3-D Analysis of the 'Blair Cuspids' and Surrounding Terrain

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An analysis of an unusual collection of objects in a region north of the crater Ariadaeus B is performed. These objects, known as the 'Lunar Spires' or 'Blair Cuspids,' were imaged by a Lunar Orbiter spacecraft in 1966. A digital elevation model (DEM) is computed over the area with a single image shape-from-shading algorithm. Using the DEM to estimate local slope we confirm the tallest cuspid to be about 50 feet in height. Synthetic stereo images are created in order to visualize the cuspids and their surrounding terrain in 3-D. Of particular interest is a large rectilinear depression adjacent to the objects. This depression appears to be the deepest part of a larger network of rectilinear collapses of the surface similar to those that have been studied by Arkhipov. Correlations between the geometry of the cuspids, the rectilinear collapses, and subtle surface lineaments are identified.

1. Introduction

In the mid 1960s, in preparation for the Apollo missions, a series of Lunar Orbiter spacecraft were sent to the Moon to search for suitable landing sites. On November 22, 1966 Lunar Orbiter 2 photographed a number of objects on the surface that cast extremely long shadows (Figure 1)[1]. According to NASA, based on the length of its shadow, the largest object was about 50 feet wide at its base and 40 to 75 feet tall[2]. On seeing the photo, William Blair, an anthropologist at Boeing (the company that manufactured the Lunar Orbiter) was reminded of patterns seen in aerial survey maps of prehistoric archaeological sites. Intrigued by the length of the shadows, apparent geometrical layout, and proximity to an unusual rectangular depression, he suggested the objects might be artificial in origin[3]. Blair fit a series of isosceles and right triangles to the objects (Figure 2). He argued that if the objects were the result of some natural process on the Moon, they would be distributed randomly, forming scalene or irregular triangles.

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[1] *Washington Post*, November 23, 1966 (http://www.astrosurf.com/lunascan/2cusp.htm).
[2] NASA/Langley Research Center Press Release, November 22, 1966.
[3] *Boeing News*, Vol. 26, No. 3, March 30, 1967 (http://www.astrosurf.com/lunascan/1cusp.htm).

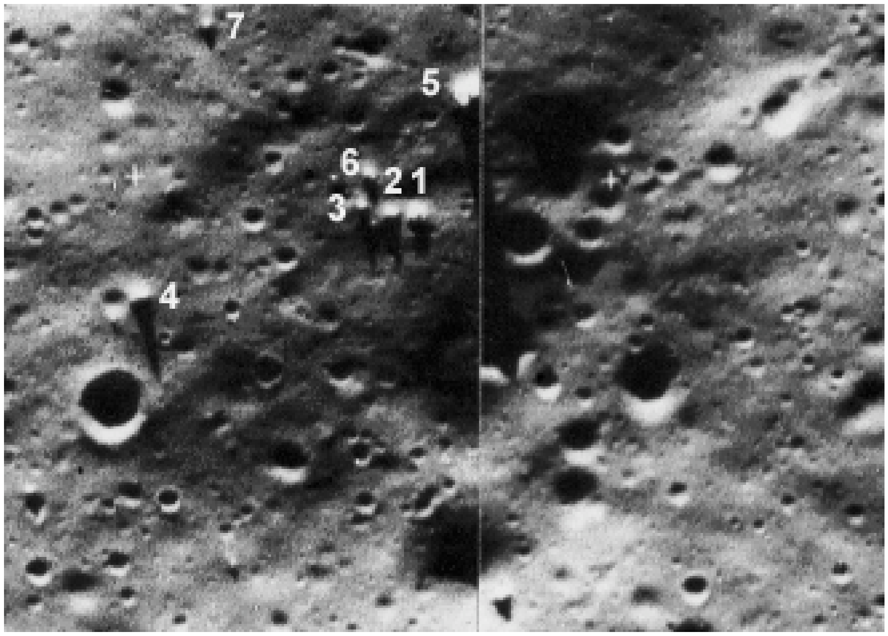

Figure 1 A portion of Lunar Orbiter image LO2-61H3 showing seven vertical objects casting long shadows on the surface of the Moon[4].

Blair's hypothesis al was dismissed by members of the lunar science community. According to Richard Shorthill, a geologist at Boeing, "There are many of these rocks on the Moon's surface. Pick some at random and you eventually find a group that seems to conform to some kind of pattern[5]." NASA geologists speculated that the objects, which they refer to as 'protuberances', could be blocks of material expelled from a crater by a meteoric impact, volcanic material ejected through faults in the lunar surface, or the eroded cones of old volcanoes[6].

In 1996, the original Lunar Orbiter photograph of these objects (LO2-61H3) was located in the archives of the National Space Science Data Center (NSSDC), digitized, and analyzed. By analyzing the shape of their shadows, Fleming has shown the objects to be pyramidal or conical in shape[7]. He also found a second image taken from a slightly different angle (LO2-62H3) that showed one of the objects (number 5 in Fig. 1) to have a rectilinear base[8].

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[4] http://vgl.org/webfiles/lan/cuspids/LO2-61H3.gif
[5] *Boeing News*, Vol. 26, No. 3, March 30, 1967 (http://www.astrosurf.com/lunascan/1cusp.htm).
[6] *Newsweek*, 5 December 1966.
[7] http://vgl.org/webfiles/lan/cuspids/cuspids.htm.
[8] Cuspid 5 is cut off in LO2-61H3 at a framelet seam. The second image, LO2-62H3 shows the entire object (see http://vgl.org/webfiles/lan/cuspids/cuspids4.htm).

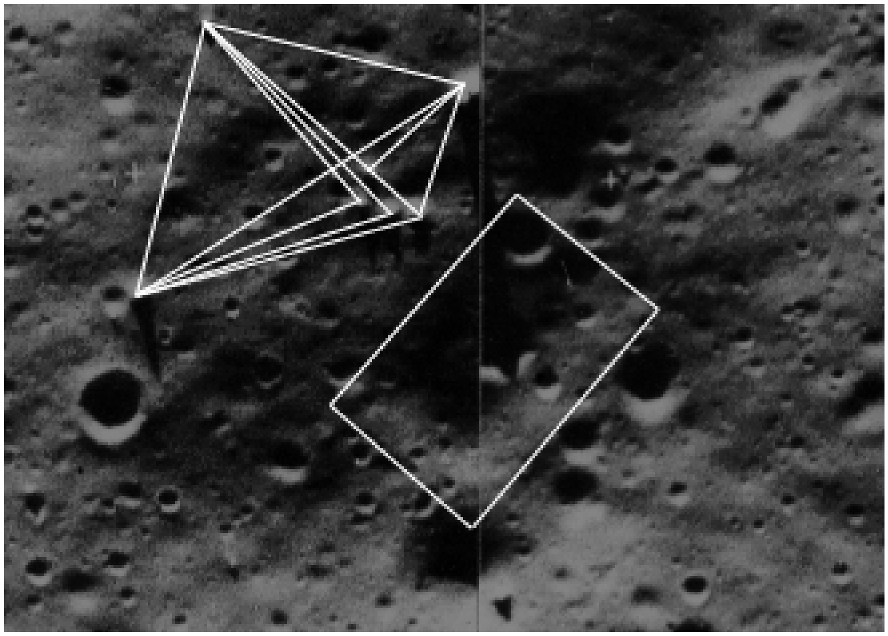


Figure 2 Triangles can be formed by drawing lines between selected objects. The boundary of the rectangular depression is also indicated.(Graphics are reproduced from newspaper photograph[9].)

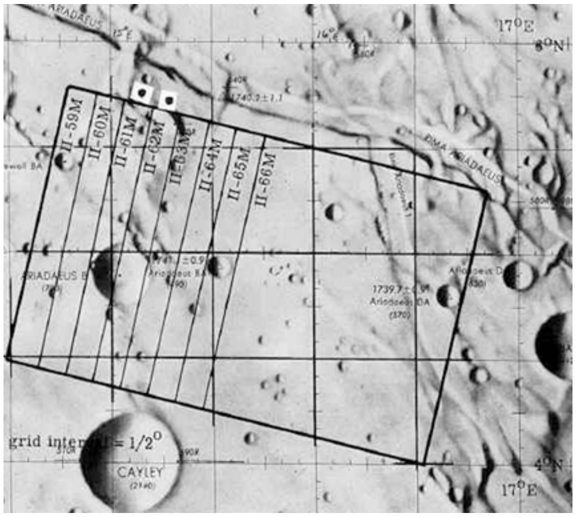
Prompted by the unusual morphology of these objects and their proximity to a rectangular depression in the surface, a 3-D analysis of the original LO2-61H3 photo was performed. Previously, some confusion existed concerning the location of these objects on the lunar surface. Section 2 correctly locates them about 1/3 mile north-northeast of the crater Ariadaeus B at about 5 deg. N by 15 deg. E. In Section 3, a digital elevation model (DEM) over the area of interest is computed using a single image shape-from-shading (SFS) algorithm. Using slope information from the DEM to correct for increased shadow length, the tallest object is found to be about 50 feet tall — consistent with both NASA's original estimate, and Fleming's more recent estimates based on shading and shadow analyses. In Section 4, the DEM is used to create a series of synthetic stereo images in order to visualize the cuspids and their surrounding terrain in 3-D. We show that the rectangular depression appears to be part of a larger network of collapsed features similar to those that have been studied by Arkhipov.[10] Section 5 discusses our findings and suggests areas for future work.

2. Region of Interest

In the original NASA press release, the cuspids were said to be located at 4.5 deg. N by 15.3 deg. E, on frame H61, framelets 383 and 384. Generally speaking, this region is on the western edge of the Sea of Tranquility, about 300 km northwest of the Apollo 11 landing site. More precisely, NASA's coordinates would place the objects about 15-20 km southeast of

[9] *Los Angeles Times*, Final Edition, January 26, 1967 (http://www.astrosurf.com/lunascan/4cusp.htm).
[10] A. Arkhipov, "Toward Lunar Archaeology," *New Frontiers in Science*, Vol. 1, No. 2, Winter 2002.

Ariadaeus B, which is outside the LO-2 imaging footprint for that frame. Using Lunar Orbiter and Clementine imagery (Figures 3-5), it can be shown that the high-resolution framelets are actually located near 5 deg. N by 15 deg. E, which is within the footprint area. This revised location is north of the crater Ariadaeus B, and south of Rima Ariadaeus.



e 3 Footprints of medium-resolution Lunar r 2 (LO-2) ground tracks[11]. Dots identify d tracks over crater Ariadaeus B.

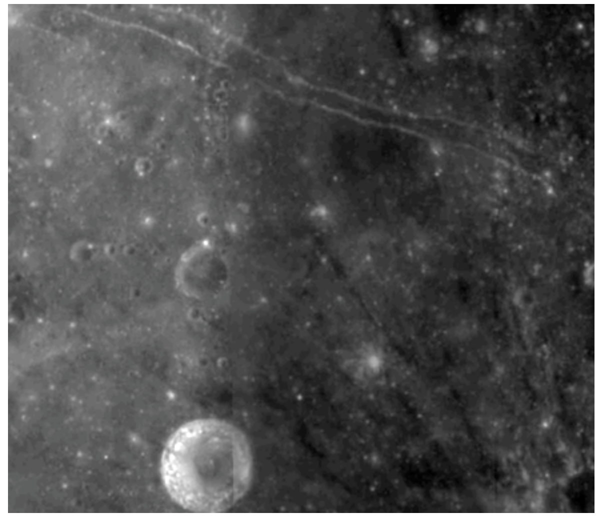
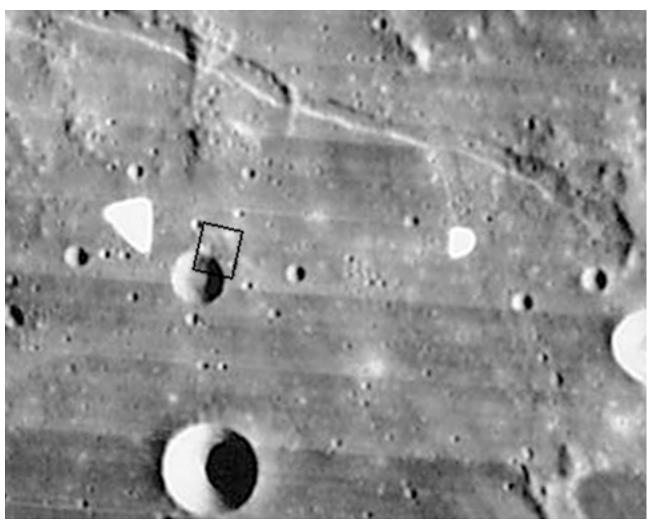


Figure 4 Low resolution mosaic of Clementine imagery (from bi03n015.img[12]) over the area corresponding to Figure 3.



e 5 Lunar Orbiter 4 image[13] showing the footprint of high resolution LO-2 imagery (see Figure 6).

[11] http://www.astrosurf.com/lunascan/footprint.jpg
[12] http://pdsimage.wr.usgs.gov/CDROMS/cl_3002/browse/medium/bi00_35n/bi03n015.htm
[13] http://cass.jsc.nasa.gov/research/lunar_orbiter/index.html

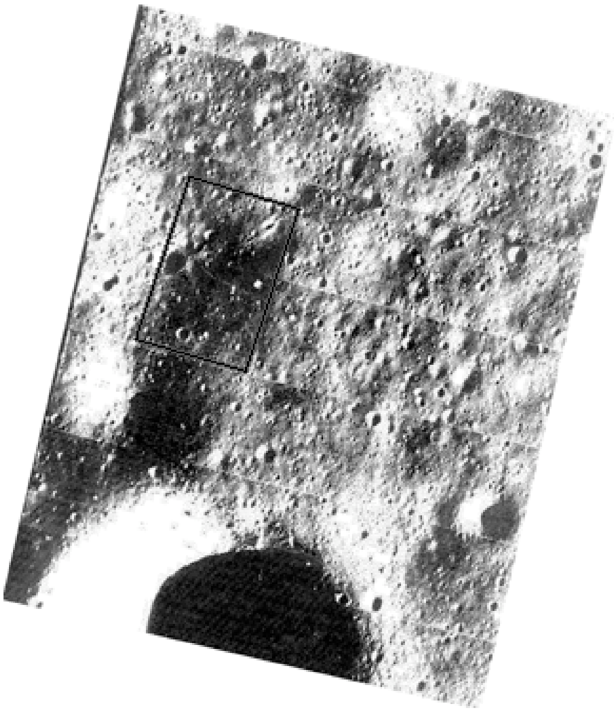


Figure 6 A portion of the LO2-62H3 image collected along the ground track north of Ariadaeus B[14]. This image is over the rectangular region identified in Figure 5.

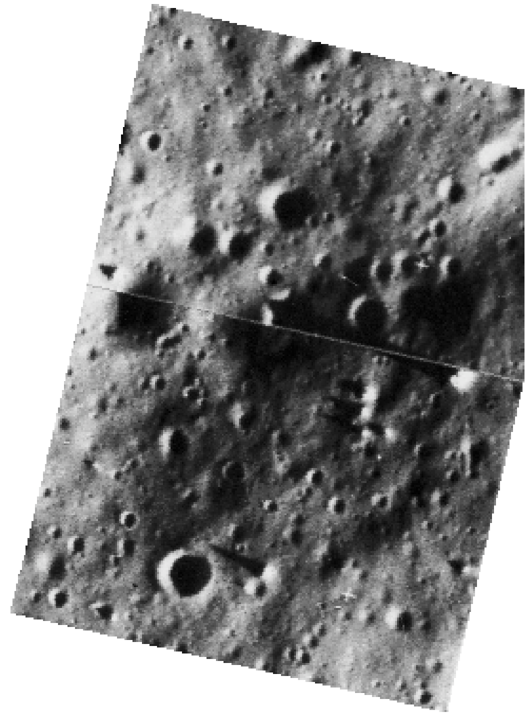


Figure 7 LO2-61H3 from Figure 1 after bei and rotated. This image corresponds rou rectangular region identified in Figure 6.

Figures 6 and 7 depict the relation of the same area shown in Figure 1 to that of the high resolution framelets and their approximate ground track north of Ariadaeus B. Note that this image is flipped in the scan-line direction and rotated relative to the image in Figure 1. North is approximately up.

3. Terrain Reconstruction

Figure 8 is the digitized photo LO2-61H3 provided by Fleming[15] after it has been smoothed and subsampled by a factor of two. It is rotated so that the sun, which was 11 deg., above the eastern horizon, is toward the right. The line across the middle of the photo is a seam between film strips (framelets). The white crosses are calibration marks on the camera that are spaced about 750 feet apart on the ground (therefore the effective image resolution of this image is 4.2 feet/pixel).

[14] http://www.astrosurf.com/lunascan/LO2-62H3.jpg
[15] http://vgl.org/webfiles/lan/cuspids/LO2-61H3.gif

A shape-from-shading algorithm[16] was used to compute a digital elevation model (DEM) over the area. Shape-from-shading integrates image brightness information along lines in the direction of the sun to obtain height estimates. Figure 9 shows the resultant DEM rendered as a false color image. Figure 10 superimposes equally spaced elevation contour lines over the original image to show the correspondence between the image and its underlying topography.

To verify the accuracy of the DEM, a shaded rendition of the DEM was generated using the LO2-61H3 sun azimuth and elevation angles. That the predicted image (Figure 11) is in good agreement with the original image (Figure 8) confirms the relative accuracy of the DEM.

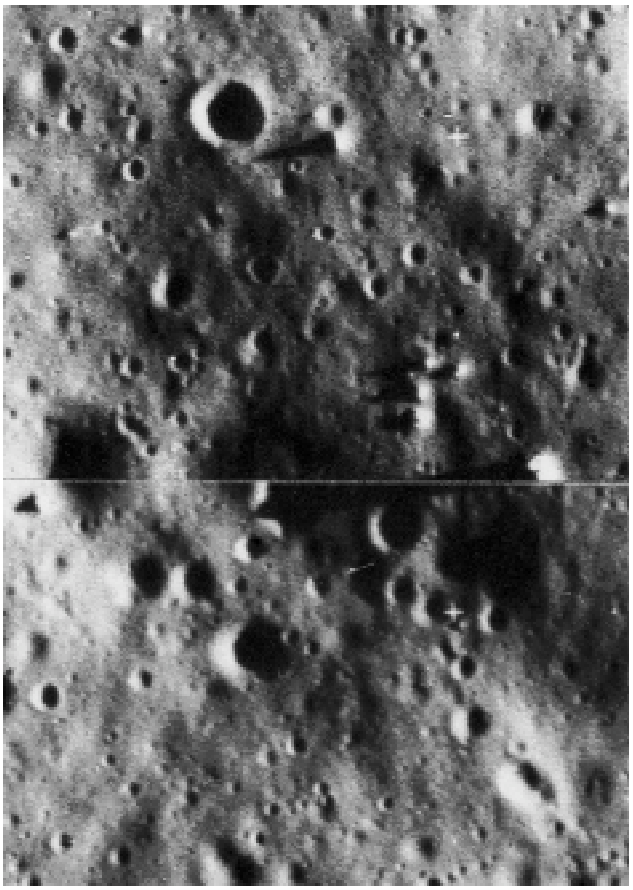


Figure 8 Reduced version of portion of Lunar Orbiter image LO2-61H3 rotated so that north is up.

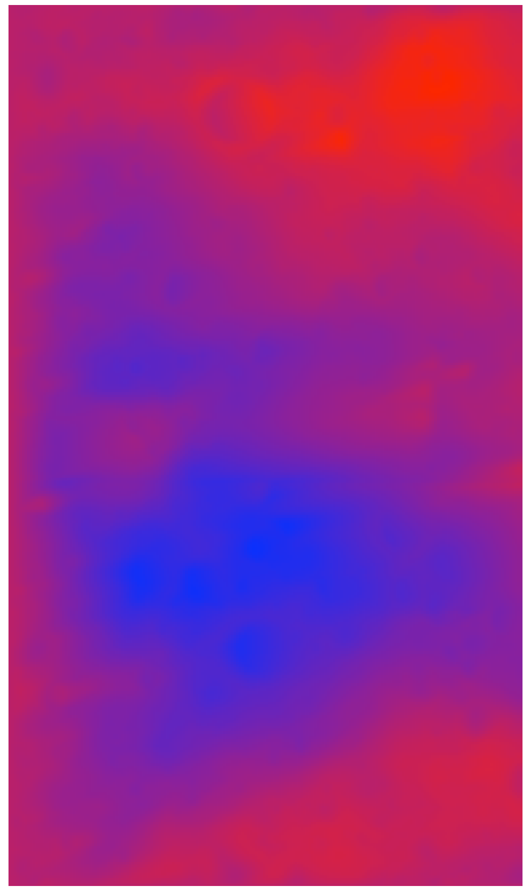


Figure 9 False color rendition of DEM sho lower areas in blue and higher areas in re

[16] http://www.martianenigmas/Articles/SFS/sfs.html

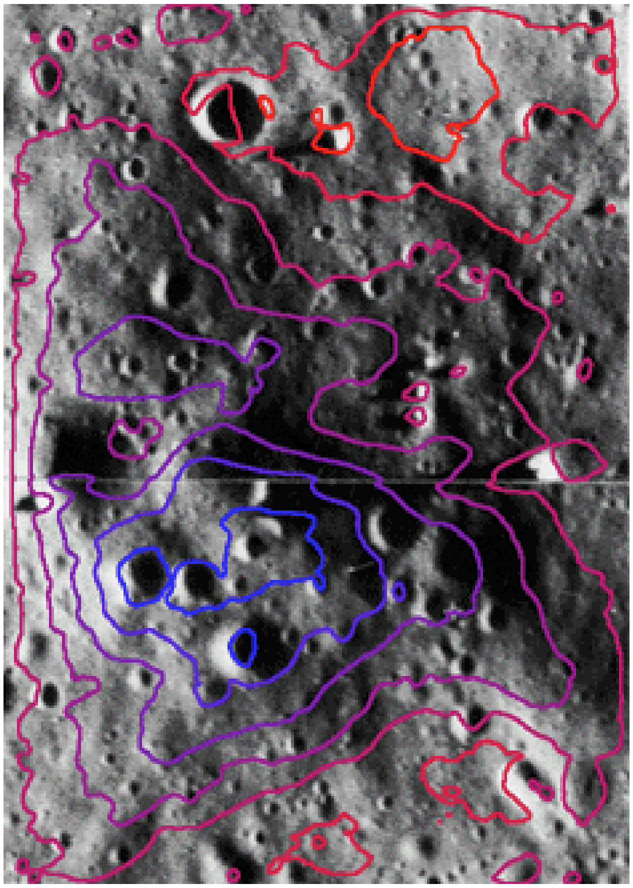


Figure 10 Contour lines from DEM superimposed onto Lunar Orbiter image.

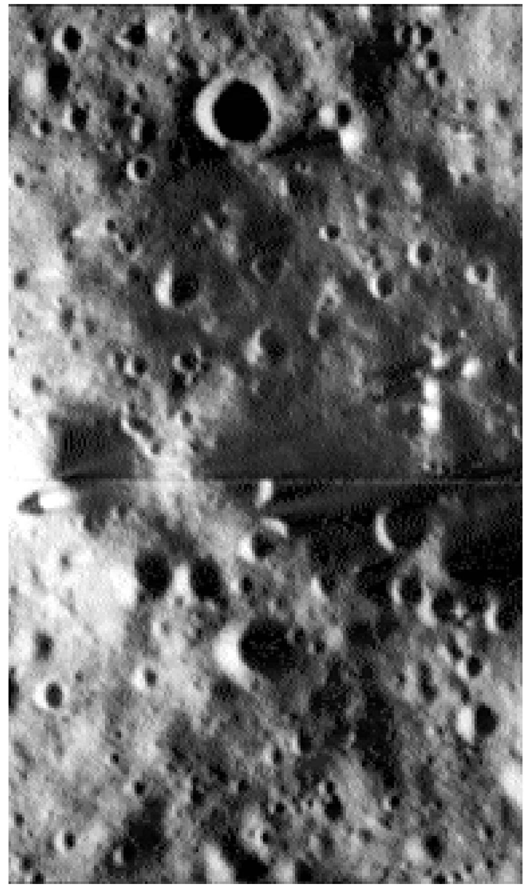


Figure 11 Shaded image computed from I based on a Lambertian surface reflectanc function. Similarity to image in Figure 8 v accuracy of DEM.

To assess the metric accuracy of the DEM we use it to estimate the height of object 5 from its shadow. To determine the height of an object from its cast shadow one must known the sun angle and local slope. Figure 12 is a cross-section of the elevation surface starting from a point to the side of object 5. It follows the terrain along the line parallel to the cast shadow in the direction away from the sun. Moving left to right along the elevation profile, the terrain slopes down away from the object. The average slope is about 5.7 degrees. Thus, the effective elevation angle of the sun is the angle of the sun above the horizon minus the local slope, 11-5.7 = 5.3 degrees. Using a measured shadow length of 513 feet, the height of the object is 513 x tan(5.3 deg.) = 47.6 feet. Fleming's estimate of the local slope, 6.9 degrees, leads to a height estimate of about 61.6 feet[17].

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[17] We did not correct for the nonlinear relationship between photographic density and light intensity as Fleming did in his analysis (see http://www.Vgl.org/webfiles/lan/cuspids/cuspids5.htm). This is one possible source for the difference between slope estimates.

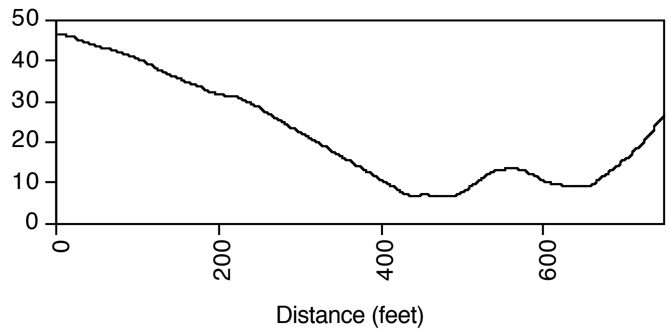
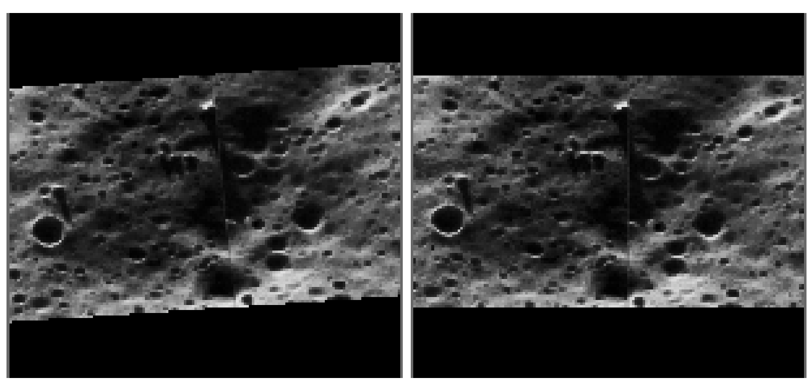


Figure 12 Elevation profile along shadow cast by object 5.

4. Scene Visualization

Given an image and its height map, views from other perspectives can be produced using computer graphics rendering techniques. By generating two views from slightly different positions and presenting them separately to the left and right eyes, a 3-D stereoscopic effect is produced. A variety of simulated stereoscopic views are presented in Figures 13-21[18].

Figure 13 (below) presents 3-D views of the image in Figure 8 mapped onto its elevation surface (Figure 9). As seen in these renditions the terrain is highest in the top portion of the image (Figure 8). From top to bottom, it slopes downward with the lowest point appearing to lie within the rectangular depression. Continuing down, the terrain again rises, but to a height somewhat lower than that at the top. A similar trend occurs right to left.



[18] To view these images in stereo, look away from picture and focus at a point in the distance. Then shift your gaze to the picture. You should see three images. Concentrate (but don't focus) on the middle image and try to bring different parts of the view into correspondence. This will take some practice. If you have difficulty seeing stereo, try moving back from the page. Also, it helps if the page is flat and well lit.

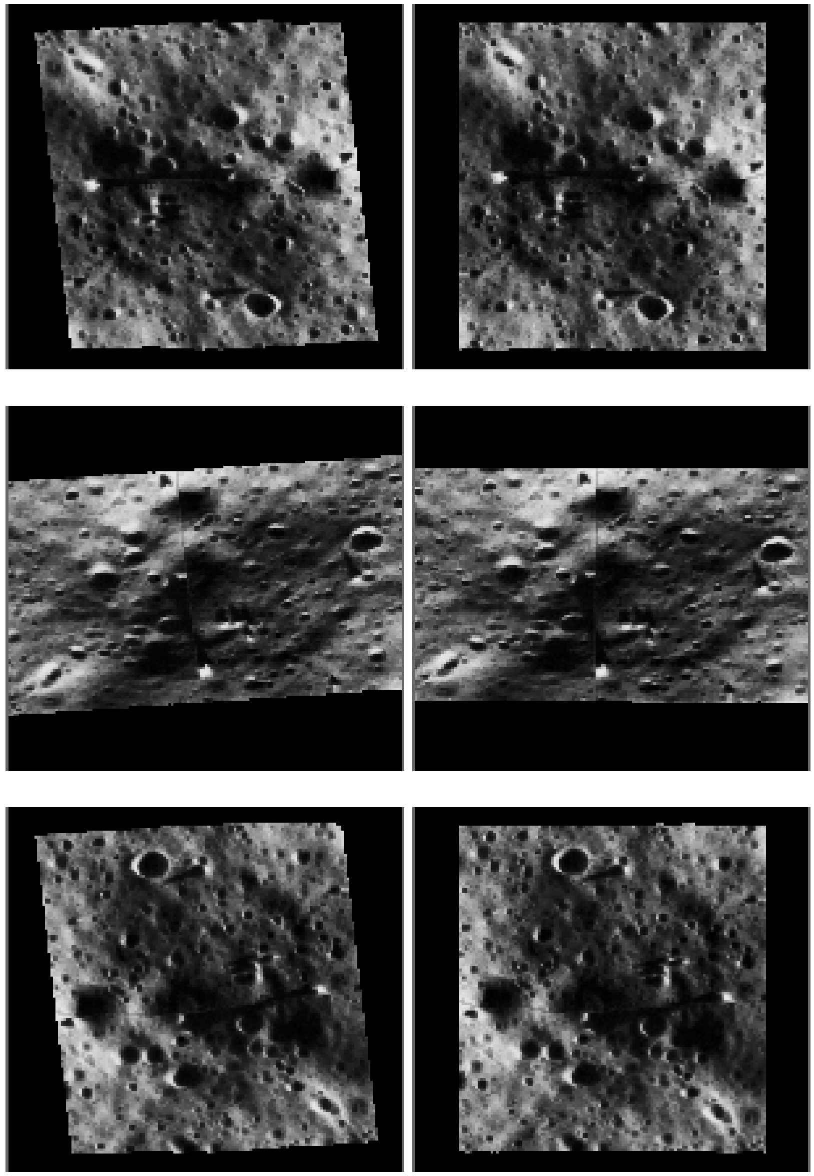


Figure 13 An overview of the region of interest looking from the left, top, right, and bottom, 50 degrees above the horizon at 0.2x magnification.

Figure 14 shows the terrain surrounding objects 1-3. As in object 5, a depression in the terrain behind these objects is evidently responsible for the elongatedness of their shadows as well.

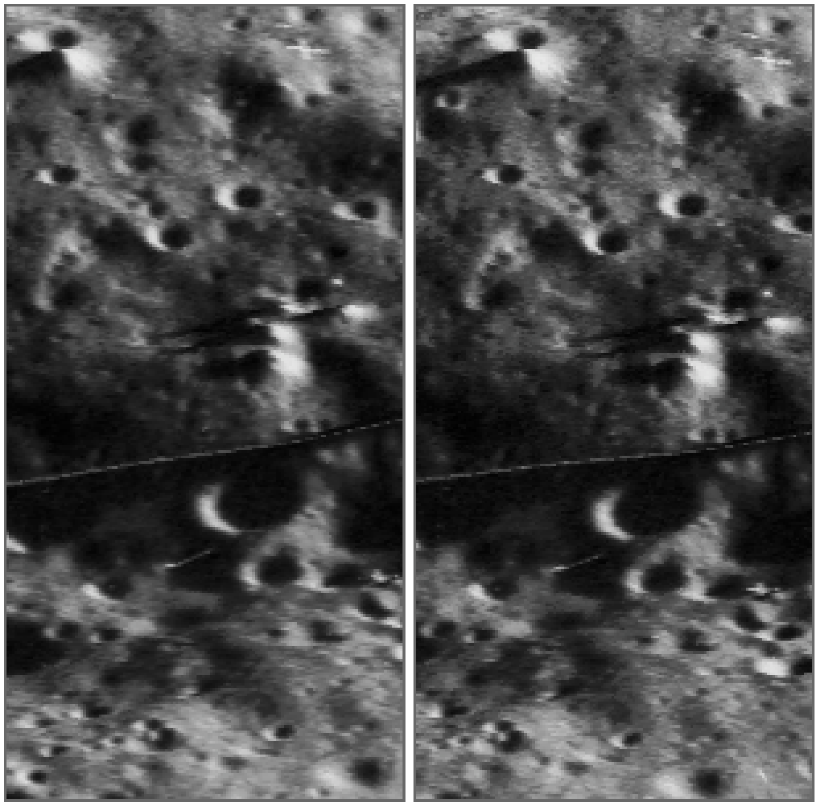


Figure 14 Objects 1-3 in foreground looking from the bottom, 30 degrees above the horizon at 1x magnification.

Figure 15 renders all of the objects in the context of the surrounding terrain. Object 4 is near the top. Between object 4, and the group of objects 1, 2, 3, and 6 is a broad area that is lower than the terrain above it but higher than the rectangular depression below. The depression is in the foreground with the shadow of object 5 cutting across it. An alternative view is presented in Figure 16.

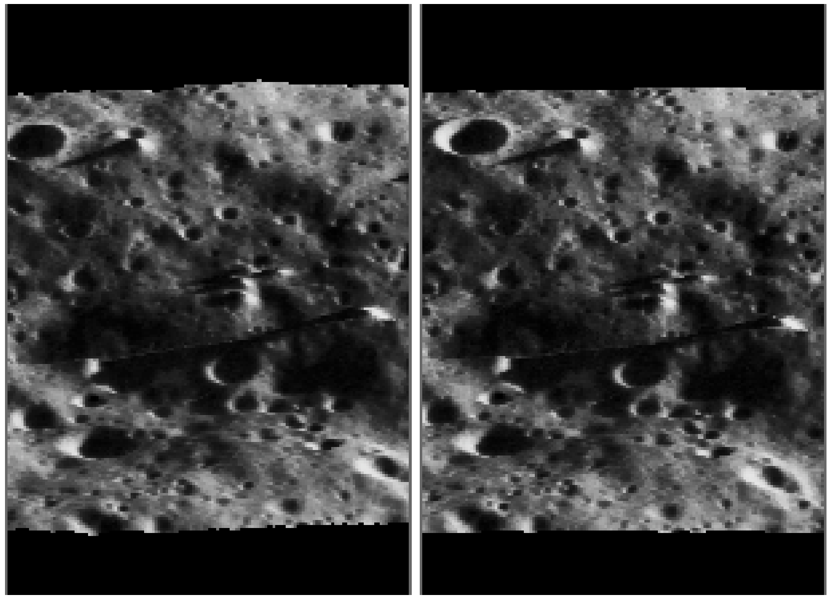


Figure 15 Looking down from 30 degrees above the horizon at 0.5x magnification on objects 1-6 with the rectangular depression in the foreground.

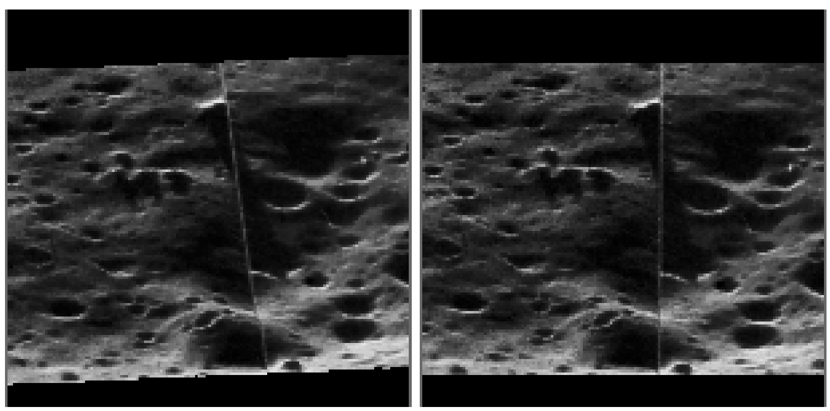


Figure 16 Looking right from 30 degrees above the horizon at 0.5x magnification on objects 1,2,3,5, and 6 with the rectangular depression in the foreground.

These views confirm the fact that it is the objects casting shadows on terrain that is sloped away from the sun which is responsible for the exaggerated length of their shadows.

The perspective view in Figure 17 confirms the objects to have a cuspid-like, or in the case of object 5, a bicuspid-like shape. The down-looking view in Figure 18 suggests that objects 1 and 2 are emplaced on a pedestal or base of some kind.

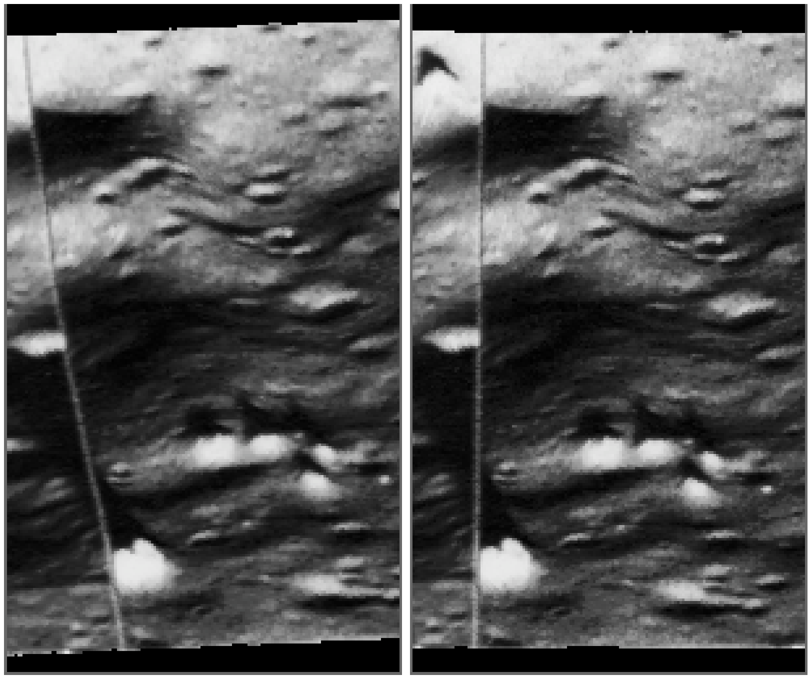


Figure 17 View from the left of Objects 1, 2, 3, 5, and 6, 30 degrees above the horizon at 1x magnification.

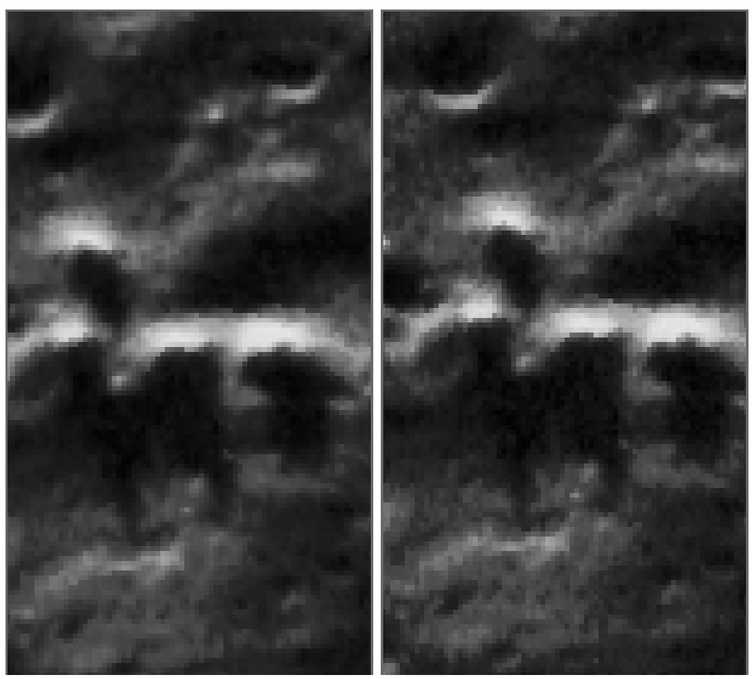


Figure 18 Close up view looking to the right on Objects 1, 2, 3, and 6 from 50 degrees above the horizon at 2x magnification.

Figure 19 shows the shadow of object 5 falling over the rectangular depression. The depression is particularly intriguing; Figure 20 is a stereo view of it from a higher look angle. Its sides appear to be very straight and contain subtle linear features (lineaments) that appear like a series of very small craters or pits distributed in a line.

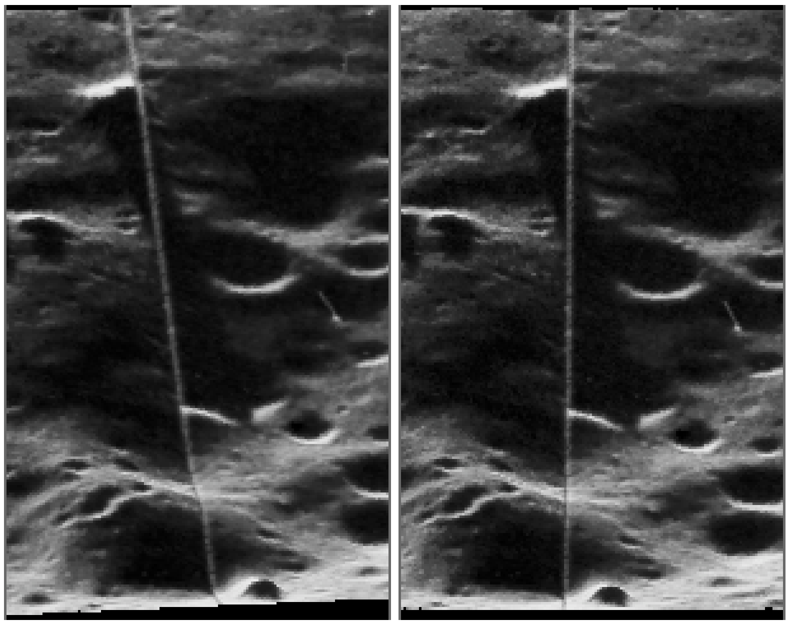


Figure 19 Object 1 and shadow falling across rectangular trench looking right from 30 degrees above the horizon at 1x magnification.

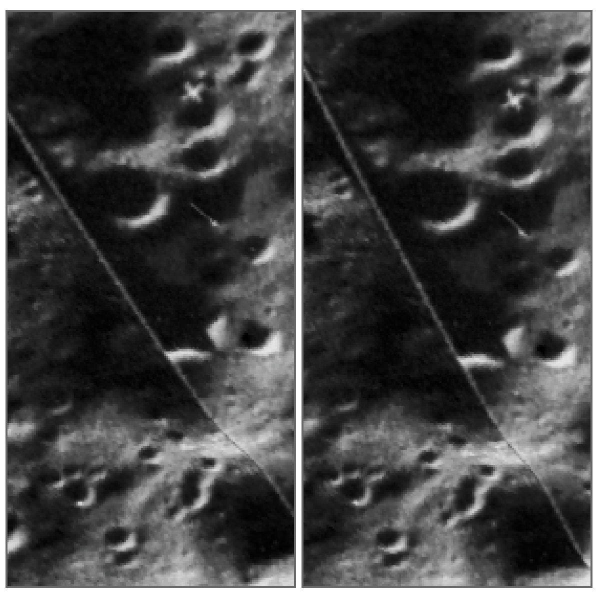


Figure 20 View of rectangular depression from 50 degrees above the horizon at 1x magnification.

An overhead synthetic stereo image of LO2-61H3 (Figure 21) reveals that the rectangular depression is the deepest part of a larger network of rectilinear collapses of the surface. One possibility is that this network is geological in origin, perhaps connected with Rima Ariadaeus to the north. On the other hand, its similarity to Arkhipov's quasi-rectangular ruin-like patterns of depressions and lineaments[19] suggest the possibility that it might be an artificial structure.

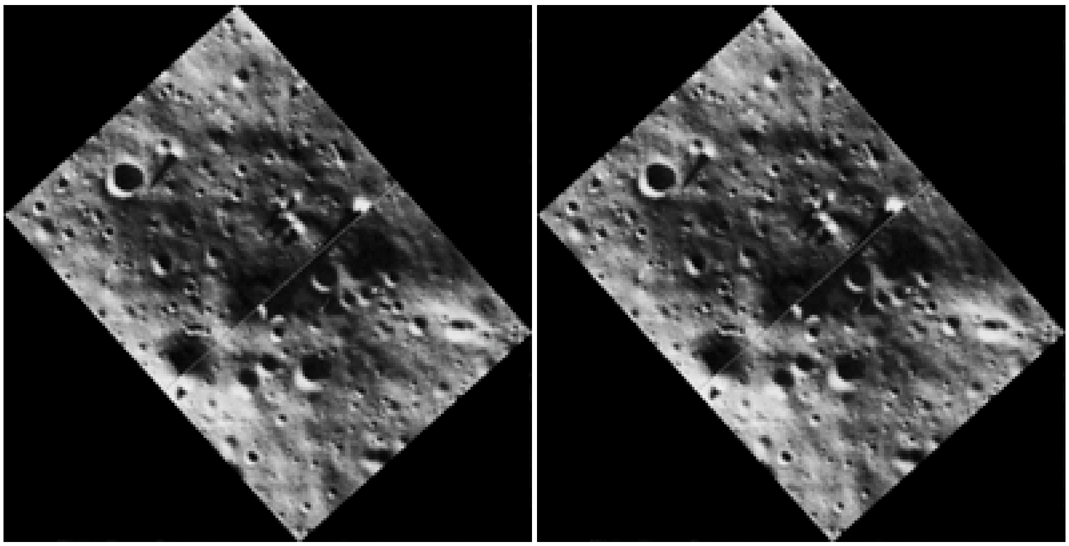


Figure 21 LO2-61H3 rotated by 40 degrees to emphasize subtle horizontal and vertical structure in the background.

5. Discussion

The size of the rectangular depression is about 100 by 150 meters. This is about the size of similar features found in Arkhipov's wafer- and lattice-like structures. It is possible that this network of collapses is a part of a larger structure. Figures 21 and 22 have been rotated to better show the rectilinear shape of the main depression and surrounding collapses (boundaries depicted by green lines in Figure 22). Subtle lineaments aligned in the horizontal and vertical directions (shown in blue in Figure 22) are also evident. In this rotated reference frame, horizontal and vertical lines (red) can be drawn connecting the approximate centers of objects 3 and 5, and objects 1, 6, and 7, respectively. Intriguingly, the sides of the depression and collapses, the lineaments, and these lines between the cuspids all lie in the same directions.

At low sun angles, shadows can create the illusion of oriented structures. Line-scan sensors and photo scanners can also introduce artifacts that give the impression of a linear structure. In Figures 21 and 22, these directions lie about 45 degrees away from the vertical and

[19] A. Arkhipov, "Toward Lunar Archaeology," *New Frontiers in Science*, Vol. 1, No. 2, Winter 2002.

horizontal axes. Thus the rectilinear structures/alignments cannot be caused either by lighting effects or scanning artifacts.

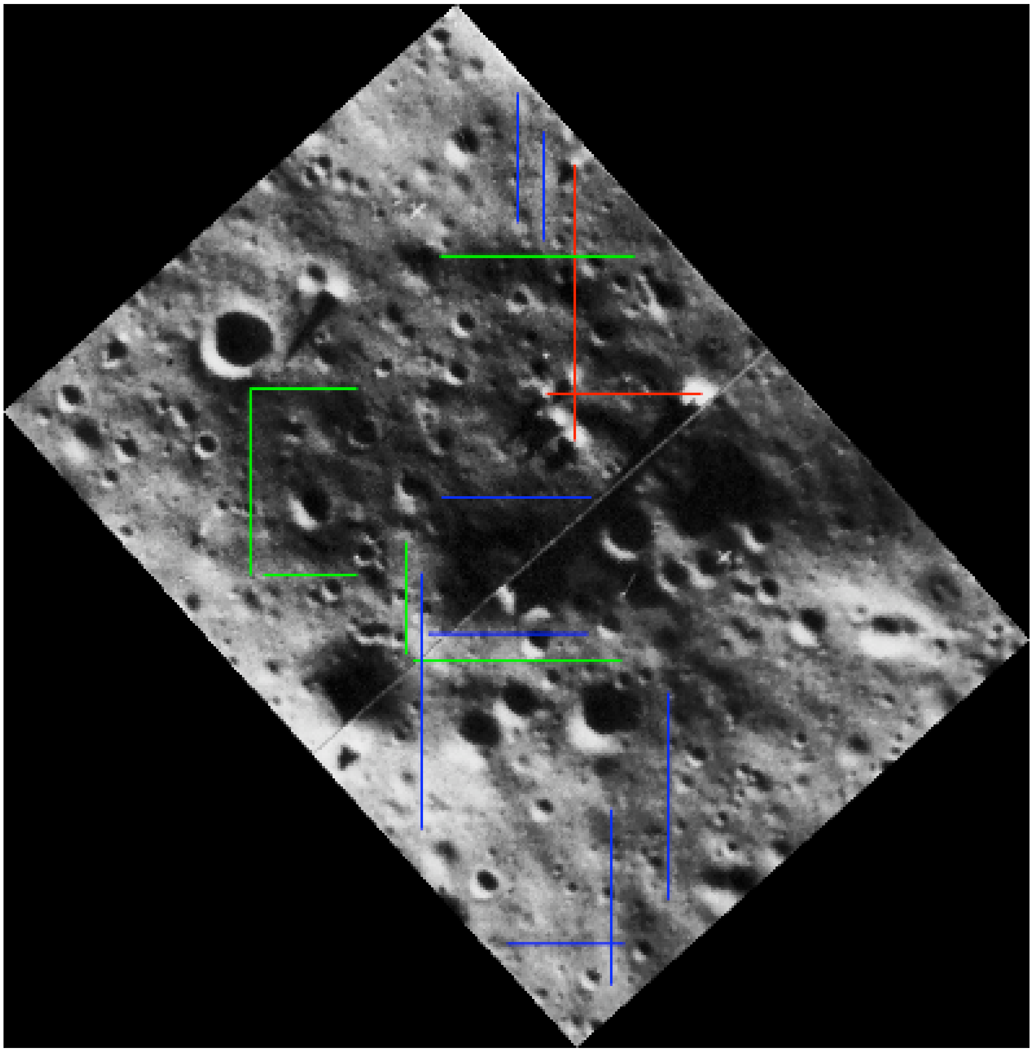


Figure 22 Correlations in horizontal and vertical alignments and structure between objects 1,3,5,6, and 7 (red), edges of rectangular depressions (green), and lineaments (blue).

In summary, the key features that suggest that these objects and their surrounding terrain may be artificial in origin are:

- the presence of multiple objects, conical or pyramidal in shape, that do not appear to be typical rocks or outcroppings.
- perpendicular alignments between five of the seven objects
- a network of rectangular collapses of the surface
- horizontal and vertical lineaments

- correlations in alignments between these objects, the orientation of the rectangular depression, and the direction of lineaments

Having precisely identified the location of the cuspids, it is now possible to determine if any Clementine imagery is available of the area. If so, a more detailed analysis of the cuspids morphology, as well as that of the surrounding network of collapsed terrain, may provide further insight into the origins of these surface features.

Mark J. Carlotto received B.S., M.S., and Ph. D. degrees in Electrical Engineering from Carnegie-Mellon University in 1977, 1979, and 1981. He has over 20 years of experience in satellite remote sensing and digital image processing. Dr. Carlotto has studied anomalous phenomena including unusual features on the Moon, on Mars, and in space. His book, *The Martian Enigmas* describes in detail his analysis of imagery of the Face and other possible artificial objects on Mars imaged by a Viking Orbiter spacecraft in 1976. Dr. Carlotto has published over seventy papers in technical and scientific journals and conferences. His work has been reported in *New Scientist, Omni,* and *Newsweek,* and has appeared in numerous television programs including Carl Sagan's *Cosmos* series, and *Sightings*.