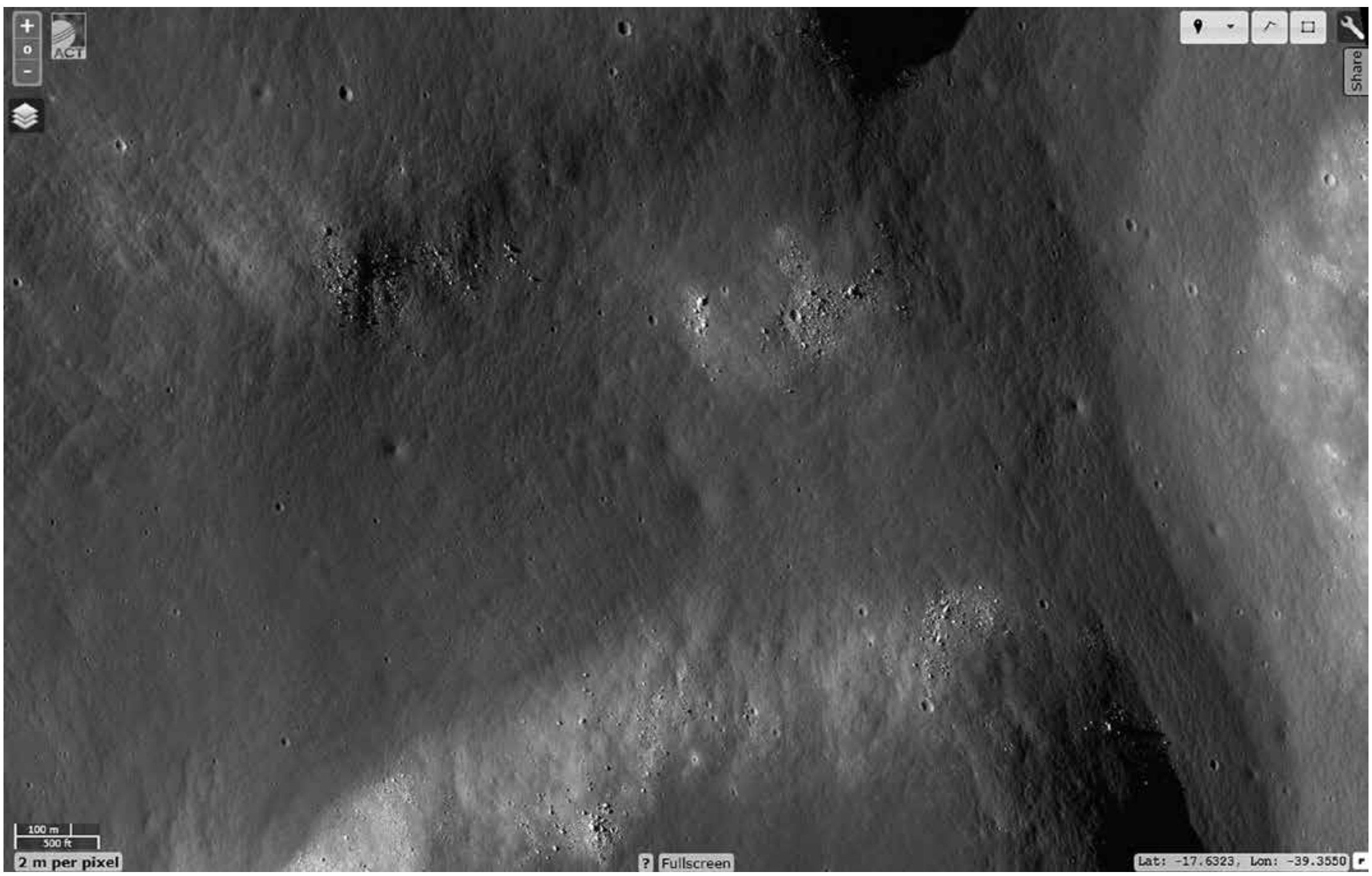
Devoted to the Study of Earth's Moon

Vol. 33 No. 1 Spring/Summer 2014

SELENOLOGY

The Journal of the American Lunar Society



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The official journal of the American Lunar Society, an organization devoted to the observation and discovery of Earth's moon.

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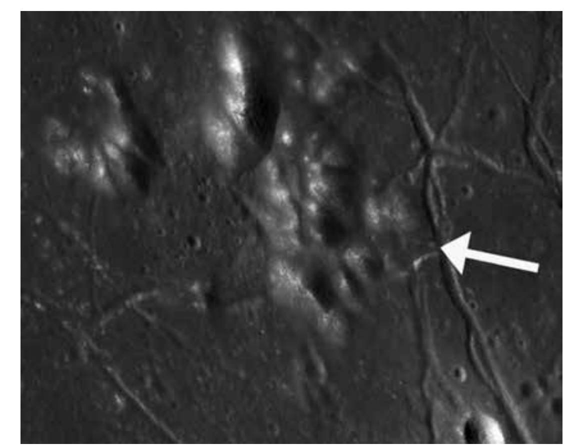

Cover:

High-resolution LROC image of craters and ejecta inside one of Gassendi crater's rilles. The image on the left provides the location of the cover image.

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Gassendi Crater Re-examined

by Steve Boint

Years ago, before NASA turned its orbiters loose on Luna, I used to measure the rim and peak heights of Gassendi crater from photographs taken in my driveway. Something about the crater fascinated me. Recently, I wondered what the LROC Quickmap website could show. A whole new Gassendi opened up. Quickmap is a clickable map of the lunar nearside which can be zoomed in with different overlays provided. This means that high resolution images are available for many locations. Additionally, the Clementine UVVIS spectroscopic images and several Chadrayaan-1 datasets are available on Quickmap.

3,600,000,000 plus or minus 700,000,000 years ago, a meteor impacted the northeastern rim of the Humorum basin[1]. It left a crater 110 km in diameter slanting downward on the wall of Humorum, which itself had formed only recently. Sometime later, lava flooded the Humorum basin, creating Mare Humorum, but although this lava filled the Humorum crater to a depth of several kilometers at its deepest point, the lava may not have breached Gassendi.

Even a cursory glance at Gassendi shows that the impact formed multiple central peaks in the crater and that, at some time after the impact, lava flowed in and filled the crater almost to overflowing, lifting and cracking the existing floor and at least nearly flooding over the low point in Gassendi's rim (Fig. 1). Perhaps it did flood over the low point, flowing in from Humorum or out from Gassendi (having risen from cracks in the wall of Gassendi crater); past images have not had the resolution to determine for certain if this occurred.

Quickmap has a tool that allows the user to draw a line on the image of the moon and the software will provide an elevation graph of the path of the line—using LRO's laser altimeter data. The graph always begins where the unlabeled end of the drawn line is and terminates at the end containing location data (Fig. 2, 3). As expected from the visual image, the crater rim reaches its lowest point on its southern end. I was startled to note a change in height near Gassendi's northern parts, both sudden and rapid and then, upon inspection, to find that it correlated to the higher parts of Gassendi resting

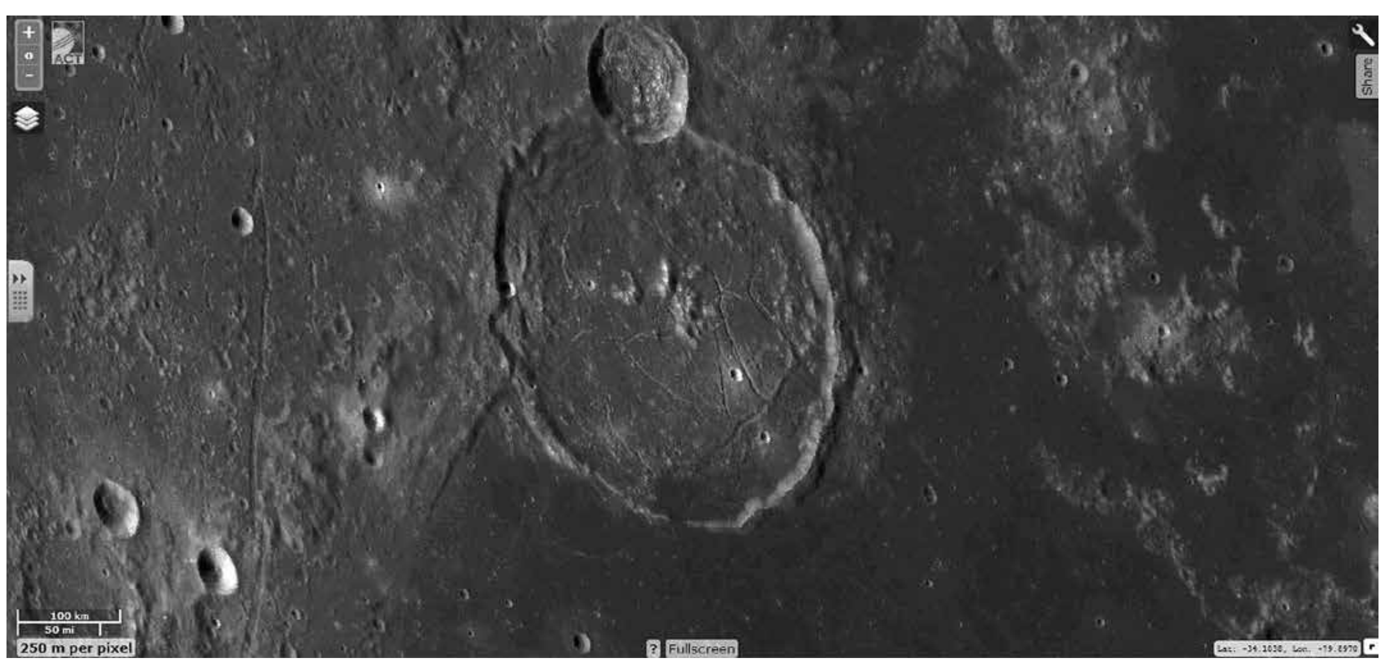


Figure 1: Gassendi crater

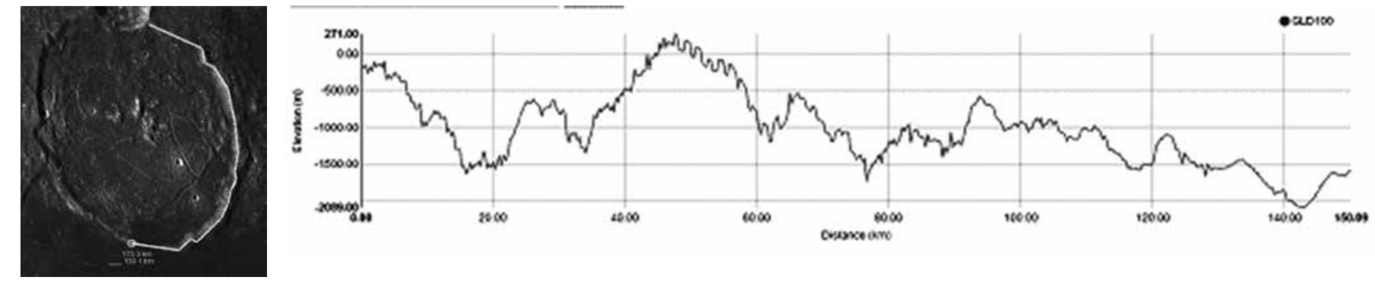


Figure 2: Vertical displacement of Gassendi's eastern wall. Vertical axis is exaggerated. The southern gap is the right-hand edge of the chart.

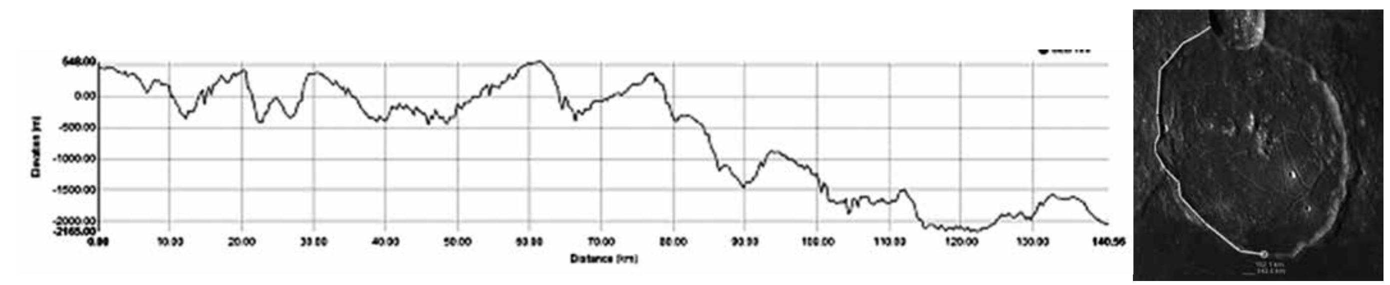


Figure 3: Vertical displacement of Gassendi's western wall. Vertical axis is exaggerated. The southern gap is the right-hand edge of the chart.

on the top of the rim of Humorum while the more southern parts of Gassendi had formed on the steep slide of Humorum's wall (currently mostly buried in lava).

The central peaks of the Gassendi are interesting. (Fig. 4). First, note the strange shape of the peak on the east. Not only are the peaks of this mountain rounded in a parallel fashion but they resemble a splash coming from a western puddle and spraying to the east. Interestingly, on their western end is a roundish area which might well be either the ruins of a crater that formed the peak or of a crater that broke down the peak (but this latter explanation doesn't explain the rounded shape of the peaks). But, in either scenario, what happened to the peaks on all but the south and east? Besides, the peaks are rather large to have come from the formation of the crater on their northwest. Could it be merely a chance conjunction? I would appreciate hearing from readers who could explain this feature (Figs. 5-6).

The other peaks appear to be of rather standard shape (Fig. 7). Composition of the peaks is different from the floor of the crater (Fig. 8). Additionally, the composition of some of the rilles differs from that of the floor. The peaks and floor of Gassendi probably consist of anorthosite, standard for highlands material, with the more mafic lavas having risen beneath the floor and become visible through the cracks. This tripartite structure supports the notion that Gassendi's floor was raised by lavas rising beneath it.

The nighttime soil temperature overlay ties the central peaks to the layer below the crater floor—note the similarities between the peaks, the larger

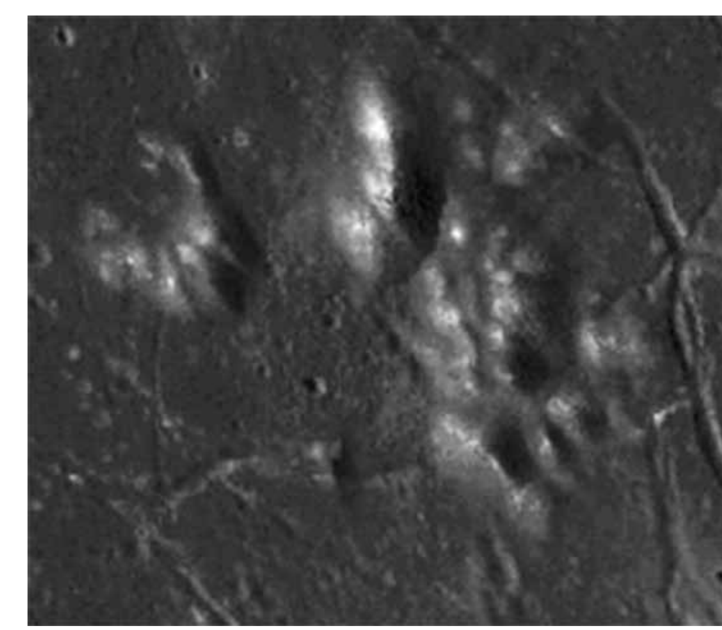


Figure 4: Central Peaks

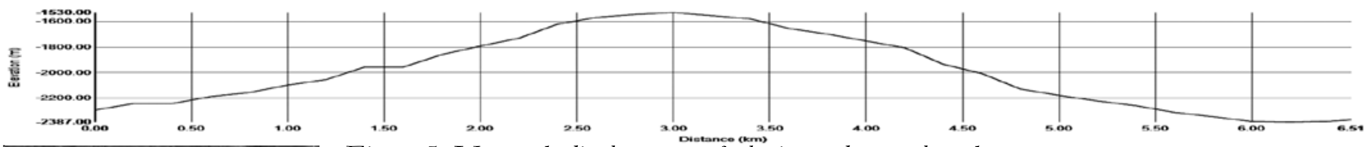
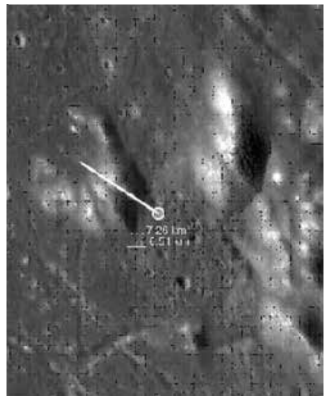


Figure 5: Vertucak displacement of the imaged central peak.



craters inside the basin, and the cracks in the lava surface. The crater rim does not appear to share this composition (Fig. 9). Soil temperature is related more closely to particle size (pulverized regolith vs. solid rock) than to chemical composition. The peaks, smaller crater walls, and cracks appear to be made of boulders and/or sheer, solid rock cliffs while the floor of Gassendi is regolith.

The standard Christiansen Feature Index shows the peaks tending toward a composition where plagioclase feldspar is common and the surrounding mare tending toward olivine as a major component. [I admit not having found explanations of how the base grayscale map (WAC Mosaic + NACS) was generated or how the Christiansen Feature Index is generated, but find it suspect that the grayscale image is almost an exact match in tone to the Christiansen Feature Index, with high grayscale albedo corresponding almost exactly to plagioclase feldspar.] Albedo can be a problem in spectroscopy[2].

Plagioclase, a rock formed by the cooling of lava, is prominent in the lunar highlands. Olivine, a heavier chemical than plagioclase, is suspected of being a major component of the lunar mantle 70-100 km beneath the regolith. Previous work by Mikhail done in the infrared identified the lower section of Gassendi with volcanic flow and crystallization[3]. When the moon first formed, it was molten. Olivine crystalized early, at a higher temperature than most rock, and its density would have caused it to sink and become the mantle as it combined with different kinds of rock. Eventually, the mantle re-melted in areas and erupted in fire fountains and shield volcanoes, forming the lunar maria. There is a chance that olivine from the mantle has been exposed on the surface by major impacts[4].

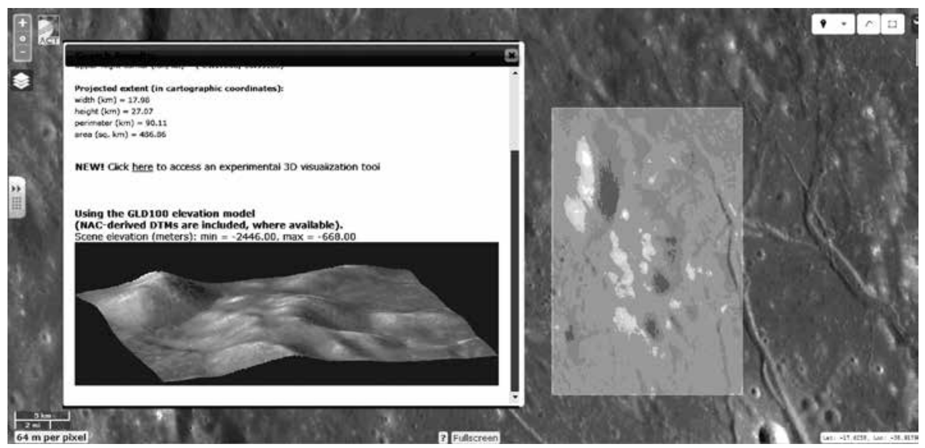
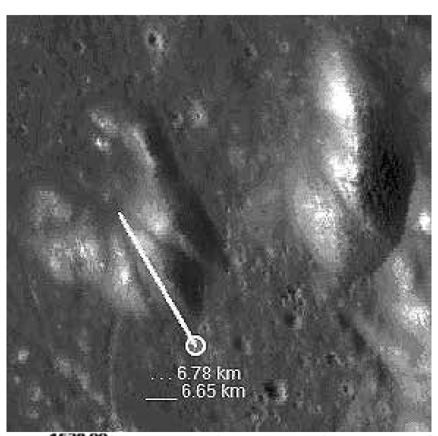


Figure 7: Quickmap's computer-generated 3-D image of the designated central peaks.



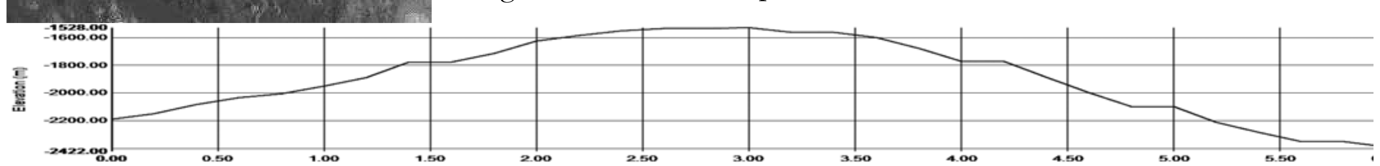


Figure 6: Vertucak displacement of the imaged central peak.

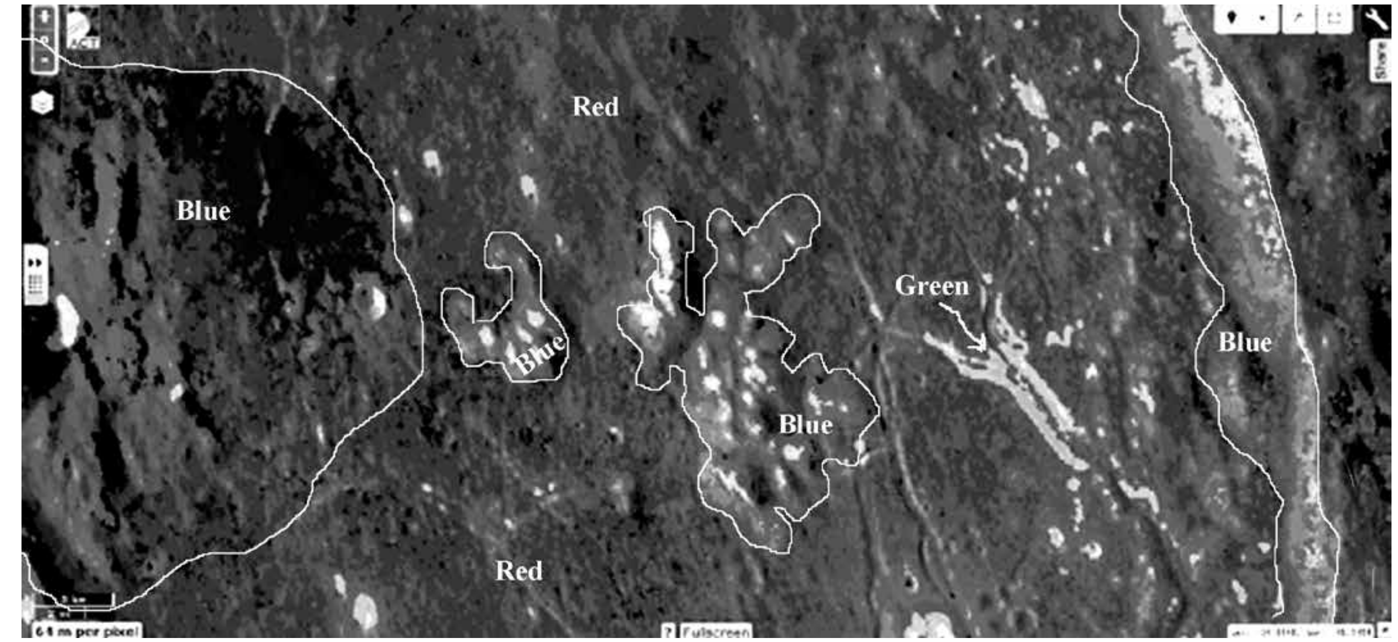


Figure 8: Clementine's UVVIS spectral image of Gassendi (the central peaks are in the center of this image) from Qhickmap. Outlines and labels added by the author.

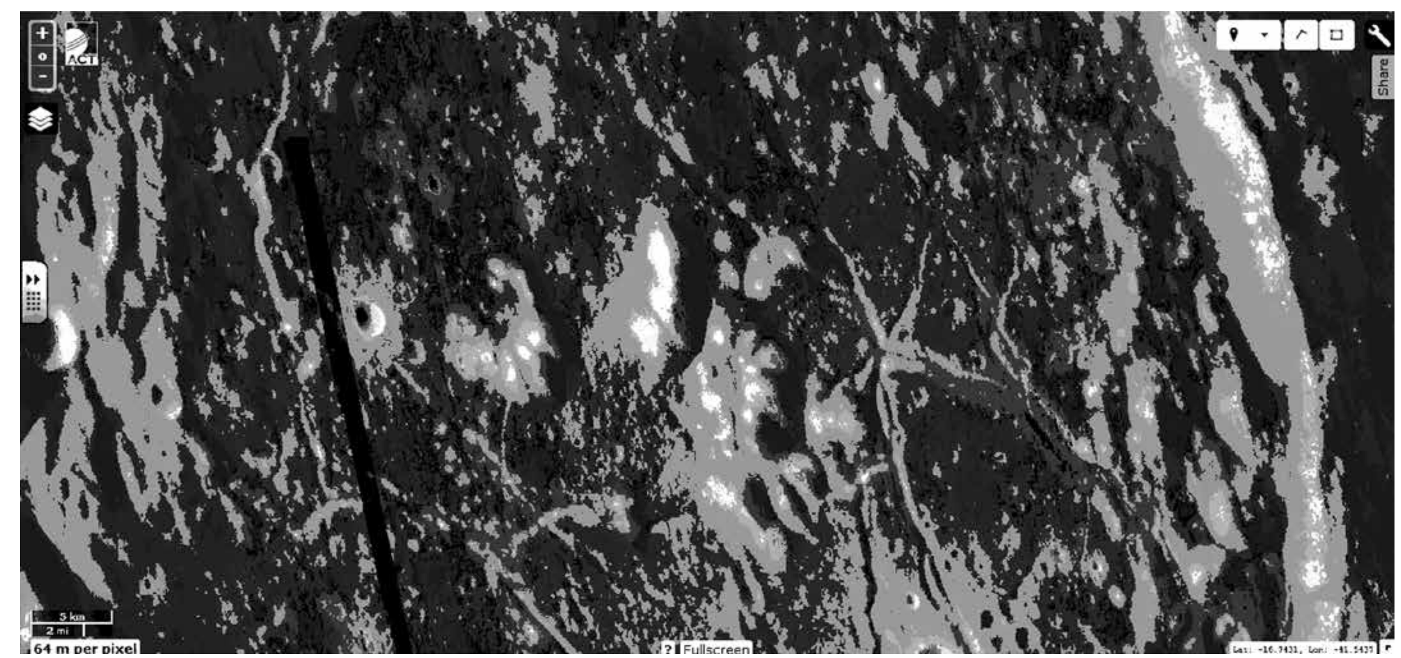


Figure 9: Quickmap's nighttime soil temperature of Gassendi crater. Lighter shadings hold more heat.

As stated earlier, Gassendi is a floor-fractured crater, having had lava rise up beneath its floor, raising the floor and cracking it. One of the first questions this raises is whether the lava which flooded Gassendi is the same composition as that which flooded Humorum basin. The Clementine UVVIS spectra show definitively that it is not; the two are separate lava flows chemically and maybe chronologically. The mare inside Gassendi is lower in titanium than is the mare outside Gassendi's rim, although it does look like some sort of mixing or overlaying occurred on the southwest, just outside Gassendi's rim (Fig. 10). Both Low and high titanium lavas are indistinguishable when looking at current surface particle size as revealed by heat retention. This may be an indication of

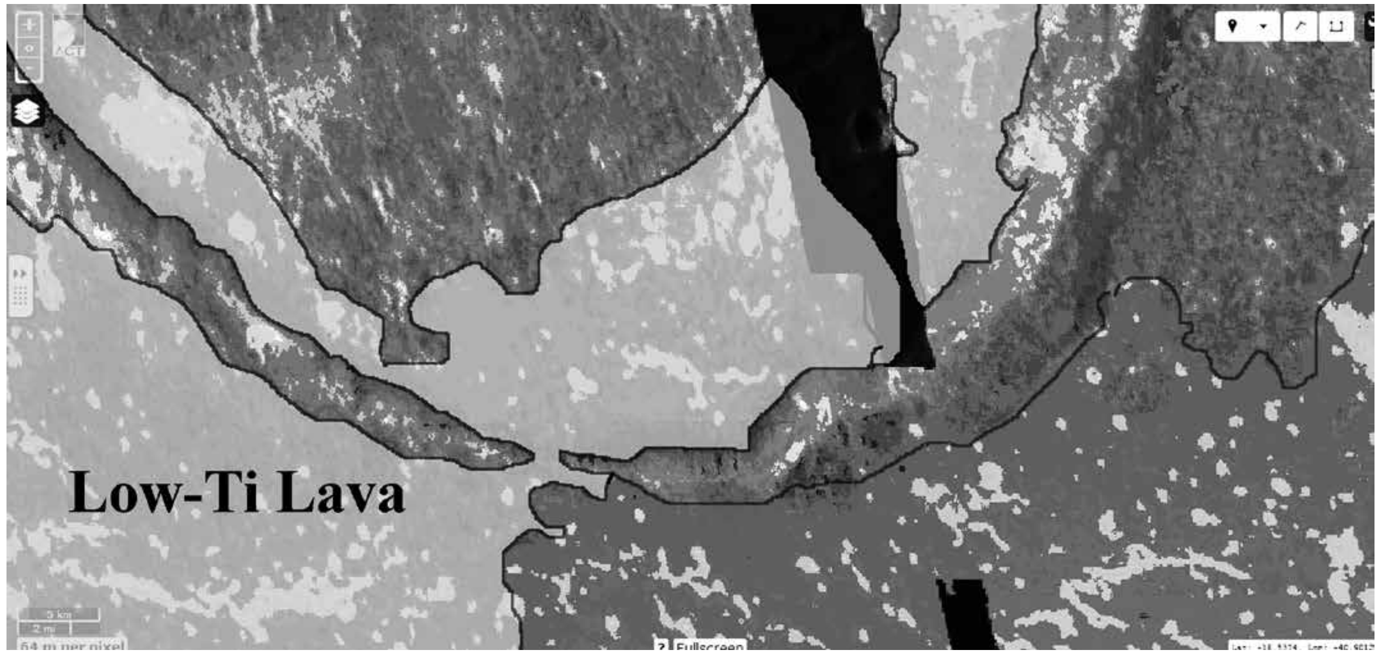


Figure 10: UVVIS spectrum showing titanium content of lavas in and near Gassendi (outlinnig and text added). Light gray is low in Ti. Dark gray is high in Ti. Black is an absence of data.

similar histories and processes at work in lavas from separate times—although the separation in times is of minor significance given the overwhelming age of all of the lavas. So their particle size is similar, but the chemical signature of the two mare areas (Humorum/Gassendi) differ. Perhaps the role the gap in Gassendi's rim played in lava emplacement can be illuminated by examining the mare fill of all of Gassendi instead of merely looking at the gap.

Looking at the UVVIS map, it appears that lava flooded Gassendi and reached the surface only in the south of the crater. North of this area, it raised Gassendi's original floor but remained buried. Did lava rise and pool in the south, stopping just short of sliding over the lowest point on Gassendi's walls or did lava from one side of the wall or the other actually flow through the low spot in Gassendi's rim, forming the pool?

As stated earlier, the rim drops steadily until reaching the lowest point in the south. Looking at Gassendi from my driveway, I often wished the low point was on an eastern or western wall; I used the shadow method for calculating feature height, and the southern edge of Cassini's rim never produced a measurable shadow, given that it was aligned with the path of the sun through the lunar sky. I had read that the rim was too tall to allow the lava to flow over it, but could not verify that with observation. I had also read the opposite. Sadly, the high resolution LROC visual images offer no help toward resolving the question (Fig. 11). There is a possible rise visible, but its extent or continuity are not clear.

However, while LRO height measurements along the rim show an unexpected gap, almost a breach, in the rim at the location of the lowest point (Fig. 11), a profile straight down the throat of the gap reveals that along this line the stump of the rim across the gap rose significantly above the mare lavas on either side (Fig. 12). Note that both maria, interior and exterior, are lower than Gassendi's gap. This would seem to support the isolation of the two lava fills.

The apparent mixing southwest of the rim remains unexplained, either the lavas which also filled Gassendi flowed up cracks in this part of Humorum, or the lavas in Gassendi and Humorum are similar but unrelated. Physical sampling might solve this quandary.

But the floor of Gassendi holds even more mystery—there is something odd here. The floor of the crater appears to have a significant collapsed

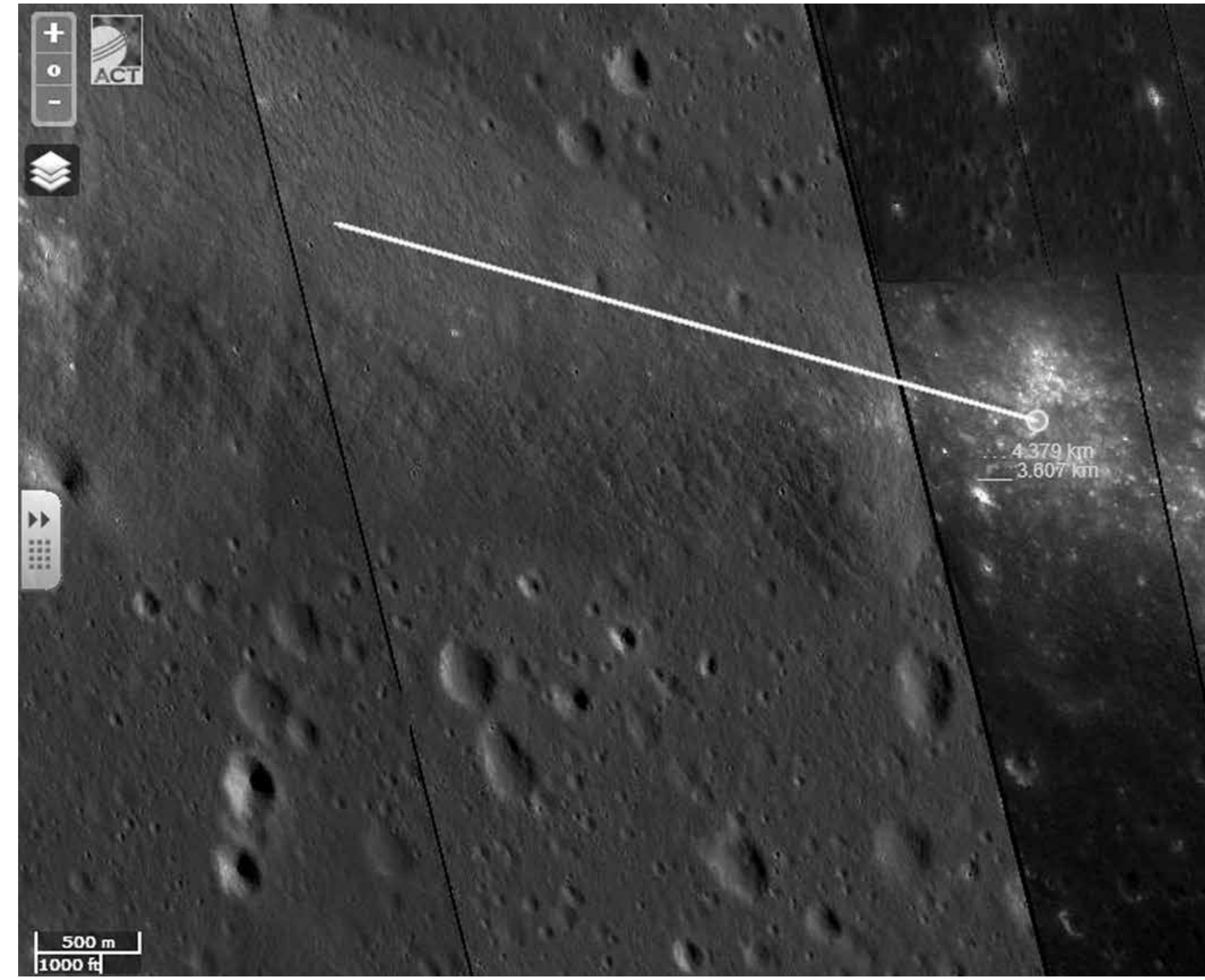
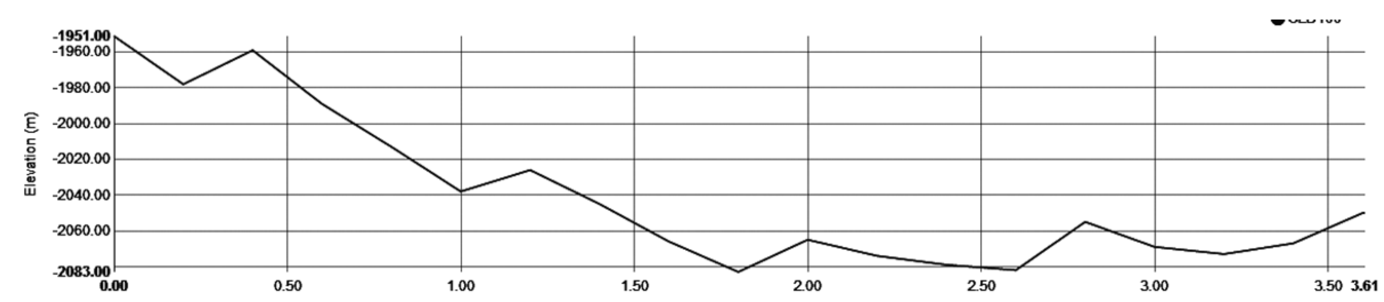


Figure 11: High-resolution LROC image of the gap in Gassendi's southern rim. The white line shows the path of the height profile below.



area, a double dip forming a low point on the southeast that encompasses only part of the low-titanium lava fill.

A series of profiles of the fill area were taken. Figure 13 shows a relatively uniform depth for the low titanium fill area. By figure 14, more than one dip was starting to show. Figure 15 shows clear signs of a double dip, one near the rim and one near the interior edge of the lava fill. A rille forms a third dip interior to the middle dip and on the edge of the low titanium region. Note the rille's depth near the 5km point of a little less than -2400m. By figure

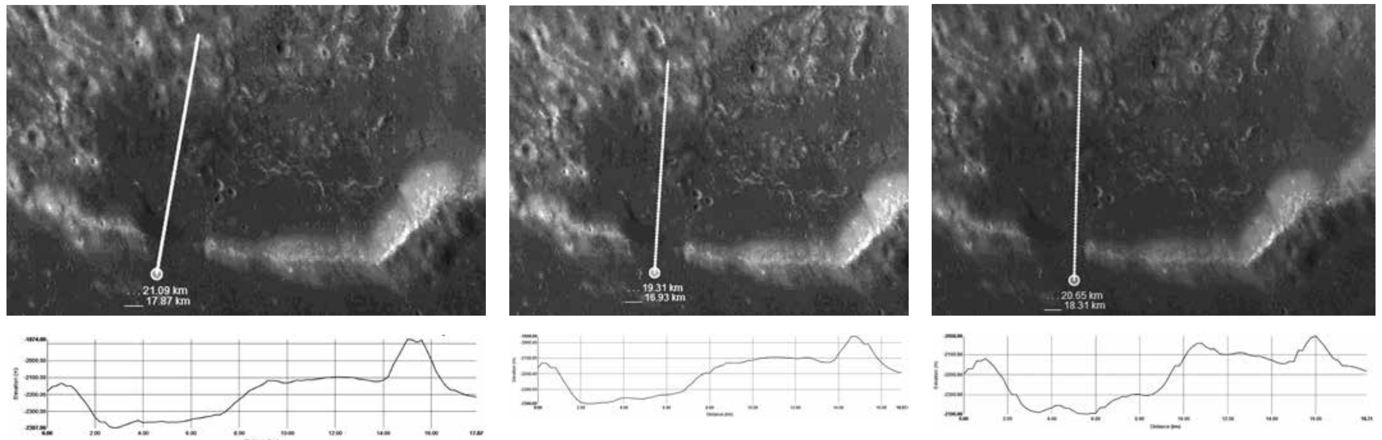
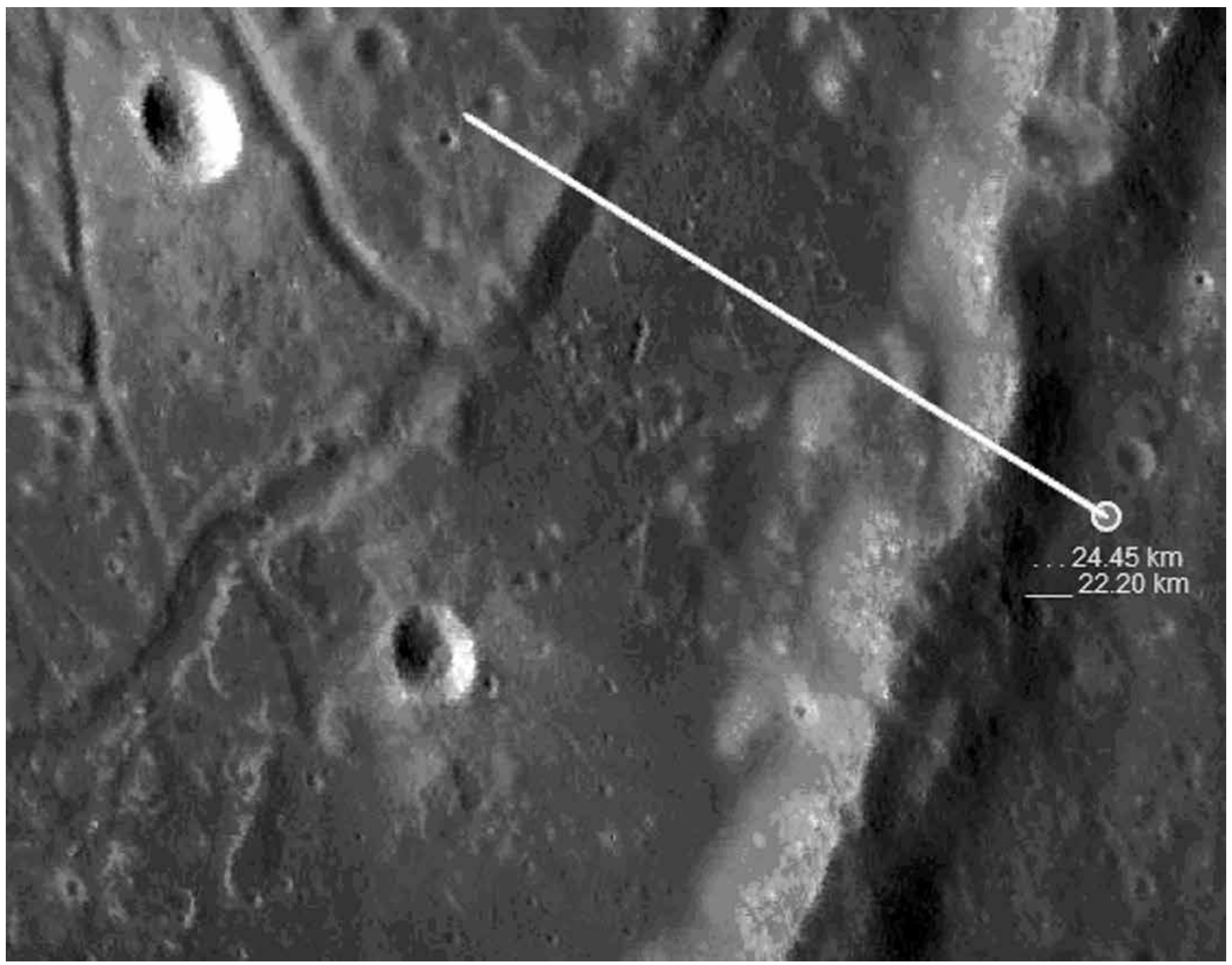


Figure 12: Height profiles from Gassendi's interior, through the gap in its rim, and terminating on Mare Humorum.



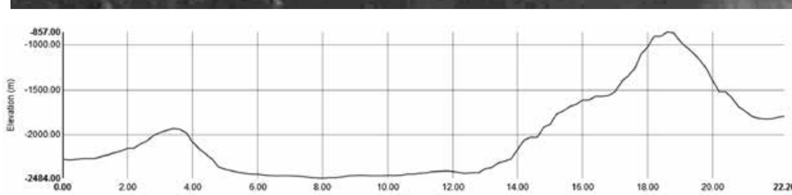


Figure 13: Profile of the northeastern region of the low titanium lava fill showing no signs of a significantly lower area.

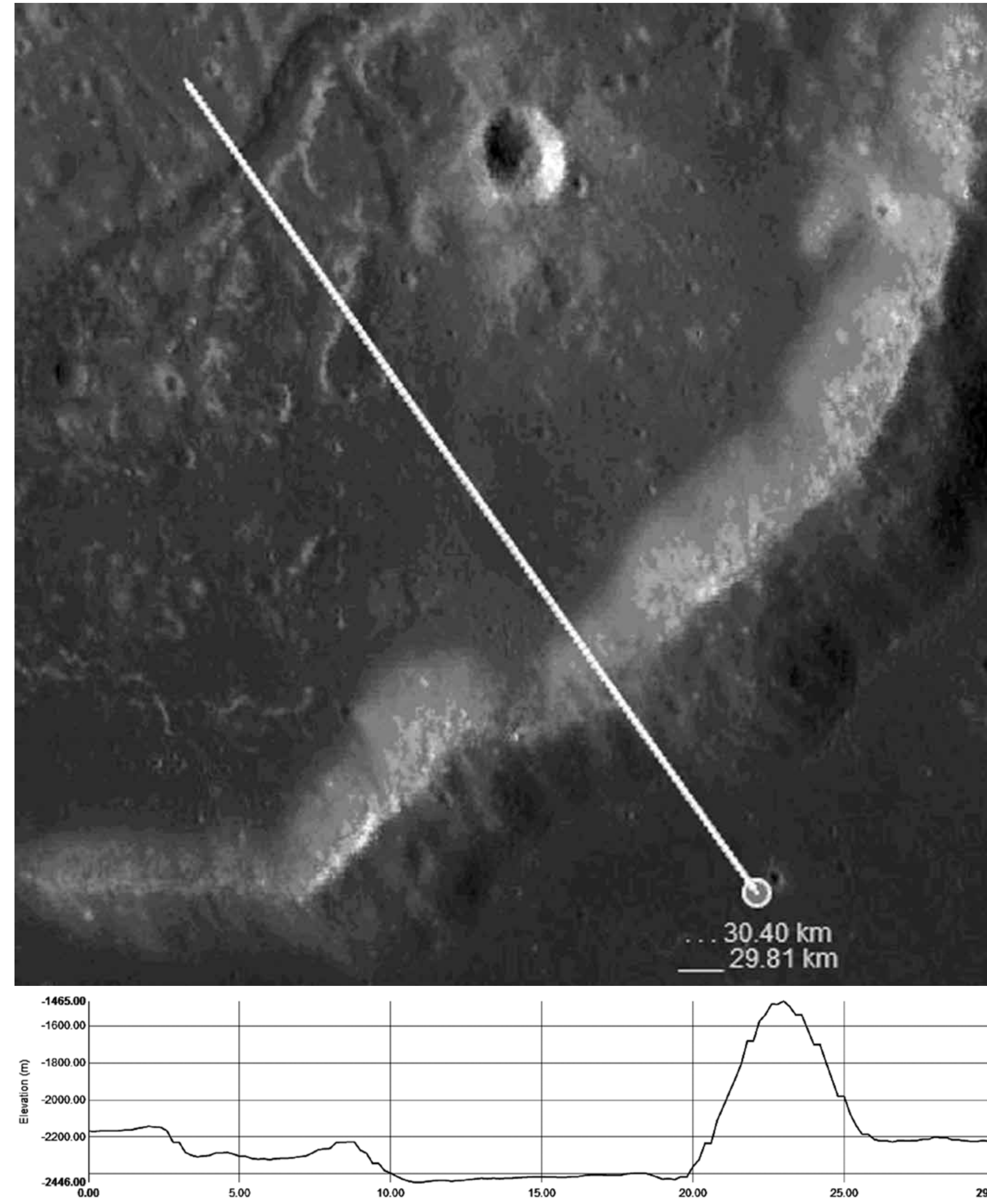


Figure 14: Profile of the southeastern region of the low titanium lava fill showing a slight rise in the surface but 2 low point resisting the rise..

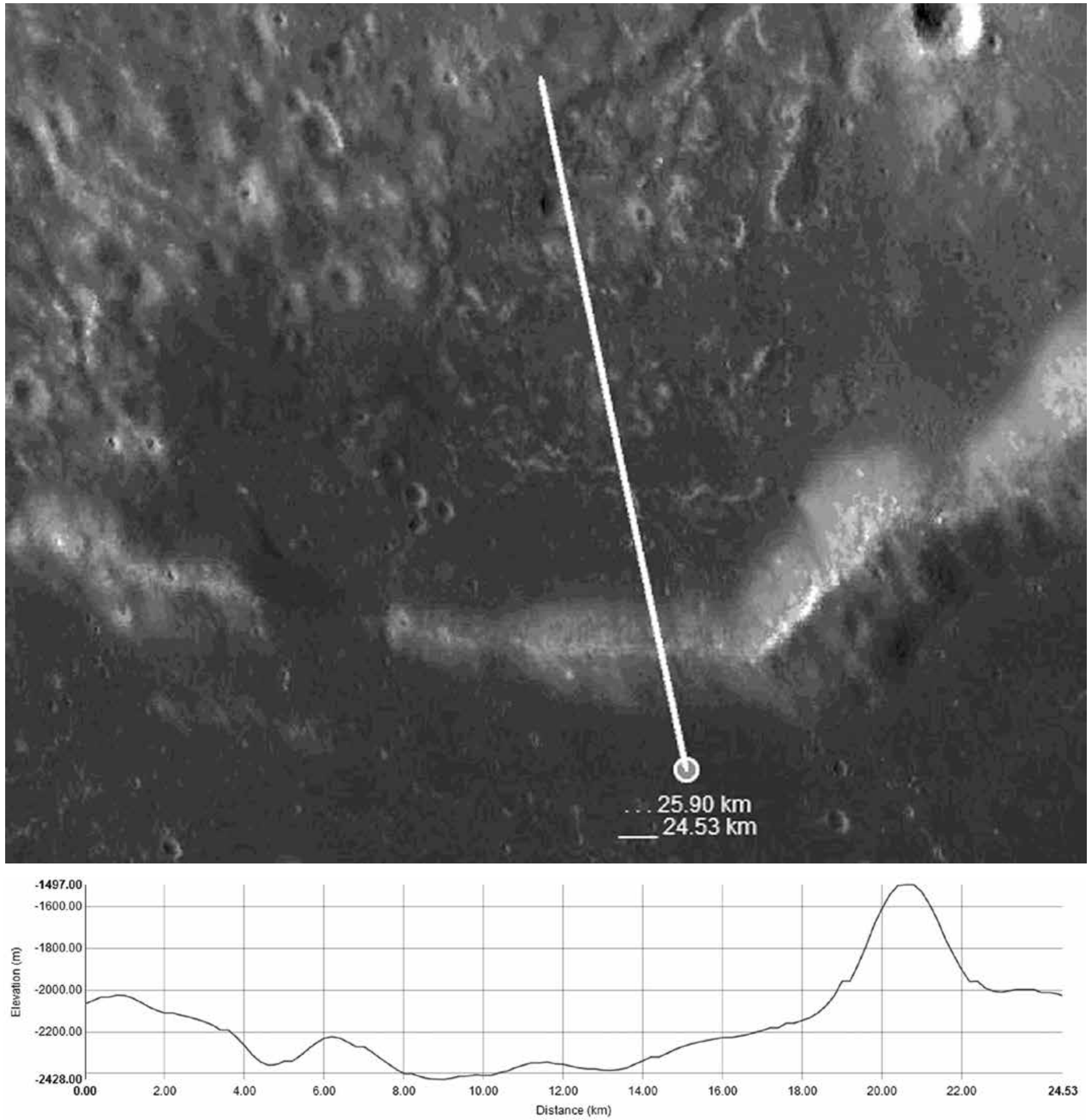


Figure 15: Profile of the southeastern region of the low titanium lava fill showing a dip on the left which correlates with the rille near the top of the line on the photograph and a double dip forming in the low-titanium fill area.

16, the rille's depth has remained the same but the center dip has become less deep; the ridge between them has become smaller. Note also that the region immediately interior to the rim has begun to bulge upward. By figure 17, the two interior dips have pretty much merged. Figure 18, instead of showing a bulge when the low-Ti area is examined along this line, shows an almost constant decline to a little lower than -2300m. Figure 17 shows the lowest point is the rille. Indeed, the mouth of the rille and a little in front of it appear to be the lowest area in Gassendi, with the low-titanium lava strangely

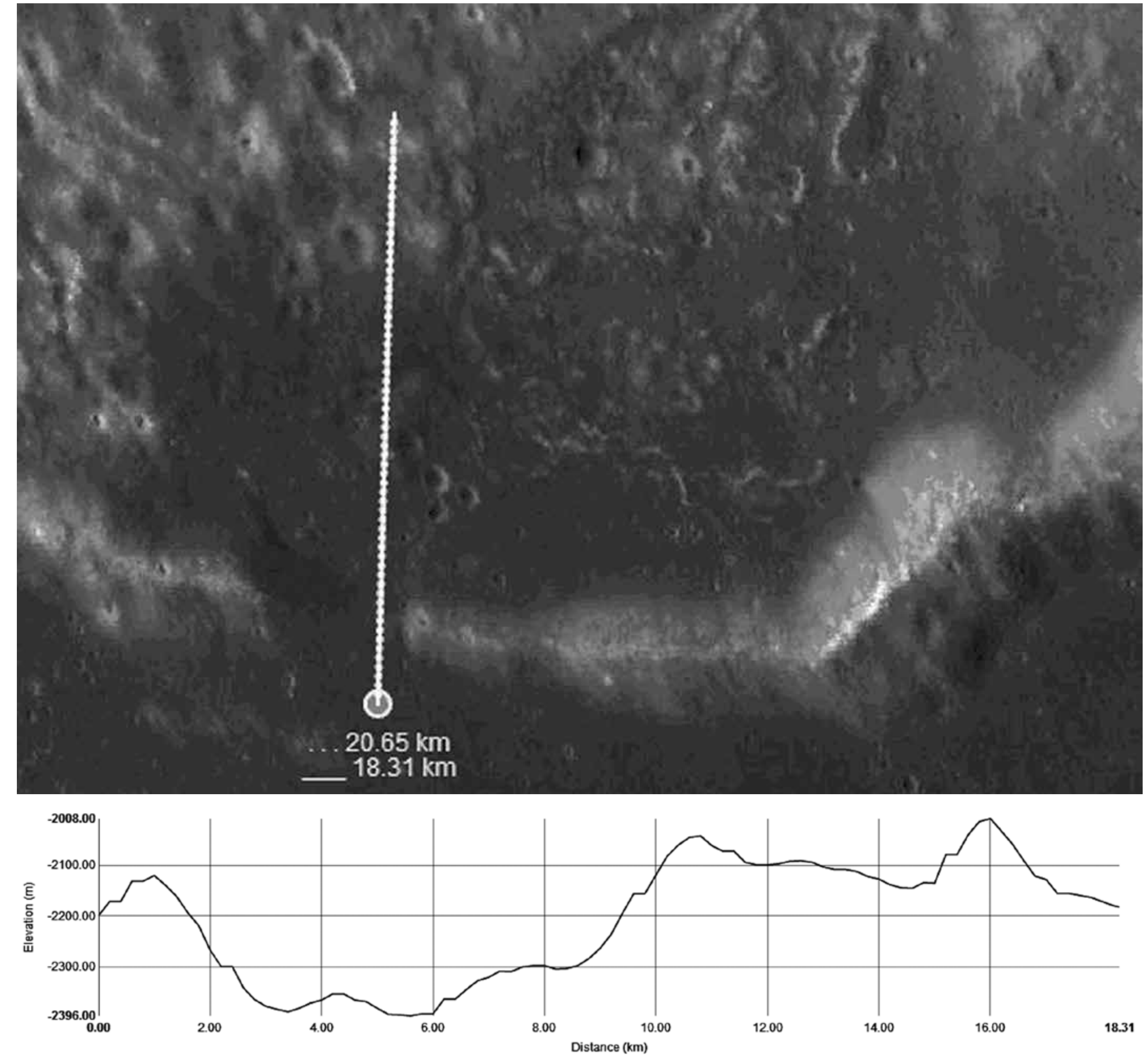


Figure 16: Profile of the southeastern region of the low titanium lava fill showing a clear double dip. Note, also, the height of the low-titanium lava inside the rim.

bulging in front of the gap, but otherwise rising northeastward, paralleling the vertical positioning of the low-Ti area in total.

Now, a guess at interpreting the data. Sometime unrelated to the filling of Humorum, lava began to rise beneath Gassendi. It must have been a slow rise because most of the floor was able to keep its integrity; instead of being flooded by the lava, the floor was pushed upward but remained a cap. It is not clear whether the floor of Gassendi was light enough to float on the in-filling lava or if it had a remarkable bonding which kept it as one piece forced upward by the lava which couldn't break through it.

Except for the floor in the south and east edge near the crater rim. Here, the floor never rose and eventually became submerged by lava or else originally rose but then cracked loose from the rest of the floor and sank beneath the lava. Perhaps the bulge adjacent to the gap in Gassendi's southern

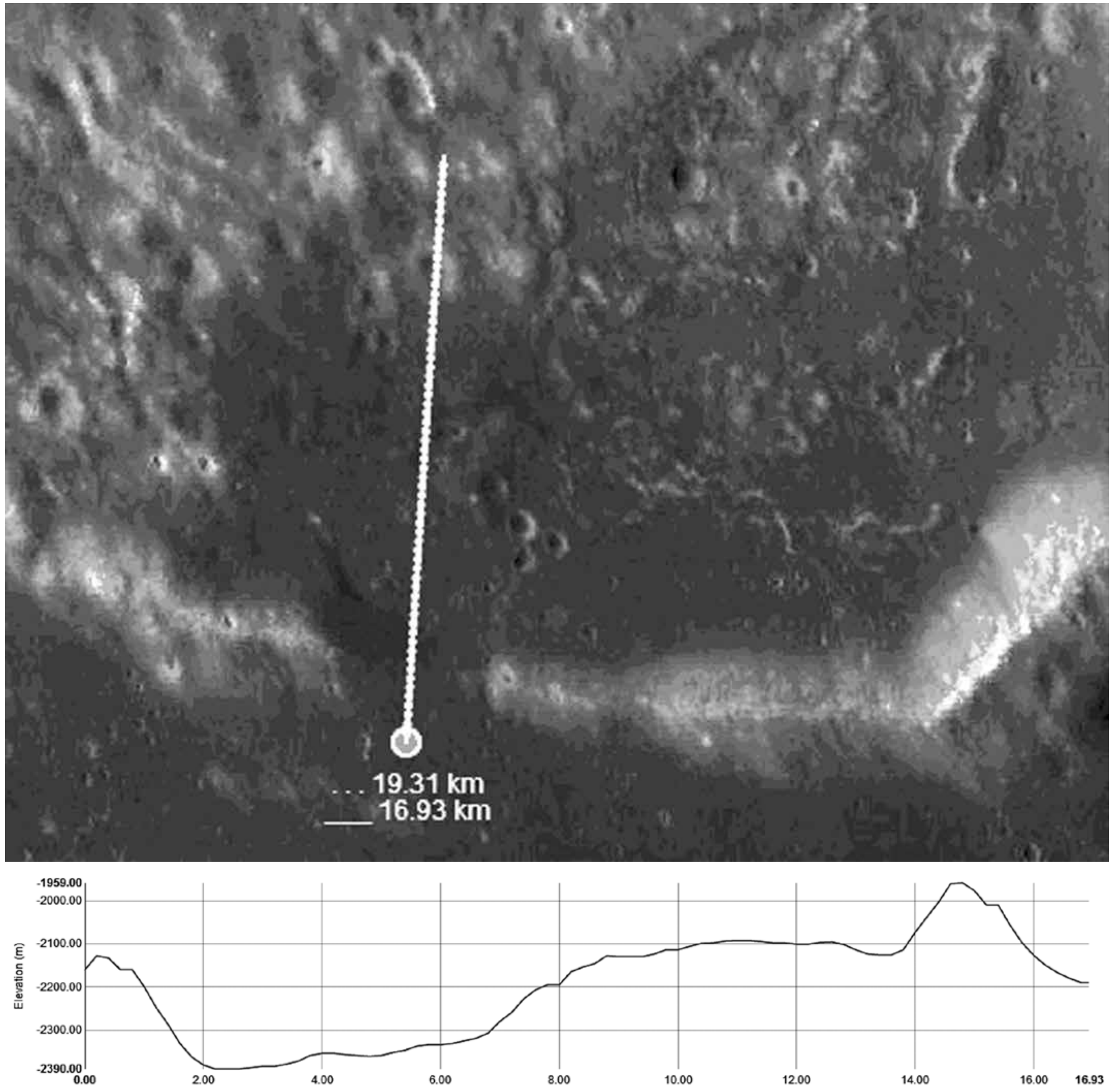


Figure 17: Profile of the southeastern region of the low titanium lava fill. At this point, the double dip has become a single dip.

walls provides a clue as to which scenario actually occurred. The only reason I can come up with for the bulge is that it is lava (based on Clementine UVVIS spectroscopy) overlying the slumped rim, the slumping of the top of the lower Gassendi rim that then formed the gap.

Several features could be tied together if the rim collapse and the floor collapse occurred at the same time. So what happened on and beneath the floor of Gassendi? Perhaps the lava started rising, pushing the floor up and then a sudden collapse of the southern part of the floor led to a collapse of the southern rim where the gap is. Lava continued to well up from beneath the crater floor: the main floor continued to rise and in the south where the floor had collapsed and no longer rose, lava flooded

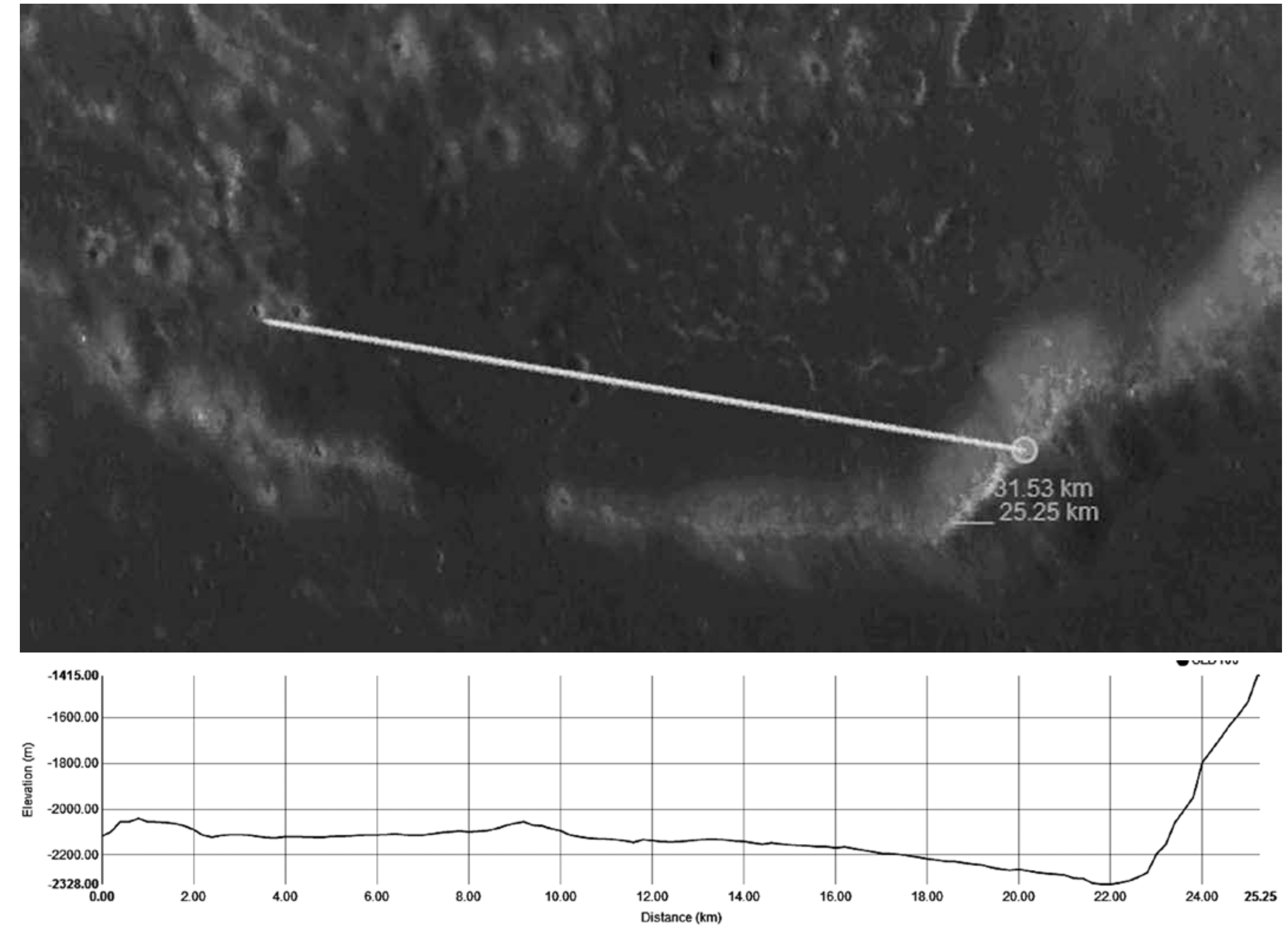


Figure 18: Profile of the southeastern region of the low titanium lava fill showing that along this line the lava fill shows a steady decline to a point just inside the rim.

over the southern floor.

Indeed, the low-Ti area is significantly lower in elevation than is the northern 2/3 of Gassendi's floor. What had been seen as a rille separating the upper 2/3 of the floor and the lower 1/3 appears, under these high resolution images, to be the crack separating the two floor areas. Significantly, the lowest point (the double dip) falls in line with this crack between the two sections. It is probably related, part of the stress line. I've seen similar fractures in thin ice when it's been hit by a sharp object, even to the point of having a bulge formed by compression beside the point of impact opposite the main cracking.

So how did the low-titanium lavas get all the way up onto the bulge inside the gap? The bulge is above the maria inside and out of Gassendi. Perhaps the lava started there (among other places like the northern edge of the rille which drops down to the low point in Gassendi's floor). If the southern rim had a crack in it which provided a source for the lava, this might explain the slight amount of low-Ti lava outside of Gassendi on its southwest. Sadly, lava tubes and other evidence of volcanic activity are missing from this portion of the rim—so it probably was not the lava source. I remain unable to reconcile the spectral and elevation data in regard to the bulge.

In AN INVESTIGATION OF CRYPTOMARE AND PYROCLASTIC DEPOSITS IN THE GASSENDI REGION OF THE MOON[5], a feature in the northeast of Gassendi is adentified as being a drained lava lake. Mention is made of lava terracing around its base and that its interior

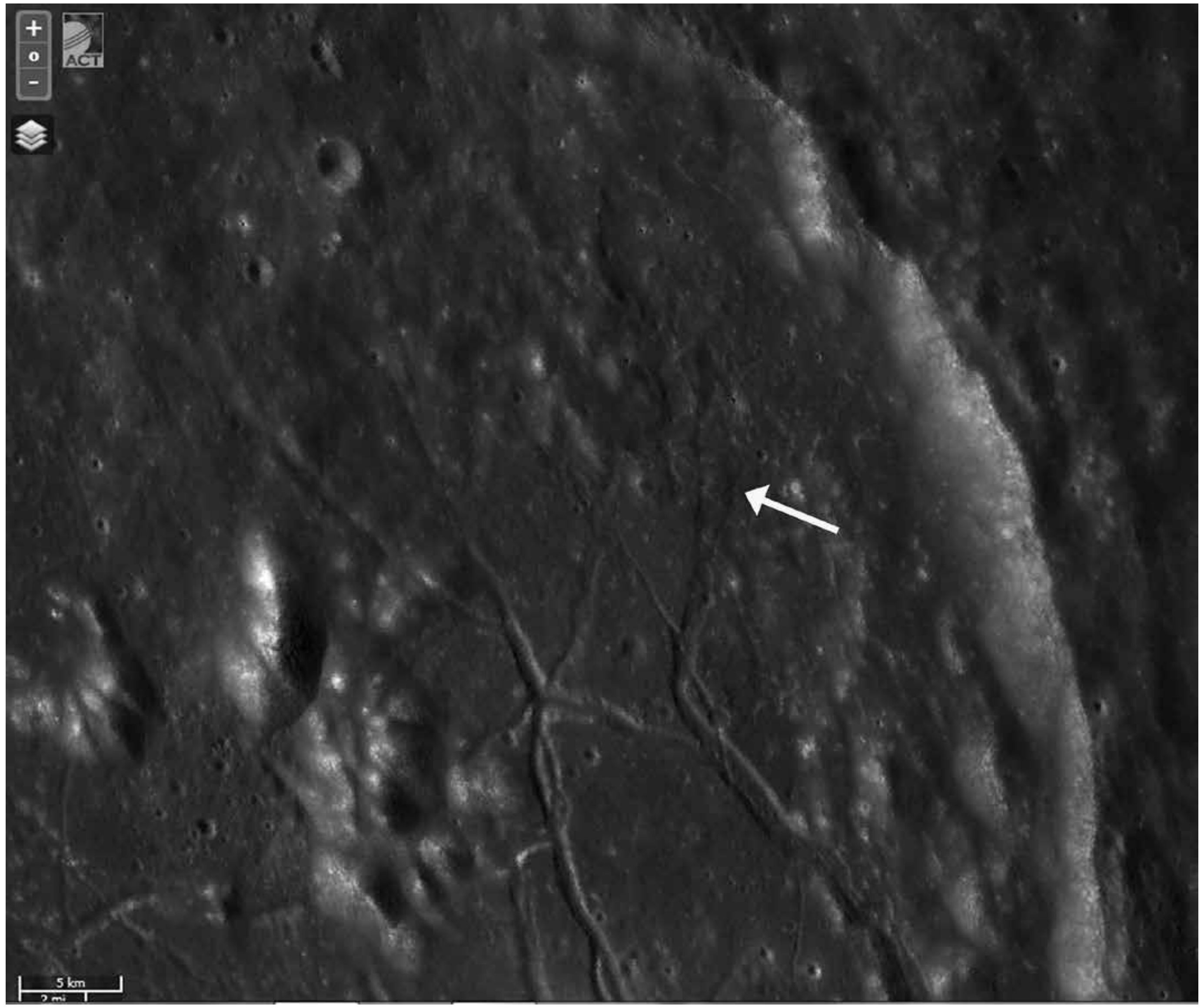


Figure 19: Probable volcanic feature in Gassendi, either a drained lava lake with a raised center or a shield volcano.

has been raised. Looking at LRO images of the feature, to me it resembles, very strongly, a shield volcano – actually a cluster of 3 shield volcanos (Fig. 19, 20). Hawke, et.all, don't provide details of how this determination was made, so I decided to let Quickmap provide the answers, if it could. The 3-D image and the profile both show the center as raised higher than the surrounding terrace (Figs. 22, 23). Sadly, both are lacking in detail. Apparently, not enough altitude measurements are recorded here for the LRO maps to provide a definitive identification. However, the profile shows the edge of the "dome" to be a slope downward and shows no sign of a rim that could function as the edge of a lava lake. The Clementine UVVIS spectra show the surrounding ridge (or lava terrace) to be of mare material while the remainder of the dome is regular crater floor regolith. However, one crater on the northwestern dome reveals the spectra for mare material on its walls and in its ejecta. Clearly, the domes are made of lava. To me, the LRO Quickmap evidence strongly supports a grouping of shield volcanos.

Again, these are the thoughts of a non-geologist. I wait eagerly to be corrected in my interpretations. Additionally, I'm sure I've missed very important objects in the basin and would enjoy future articles or emails correcting and/or adding to what has been written. But one thing is certain: the Quickmap site has opened up a new Gassendi.

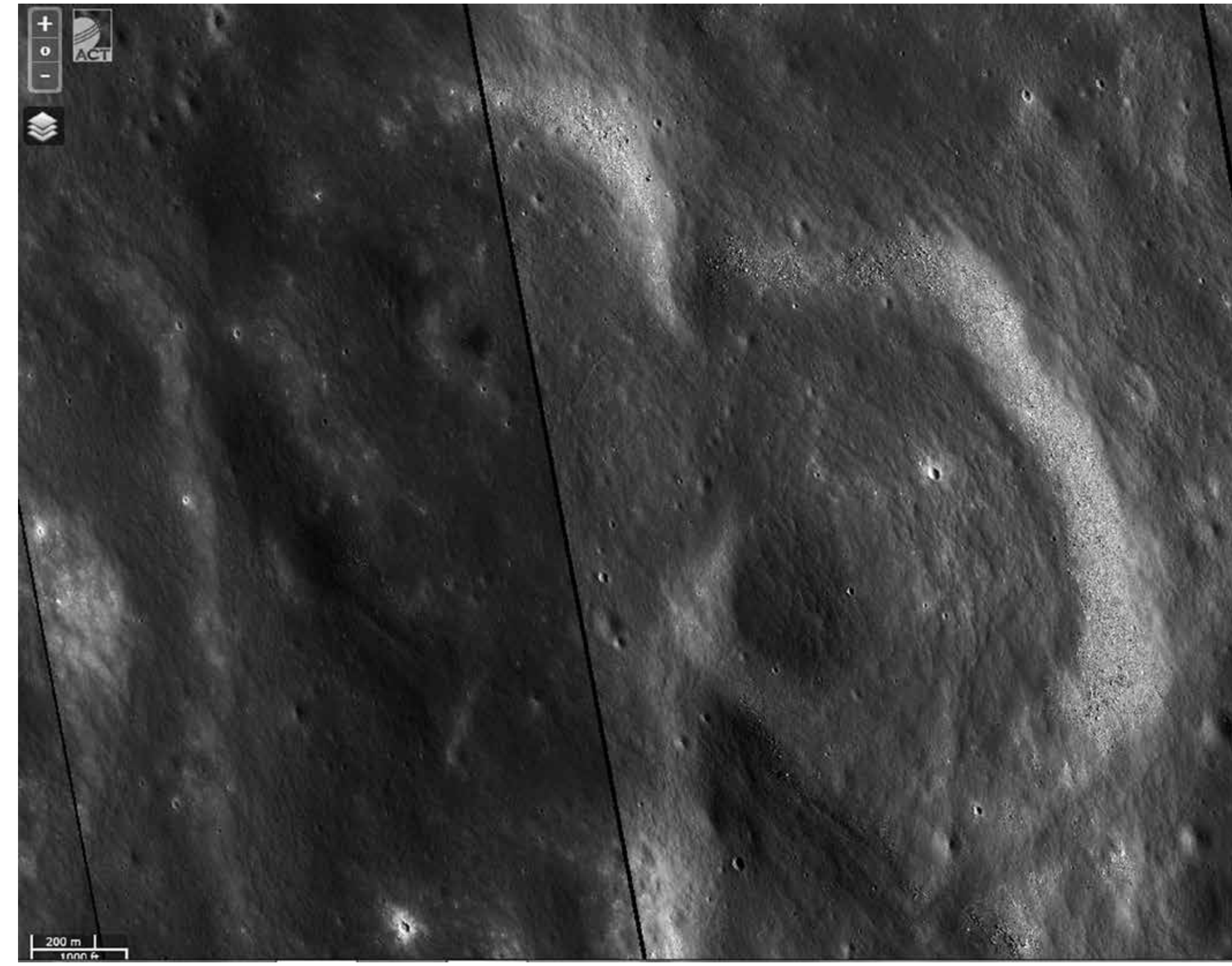


Figure 20: High-resolution image of the probable volcanic feature in Gassendi.

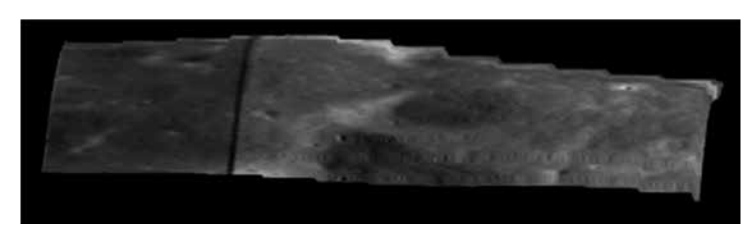


Figure 21: Quickmap generated 3-D perspective image of the probable volcanic feature in Gassendi.

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[1,3] 4/23/2014 Gassendi crater - clue on the thermal history of Mare Humorum / SMART-1 / Space Science / Our Activities / ESA. *http://www.esa.int/Our_Activities/Space_Science/SMART-1/Gassendi_crater_-_clue_on_the_thermal_history_of_Mare_Humorum*

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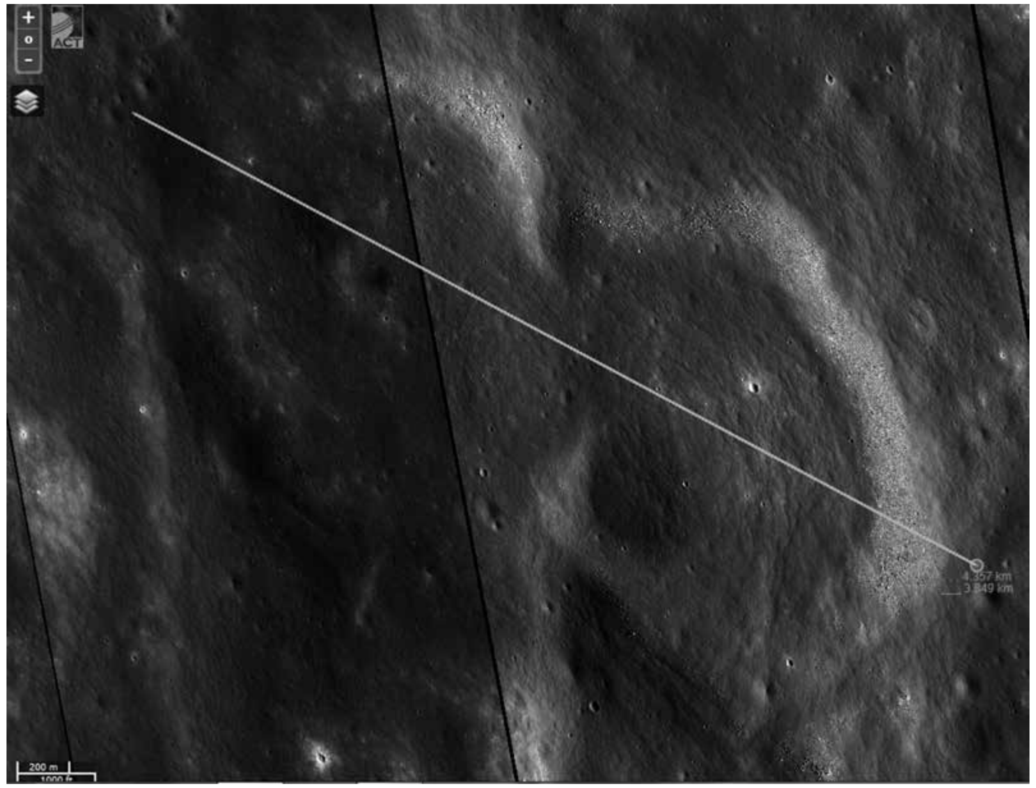
[4] Possible mantle origin of olivine around lunar impact basins detected by SELENE. Yamamoto, Nakamura, Matsunaga, Ogawa, Ishihara, Morota, Hirata, Ohtake, Miroi, Yokota, Haruyama. Nature Geoscience 3, 533-536 (2010), www.nature.com/ngeo/journal/v3/n8/full/ngeo897.html.



[5]AN INVESTIGATION OF CRYPTOMARE AND PYROCLASTIC DEPOSITS IN THE GASSENDI REGION OF THE MOON, B.R. Hawke, T.A. Giguere, J.J. Gillis-Davis1, P.G. Lucey, C.A. Peterson, S.J. Lawrence, J.D. Stopar, and M.S. Robinson (1894.pdf, 44th Lunar and Planetary Science Conference, 2013)

LROC *Quickmap. http://target.lroc.asu.edu/q3/*

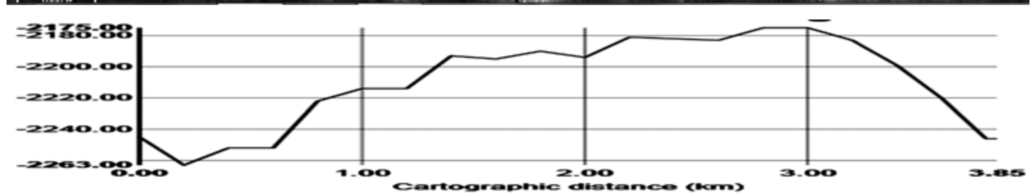


Figure 22 above: Profile of a probable volcanic feature in Gassendi. Vertical exxageration of a factor of 10. Distortion occurred when the graph was stretched horizonally in Photoshop.

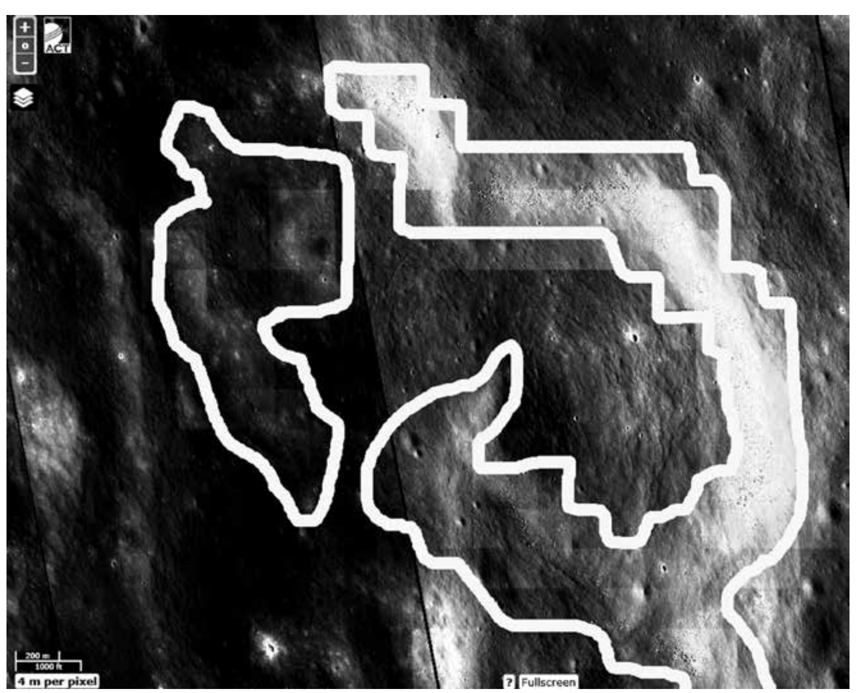


Figure 23 left: Clementine UVVIS spectrum of the probable volcanic feature showing hints of lava inside the white lines (white lines added by author).

Observation of the April 15 Lunar Eclipse
by Robert H. Hays, Jr.

I had a very good view of most of the April 15 total lunar eclipse. The weather outlook was poor at home with snow and clouds likely to persist, so I drove westward on the 14th for better prospects. I ended up in West Union, Iowa, about 60 miles northwest of Dubuque. A motel there had a nice open area for suitable observing if the sky cleared. It was still quite cloudy there near sunset, but there were signs of clearing. The sky was clear when I was roused from a nap near midnight. Most of my visual observing was done with an 80mm refractor at 44x; I also used 10x50 binoculars. A 5-inch Celestron was also used, mostly for photography . All times in this report are UT. A radio airing CHU was on most of the time.

I noticed the penumbral shading with the naked eye at 5:24 while finishing my set-up. It was already clearly visible with the refractor a couple of minutes later. This grayish shading gradually increased in intensity until first umbral contact. My main activity during the partial phases was crater timings. Sometimes I used a stopwatch, but I generally watched the umbra's edge pass over the crater while listening to CHU (Its signal was steadier than that of WWV that night). A tape recorder was also used for closely spaced events and for large craters. Their estimated accuracies are 10-15 seconds. It would take only that long for the umbra's motion to be evident at a crater.

There were red tints inside the umbra as early as 6:15 (less than 20 minutes after first contact); this meant that totality would be at least fairly bright. By 6:45, the portion farthest inside the umbra was a vivid red while the edge had a pale blue-gray tint. This tint replaced the last bit of whitish light as totality began. Early in totality, the moon nearest the umbra edge was a bright orange-red, but the orange color disappeared as totality progressed. The entire moon was shades of red near mid-eclipse. The northern limb was moderately dark, while the southern limb was quite bright. This was, overall, a fairly bright eclipse. The maria were all visible with the naked eye and any crater suitable for timing was visible with the refractor. My Danjon rating was 3.0 at 7:45. This eclipse looked much like the one in January 2000. That one was also fairly bright and the moon's path through the shadow was almost the same at both events. The proximity of Spica, and to some extent Mars, added to the scene. The binoculars probably gave the best view with Spica about *2degrees* west of the moon and 5th-magnitude 76 Virginis less than a degree to the north. Totality ended as it had begun. Second and third contacts were fairly crisp and could be timed to about 10-15 seconds accuracy. First contact was not as sharp, and could be timed to only about 20 seconds at best.

My view had been clear through third contact. However, some scattered to broken cumuliform clouds came down from the northwest shortly afterward. I was still able to follow the closing partial stages to some extent, but the clouds allowed only four crater exits to be timed, after having recorded 11 entrances. Ironically, Plato was one of those whose exit was timed. I had skipped its entrance because it conflicted with those of Pytheas and Copernicus. I had just timed Pytheas, and Plato was already well inside the umbra at 6:19 when Copernicus started entering. It was a bit much to time two large craters at the same time, though I did time the entrance of Timocharis then. The exits of all three of those other craters were lost in clouds. Fourth contact was also clouded out. The moon came out of the clouds shortly afterward and I had a clear view of the penumbral shading as it faded away. I lost this shading at 10:07 with both the naked eye and the refractor.

This was still a very good eclipse even with the late clouds. I probably traveled farther than I needed to, but some travel was likely necessary. I don't think I would have seen any of it from home. My 15 crater and three contact timings are shown on [the next page]. The times of Grimaldi, Copernicus, Tycho and Plato are the means of opposite side contacts. [Page 20] also has four color sketches. The first of these was when the early stages were well along, and the red coloring was quite pronounced. The second one was not long before mid-eclipse when the moon had varied red tones. The next one was shortly before totality ended and the blue-gray umbra edge had appeared. The last one was during my clearest spell of the late partial stages and shows some of the last red coloring at this eclipse.

CONTACT AND CRATER TIMINGS - TOTAL LUNAR ECLIPSE - APRIL 15, 2014

(UT TIMES)

UMBRAL CONTACTS

CONTACT I ----- 5:57:55

CONTACT II ---- 7:06:40

CONTACT III --- 8:24:40

CRATER ENTRANCES

ARISTARCHUS ----- 6:06:30

GRIMALDI -------- 6:06:40

PYTHEAS --------- 6:17:30

TIMOCHARIS ------ 6:19:50

COPERNICUS ------ 6:19:55

MANILIUS -------- 6:32:45

MENELAUS -------- 6:36:00

PLINIUS --------- 6:39:35

DIONYSIUS ------- 6:40:45

TYCHO ----------- 6:44:30

PROCLUS --------- 6:48:15

CRATER EXITS

ARISTARCHUS ----- 8:44:15

PLATO ----------- 9:03:35

MANILIUS -------- 9:10:35

MENELAUS -------- 9:14:10