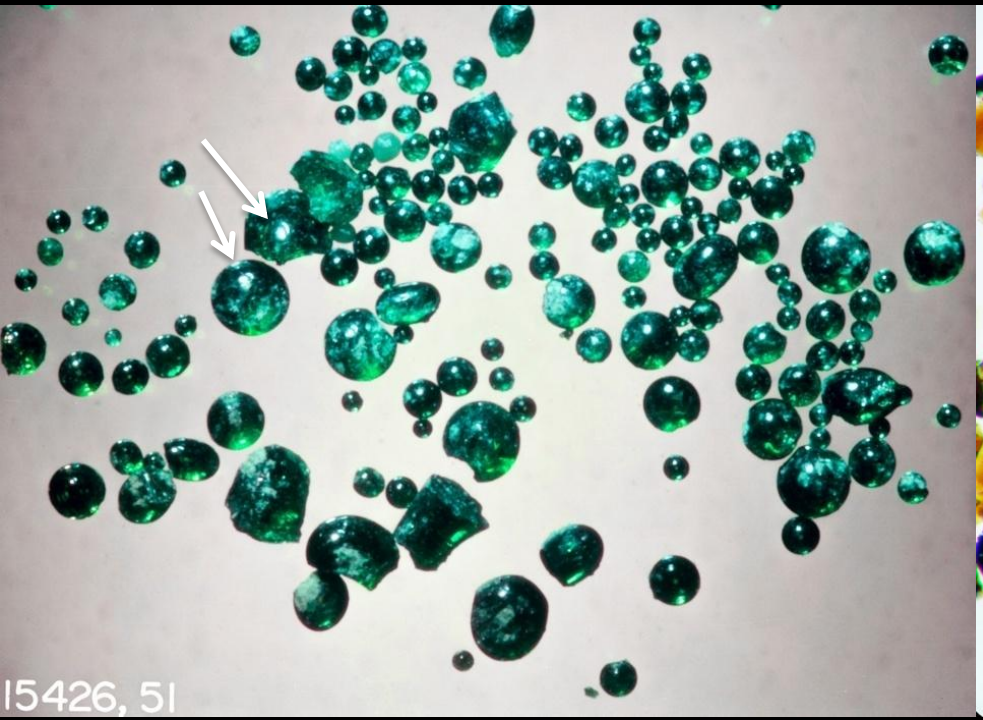
After taking 7 photos of the trench, Cernan moved approximately 50 m to the southeastern side of the rim and took 2 panoramas of the crater. Seven of those photos were color balanced and assembled into this view of the crater showing orange/red colorations in the walls and out over the rim. (Derivative composite of NASA photos AS17-137-21005, -21000, -21001, -21002, -21003, -21004, and -21024. Copyright © 2018 by Tranquillity Enterprises, s.p. Courtesy of Tranquillity Enterprises, s.p.


a.


b.

Slide # 5

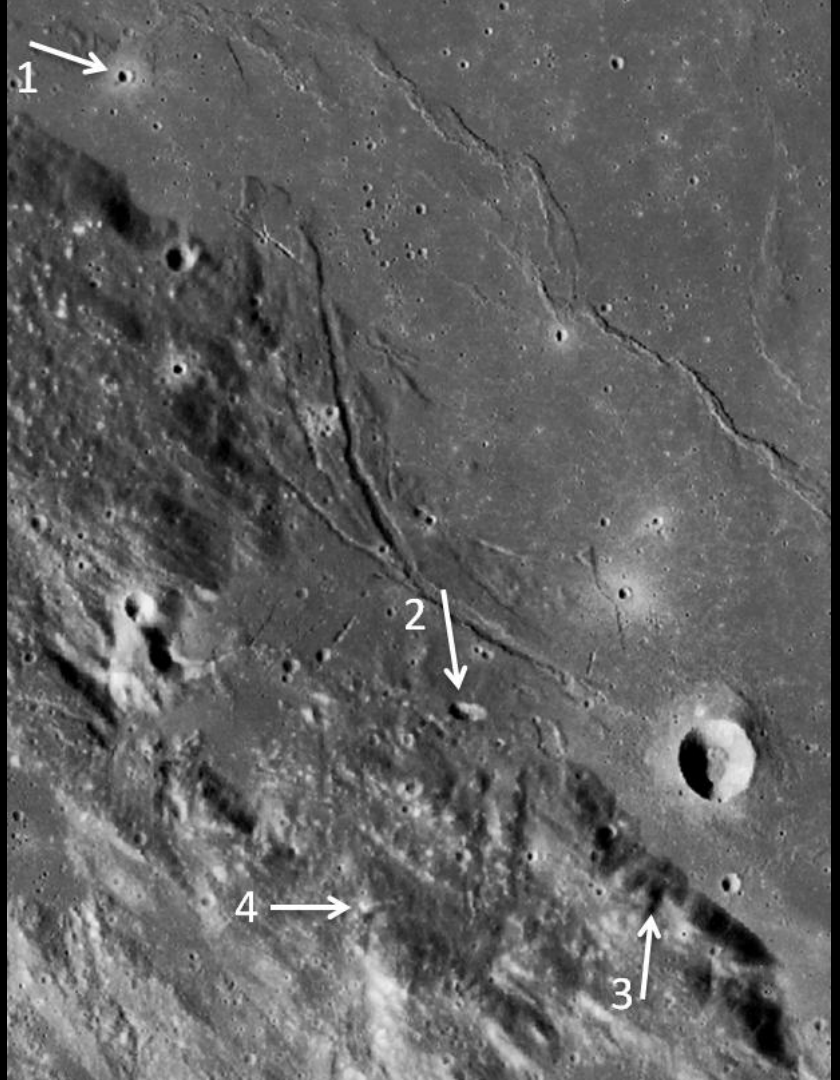
From Apollo 15, at left is the original raw JSC scan of AS15-86-11666. All four scans of the green soil sample area photos at Spur Crater were similarly overexposed. Rock samples 15425 and 15426 are indicated by the black arrows in the left panel. The color-balanced version of the same scan is at right (AS15-86-11666_cw2). Note the top 3 colors of the gnomon color bar are blue, red, and green. In order to bring out the green soil color patterns, the intensity of the green channel was matched to that of the green color chip after the latter was contrast-balanced. (*left*: NASA photo. *right*: Derivative copyright © 2018 by Tranquillity Enterprises, s.p. Courtesy of Tranquillity Enterprises, s.p.


15426, 51

Slide # 6

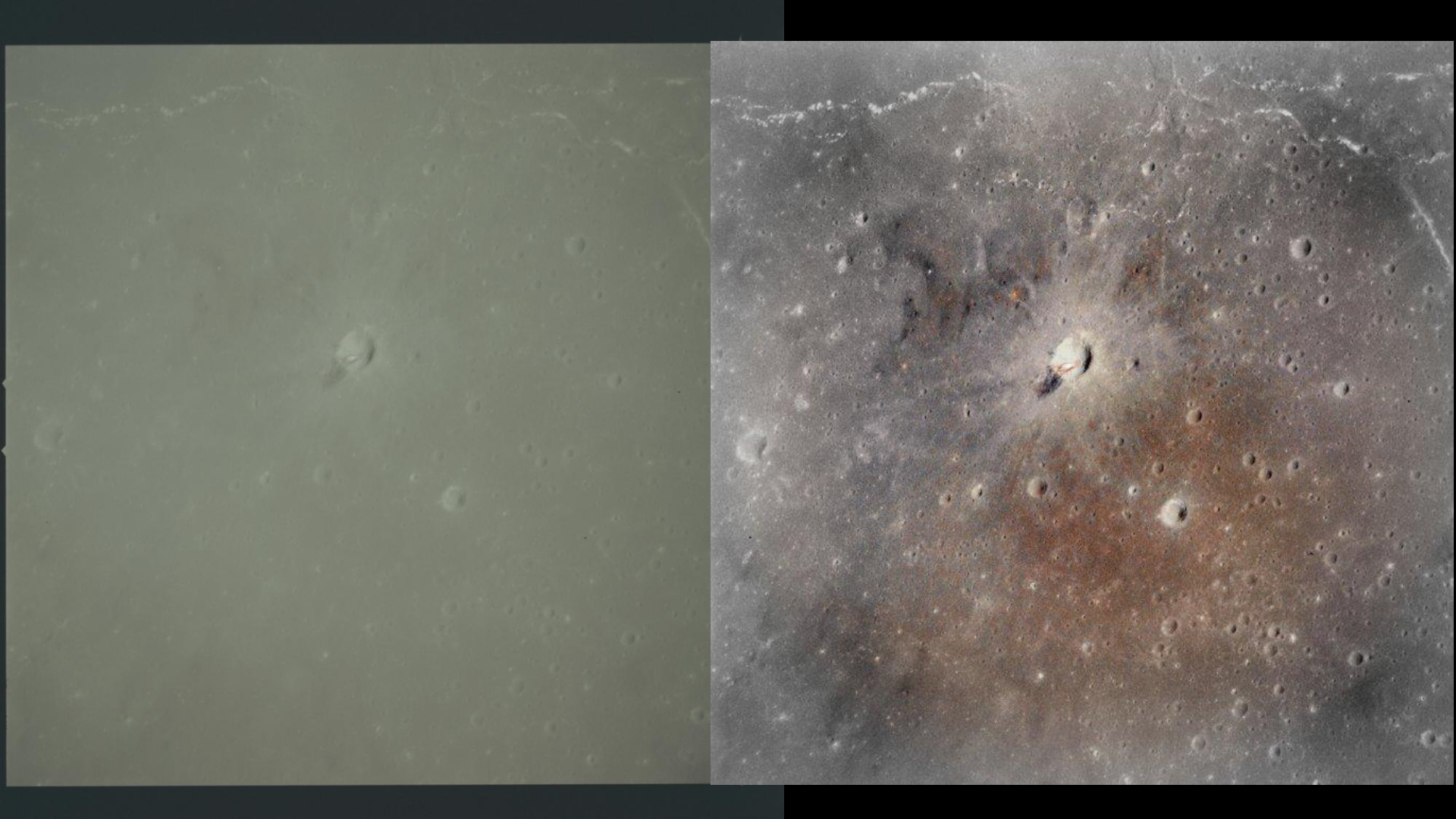
A transmission photomicrograph of the green soil adhering to sample 15426 is shown at left; and a similar one of the glass beads from the core sample, 74001/2 at Shorty Crater.

The differences in color of the glass between various sites and samples appear to be related to the iron/titanium ratios of the glass, with red and orange resulting from low Fe/Ti. That is, they are rich in titanium and low in silica. The black color of beads is a consequence of the partial devitrification of the colored glass that results in dark crystallites in clear glass. You can see some of the clear glass in a few of the black beads in this slide marked by the black arrows. This is also somewhat less apparent in the green beads from rock sample 15426, also marked by white arrows. (left: NASA photo S79-32188; right: NASA photo S73-15171).


1
2
3
4

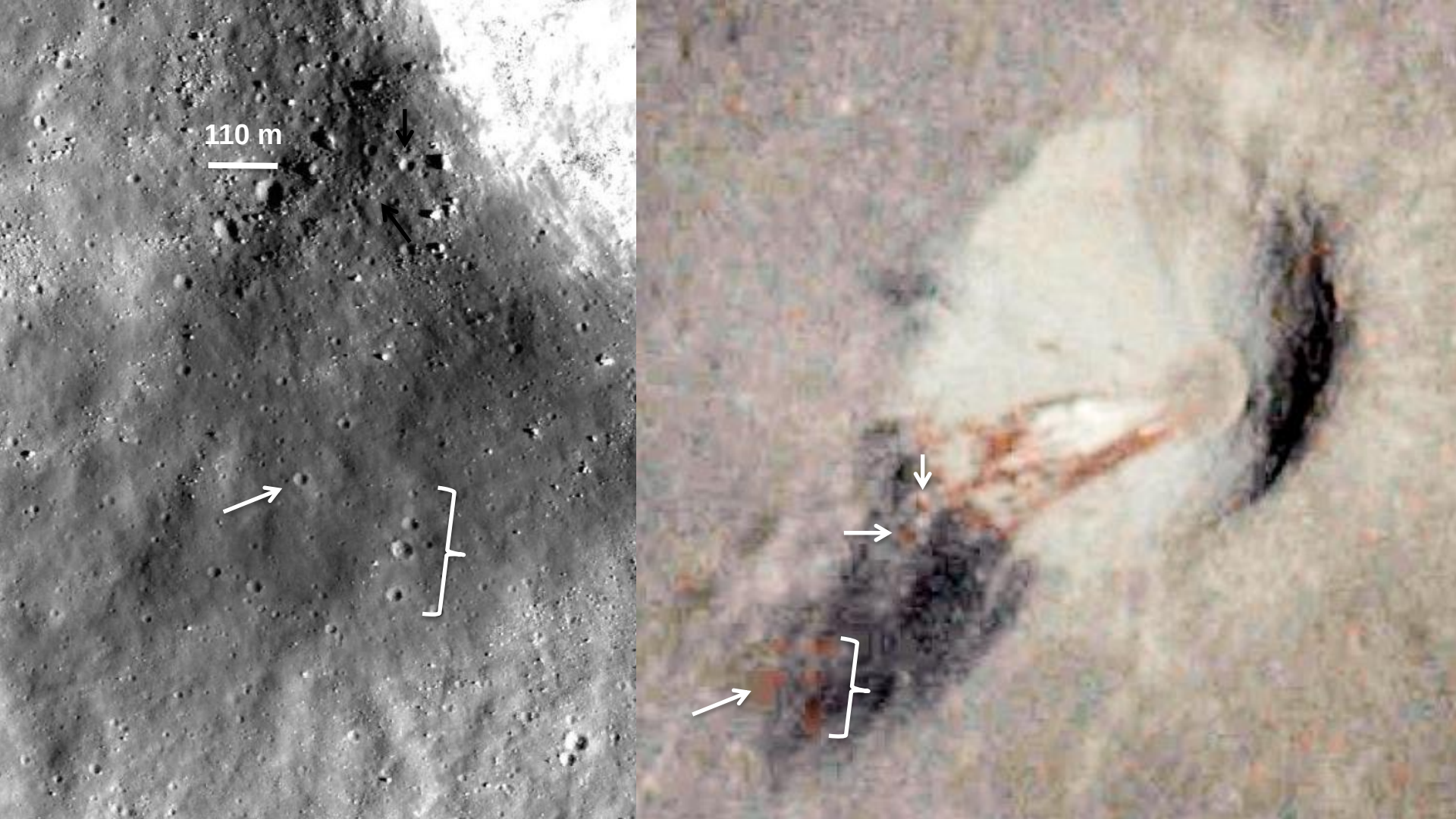
Slide # 7

Moving now to the orbital results, The 4 areas I want to discuss are located at the southwestern edge of *M. Serenitatis*. No. 1 at upper left is a ~2 km crater with a tapered black ash ejecta deposit, and an M-shaped set of red streaks on the interior western wall. No. 2 is a kidney shaped volcanic vent near the *Haemus Mts*. No. 3 is a depression in the *Haemus Mts*. that I have called *Vulcanis Lacus*. And no. 4, middle left towards the bottom, is a crater with a red plume discussed by Lucchitta & Schmitt (1974). The large 12 km diameter crater at lower right is *Sulpicius Gallus*. (Background photo is from the Lunaserve webmap, http://webmap.lroc.asu.edu/lunaserv.html)



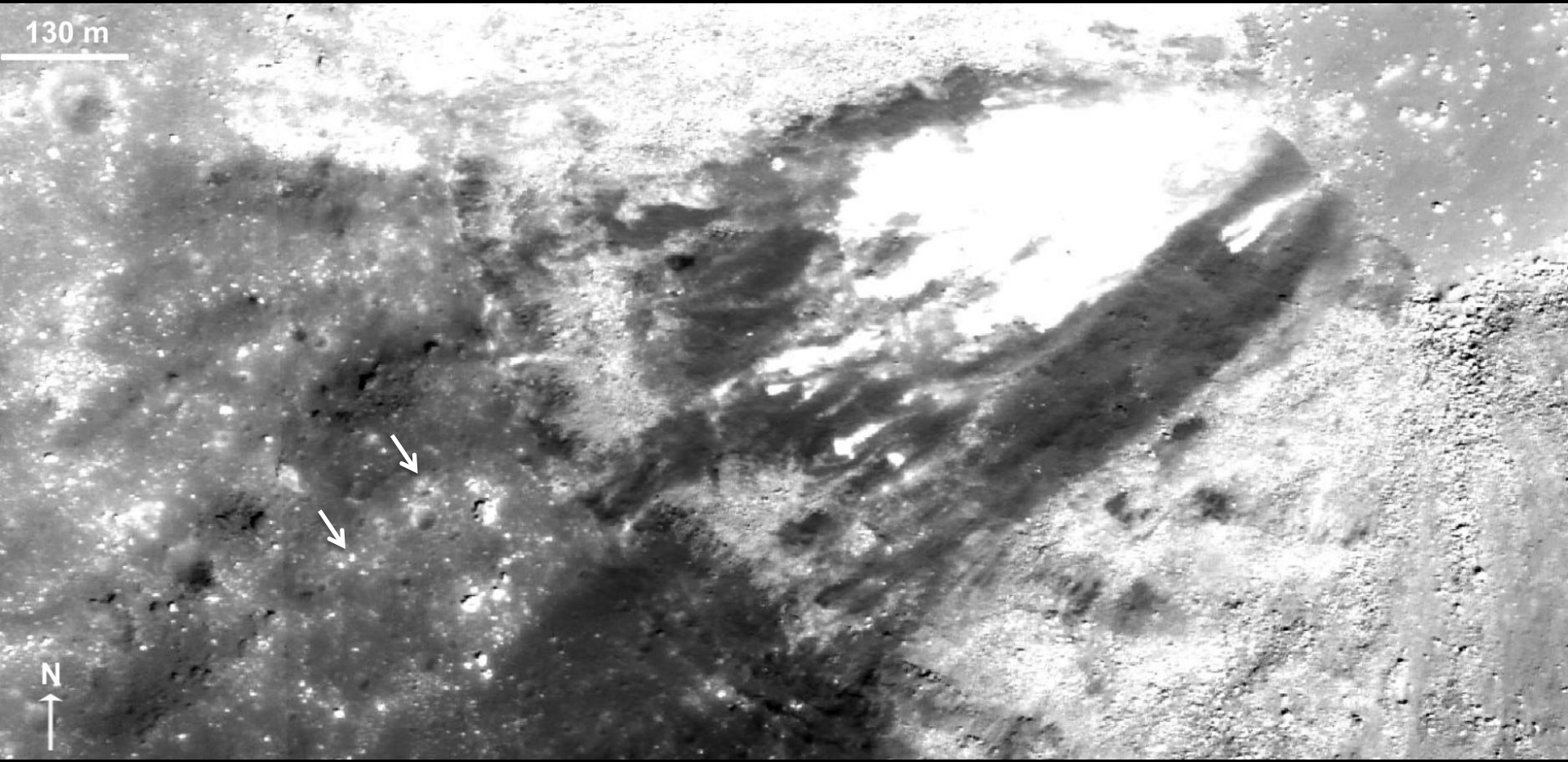
Slide # 8

This photo of the red streaked crater near the center with black ash tongue was photographed by Jack Schmitt on rev. 65. Hasselblad photo A17-149-22881, 250 mm lens, sun el. 40 , alt. = 113 km. (*Left*): Original JSC scan. (*Right*): contrast & color-balanced version of same. I shall describe some of the features of the red-streaked crater. There are other areas of smaller craters with red halos or aureoles which I don't have time to describe in more detail. These are treated in a *JGR-Planets* paper with the same title and authors as this presentation that has passed the first round of reviews. (left: NASA photo AS17-149-22881; right: color-corrected version)


110 m

Slide # 9

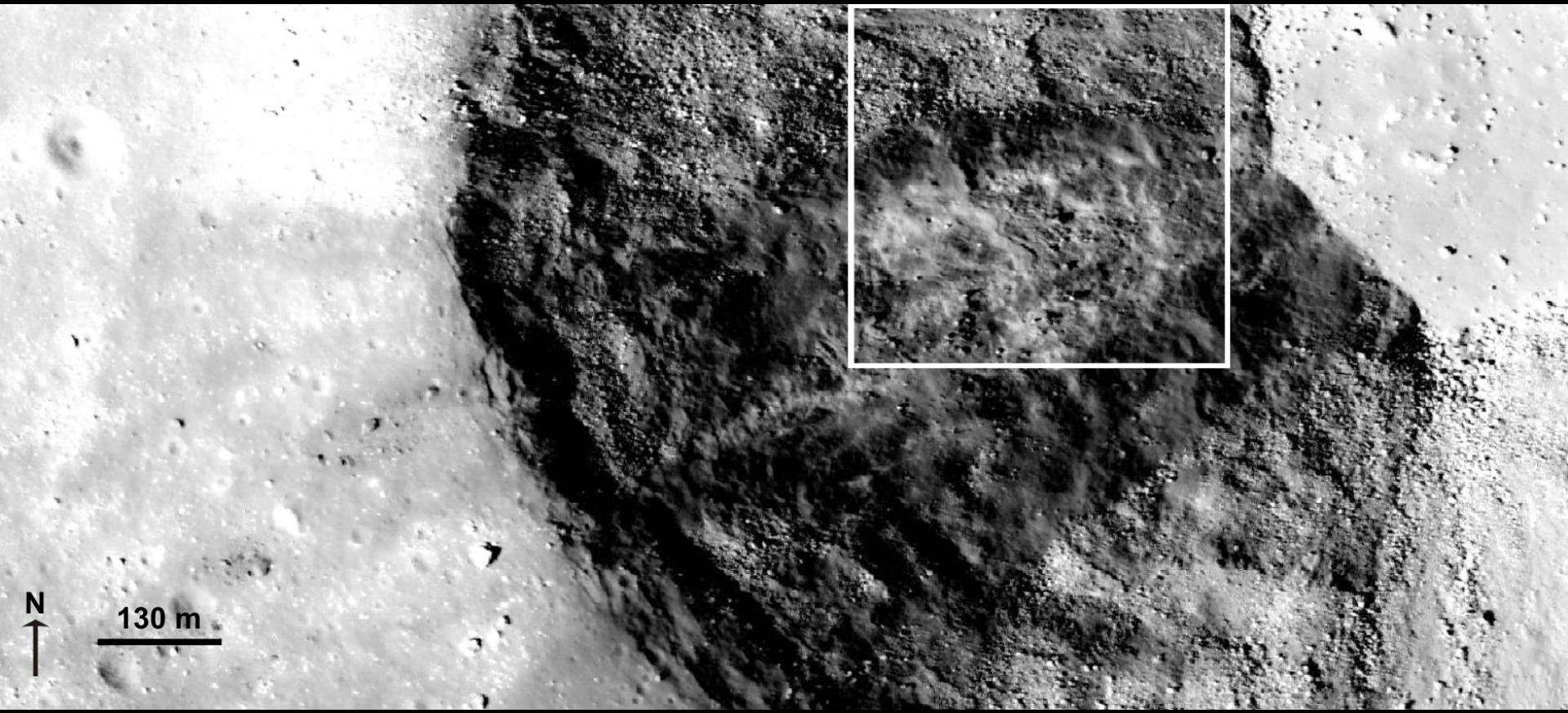
The right panel is the crater with M-shaped red streak in its interior enlarged from the previous frame. The crater is ca. 2 km in diameter, and the black ash tongue at lower left is ca. 1.25 km from the rim to its apex. Several red ringlets have been marked in that ejecta, 4 of them outlined by the brace. The left panel is part of an LROC Quickmap view at a lower sun angle with the features resolved. The vertical arrow near the crater rim points to a small X-shaped ejecta blanket of a lighter albedo than the surroundings. The right view shows a red spot in that position as well as one below it. The 4 red circlets at the brace correspond to the light albedo ejecta around the 4 craters marked in the left panel. The lower diagonal arrow points to a light albedo-red ring correspondence. The Quickmap view can be accessed at: http://bit.ly/2VBGThm


130 m
N

Slide # 10

As for the red M-shaped streak, this Quickmap LROC photo shows that it is comprised of at least two different albedo shades. Especially noteworthy is the split, or fork, in the right-hand component of the M, which coincides with the similar split in the red streak of the Hasselblad photo just seen. The arrow at left points to the crater seen in the previous slide with the X-shaped ejecta pattern, and the red spot below it is seen to be a light albedo area with several light colored boulders and a crater in it. The nature of the triangular or arrow head shaped bright central area is clarified in the next LROC view.

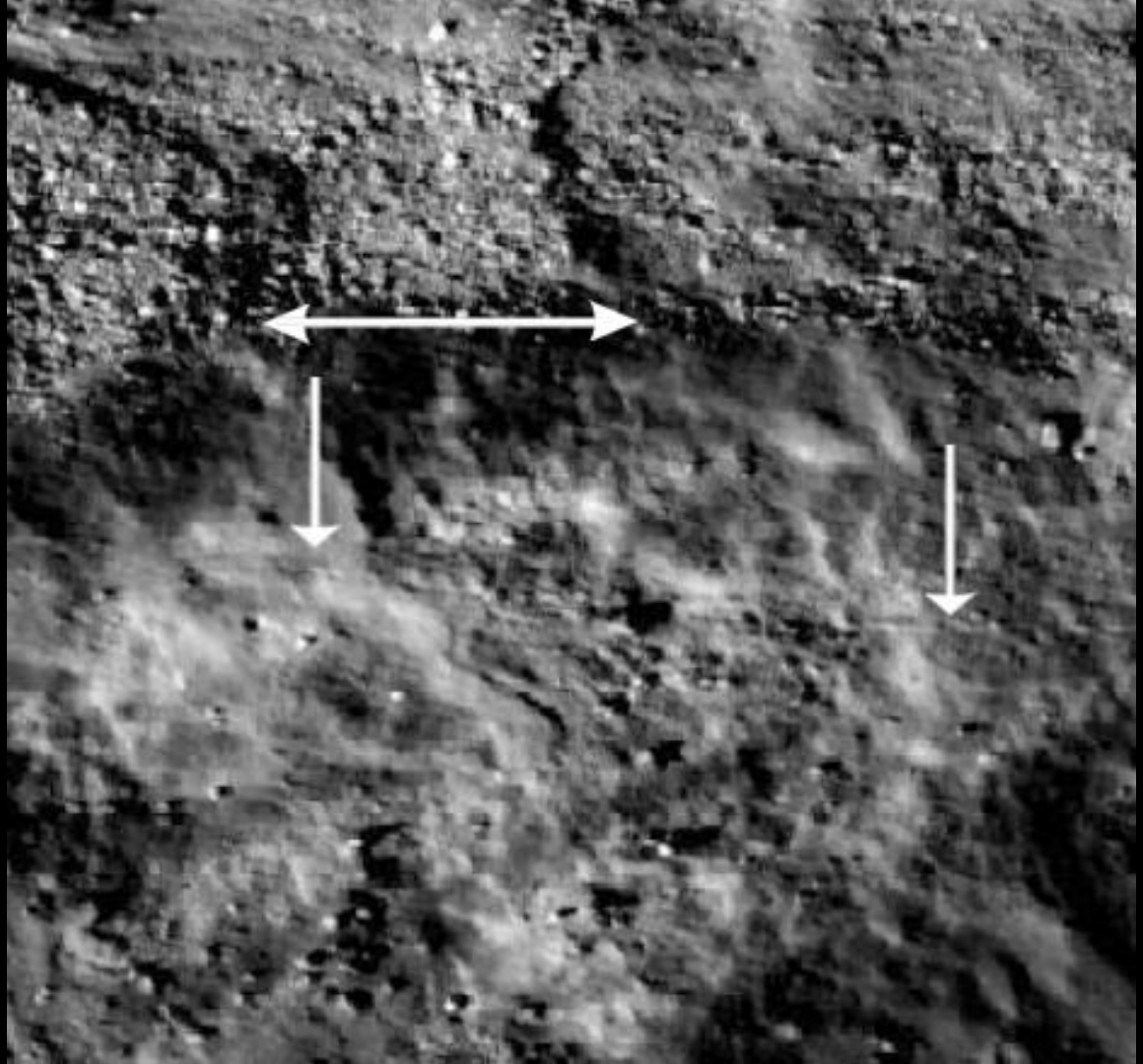
Readers can access this Quickmap view at: http://bit.ly/2D3Brwn


N
130 m

Slide # 11

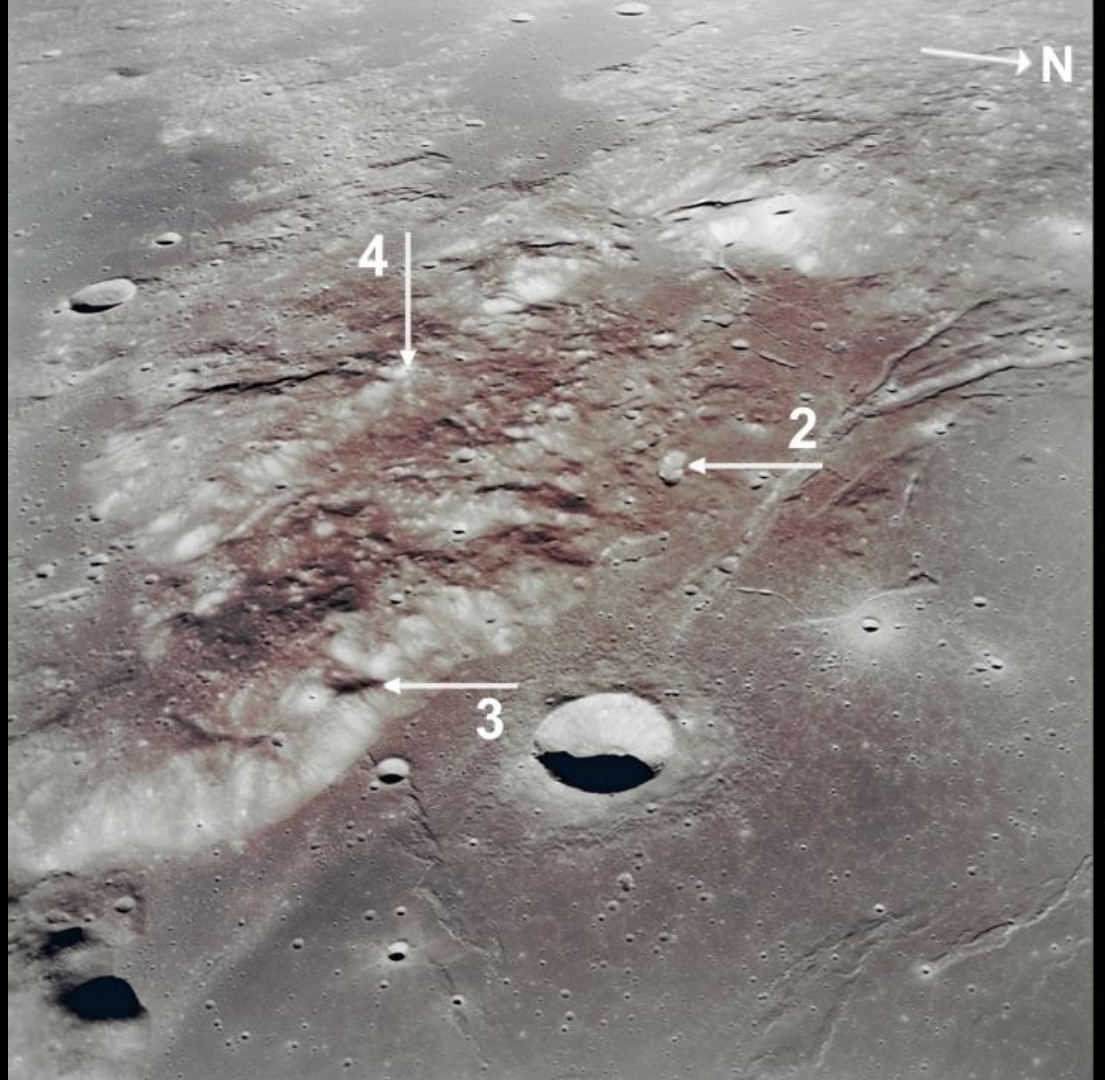
Another Quickmap LROC photo revels the complex nature of the bright wedge-shaped area seen in the Hasselblad photo in the previous slide. And an enlargement of the box shows in the next slide…

(Readers can also acquire this Quickmap view at: http://bit.ly/2jZ9orU)

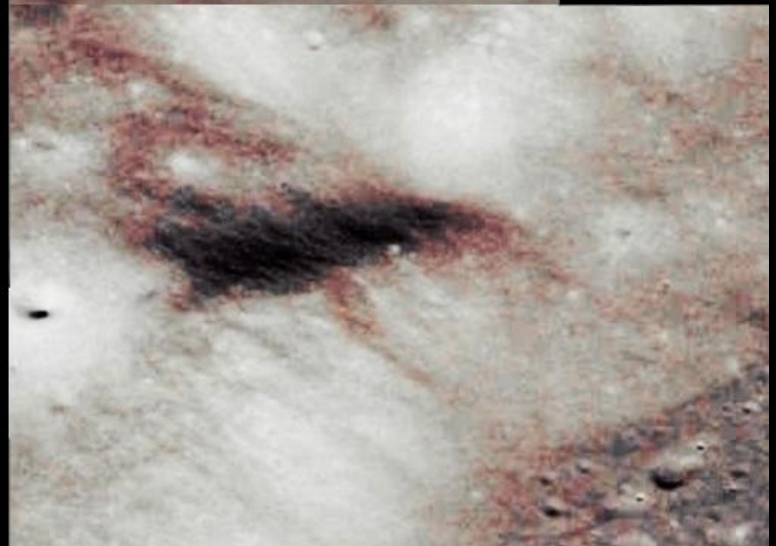


Slide # 12

Two concentric, parallel channels with meanders. The double-headed arrow points to the channels, which Jack Schmitt has interpreted to be slump scarps. They are separated by ca. 150 m at the top narrowing down to ca. 100 m at the lower right. The two vertical arrows point to another fissure which crosses the slump scarps at an angle. At the left arrow two parallel lines can be seen. (Enlargement from previous slide)

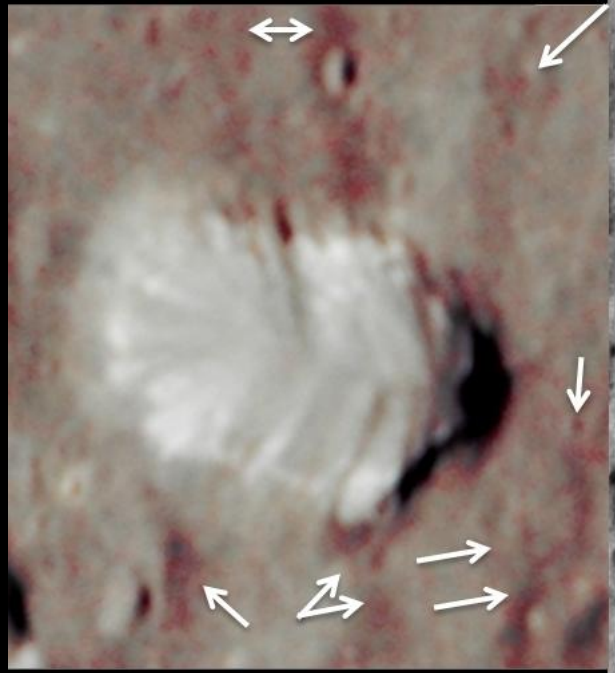

N
4
2
3

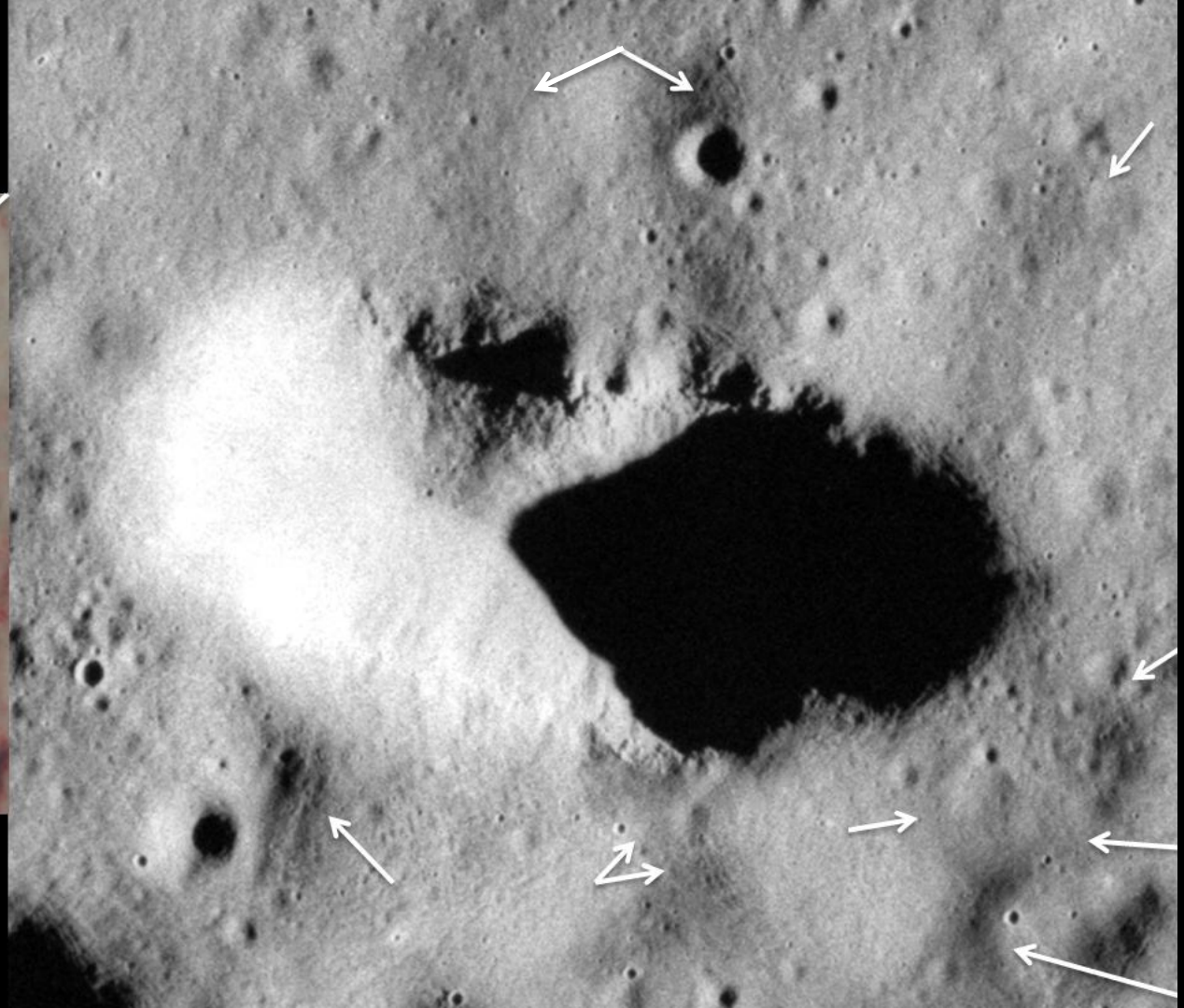

2


3

Slide # 13

AS17-153-23571. This is a Hasselblad image (*left*) taken by Ron Evans on rev. 39 using the shorter f.l. 80 mm lens. *Left*. The full contrast color-balanced frame showing the *Haemus Mts* covered with red and black ash deposits. At right is an enlargement of a kidney-shaped crater (vent) marked in the left frame by arrow # 2. Arrow #3 in the lower part of the frame is pointing to a black ash filled depression in the mountains, that I called *Vulcanis Lacus*. Note the red streams flowing out of the depression and down the slope to the mare floor below. Arrow #4 points to the crater with red plume discussed by Lucchitta & Schmitt (1974). These areas will be shown in further slides below. (left: color-corrected version of NASA photo AS17-153-23571)





Slide # 14

Apollo 17 metric mapping camera frame AS17-M-1233 (rev. 28; vertical; sun el. = 8) (*right*) of the kidney-shaped vent compared with an enlargement of the Hasselblad image rotated to match the orientation (*left*). Arrows at top mark the reddish areas in the Hasselblad slide and the correspondence at right is with the dark albedo areas. Arrows at the bottom right point to the backward-S reddish area seen in the Hasselblad photo. Bottom arrow at left points to an additional reddish area. The double arrows, likewise. The reddish rim on the right side of the vent is closely followed by a dark albedo zone in the metric mapping frame. (*left*: enlargement from previous slide; *right*: NASA photo AS17-M-1233)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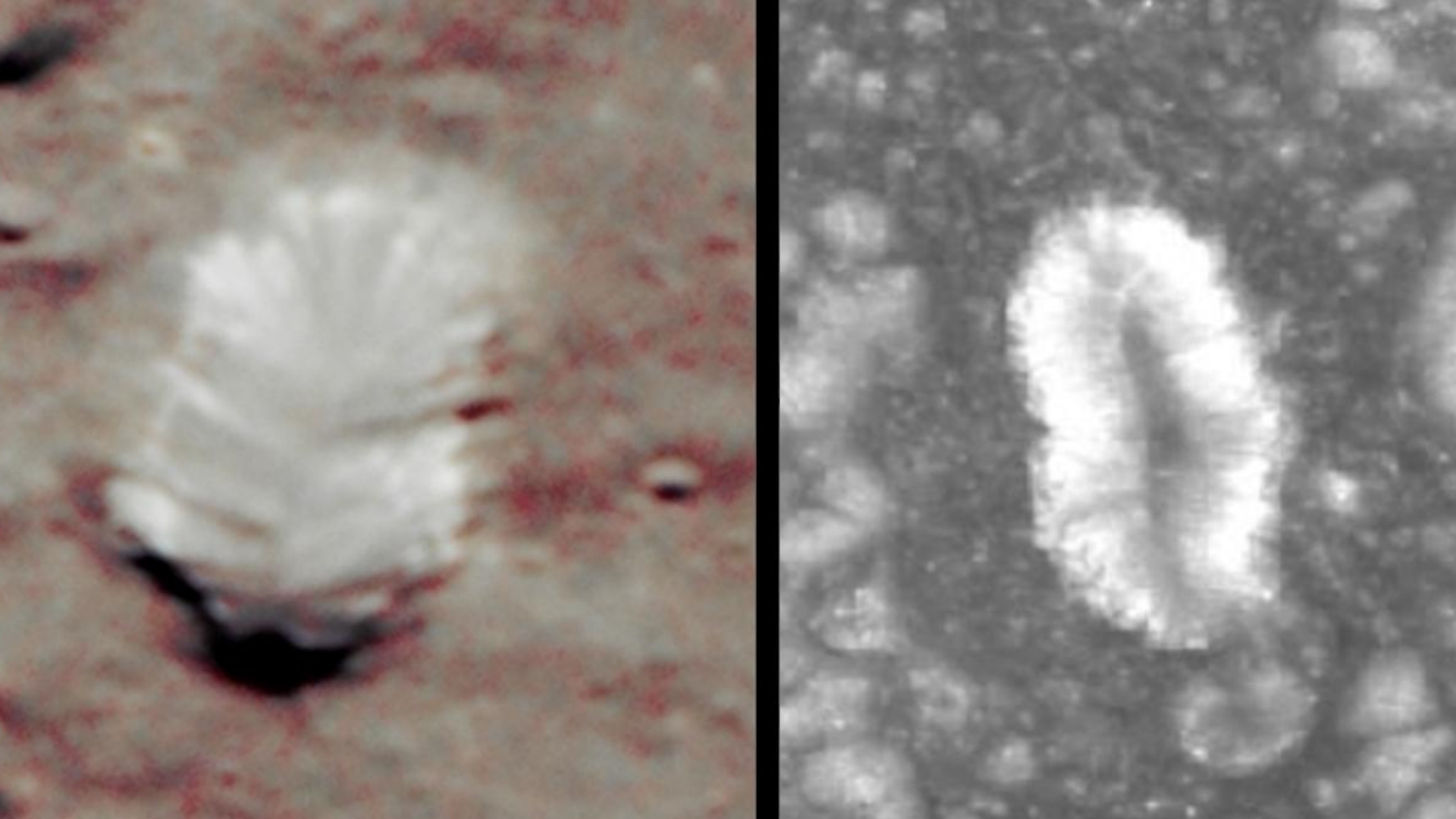
Slide # 15

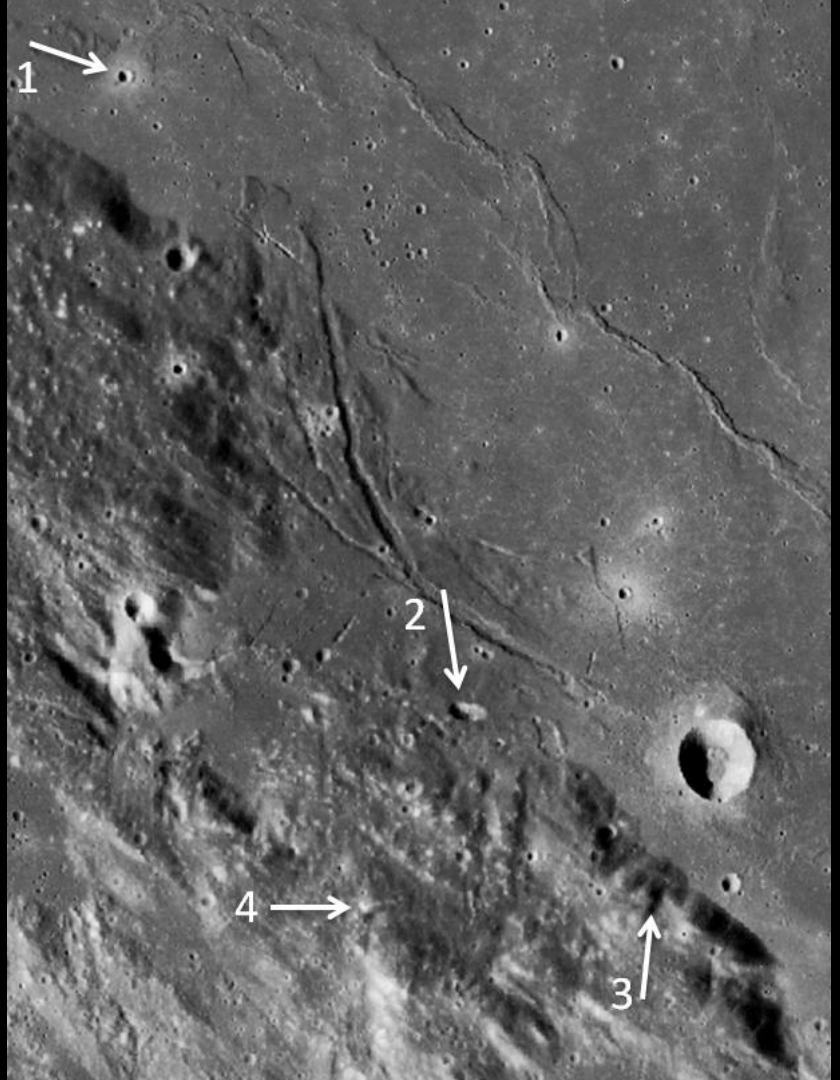
An almost identical feature has been observed to the SW of *M. Orientale* seen in this LROC QuickMap view. Head, Wilson & Weitz (2002) in a 2002 *JGR-Planets* paper examined this area and postulated the kidney-shaped central feature to be a volcanic vent that produced the black ash ring surrounding it in a pyroclastic eruption. A comparison with the feature near *Sulpicius Gallus* is shown in the next slide.

Readers can also access this Quickmap view at: http://bit.ly/2Dep5SE



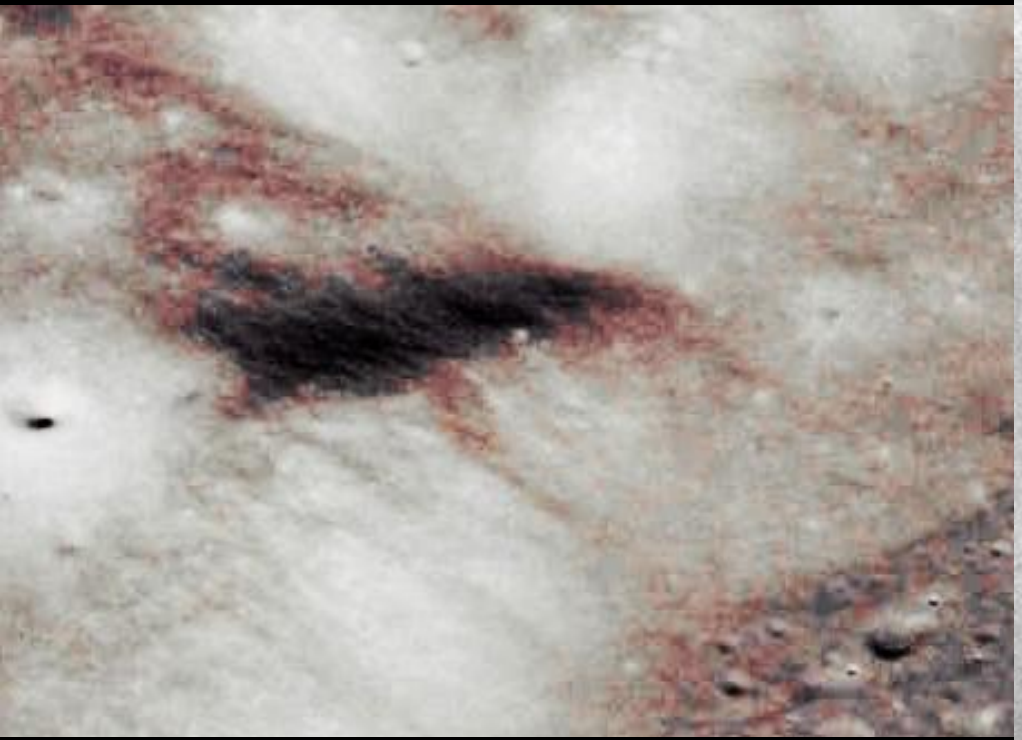
Slide # 16

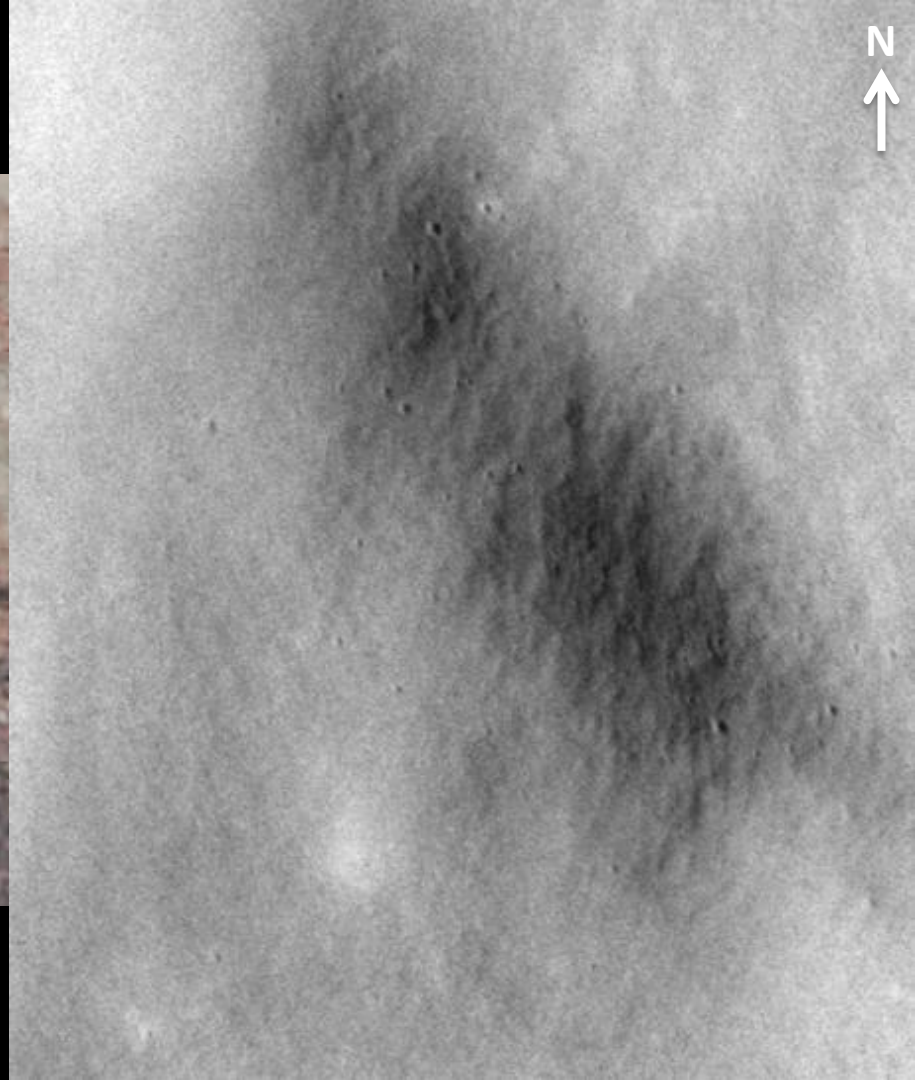
The *Haemus Mts*. kidney-shaped vent compared with the one in *M. Orientale* located more than a quarter of a hemisphere away. The vent at left, however, is ca. 5.5 km in length, whereas the one near *M. Orientale* is ca. 20 km in length! (Enlargements from previous slide nos. 13, 15)


1
2
3
4

Slide # 17

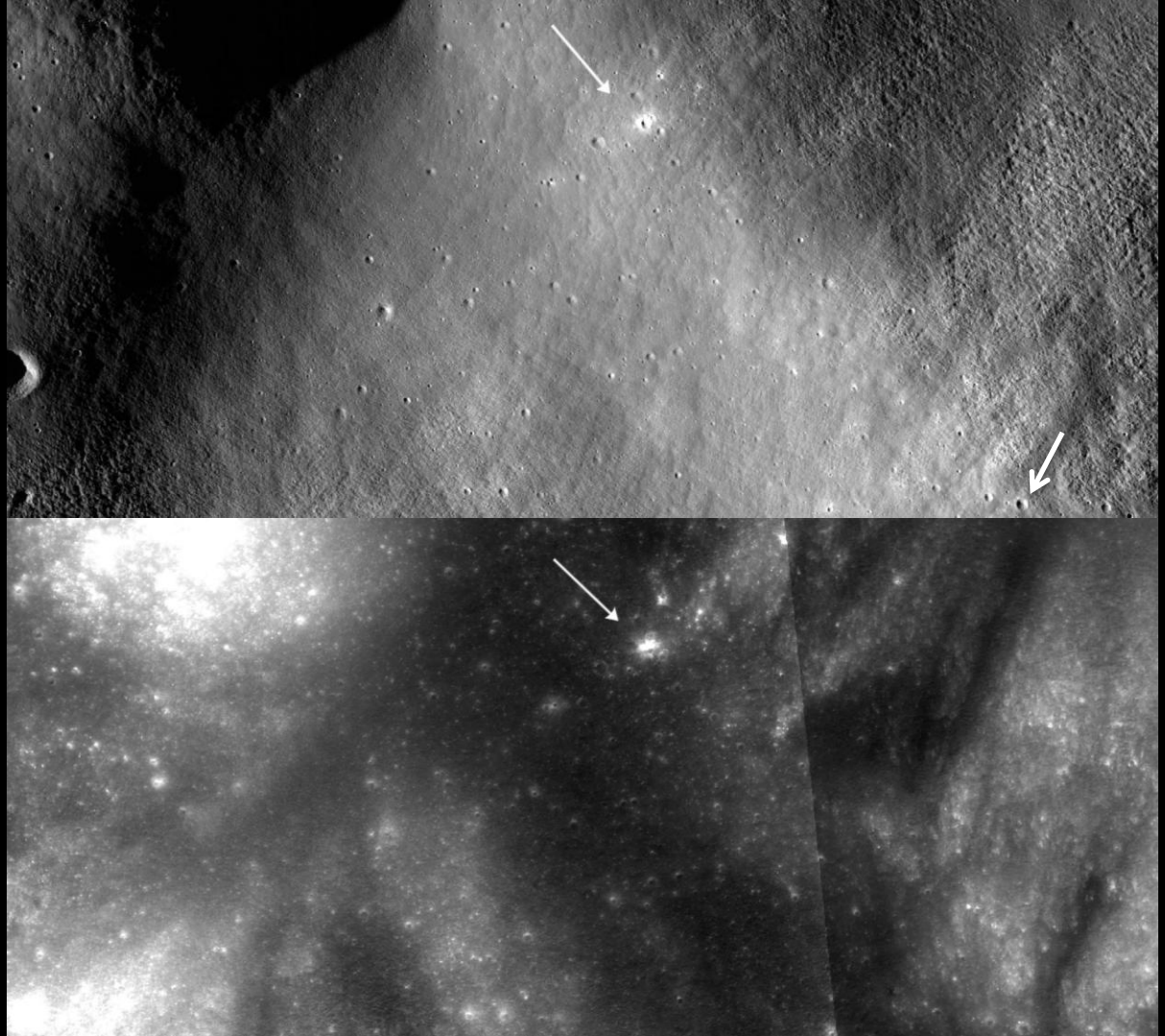
Let us move on to area no. 3, the site I have called *Vulcanis Lacus*. (Background photo is from the Lunaserve webmap, http://webmap.lroc.asu.edu/lunaserv.html)




N

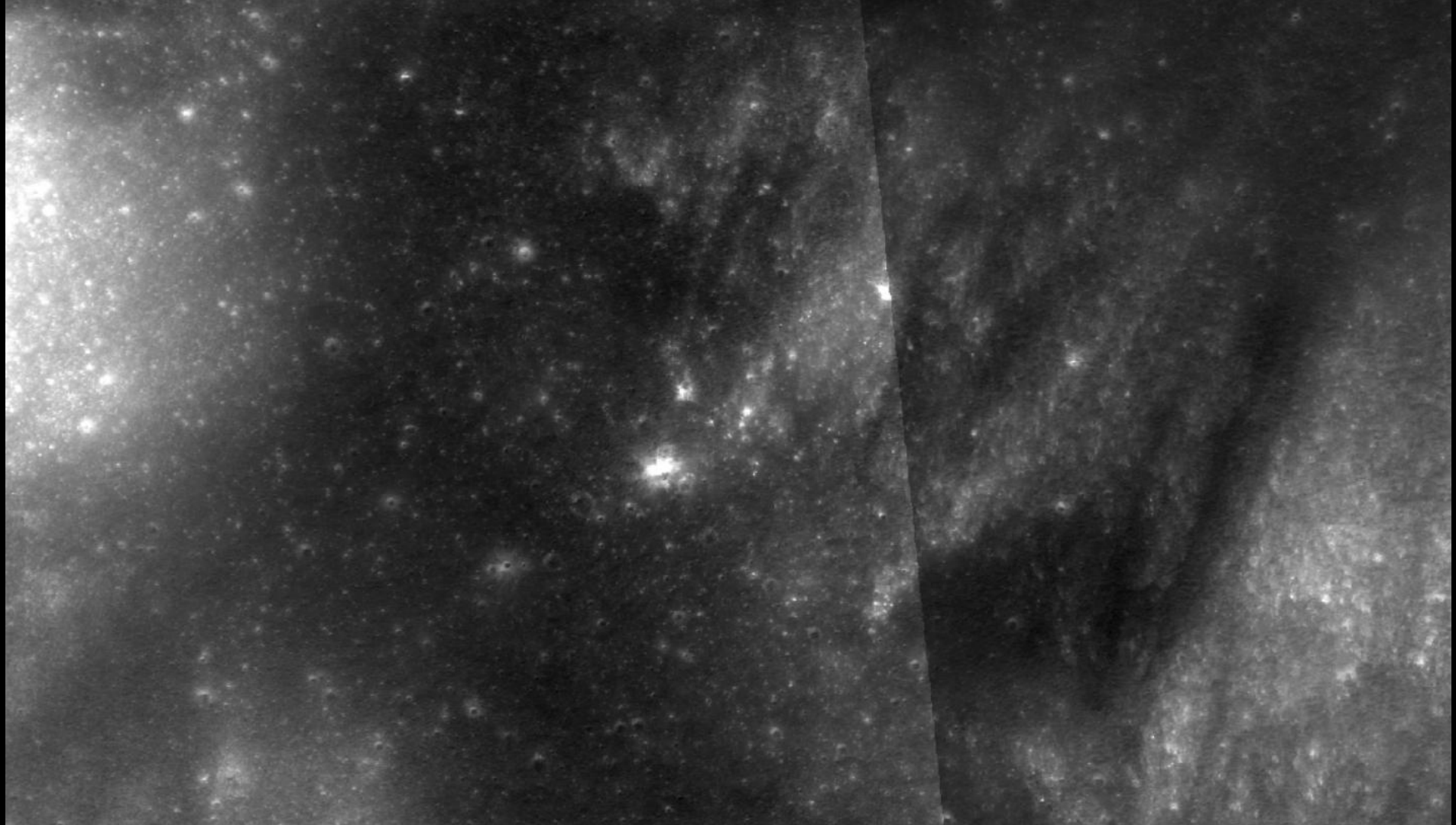
Slide # 18

Left is an enlargement from Ron Evans' photo shown earlier. And at right, the enlargement of AS17-M-1816 on Rev. 38, with solar el. = 19 . The interior of the depression, filled with sunlight, shows some very interesting detail. Note the bright spot on the rim in the Hasselblad photo is the crater with bright ejecta blanket at the upper middle of the right panel. On the western slope of the depression, a series of craters along the top or rim appear to have emitted a number of anastomosing debris flows. The lowest is a very dark grey; the next highest is a medium grey; and the highest is a very light grey. The middle and top layers form a debris flow pattern over the lowest dark grey level. Metric frame M-1817 forms a stereo pair from which the relative elevations of the 3 albedo flows can be easily seen. (*left*: enlargement from slide no. 13; *right*: NASA photo AS17-M-1816)



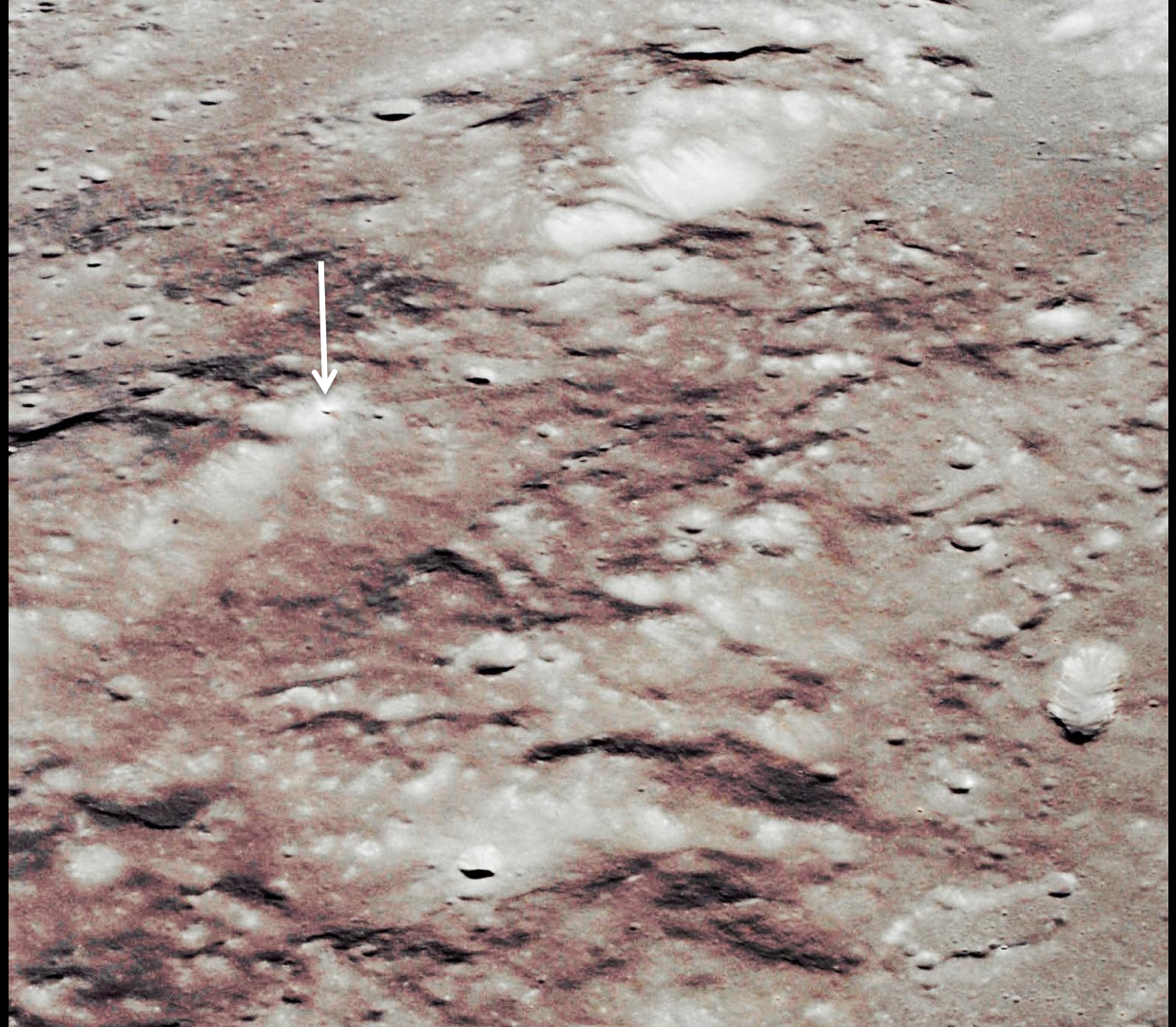
Slide # 19

The bright crater at upper arrow is ~55 m across. Distance of line of craters along rim from the bright crater to lower marked crater is ~3 km. Top view shows a ridges-and-swales pattern especially on the outer slope with a 1-10 m wavelength; and a somewhat larger wavelength pattern on the inner slopes. Such patterns are characteristic of avalanches on the Earth. The 3 albedo shades of the anastomosing pattern are also seen. The small craters in line along the rim of the depression can be followed from the bright crater down to the right and the line bifurcates into two branches at the lower right, more easily seen in the higher sun angle photo at the bottom. The flow pattern down to the mare floor at upper right is better seen in the next slide. The corresponding Quickmap views are (*top*): http://bit.ly/2D7xjvz; (*bottom*): http://bit.ly/2D6OFsv



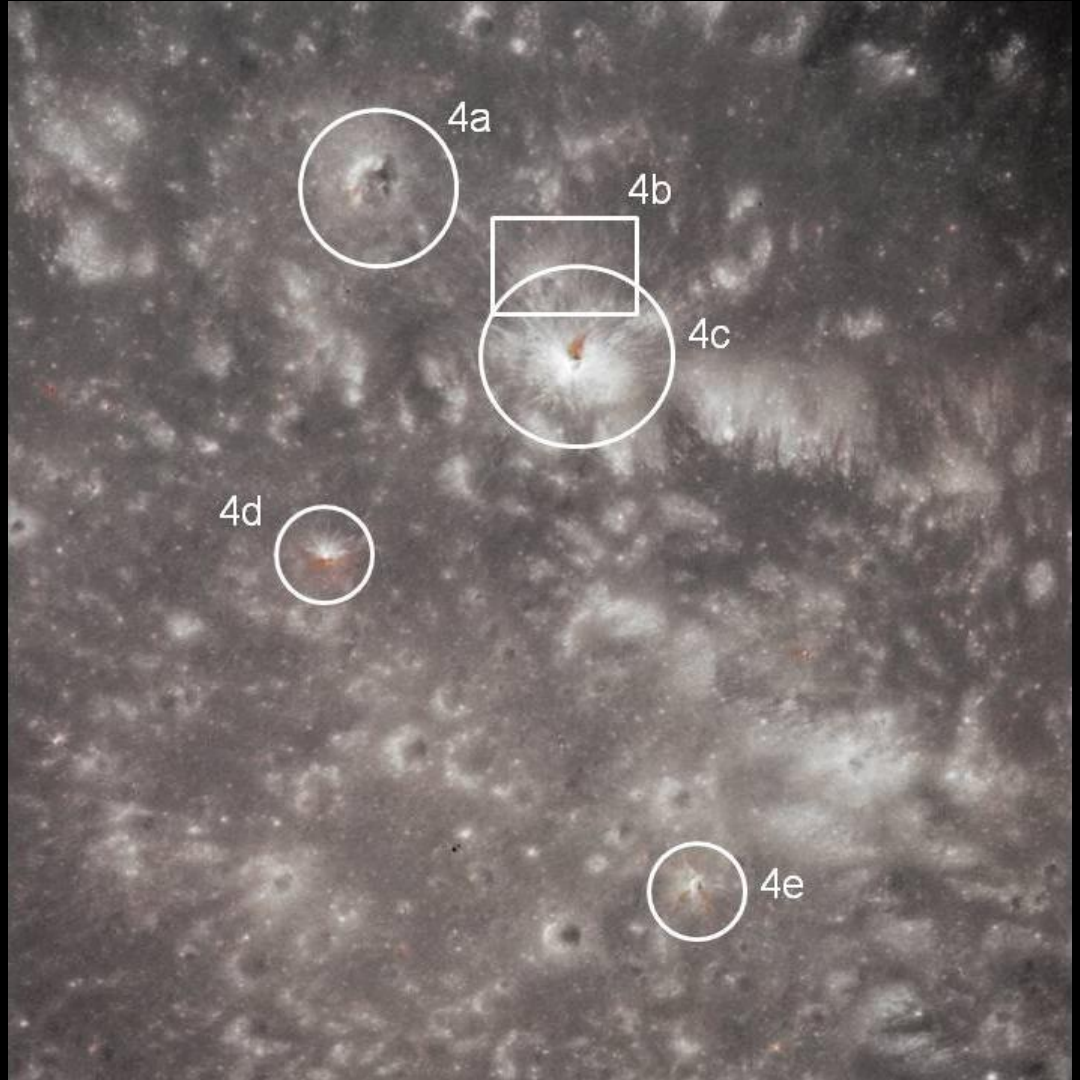
Slide # 20

Which has its center moved a bit further to the north. Also the line of craterlets or vents are easier to see. We have interpreted this line of vents as the sources of fire fountains erupting over time to produce the red/orange debris flows seen in the Hasselblad view that Ron Evans made (slide no. 13).



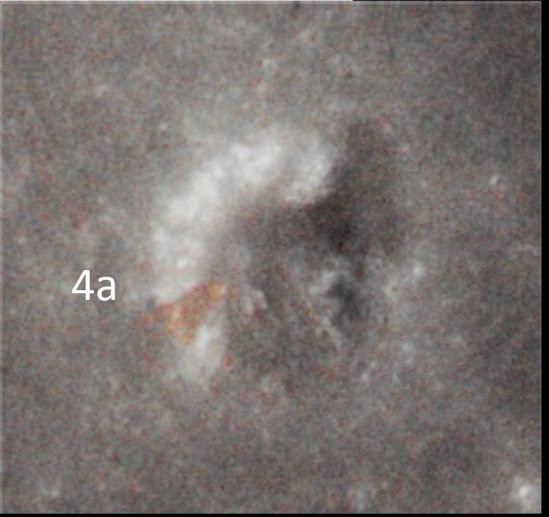
Slide # 21

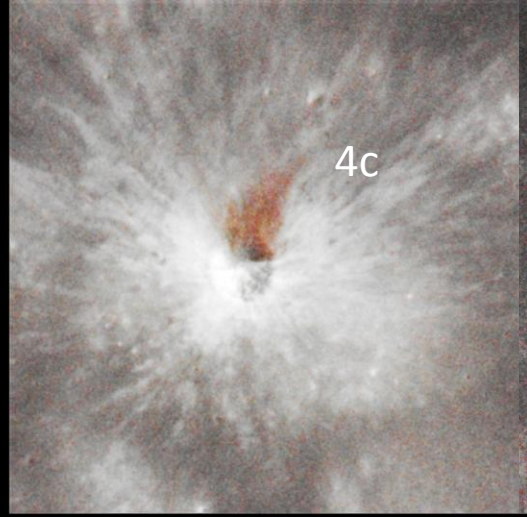
The no. 4 crater with red plume discussed in some detail by Lucchitta & Schmitt (1974) is shown in this enlargement of the Ron Evans' photo (slide no. 13). The kidney-shaped vent is on the mare plain at right. The next 3 slides add color to their description and expand it.

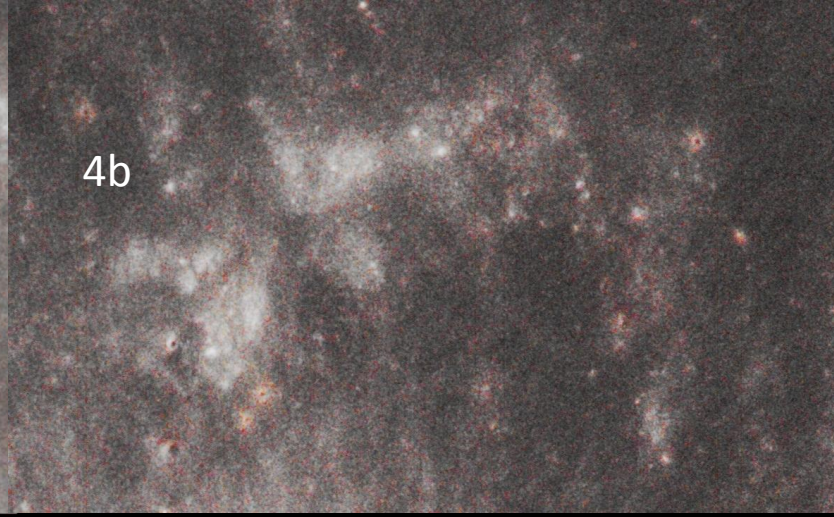

4a
4b
4c
4d
4e

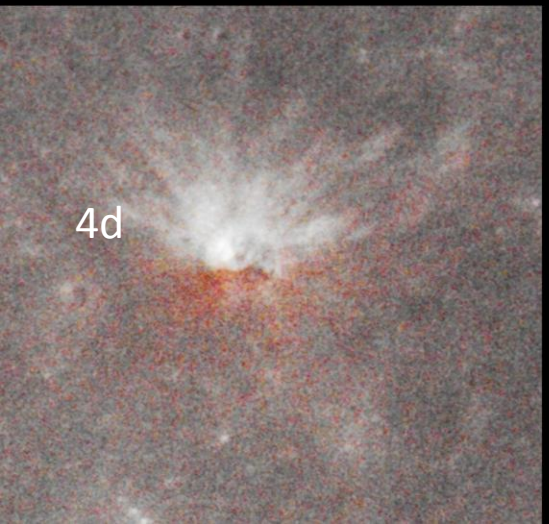
Slide # 22

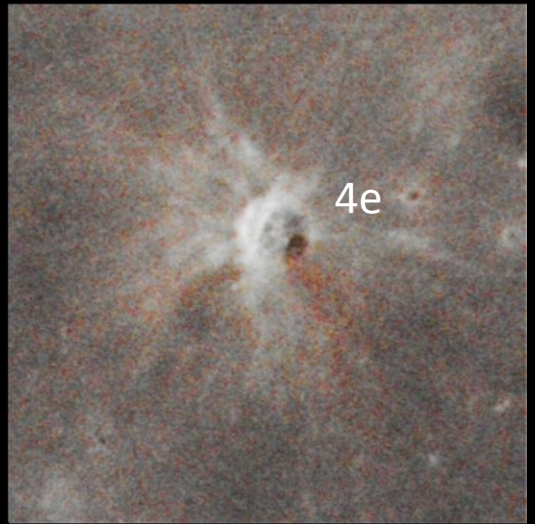
This Hasselblad frame is AS17-152-23284 taken by Jack Schmitt on rev. 74, sun el. = 50 , alt. = 114 km, 250 mm lens, camera tilt = 15 , az = 19). The principal feature that Lucchita & Schmitt (1974) discussed in their paper is here labeled 4c. They were not able to show this photo in color, however. I have labeled 4 other features associated with red patterns which are marked 4a,b,d,e and are shown in the next slide. (color-corrected version of NASA photo AS17-152-23284).


4a


4c

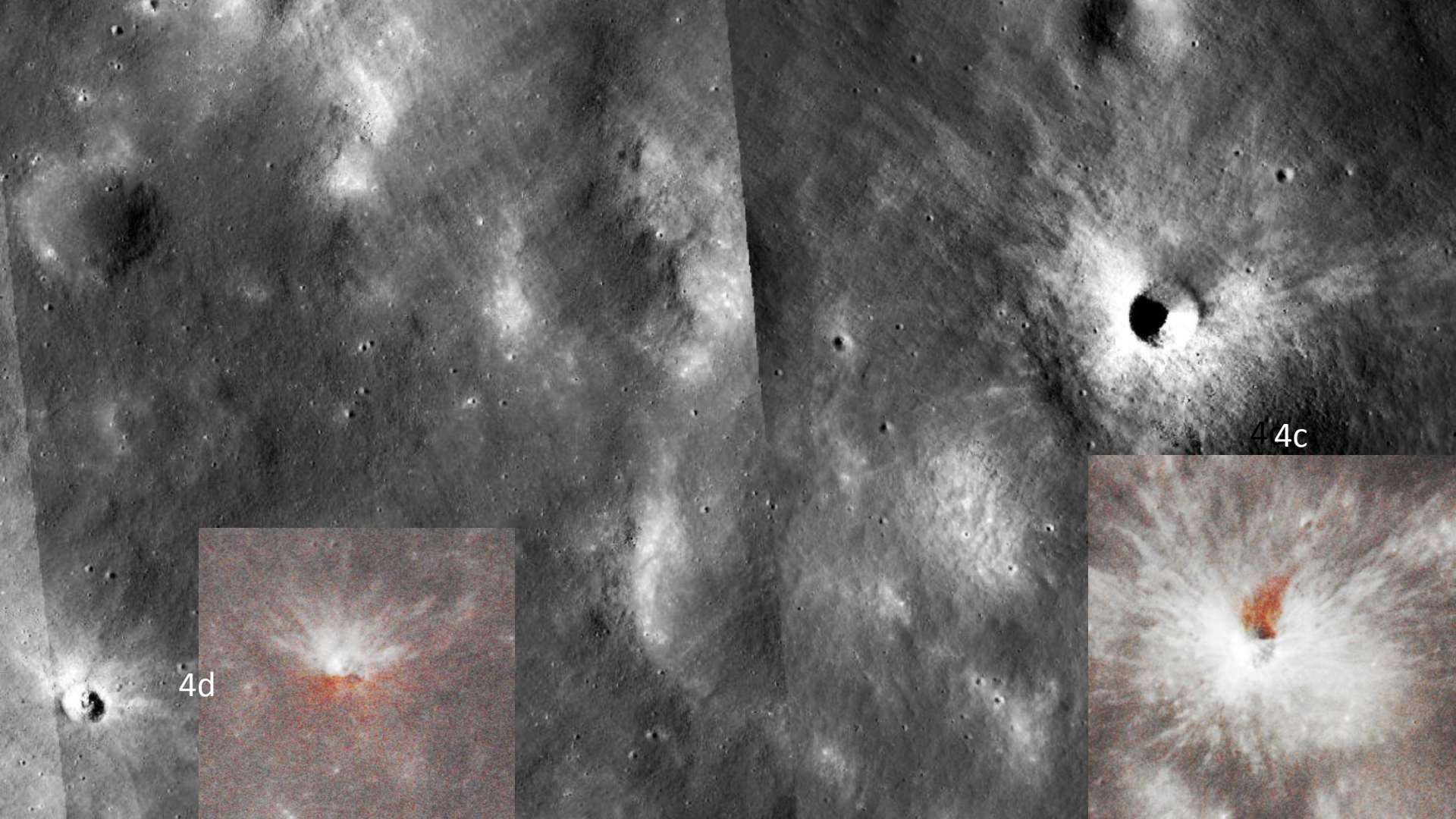

4b


4d


4e

Slide # 23

Enlargement of the 5 areas from the previous slide. 4c, 4d & 4e have red ejecta blankets; but 4a shows a red debris slide down part of the southwestern interior wall. 4b shows part of the northern ejecta blanket of crater 4c penetrated by numerous small craters with red ejecta patterns scattered throughout the blanket.


4c
4d

Slide # 24

An LROC QuickMap view of craters 4c,4d (slide no. 23) showing the dark albedo plume for no. 4c and the inset showing it red. Similarly at lower left, crater 4d has a darkish fan-shaped albedo ejecta blanket on the south side and the inset shows it to be red. Crater 4c is 460 m in diameter; and crater 4d at left is 210 m in diameter. The corresponding Quickmap view can be accessed at: http://bit.ly/2VDbye6

CONCLUSIONS

1. **By analogy with the color-corrected photos of orange/red and black ashes sampled at Shorty Crater, colored ash units can also be identified and mapped in the southwestern edge of *Mare Serenitatis*.**

2. **Impact craters penetrate to variable depths in local pyroclastic ash deposits, generally depending on their diameter. The resulting ash exposures in or around such craters provide a systematic means of determining the stratigraphy and relative ages of the ash sequences.**

3. **Stereo viewing of areas with pyroclastic ash deposits greatly enhances mapping quality.**

4. **Finally, studies involved in mapping and interpreting regional pyroclastic ash deposits would be greatly assisted by a new photographic orbiter satellite around the Moon with color camera(s).**