Lunar Section
BAA
British Astronomical Association

Acting Director: Anthony Cook.
Editor: Barry Fitz-Gerald.

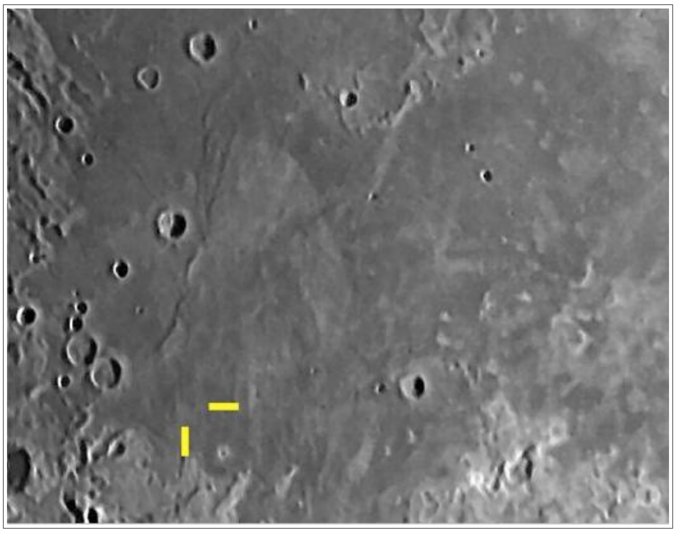
LUNAR SECTION CIRCULAR

Vol. 59 No. 11 November 2021

From the Director

We have a “nearly” total lunar eclipse this month on Friday 2021 Nov 19. The bad news for UK based observers though is that it will be visible barely for the first contact before the Sun rises and the Moon sets – the further west you are though, the better your chances from the British Isles. First contact of the umbra is at 07:19UT. There is a much weaker penumbral shadow eclipse phase, which starts at 06:02UT – so that could be worth trying. However, anybody over in South America should obtain a splendid view of everything from first to last umbral contact - so I look forward to showing any images, from that continent, that are sent in.

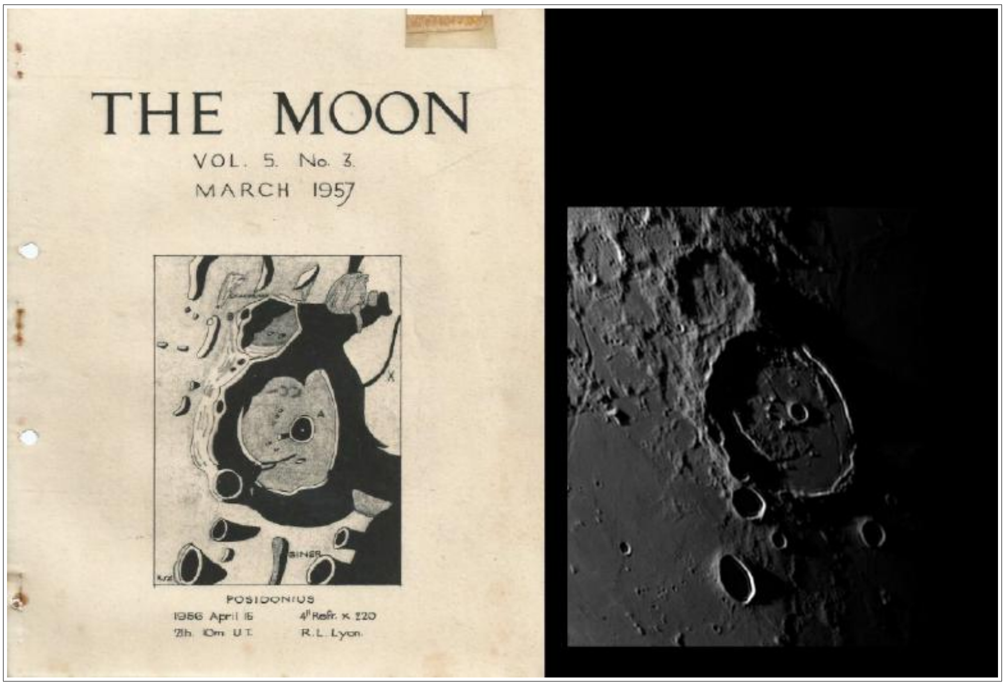
I have started two projects this month for lunar section members. Firstly, have you ever wondered what the Moon would have looked like though a telescope, on the day that Neil Armstrong set foot upon the Moon? Most astronomers of the time were probably glued to their TV screens rather than out observing .



The Apollo 11 landing site. What the lunar surface would have looked like, through an Earth based telescope, at the moment that Neil Armstrong set foot upon the Moon. Imaged by Valerio Fontani (UAI) on 2021 Oct 12 UT 18:23. The yellow rectangles indicate the approximate location of the landing site.

But from a historical point of view, it might be interesting to have similar illumination images, to within ±0.5° for the 55th or 60th anniversaries in 2024 and 2029 respectively.Of course, these could be generated with simulation software such as LTVT, but experience shows that these do not replicate ray material well over different lunar phases. I have loaded up some predictions for Apollo’s 11,12,14-17 landings onto the Lunar Observing Schedule web site* for those who are interested in trying. The aim here is to see who can produce the highest resolution earth-based context view of the landing sites at specific colongitudes. We have already had one image sent in, from Valerio Fontani, a UAI member in Italy.

Another project idea was prompted by an email from Rod Lyons in which he said he was fascinated by the Posidonius article in the October circular. Rod recalled how he had studied the area in the 1960’s and one of his early sketches made it onto the front cover the section’s “The Moon” publication that ran from 1950-1967. This got me thinking about how interesting it would be to compare the best quality sketches from the 1950’s onwards with modern day imagery. It could tell us a lot about the pros and cons of both techniques and allow us to revisit the lunar geology questions that were discussed over that era and how interpretations have changed since then. I will start putting entries into the Lunar Observing Schedule web site for similar illumination, and where necessary similar libration, so we can make direct comparisons between the sketches and what can now be captured by CCD. I have already found a similar illumination image in the ALPO/BAA archives for Rod’s Posidonius sketch.



Posidonius orientated with north towards the bottom. (Left) A sketch from “The Moon” by Rod Lyons. (Right) An image by Brendan Shaw taken on 2013 Feb 15 UT 19:16

Hope you enjoy the November edition of the circular.

Tony

* https://users.aber.ac.uk/atc/lunar_schedule.htm

Editor Comments: Browsing through some old editions of The Moon on the section publication page I was interested to see the amount of correspondence received from members regarding the contents of previous issues. It might be an idea to re-instate this in the LSC. To this end I would welcome any comments or points you wish to put across regarding the articles in the LSC, this is your newsletter, and it would be good to hear your opinions. If you feel like contributing in this way please contact me or the Acting Director Tony Cook, and I will endeavour to include your communications in subsequent LSC's.

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Correspondence Received

From Maurice Collins (New Zealand)

I was asked and interesting question by Monolo Rodriguez: *"Could you explain to me why the contrast of the relief acquires those textures like plaster, of a Greek or Assyrian bas-relief? Is it perhaps the angle of incidence of the light at that lunar limb? That aspect has always aroused my curiosity, it does not appear in other areas."*. What I think is happening is that the lunar soil likes to reflect most of its light back along the path it came, (like at Full Moon), and in the eastern limb most of the light and almost all of any white shiny crater walls face away from us. Most of what we see is shadow filled craters or forward scattered light of lower intensity, so it looks grey and low contrast and plaster-like.

From Jason Wentworth (USA)

I found something that is not only exciting from a space archaeology perspective, but should also make low-orbiting lunar space stations (which would provide easier and cheaper access to [and from] the lunar surface and lunar orbit, and--with at-station re-fueling--easy access to the Earth and other bodies) practical. This may sound crazy (it did to me, too, but Scott Manley has plenty of highly-suggestive evidence here (also, see a paper by James Meador), but Apollo 11's "Eagle" Lunar Module Ascent Stage may still be in lunar orbit today, and the orbit appears to be stable. It all started when a researcher was trying to find the crater that Eagle's Ascent Stage created when it hit the lunar surface (all, or nearly all, of the other manned and unmanned lunar spacecraft and upper stage impact craters have been found), which required data on how Eagle's orbit changed over time, but: to the researcher's great surprise, the sophisticated celestial mechanics software--the same software that NASA uses today to design mission trajectories (astronomers also use it)--predicted that no impact had occurred (or would occur), even for worst-case scenarios of the orbit Eagle had when abandoned in lunar orbit on July 21, 1969.

It was a shock to the researchers who ran the professional orbit analysis software forward in time, expecting to discover about when and where Eagle's Ascent Stage impacted--then discovering that *no* impact was indicated at all. Apparently (as Scott Manley described) if a vehicle enters, or is left in, a low lunar orbit whose period, inclination, perilune, and apolune are "just right" (including when the orbit is established) with respect to the mascons, the complex interactions between the gravitational tugs of the mascons, the Earth, and the Sun "conspire" to create a low lunar orbit for a Moon satellite whose perilune & apolune cyclically rise and fall, but whose perilune never intersects the Moon's surface. Such orbits--around the Moon, Mercury, Ceres, Vesta, etc.--would be very useful parking orbits (and space station orbits) that would require no propellant to maintain, once achieved.

With favourable lighting and viewing angles (especially at maximum elongations; numerous observations would be needed in order to "catch" these), BAA members with CCD telescope cameras and "binning" software could possibly detect Apollo 11's Eagle Ascent Stage (and the Descent Stage of Snoopy, Apollo 10's Lunar Module, which may also be in a "frozen" lunar orbit). The free software that NASA uses for mission trajectory design (which Scott Manley mentioned in his you tube video, might have a feature to generate—or be otherwise useful for making—ephemerides for the best times to search for both LM stages.

Observations Received.

Observations have been received from the following:

Maurice Collins (New Zealand), Valerio Fontani (Italy - UAI), Rik Hill (USA), Rod Lyons (UK), Luigi Morrone (Italy), Alexander Vandenbohede (Belgium) and Ivan Walton (UK).

The best observation from each will be shown within the circular. Note that all other observations are made available to researchers within the Lunar Section upon request.

Please send future observations in by the 20th of the month for inclusion in the circular.

Note: *Directors comments in italics.*

Aristarchus.

Fig.1 Aristarchus and surrounds captured by Rod Lyon and orientated with north towards the top. Date and UT etc given in the text beneath the picture.

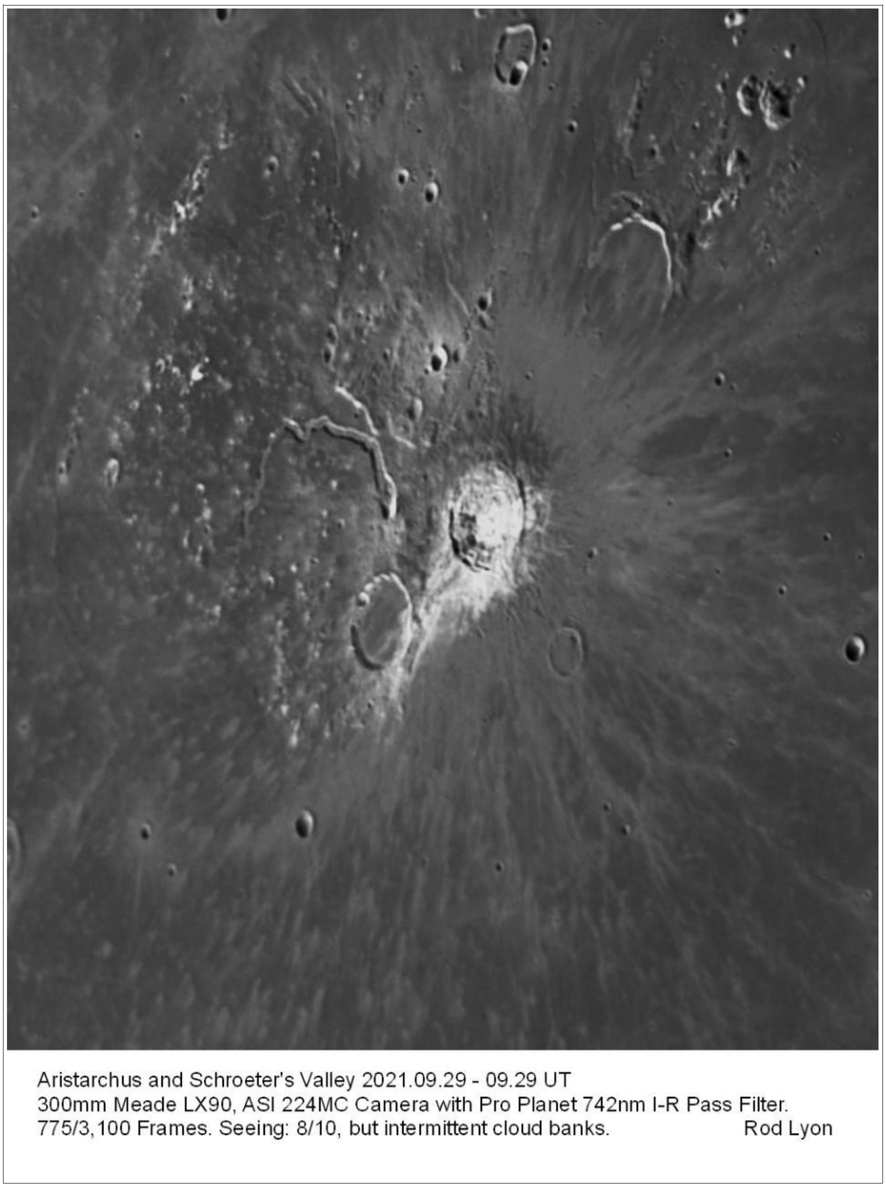

Fig.1 Aristarchus and surrounds captured by Rod Lyon

Rod comments: “I was particularly pleased that I was able to obtain a good image of Aristarchus and Schroter's Valley - taken at 10.30 in the morning (BST) - which unusually for me, because of the extreme brightness of the crater's interior, did produce good detail of the internal terracing etc. Normally when I get the chance to image this crater, I cannot seem to get the balance right to show much detail because of this brightness within the crater.”

Sinus Iridum.

Fig.2 Sinus Iridum as imaged by Rik Hill, using the instrument & taken at the date/UT, given on the image. Made from a montage of most of four images each stacked from 1800 frame AVIs using AVIStack2 (IDL) assembled with Microsoft ICE and finish processed with GIMP and Irfan View.

Fig.2 Sinus Iridum as imaged by Rik Hill.

Rik comments: “There are so many wonderful things to see in the lunar southern highland region It was a good, clear, calm evening and I was imaging Jupiter and Saturn after finishing with Venus. I took a pair of binoculars and looked at the Moon. There was an odd appendage to the north on the terminator. As soon as I could I turned to the Moon and found that I had caught the moon at the brief time when the floor of the great embayment, Sinus Iridum (411km dia.) is in shadow but the Montes Jura that make up the west wall of Iridum were catching the sunrise. On the south you can see Promontorium Heraclides (1700m alt.) also catching the first sunlight of the lunar day. Opposite this on the northern edge of the Sinus you see the taller Promontorium LaPlace (2600m alt) well in the sunlight. To the right of this are the Montes Recti (1800m alt.) leading further to the wonderful collection of peaks, the Montes Teneriffe (1450m max. alt.) ending in the dramatic Mons Pico (2400m alt.). The small isolated mountain south of Pico is unnamed.

Outside the mouth of Sinus Iridum are the guardian craters of Helicon (26km) left and Le Verrier (20km) right. Look at the similar structure to the interior walls of the two, probably the result of slumping. In the lower right corner of this image is the little crater Kirch (12km). Directly above this in the upper right corner is the great crater Plato often called a "walled plain". Because it is so identifiable and easy to find, it is one of the first features new lunar observers learn about. This terminator was a great view in binoculars and in the telescope!

Sinus Iridum.

Fig.3 A mosaic of images covering Sinus Iridum by Luigi Morrone, taken on 2021 Oct 17 at 19:26 UT. North is towards the top. The equipment used was C14 Edge HD, Fornax52 mount, ASI 174MM, Barlow Zeiss, Baader R+IR610nm.

Fig.3 Sinus Iridum as imaged by Luigi Morrone.

Luigi's image was taken about a day after Rik's image of the same area, but you can still see a wealth of wrinkle ridges on the mare and other detail on the mare. The Russian Luna 17 (Lunokhod 1) and Chinese Change'3 have both landed in the vicinity.

Copernicus.

Fig.4 Copernicus as imaged by Maurice Collins on 2021 Oct 15 UT 07:35 using a C8 scope and a QHY5III462C camera. North is towards the top.

Fig.4 Copernicus as imaged by Maurice Collins.

Copernicus is a 93 km crater in diameter and believed to have formed 800 million years ago as deduced by some of the rocks in the ejecta field that were recovered by Apollo 12 astronauts and radio-isotopically dated back on Earth. A geological era, known as Copernican era craters, is named after Copernicus and spans from 1.1 billion years ago until the present day. To the top right *of Copernicus is Eratosthenes crater, which also has a geological era named after it but which spans 1.1 to 3.2 billion years ago.*

Gauss and surrounding area.

Fig.5 The Gauss area of the Moon as imaged by Alexander Vandenbohede on 21 October 2021 with a C8 F10 using a 1.5x Barlow, IR pass filter and ASI290MM. Seeing was not very good but usable and Fig.6 an LTVT map projected view of the area.

Fig.5 The Gauss area of the Moon as imaged by Alexander Vandenbohede.

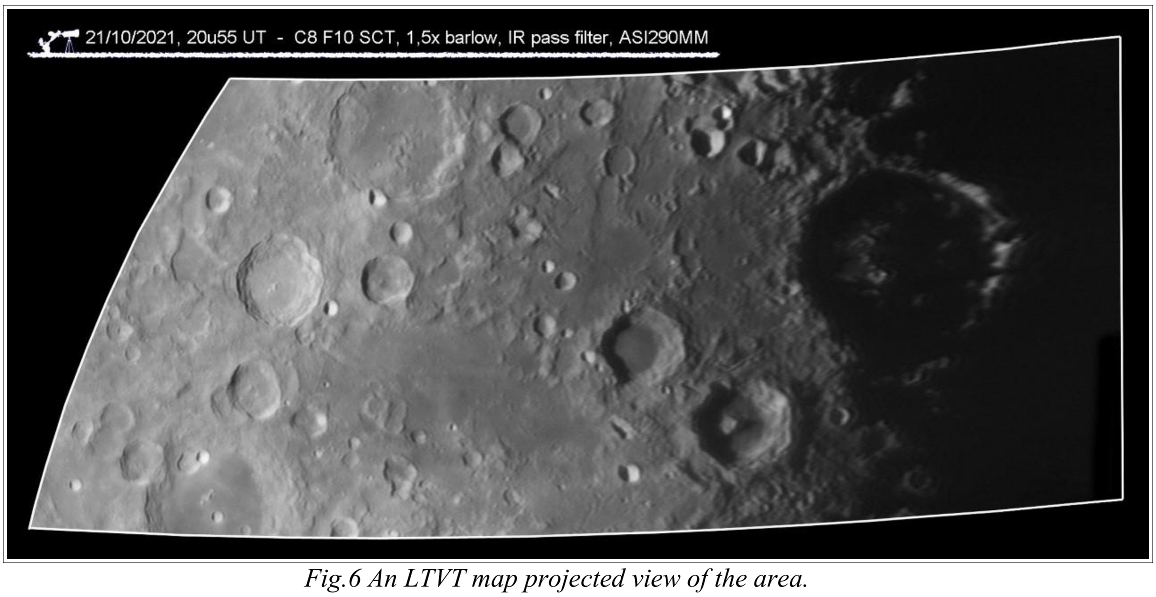

Fig.6 An LTVT map projected view of the area.

Alexander comments that libration was favourable to observe the north eastern rim of the Moon whereby Gauss was right on the terminator. The crater was already almost completely filled with shadow. With LTVT, Alexander reprojected the image to have a perpendicular view on the region. It shows a little bit more detail on the floor of Gauss that is still catching the last of the sunlight.

Besides Gauss, the crater Hahn, with the central peaks, and the crater Berosus are prominent in the view.

Mares Crisium, Imbrium, Serenetitatis, Tranquilitatis and Vaporum.

Fig. 5 This image of no less than four mares on the north east quadrant of the Moon was captured by Ivan Walton on 2021 Sep 21 at 22:50UT and orientated with north towards the top.

Fig.5 Four mares on the north east quadrant of the Moon captured by Ivan Walton

This is one of the areas of the Moon where it is possible to capture several mare regions together. Mare Serenitatis is the central mare here but merges into Tranquilitatis, with a slight merger into Imbrium. Mare Vaporum and Crisium are more self-contained.

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Lunar Occultations November 2021

by Tim Haymes

Time capsule: 50 year ago in the November 1971 issue: [With thanks to Stuart Morris for the LSC archives. https://britastro.org/downloads/10167]

· Patrick Moore resumes directorship with "misgivings". He will do his best. Phil Ringsdoor remains assistant director.

· The mock Moon report (Stanier) is discussed. UFO reports were received by Jodrell Bank. Sightings in the News are of a strange moving coloured light.

· Miss C. Botley gives a learned account of the "Counter Moon".

· G. Kirby reports 8 occultation with RGO O-C values. He asks how his O-Cs compare with other observers.

G Kirby's O-C values – Then and Now (Weymouth, UK)

I compare the reported O-Cs for Mr Kirby's observations: The RGO (Watts Limb profile) vs modern LOLA limb corrections (IOTA)

ID	Ph	Date	UT*	O-C(RGO**)	O-C(IOTA)
ZC 539(19 Tau)	RD	1970 09 20	02:22:48.1	-0.32	-0.15
ZC 542(22 Tau)	RD	1970 09 20	02:59:14.5	0.28	0.49
ZC 538(18 Tau)	RD	1970 09 20	03:00:03.7	0.34	0.02
ZC 538	DD	1971 02 03	18:51:19.5	-0.71	0.16
ZC 555	DD	1971 02 03	20:33:00.5	0.48	0.14
ZC 571	DD	1971 02 03	22:22:27.1	-0.19	0.11

*UT from the Occult4 Database **Reported in LSC Vol 6, No 10, page 83.

IOTA results: Average 0.12, StdDev = 0.19

Conclusion: The O-C for the IOTA data reduction with Occult4 is good. All residuals are less than those reported in 1970, with one exception: 22 Tauri (zC542). This has double the residual(0.28=> 0.49). WHY ? unless the residual in the LSC was incorrectly typed.

Report: Graze of SAO 190087 (S England on October 14)

The BAA Handbook page 44 lists this graze (#14). The Horsham Astronomical Society requested information via a Zoom meeting. I was pleased to make their acquaintance and I explained the use of the Occult4 predictions in planning to observe. The event was at low altitude (11 degrees) likely making the conditions more difficult. One interesting aspect was a flat region in the limb profile around mid-graze. There were a large number of possible contacts which could have been impressive. No observing team was raised owing to time of day and travel distance – ca 70 mile round trip.

Star and Moon altitude is an important consideration particularly in today's climate of high fuel costs when the "return" in terms of "chances of success", is not particularly great. My thanks to Horsham for inviting me. I wish them good observing in the future.

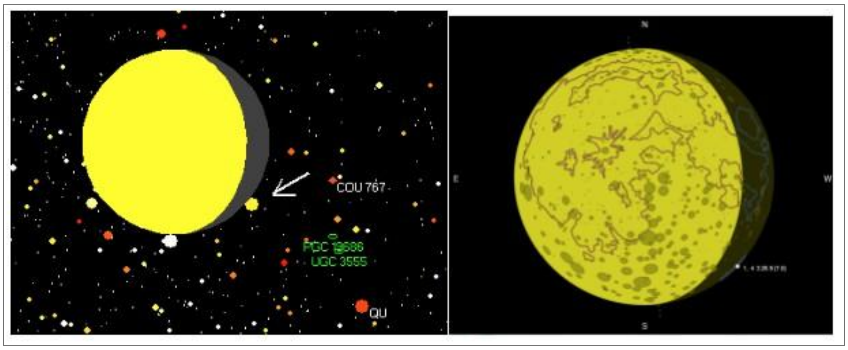
This Month.

The best series of RD event are predicted for the nights of November 21/22/23/24 as the Moon passes through Leo and Gemini. There are a few double stars to look out for.

Of interest is the reappearance of ZC 1046 on Nov23 at about 0403UT. Occult4 marks this as a double star with a separation of 0.1" arc in PA 57. This is too close to be observed visually and is not marked as a double in SkyMap Pro. Even so, it is in the WDS and the components are of equal magnitude at 7.8/7.8. The time separation computed is 410ms, so should be an easy measurement by video.

Request for observation:

Please observe this and estimate the magnitude difference of the components. There is no light curve for this star, so will be the first to be recorded – good luck.



Sky Map pro simulation Occult 4 diagram for the RD.

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Occultation predictions for North Oxfordshire for 2021 November

Longitude 1 18 46 W ,  Latitude  51 55 41 N,  Alt.  119m;  Moon Alt>5 degrees
Some fainter predictions may be omitted near Full Moon.

      day  Time      P   Star  Sp  Mag  Mag     % Elon Sun  Moon   CA   Notes
y   m  d  h  m   s        No        v    r     ill     Alt Alt Az
21 Nov  1  2 46   5.5 R  118843 G0  8.5  8.2   18-  50       6  84  46N
21 Nov  1  3 20 49.9 R  118854 K0  8.9  8.4   18-  50      11  91  84S
21 Nov  1  3 26 29.7 R    1659 K0  6.7  6.0   18-  50      12  92  87N
21 Nov  1  4 22 21.1 R  118880 K2  8.3  7.6   17-  49      20 103  60N
21 Nov  3  5 55 40.9 R    1898 G5  8.7  8.3    4-  22 -11 10 110  82N
21 Nov  8 17 31 53.2 D  187181 K2  8.6  7.9   20+  53 -10  7 205  68S
21 Nov  8 18 52  9.5 D    2721 B8  3.2  3.2   21+  54       1 222  31N phi Sag Dbl*
21 Nov  9 17  8 58.3 D    2887 K2  7.7  7.0   30+  67  -7 12 187  66S
21 Nov  9 18 40 22.9 D  188607 K2  8.3  7.6   31+  67       8 207  61S
21 Nov 11 19 19 40.2 D  164654 F6  7.7  7.4   53+  93      18 192  62N
21 Nov 12 20 21 32.9 D  165227 K0  8.1  7.6   63+ 106      22 197  18N
21 Nov 13 17 58  9.8 D    3450 F0  8.5  8.3   72+ 117      23 147  90S
21 Nov 13 22 29 22.1 D  146764 K0  8.0  7.5   74+ 118      22 219  56S
21 Nov 15  0 12 43.6 D      44 F8  7.4* 7.1   83+ 131      20 235  39S
21 Nov 15  0 29 17.6 D  128707 K0  6.9* 6.4   83+ 131      19 239  49N
21 Nov 15 23 30  3.9 D  109653 K0  7.2* 6.6   89+ 142      35 217  78N
21 Nov 16 23 15 19.4 D     269 K0  7.0* 6.4   95+ 153      44 203  57N
21 Nov 17  0  9 38.4 D  110153 K0  8.3  7.7   95+ 153      40 220  57N
21 Nov 17 19 48 14.4 D   92971 F5  8.0  7.8   98+ 163      36 121  39N
21 Nov 18  3 49 54.4 D     394 K0  7.5  6.9   98+ 166      21 265  45N
21 Nov 20  6  1  1.3 R     631 F0  5.6* 5.5   99- 171      21 279  45N 51 Tau Dbl*
                           631 is double: AB 5.6 8.1 0.07" 302.6 dT = +0.08s

21 Nov 20 20 43  0.7 R     734 K0  6.6  6.0   98- 163      34  95  51N
21 Nov 20 22 26 16.3 R   76853 F5  7.5  7.2   98- 163      49 118  63S
21 Nov 21  0 25 42.0 R   76875 A5  8.9  8.7   98- 162      61 161  64N
21 Nov 21  2 26 49.6 R   76913 K2  8.6  7.9   97- 162      58 216  78N
21 Nov 21  2 54  3.5 R   76921 A2  8.6  8.5   97- 161      56 226  83S
21 Nov 21  3  4 26.7 R   76931 K0  8.3  7.7   97- 161      55 230  34N
21 Nov 21  3 51 40.0 R   76947 K0  7.7  7.0   97- 161      48 244  87N
21 Nov 21  3 58 14.6 R   76952 K0  7.2  6.6   97- 161      48 245  61S
21 Nov 21 20 27 48.1 R   77485 G5  7.9  7.3   94- 153      25  81  71S
21 Nov 21 20 57  8.4 R   77513 K0  7.5  6.9   94- 152      30  87  75N
21 Nov 22  1 35 43.1 R   77687 A0  8.5        94- 151      64 170  56N HDS791
                         77687 is double: AB 9.1 9.5 0.10" 108.0 dT = +0.35s

21 Nov 22  1 56 16.9 R   77698 A2  8.6  8.4   94- 151      64 180  73N
21 Nov 22  3  4  3.7 R   77736 A2  7.9        93- 150      61 212  42S COU902
21 Nov 22  3 27 54.3 R   77742 K0  8.7  8.1   93- 150      59 222  88S
21 Nov 22  4 30 31.4 R   77778 K0  8.0  7.4   93- 150      51 242  81N
21 Nov 22  4 32 16.6 R     902 K0  6.6  6.1   93- 150      51 243  18N
21 Nov 22 23 28 13.1 R X  9665 K7  8.6  7.8   89- 141      45 107  57S
21 Nov 23  1 49 18.8 R   78744 A0  8.5  8.4   88- 140      62 152  48N
21 Nov 23  4  3 26.9 R    1046 F8  7.0  6.7   88- 139      60 216  44S Dbl*
                          1046 is double: AB 7.8 7.8 0.10" 57.0 dT = +0.41s

21 Nov 23  4 55  5.1 R   78821 K5  8.8  8.0   88- 139      55 234  24S
21 Nov 23  5 19  2.3 R   78824 F0  7.9  7.7   88- 139      52 242  60S
21 Nov 23 23 26 23.7 R   79544 F0  8.4  8.2   82- 130      37  96  29S
21 Nov 24  1 40 59.4 R   79610 F8  7.2* 7.0   81- 129      55 130  17S
21 Nov 24  6 41 48.6 R   79720 K0  8.8  8.2   80- 127  -9 47 249  11N
21 Nov 25  3 43 58.2 R   80288 K5  8.6  8.2   73- 117      60 160  48N
21 Nov 25 22 53 46.6 R   80764 K2  7.8  7.0   65- 107      14  75  66N
21 Nov 26  0 56 17.0 R    1390 G0  7.7* 7.4   64- 106      32  98  61N

21 Nov 26  3 38  2.8 R   80842 F0  8.9  8.7   63- 105      53 141  64S
21 Nov 27  1 22 55.5 R    1499 K0  7.1  6.4   54-  95      26  97  87N
21 Nov 27  4 20 58.7 R   99062 G5  8.9  8.4   53-  94      49 142  64N
21 Nov 27  6 27 50.1 R   99091 G5  7.3       52-  93 -11 53 190  65N
21 Nov 28  4 47 32   M   99474 F8  8.4        42-  81      42 139   6S Dbl*
                       99474 is double: AB 8.59 9.87 0.59" 302.6 dT = +2sec

21 Nov 29  3 11 53.7 R    1725 K0  7.6* 7.1   33-  70      20 107  28N DBl*
                      1725 is double: AB 7.4 7.6 0.10" 104.3, dT = +0.11sec

21 Nov 29  4 53 16.8 R  119146 F5  8.4  8.2   32-  69      33 131  80N Dbl*
                    119146 is double: ** 9.4 9.4 0.10" 131.0, dT = +0.22sec

21 Nov 30  3 25 39.7 R  138961 K0  8.3  7.8   23-  57      10 104  43N
21 Nov 30  5 12 22.8 R  138977 F5  8.8  8.6   22-  56      24 128  74S
21 Nov 30  6  5 27.4 R    1844 K5  8.9  8.1   22-  55      29 141  55S
21 Dec  1  5 10 19.8 R  139493 F5  8.0  7.8   13-  43      12 119  17N
21 Dec  2  5 41 46.8 R    2087 K3  8.8  8.0    6-  29       4 119  73S
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Prediction up to Dec 3rd

Key:

P = Phase (R or D), R = reappearance D = disappearance

M = Miss at this station, Gr = graze nearby (possible miss)

CA = Cusp angle measured from the North or South Cusp. (-ve indicates bright limb)

Mag(v)* = asterisk indicates a light curve is available in Occult-4

Star No:

1/2/3/4 digits = Zodiacal catalogue (ZC) referred to as the Robertson catalogue (R)

5/6 digits = Smithsonian Astrophysical Observatory catalogue (SAO)

X denotes a star in the eXtended ZC/XC catalogue.

H denotes the HIPparchus catalogue

The ZC/XC/SAO nomenclature is used for Lunar work. The positions and proper motions of the stars in these catalogues are updated by Gaia.

Detailed predictions at your location for 1 year are available upon request. Ask the Occultation Subsection Coordinator: tvh dot observatory at btinternet dot com

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Lunar domes (part LII): A dome near the lunar crater Hansteen
by Raffaello Lena

In this contribution I describe a large dome situated to the north of Mons Hansteen. The selenographic coordinates of the dome, termed Hansteen 2 (Ha2), are 10.57° S and 48.30° W. The elongated base diameter of this flat dome was determined to be 21.0km×16.7km, and it is detectable in the image taken by Jim Phillips on October 30, 2009, at 02:11 UT.(Fig. 1). Using an image-based photoclinometry approach to reconstruct the three-dimensional shape of Ha2 the height amounts to 85 ± 10m, resulting in an average flank slope of 0.52°. The edifice volume corresponds to 11.8km³. I have also used ACT-REACT Quick Map tool to obtain the cross-sectional profile for the dome (Fig. 2).

A combined approach was then used to construct a DEM of the dome using a WAC image superimposed onto the corresponding LOLA 1/512° DEM (cf. Fig. 3). Clementine UVVIS imagery indicates a 750 nm reflectance of R_{750} = 0.0956, a moderate value for the UV/VIS colour ratio of R_{415}/R_{750} = 0.6116, indicating a moderate TiO_2 content, and a high R_{950}/R_{750} ratio of 1.0312 indicating a high optical maturity and thus a high exposure age of the dome surface. The absence of a spectral contrast between Ha2 and the surrounding surface indicates that the dome is not a piece of pre-existing elevated terrain later embayed by basaltic lava, a so-called kipuka. A rendered image displays the shadow length cast by a dome and is useful for simulating particular situations, showing how rapidly the appearance of domes changes with increasing solar elevation. LOLA DEM was thus used for the rendered images with different solar illumination angle, which show the dome Ha2, reported in Fig.1a (solar altitude of 1.56°), under 0.65°, 0.90° and 1.10° of solar altitude, respectively (cf. Fig. 4).

As very low solar illumination angles are required to reveal the gentle slopes of lunar domes, most of these subtle structures do not appear in the available sets of orbital images. Lunar Orbiter image IV-149-H2 of Ha2 dome is shown in Fig. 5b. The Lunar Reconnaissance Orbiter (LRO) WAC image (Fig. 5a) shows a flat surface and an elongated shape of the dome, with the presence of some embayed non-volcanic hills on its summit.

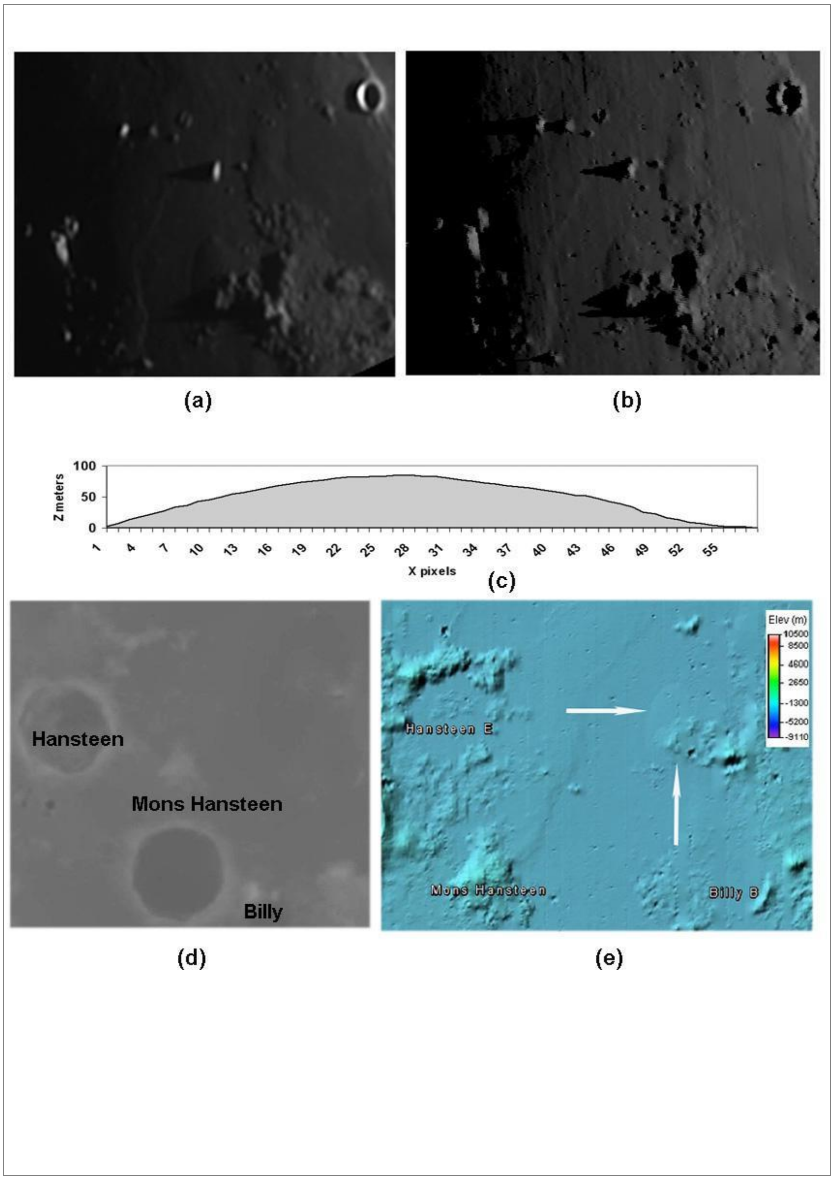


Figure 1: (a) Telescopic image (solar altitude of 1.56°) of the lunar dome Hansteen 2 of possibly intrusive origin. (b) Image simulated based on the LOLA DEM using LTVT, assuming the same illumination conditions as in Fig. 1a. (c) Cross-sectional profile of Hansteen 2 in east-west direction. The vertical axis is 30 times exaggerated; the curvature of the lunar surface has been subtracted. (d) Section from the LOLA DEM. (d) LOLA DEM color hill shade including Hansteen 2 dome (LMMP Nasa) including the covered range of elevation values.

Figure 2: Cross sectional profile of the examined dome in E-W direction.

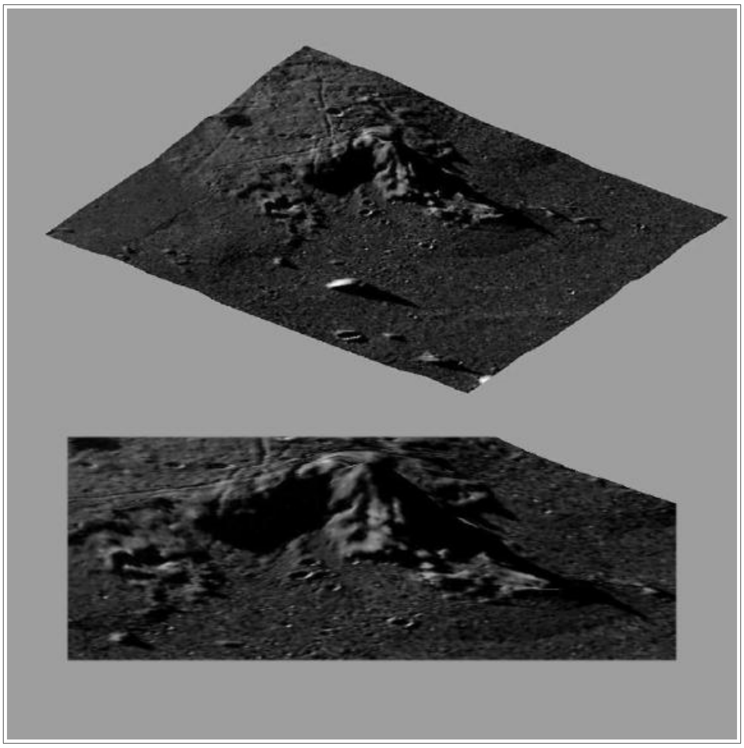
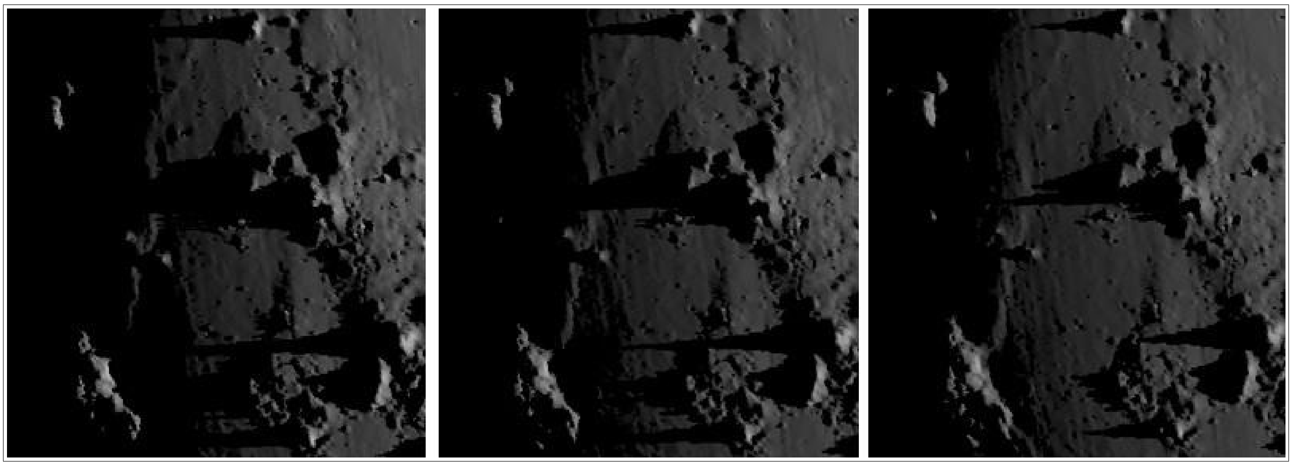


Figure 3: Refined DEM of the dome Hansteen 2 obtained based on a WAC image superimposed onto the corresponding LOLA 1/512° DEM.



a b c

Figure 4: (a-c) Rendered images, obtained with the LOLA DEM, displaying the dome Hansteen 2 under a solar altitude of 0.65°, 0.9° and 1.1°, respectively.

In contrast to effusive lunar domes which are characterised by relatively sharp and circular boundaries, Ha2 is of strongly elongated shape, its surface merges smoothly into the surrounding mare surface, and a clear boundary is absent. Some non-volcanic hills located on its summit are embayed by lavas. Presumably, these hills are part of the underlying rugged basin floor below the mare lavas. Furthermore, Ha2 has no effusive vent (but this may also be the case for effusive domes if they were plugged by lava), and it is characterised by a much larger diameter and a much lower flank slope than all lunar effusive domes examined so far.

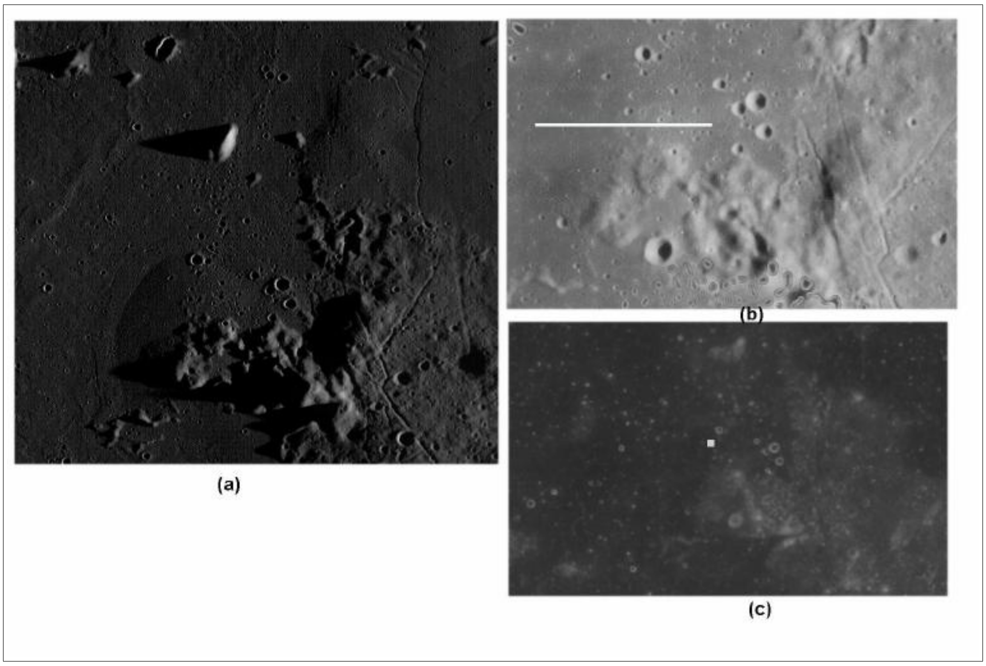


Figure 5: (a) WAC image M116629324ME of the dome Hansteen 2 (b) Lunar Orbiter image IV-149-H2 of the dome Hansteen 2. Due to the comparably high illumination angle, the dome itself is not clearly visible. The white line indicates the location of the cross-sectional profile shown in Fig. 1c. (c) Clementine 750 nm image, including the dome. The white square indicates the location of the spectral data examined.

According to the morphometric properties determined for this dome it belongs to class In2 in the classification scheme for candidate intrusive domes introduced in previous studies. Based on a laccolith model, I have inferred an intrusion depth of 1.2km and a magma pressure of 9.5MPa for a lunar laccolith with the horizontal and vertical dimensions of dome Ha2.

When assuming an intrusive origin of the dome Ha2, this would indicate that laccolith formation proceeded until the second stage characterised by flexure of the overburden.

References

[1] Lena, R., Wöhler, C., Phillips, J., Chiocchetta, M.T., 2013. *Lunar Domes: Properties and Formation Processes*, Springer Praxis Books.

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The origin of Rim Moat Domes
by Barry Fitz-Gerald

Ring Moat Domes or RMD's are currently one of the hottest topics in lunar science, known about for some time[1] they have been studied intensively more recently with their nature, origin and distribution analysed in some considerable detail[2][3][4]. RMD's are small dome shaped mounds with diameters ranging from several tens to several hundred meters (generally < 1km) and heights up to several meters (Fig.1). The moat, from which they get their name, can be several tens of meters wide and several meters deep. They are found almost exclusively within the lunar maria, sometimes in abundance such as that shown if Fig.2 which is immediately north of Sinas E in Mare Tranquillitatis. This particular field of RMD's is located on a large dome like swelling some 20kms in diameter, an association which together with their presence on the mare lava plains has led to the assumption that they are volcanic structures of some sort. There are no terrestrial analogues that may offer clues as to their origin and spectroscopically they are indistinguishable from the surrounding mare surface deepening the mystery of their true nature.

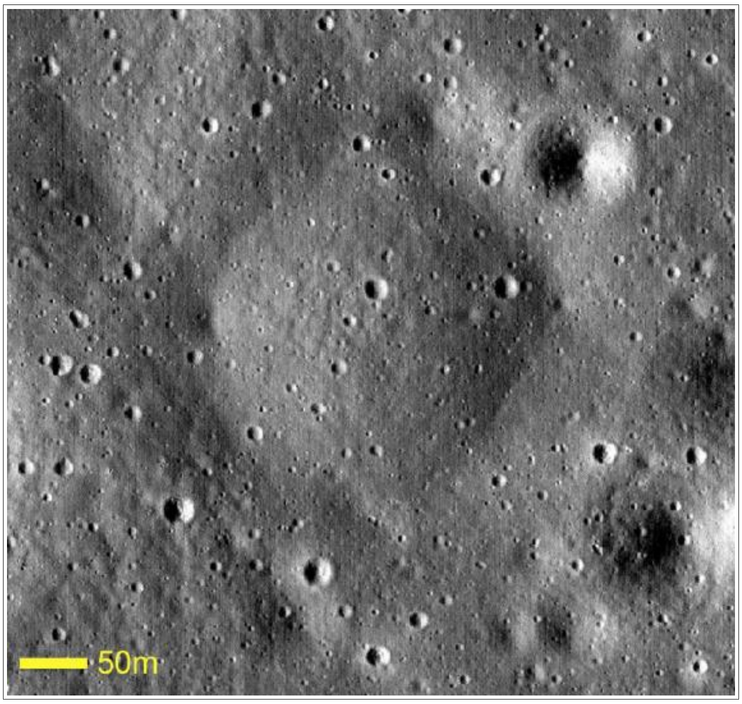

Fig.1 a typical Ring Moat Dome (RMD) in Mare Tranquilitatis showing the central dome and peripheral moat.

The primary theoretical model for their formation is that they represent the eruption of an extremely foamy, highly vesiculated lava from a thick mare lava flow that has a chilled, solidified surface crust but a still molten interior. The frothy lava is produced as changing geochemical conditions within the still molten lava produces a final but intense pulse of exsolved gases, turning the molten lava into a froth. As this lava erupts at the surface, the gas expanded violently into the vacuum and shred the surrounding lava into small, rapidly solidifying glassy shards. This results in the formation of a highly vesiculated lava dome with a surface mantling, several meters deep, of extremely fragmented lava.

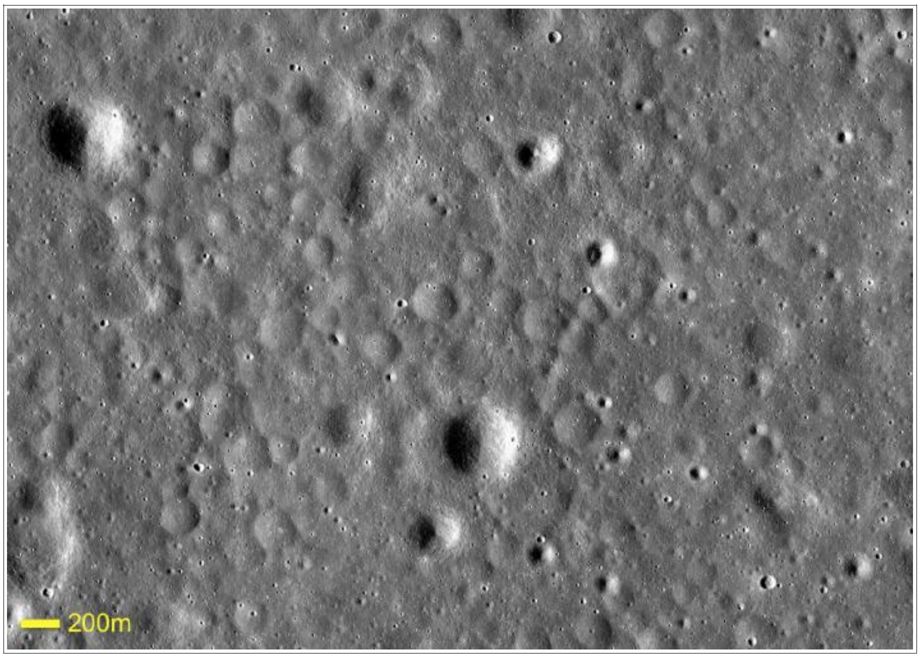

Fig.2. A field of RMD's located on a dome like rise within Mare Tranquilitatis just north of the crater Sinas E.

This thick coating of fragmented material explained a rather puzzling anomaly regarding the age of RMD's, which is that if they are produced by the mare lava flows, then they should be of the same age as those flows and in the region of 3.2 billion years old. Surface crater counts on RMD's however suggest much younger age, somewhere around 25 million years. This was explained by suggesting that the thick mantling and underlying vesiculated lavas would act rather like an 'aerogel' and inhibit the formation and preservation of a normal population of impact craters, neatly explaining the anomalous youthful appearance. Another factor implying a younger age for RMD's is that 3 billion years of space weathering should have eroded these subtle features away – which is clearly not the case. Another age anomaly relates to the apparent encroachment of some RMD's into small craters of apparent Copernican age and therefore *only* somewhere in the region of 1.1 billion years old[5]. If RMD's are indeed the product of volcanic activity, this would imply that the volcanic activity responsible *post dated* these craters (being younger than 1.1by) and prevailing theories of lunar thermal history suggests that large scale volcanism ceased some 2 billion years ago. This age anomaly might therefore require a re-evaluation of theoretical models of the thermal history of the moon and the duration of lunar volcanism. The latest results from the Chang’e-5 mission of 1.9 billion years old basalts from its landing site in northern Oceanus Procellarum are not *too* inconsistent with the theorised cut-off of volcanic activity at 2 billion years, leaving the RMD age conundrum intact[6].

A recently proposed alternative to the magmatic foam RMD hypothesis is that a population of buried craters, which exist on an older and now submerged mare surface contributed to dome formation by providing structures within which small amounts of lava could accumulate and cause the overlying surface to bulge upwards[7]. This research suggested that the moat could result as the dome material pushed down and compacted the brecciated rocks within the buried crater, but again this model relies on volcanic activity and is therefore inconsistent with the proposed thermal history of the Moon. Having never being entirely convinced of the volcanic hypothesis I would like to propose an alternative model for RMD formation, one that that does not compromise the existing models of lunar thermal history and also accounts for some of the anomalies mentioned above. This is the result of my own analysis and has no support in the academic literature, but is I think worth considering as it appears to answer some of the questions regarding RMD's that the volcanic hypothesis does not. Firstly it is necessary to have another look at RMD's and explore their morphology and distribution.

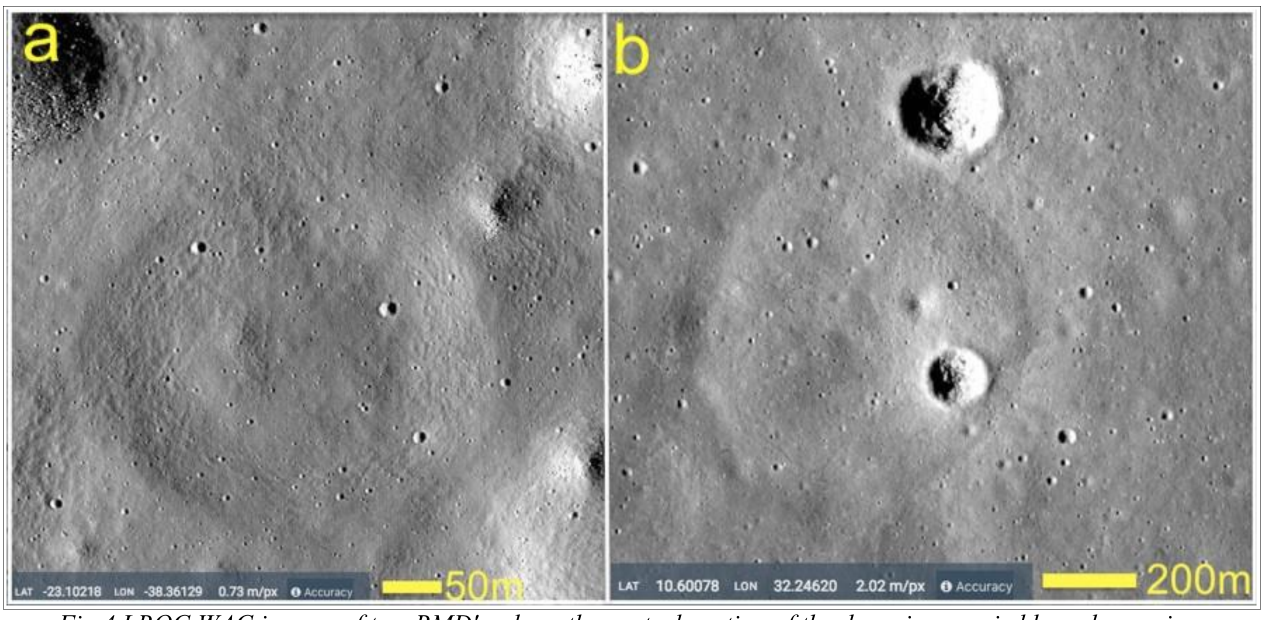

Fig.4 LROC WAC images of two RMD's where the central portion of the dome is occupied by a depression.

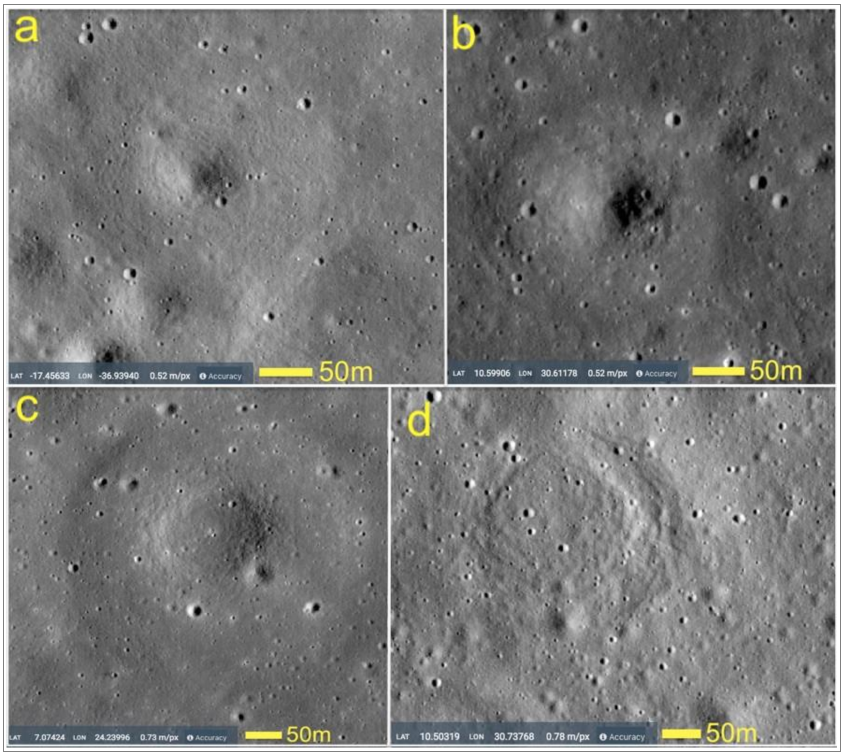

Fig.5 Various RMD's showing a progressive increase in size of the central depression. Note the moderately consistent size of the RMD's.

Numerous RMD's have a somewhat concave central area, giving the impression of a partially deflated mound, and suggestive of some form of collapse or deflation (Fig.4). This might be consistent with the magmatic foam model if the vesiculated lava of the dome compacted as the interstitial spaces collapsed under their own weight.

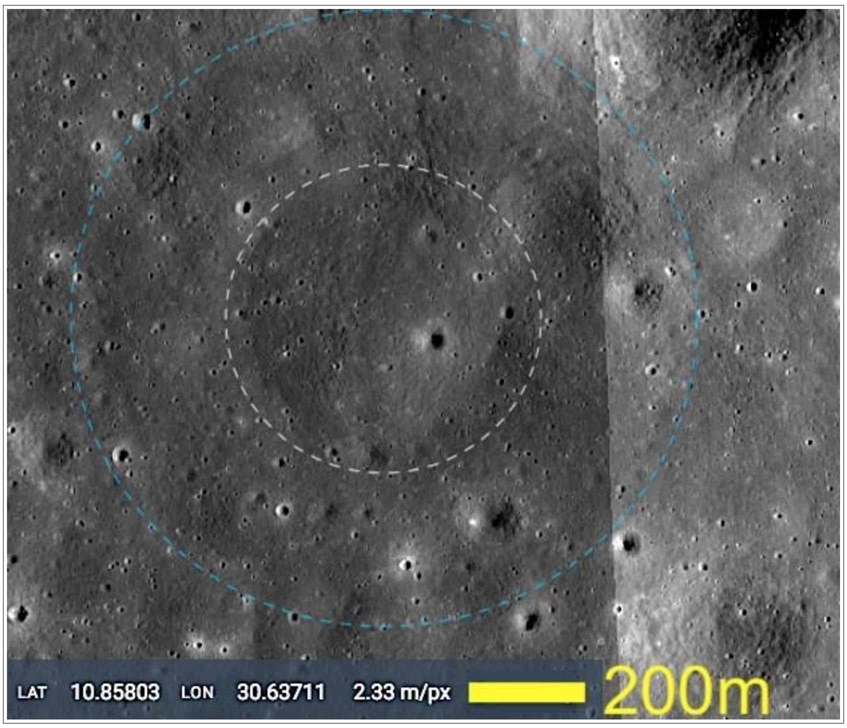

Fig.6 LROC WAC image of an RMD showing the main dome (white circle) and an outer annulus of less well defined domes beyond the moat (blue circle).

This trend continues with a number of RMD's which have distinct summit depressions that have been interpreted as vents of some form. These depressions can be found either centrally located or offset towards one side, but there is no evidence of anything erupting from them to support the volcanic vent interpretation. These depressions also range in size from relatively modest pits (Fig.5a & b) to cases where a substantial central part of the RMD is occupied by a large hollow (Fig.5c). The occasional example can be found where all that remains of the RMD is a peripheral ring surrounding an enlarged circular depression, giving the impression of a flaccid burst bubble (Fig.5d).

Many RMD's can be seen surrounded by a ring of less well developed dome like mounds, typically about 6 in number located just outside the moat (Fig.6). This concentric feature has been identified previously and termed a circumferential ridge [7] which implies a continuous structure, but the imagery suggests a discontinuous ring of individual units. This ring gives these RMD's something of a 'sunflower' like appearance with the main dome being the flower head and the ring the petals. It could be argued that where numerous domes occur together, that the *appearance* of a ring of neighbours might arise, similar to oranges arranged in a box. But many examples of this configuration can be found where RMD's are sparse, and not within a cluster of such as in Fig.2. Also the domes of the ring are invariably less well developed or distinct compared to the central RMD, an indication that this reflects a distinct morphology as opposed to a fortuitous grouping. This type of structure is unlike any volcanic feature I know of, and the number of examples visible amongst the population of RMD's suggests that it may somehow be related to how they form.

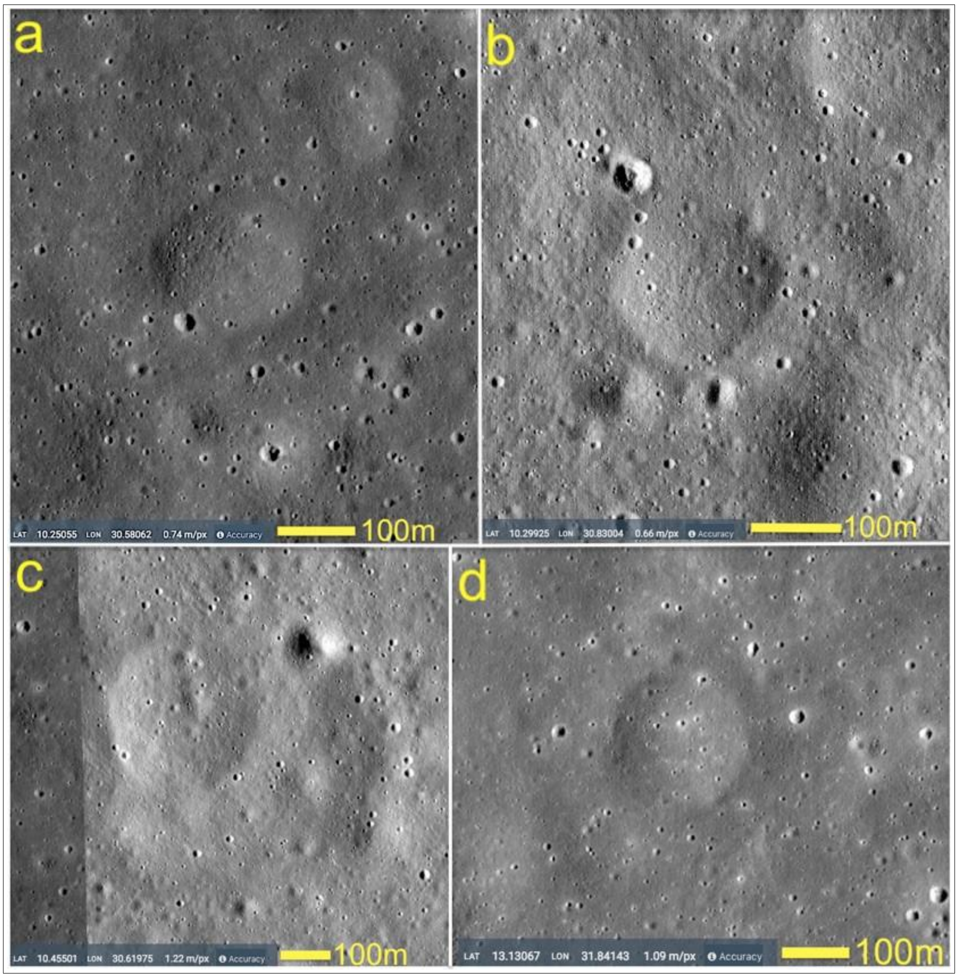

Fig.7 LROC NAC image of a number of RMD's showing the 'sunflower' configuration of a well developed central dome surrounded by an ring of usually 6 of less distinct companions.

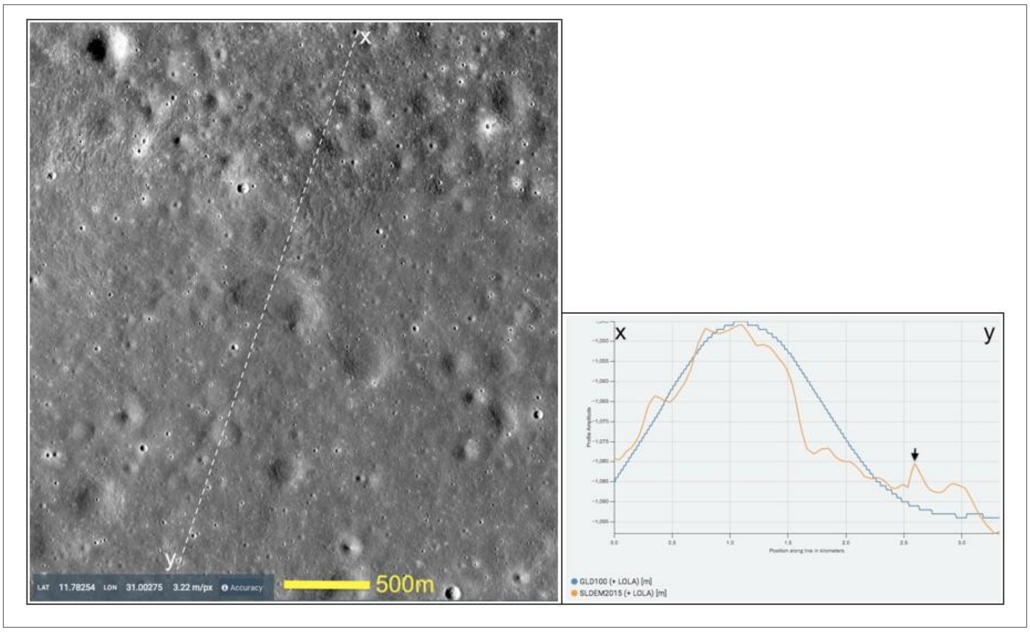

Fig.8 Left - LROC WAC image of a small volcanic dome which has a number of RMD's visible on its flanks. The topographic profile x-y passes through the summit vent and a prominent RMD on the southern flank. Right – topographic profile showing position of RMD.

One context in which RMD's are found which could be consistent with the volcanic origins is on volcanic cones and domes. Paradoxically this is not particularly strong evidence for a link between RMD's and volcanism as it is unlikely that the flanks of volcanic construct would host the thick lava flow required for the magmatic foam hypothesis. Fig.8 is one example showing a well developed (~10m high) RMD on the flanks of a small dome and is one of many RMD's on this particular feature. Another example is shown if Fig.9 which is a small volcanic cone 40kms west of the crater Carrel, with a particularly large (~500m diameter and 10m high) RMD on is southern flank. This cone also has a number of small patches on its surface which appear to be in the early stages of becoming Irregular Mare Patches or IMP's (Fig.10). These features are small and quite subtle, and can only be visualised in the LRO images taken under low incidence illumination. IMP's may represent sites of relatively recent outgassing according to one hypothetical model for their formation[9] but these examples are very subtle and I have previously described similar ones as immature Irregular Mare Patches[8]. These may represent the very early stages of the IMP forming process, where out-gassing started to remove the surface regolith, but ceased before a fully developed IMP could form. They clearly suggest some form of activity on this dome, but not one of an effusive volcanic nature. In both of these example the RMD's lie on a slope of less than 2°, on the flanks of the constructs and not on the surrounding mare surface. So whatever process forms RMD's the right conditions exists on the gentle slopes of these small volcanoes.

The greatest numbers of RMD's are found on the lava plains of the maria, but a number of RMD *like* structures can be found in non-volcanic contexts such as wrinkle ridges which are of tectonic and not volcanic origin. Fig.11 shows a grouping of RMD like features on the east facing side of Dorsa Barlow. There is a complex arrangement of lobate scarps here, and this cluster lies on something of a flat platform set in amongst the jumble of ridges. Now, I am not suggesting that these structures are directly analogous to the RMD's on the mare, as they are clearly less well defined, but their overall morphology (and in this case the clustering of 5 mounds around one central mound) is in many ways similar to what we have seen in mare RMD's.

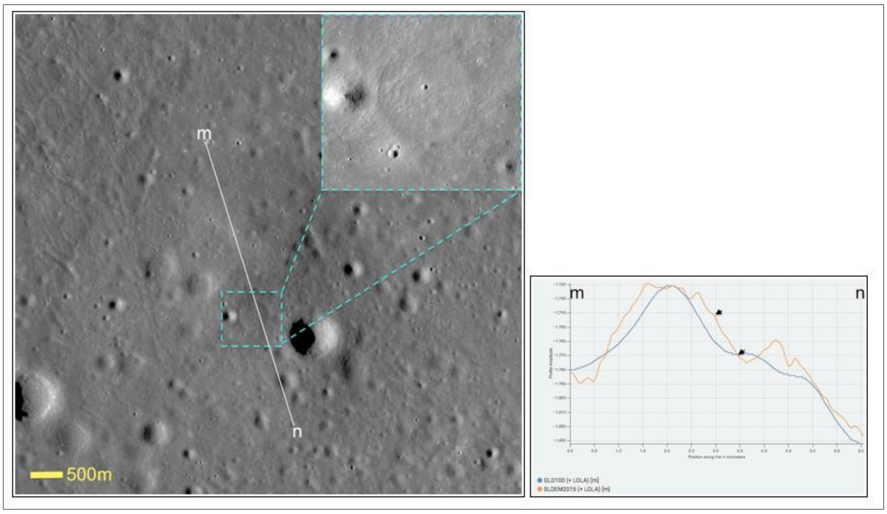

Fig.9 Left - SELENE image of a small volcanic cone 40kms west of the crater Carrel. A large RMD can be seen on the southern flank and in the LROC-WAC detail shown in the inset. Right – topographic profile along line m-n showing location of the RMD (between the 2 black arrows) on a slope of < 2°.

Further RMD like structures are shown in Fig.12 which is part of the prominent ridge system to the north of Maskelyne G, near the Apollo 11 landing site. In this case the RMD like features are arranged along the summit of the ridge, with some being quite distinct but many others less so. A final example shown in Fig.13 shows another prominent wrinkle ridge which forms part of the ridge system to the north east of the 'ghost structure' of Lamont. Here one or two quite distinct RMD like features can be seen, again on the summit of the ridge and elevated well above the mare surface, and therefore unlikely to have originated in the manner proposed in the magmatic foam model.

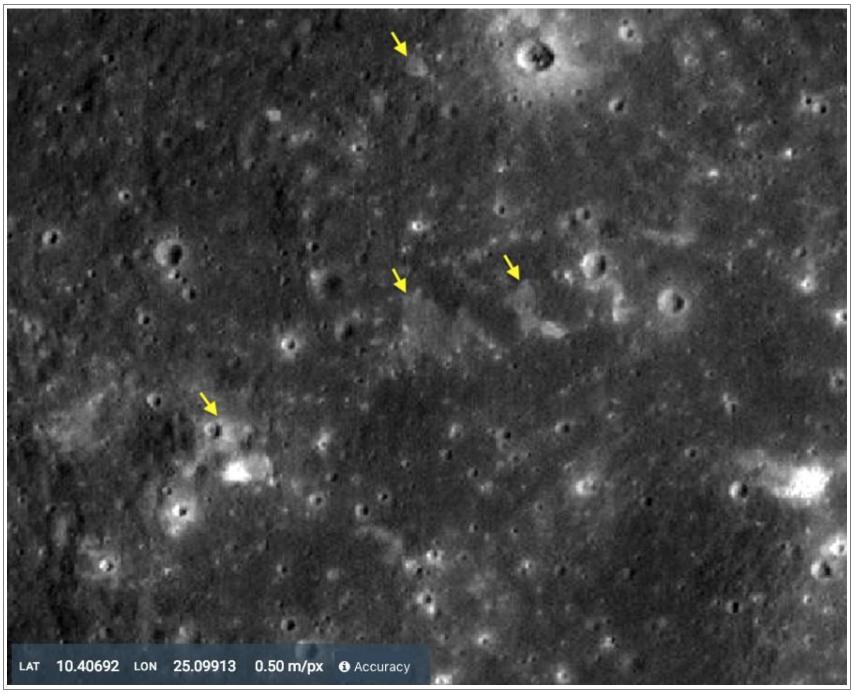

Fig.10 LROC -WAC image of the eastern flank of the small volcanic cone shown in Fig.8 showing small patches of IMP activity (yellow arrows) indicative of gas release.

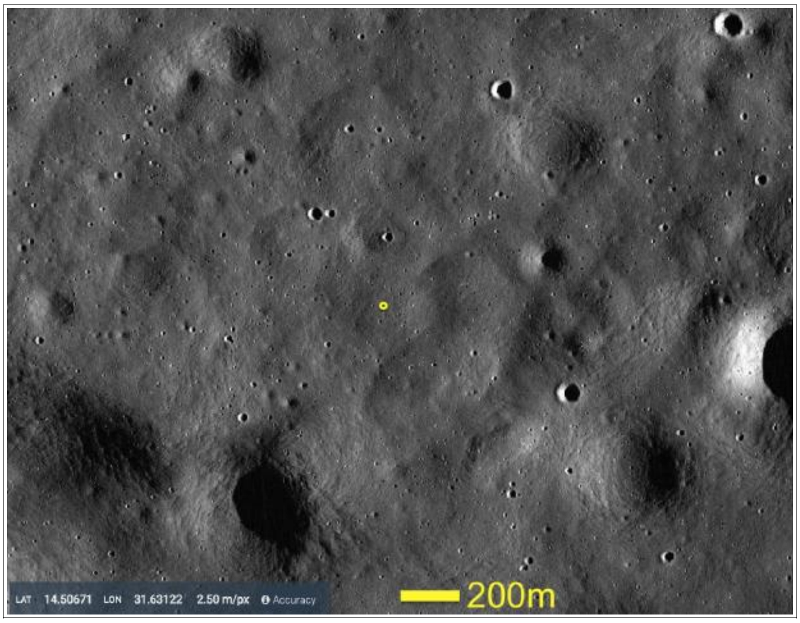

Fig.11 LROC WAC image a cluster of RMD like domes on a south facing slope associated with a wrinkle ridge. Note that in this cluster there is a grouping reminiscent of the sunflower configuration described above, with the dome with the yellow dot being the central one.

Wrinkle ridges and their smaller cousins the lobate scarps reflect compressional forces generated as the central parts of the maria subsided or as a consequence of global lunar shrinkage. They are thought to be produced by movement along low angle thrust faults as one section of crust over-rides another, and lobate scarps in particular have been implicated in the generation of many shallow moon quakes detected by seismic equipment left by the Apollo missions[10].

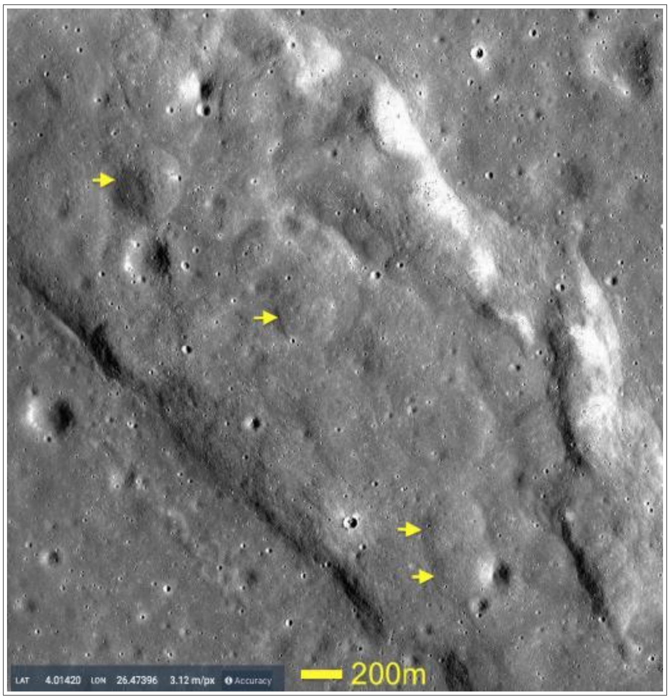

Fig.12 LROC WAC image a number of RMD like domes on the summit of a wrinkle ridge near to the Apollo 11 landing site. Yellow arrows show some of the more obvious examples, but many more less defined mounds are visible here and at other locations along this ridge.

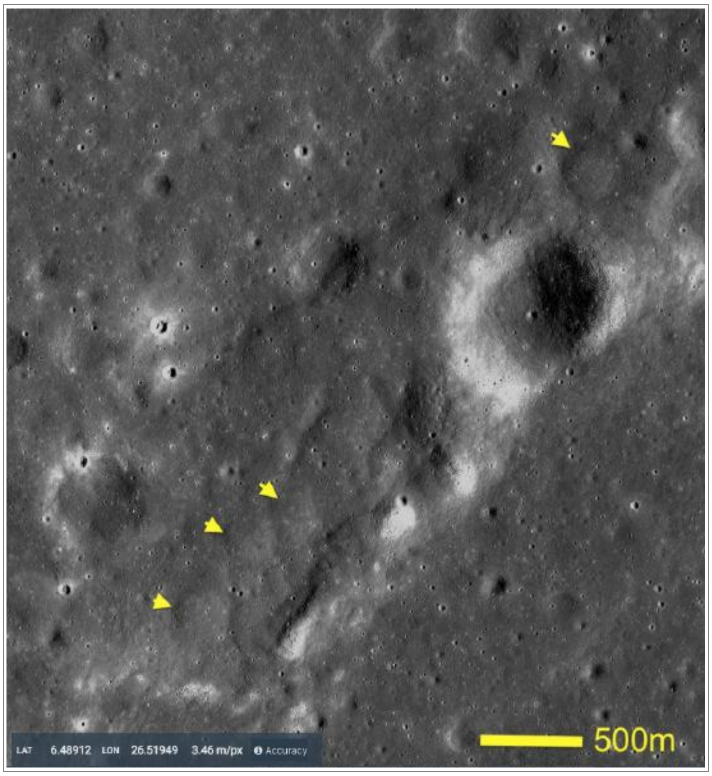

Fig.13 LROC WAC image a RMD like structures (yellow arrows) clustered on the summit of a wrinkle ridge which runs north east radially from the Lamont structure.

Seismic activity generated by these faults in the form of ground shaking is believed to be responsible for the youthful appearance and many rocky outcrops seen on some wrinkle ridges[11] and this type of surface disturbance may be responsible for the production of these RMD like structures, and by implication RMD's in general.

This type of activity has been suggested as being responsible for the production of mound like structures on Earth, so might not be an unreasonable suggestion. These mounds are known as 'Mima Mounds' which are low dome like mounds ranging up to 50m in diameter and 2m in height, found in profusion in certain parts of the North Western US[12]. They consist of unconsolidated sediments, and bear a superficial resemblance to RMD's but there the similarity ends especially as they are thought by some researchers to be the result of generations of gophers burrowing into the prairie soil with the upcast from their digging forming the mound.

This interpretation is however not wholly accepted, and one researcher stumbled on an alternative whilst engaged in a bit of DIY. The researcher, geologist Andrew Berg noticed that as he hammered away at a sheet of plywood, a thin layer of loess sediment that was lying on its surface, arranged itself into small mounds similar in appearance to Mima mounds[13]. In effect he had produced a plywood version of a Chladni Plate, which is more typically a metal plate, with a surface sprinkling of sand or salt, vibrated with a violin bow to produce varieties of geometric patterns that change as the vibrational frequency changes. The effect is named after the 18th Century physicist and musician Ernst Chladni (of meteorite fame) but apparently the polymath Robert Hooke had observed the effect previously in the 17th Century[14]. The patterns are produced as the plate (or plywood sheet) surface oscillates vertically in some areas, which are termed the anti-nodes, but remains static in others, which are termed the nodes. These nodes and anti-nodes form increasingly complex patterns as the frequency of oscillation increases. In the case of the plywood sheet, the thin particulate material moved away from the anti-nodal points and gathered at the nodes which in this case produced a network of sediment mounds. From this, Burg deduced that seismic shaking during earthquakes could have caused unconsolidated prairie sediments to be displaced from the anti-nodal points where the shaking was strongest, and towards the nodal points, where shaking was least and where it could accumulate to form the mounds.

A fair amount of research has been conducted on the various patterns that emerge in layers of granular material subject to vertical vibrations, and theory and experiment do indeed result in a diverse range of surface patterns ranging from circular spots at low frequencies through to pentagons, hexagons, stripes and even spirals as frequency increases[15][16]. Is it possible therefore that as in the Mima Mound experiment RMD's could form as the unconsolidated lunar regolith was subjected to vertical vibration during seismic events? Some simulations in which the frequency of vibration was increased result in nodes and anti-nodes appearing as concentric ridges[17], some reminiscent of the odd RMD's shown in Fig's 4 to 7.

The low lunar gravity combined with the vacuum of space might be factors which could influence the behaviour of regolith when subject to vertical oscillation, but there are many other factors that might be relevant to the seismic/RMD hypothesis. Chaldni Plates and plywood sheets are both rigid surfaces, and a rigid surface is necessary to sustain the vibrations and produce the node/anti-node pattern. The lunar surface, composed of unconsolidated regolith and brecciated rock and ejeca extending down several kilometres is hardly comparable to such a surface. The upper crust is not however not an unbroken rubble pile from the surface down to the base of the mega-regolith somewhere at around 20 kms[19] and many mare surfaces are probably underlain by a succession of massive lava flows that escaped total destruction by subsequent impacts and space weathering. This is shown in photographs of the walls of Hadley Rille which show several buried massive lava flows, up to 10m thick and extending down several tens of meters below the rim[20]. These might form surfaces from which seismic waves could be directed up towards the surface and into the more highly brecciated surficial regolith.

Another factor unique to the lunar environment is the relative duration of seismic disturbances in comparison to the Earth. Many will recall the expression '*ringing like a bell*' from the later Apollo missions, when the SIVB upper stage of the Saturn V was deliberately crashed on to the surface to generate artificial 'moonquakes'. This reflects the fact that seismic disturbances persist for a far longer within the body of the moon than on the Earth, and despite their lower intensity (with a maximum of < 3 on the Richter scale) can reverberate for prolonged periods. This would result in seismic vibrations potentially affecting the surface over a much longer duration during an event compared to one on Earth, allowing more time for the surface deposits to respond to the disturbance. Moonquakes have their foci at limited number of locations, with many of the sporadic shallow quakes associated with lobate scarps and the more regular tidally induced deeper quakes originating from a small number of 'nested' sites[21]. As a consequence the same areas of the surface may experience repeated disturbance, leading to a concentration of seismically generated surface features in a small number of locations. This could account for the fact that these surface features are not ubiquitous across the lunar surface.

If RMD'S are a result of seismic activity a number of apparent issues with the volcanic hypothesis could be answered such as:

1. *RMD's are spectroscopically identical to the surrounding mare*, this would be a natural consequence of a seismic origin as the domes would be composed of local mare regolith and be of identical composition to it.
2. *The anomalously youthful ages of RMD's,* this would reflect the fact that seismic activity appears to have continued up until the present day and so the formation of RMD's could have occurred very recently in lunar geological terms. This would explain why some RMD's appear to encroach into craters of apparent Copernican age and have a low density of surface craters.

3. *The association of RMD's with volcanic domes and cones,* this might be a consequence of seismic activity generated as the structure re-adjusted following the cessation of effusive activity. A number of lunar volcanic features do show evidence of subsidence and collapse, with their surfaces being modified long after they became dormant or inactive. This might also provide the conditions necessary for the gas release and IMP formation.
4. *The occurrence of RMD's associated with wrinkle ridges,* this would be explicable as these features are tectonic in origin and would have been the focus of seismic shaking during lunar history, independent of any volcanic activity.
5. *The morphology of RMD's* - ranging from the apparent central depressions to the cluster of less defined domes observed in the 'sunflower' configurations. This could be a consequence of the frequency (wavelength) of the seismic disturbance. More complicated nodal pattern emerge as frequency increases and this can result in concentric rings of nodes which could account for the somewhat concentric patterns noted above.

But could seismic shaking of the lunar surface cause the regolith to arrange itself into the domes we see in Fig.2, which appear to be relatively substantial, albeit small features? Such a process might be easier to accept if we look at the actual scale of these RMD's as opposed to their appearance in the LRO images. Fig.13 shows an image of a fairly typical RMD and a chocolate button, with which some of us, I am sure are all too familiar. The heigh to diameter ratio for the dome is 1:32, the same ratio for the chocolate button is approximately 1:6, so to effectively model the RMD using a chocolate button we would have to reduce the height of the chocolate at the centre of the button to a rather unimpressive 1mm. This rather frivolous comparison serves to illustrate the fact that RMD's are in reality of *extremely* limited relief, and that a seismic model does no require the unconsolidated regolith to be piled up into a substantial mound, merely to a *slightly* enhanced depth.

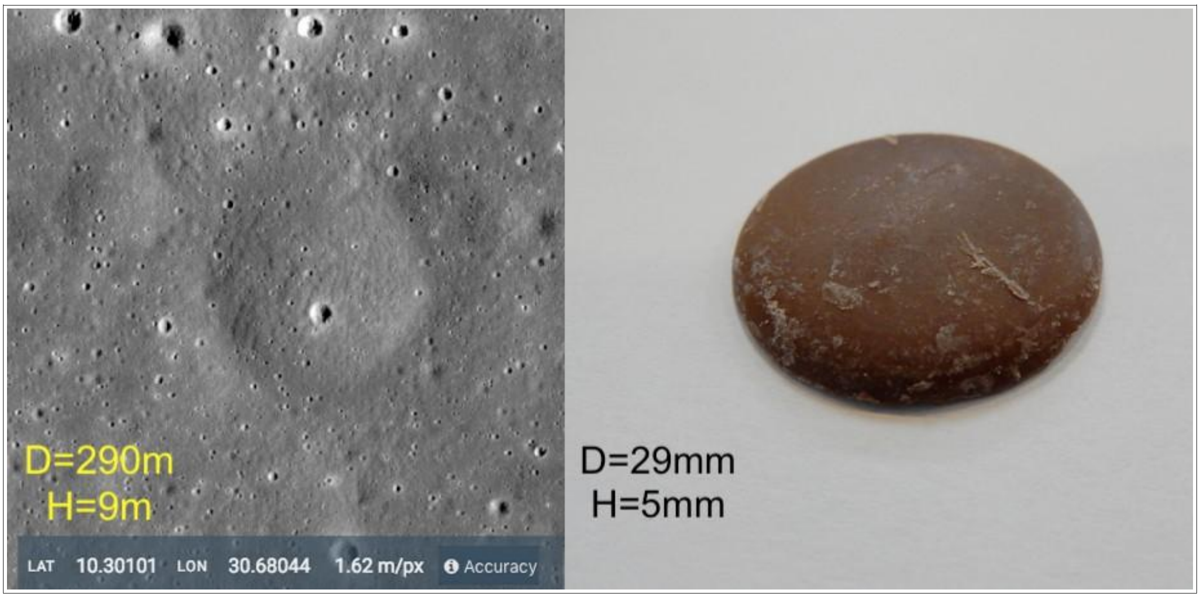

Fig.13 Left, and average RMD with a diameter of 290m and height of 9m. Right, a chocolate button of diameter 29mm and height of 5mm.To model the RMD using the chocolate button, would require its height to be reduced to a little under 1mm.

A couple of further observations may have a bearing on the RMD/Seismic hypothesis suggested here. Fig.14 is an image of a section of the surface of Mare Humorum to the south of Gassendi. RMD's are present on the mare surface here, and the bizarre topography visible in this image may also be the evidence of some form of seismically induced disturbance. As can be seen the surface is covered in a profusion of small mounds in the region of 20 to 25m in diameter, which appear in places to be partially merged into short chains. The mounds bring to mind the DIY experiment on

Mima Mounds and other experimental work which demonstrates a tendency of granular material to organise itself into mounds when subjected to vertical vibration. This might indicate that the topography we see in Fig.14 is another example of seismically disturbed regolith, where the unconsolidated surface has been mobilised by vibrations and has arrange itself according to the node/anti-node configuration.

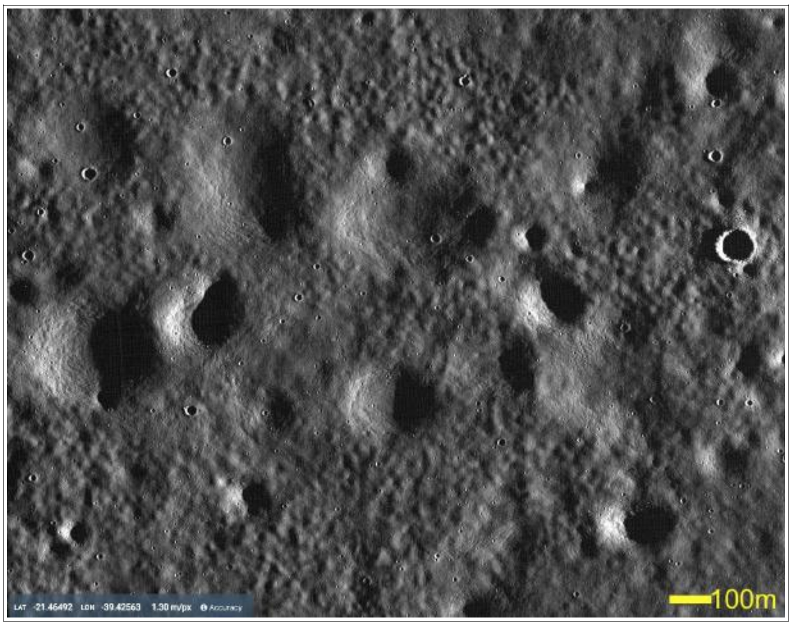

Fig.14 LROC WAC image of a section of Mare Humorum showing an unusual topography of clustered mounds.

Similar topography can be seen in association with nearby RMD's (Fig.15) whilst a comparable example of this surface morphology is also present in Mare Tranquilitatis (example at Lat:12.59424 Long: 32.82818). This unusual topography is not widespread but confined to localised areas, and so appears not to be a 'normal' mare surface configuration and its presence in areas that also host RMD's is suggestive, if nothing else.

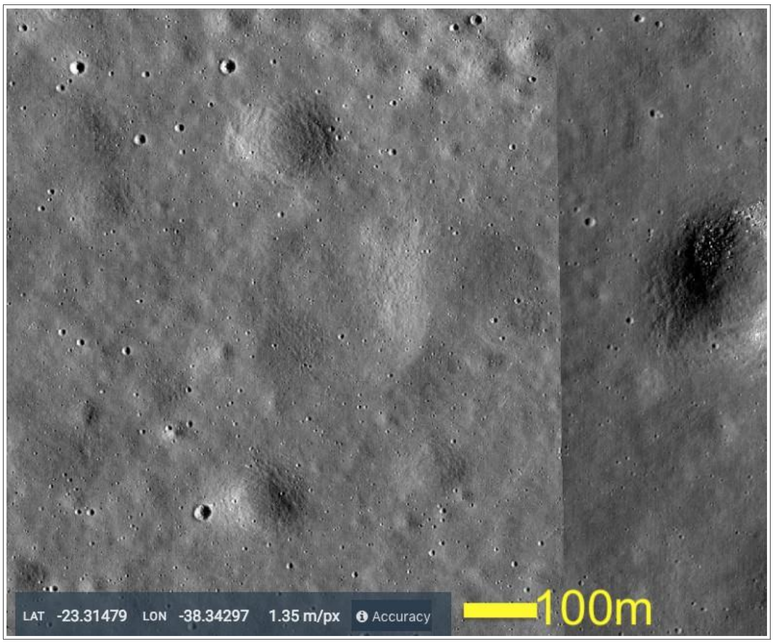

Fig.15 LROC WAC image of a section of Mare Humorum which shows and association between an RMD and the clustered mound type topography seen in Fig.14.

Fig.16 shows two examples where RMD's have a hexagonal outline with straight edges implying some form of control over the dome shape. One possible explanation could be that this reflects some form of sub-surface structure, possibly faulting or fractures, but it is difficult to see how this could acquire such a regular geometry.

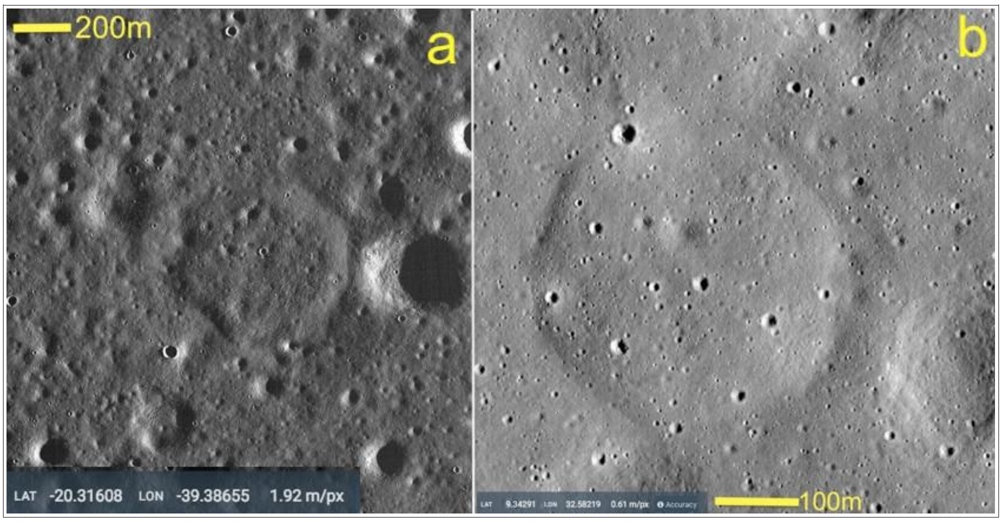

Fig.16 LROC WAC image of two RMD's that show clear hexagonal profiles with the moat comprised of 6 straight sections.

Hexagonal fractures are found in basalts columns such as the Giant's Causeway or Fingal's Cave, but the fracturing there is an order of magnitude smaller than whet we see here. Of course we have seen a somewhat polygonal arrangement earlier in the RMD's with a sunflower pattern of surrounding mounds, so some process with a tendency towards this pattern generation seems to be a possible cause. Experimental work on vibrated granular material under effectively vacuum conditions[14] produced patterns that are comparable not only to those in Fig's 14 and 15, but also produced hexagonal structures, potentially pointing towards seismic shaking as a possible explanation. Clearly there is a major problem in scaling up lab based results structures over 100m in diameter, but they are, once again suggestive!

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Many thanks to Tony Cook for useful comments and suggestions!

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Selene images courtesy of Japan Aerospace Exploration Agency (JAXA) at:
http://l2db.selene.darts.isas.jaxa.jp

Note: Illustrations contain Lat/Long co-ordinates where possible so that you can find these features up yourself at the LRO Quickmap site https://quickmap.lroc

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Lunar Geological Change Detection Programme
by Tony Cook.

TLP reports: No TLP reports were received for September, but one report came in for October and another for June.

I am grateful to Paul Zeller (ALPO) for forwarding the following report onto me of an image (See Fig 1) taken by Don Estep who had been imaging the Moon from LaPorte County, Indiana, USA.

Figure 1. *A flare effect captured on the east side of the Moon by Don Estep on 2021 Oct 08 UT 23:44 with a 600mm f/6.3 telephoto lens camera from Kingsbury Fish and Wildlife Area (approximately Lon = -86.58732°, Lat = +41.51642°) in LaPorte County, Indiana, USA. ISO setting 100 and exposure 1/30th sec. The Moon's image is orientated with north towards the top right.*

At first thought it looked to me, and Paul Zeller, that it was probably a camera read-out error as it looked horizontal. However, after checking the alignment, it was not quite horizontal, and unlike camera read out errors, which usually have sharp edges, and are often one pixel wide, this effect was 4 pixels wide and 62 pixels long. It was also brighter a little off the limb of the Moon than on it, or immediately adjacent to the Moon. The Moon's dimeter was 920 pixels or about 0.5°, making the dark streak effect about 0.03° long. If it was some eruption from the lunar surface then it would most likely be radial to the limb of the Moon, hemispherical and certainly would not have a dark straight line on the day side of the Moon as lunar curvature would make any shadow bend. Therefore, it had to be on this side of the Earth's atmosphere, or slightly above our atmosphere. So that left: planes, drones, lenticular clouds, a space station, or a spent rocket stage as the cause.

I asked Don if he had taken some before and after images, and as you can see from versions of these, I have stretched in Fig 2, the object has a clear trajectory across the Moon. The real clinching image that tells us what this object was is Fig 2 (centre) as we can see a red strobe light, typical of aircraft, and in Fig 2 (Right) you can just about make out the tail section. Strong forward scattering of light, from the Moon behind, shows up as a light streak on Fig 2 (Left and centre). Most commercial airliners have a top speed of 257m/s, so the motion blur we could expect, if the plane were flying perpendicular to the camera, in the 1/30th sec exposure, would be 8.7m. So, for a typical 50m long plane about that corresponds to ~17% of its length. This is consistent with the motion blur seen in the images in Fig 2.

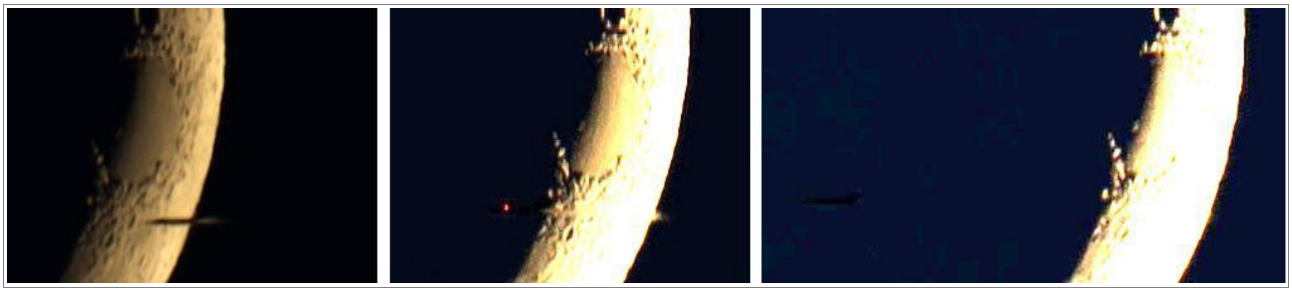

Figure 2. *A sequence of images captured on the east side of the Moon by Don Estep on 2021 Oct 08 UT 23:44 with a 600mm f/6.3 telephoto lens. Images have been contrast stretched to show up faint detail.*

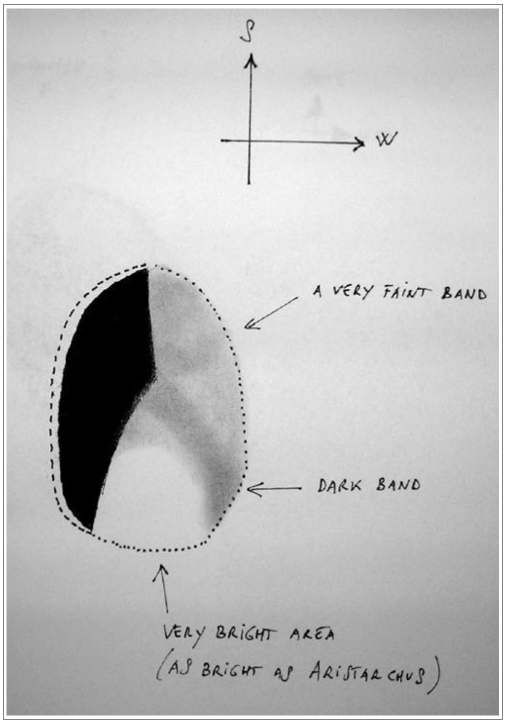

Figure 3. *Cavendish E as sketched by Massimo Giuntoli (BAA) on 2021 Jun 22 UT 20:44 and orientated as indicated by the arrows. Selenographic Colongitude = 64.0°.*

Massimo Giuntoli (BAA) has sent in an interesting sketch (Fig 3) of Cavendish E on which he noted that the northern inner slope was as bright as Aristarchus. Massimo was very puzzled by the very bright area on the north inner part of the crater. I guess this was because being in the southern hemisphere (25°S) it was sloping away from the Sun, unlike the southern rim which one would have thought would have been the brighter? Anyway, he does not think it's a TLP. He re-observed on 2021 Oct 18 UT 20:40 (64.70° Selenographic Colongitude) and Oct 19 UT 20:45 (76.9° Selenographic Colongitude) and found the northern floor still brilliant but not as it was in the June observation. I have looked through the ALPO/BAA observation archives, but cannot find any suitable images of the crater, under similar illumination, for any of the three dates above. I will put this into the Lunar Schedule web site so that we can accumulate more observations and see if the effect repeats for the 2021 Jun 22 sketch.

BAA Reports received for September included: Alberto Anunziato (Argentina - SLA) observed: Aristarchus, Fracastorius, Grimaldi, the south pole area and Theophilus. Maurice Collins (New Zealand – ALPO/BAA/RASNZ) imaged: Aristarchus, earthshine, Fracastorius, Langrenus, Moretus, Petavius, Tycho and the whole lunar Moon. Anthony Cook (Torrevieja, Spain – ALPO/BAA): imaged several parts of the Moon. Walter Elias (Argentina – AEA) imaged: Atlas and Mare Crisium. Valerio Fontani (Italy – UAI) imaged Gassendi. Rik Hill (Tucson, AZ, USA – ALPO/BAA) imaged Albategnius and Playfair. Trevor Smith (Codnor, UK - BAA) observed Aristarchus, Mare Crisium, Plato, and several other features. Aldo Tonon (UAI – Italy) imaged Eudoxus. Fabio Verza (Italy – UAI) imaged: Eudoxus. Ivan Walton (Cranbrook, UK - BAA) imaged Geminus and Torricelli B.

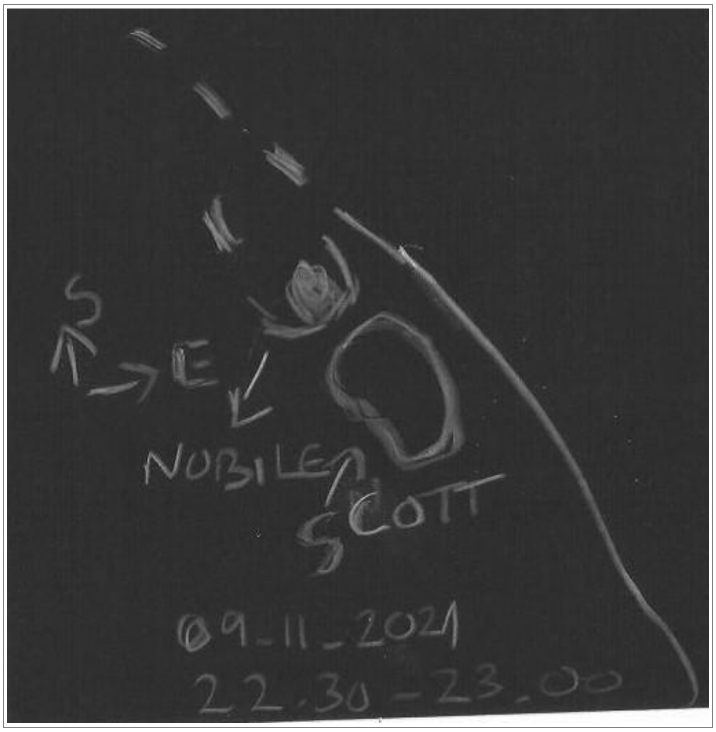

Figure 4. *A mirror reversed view of the region in the approximate vicinity of the lunar south pole. Cardinal coordinates are in the direction indicated in the sketch as is the date and UT. Sketch made by Albert Anunziato (SLA).*

The South Pole area was observed by Alberto Anunziato on 2021 Sep 11 UT 22:35-23:00 at similar illumination to the following two reports

`South Cusp 1969 Jul 19 UT 17:55-19:10 Observed by Dzapiashvili (Georgia, Soviet Union) "Saw an abnormally bright spot at end of`

S.cusp. Polariz. meas. at 8.3% at 1845-1847h (Apollo 11 watch?)" NASA catalog weight=5. NASA catalog ID #1164.

South Pole 2011 Apr 08 UT 19:30-20:00 A. Kemp (Mold, Flintshire, UK) observed that the Leibnitz peaks at the southern pole stood out sharply. However, one of the peaks was "shining like a spot light. So bright that I couldn't make out its shape". - image clear and steady with excellent transparency and seeing in the 70mm f/13 refractor (25mm and 10mm eyepieces). Inspections during the above time period revealed no changes in brightness. Previous observations of this area had never shown such an unusual brightness, and Arthur likened the brightness to "a maximum brightness of Venus shining amongst 2nd magnitude stars". The observer was an experienced observer. ALPO/BAA weight=2.

Alberto comments that there was a very bright spot almost at the southern end which could have been Nobile crater perhaps? There were also four other bright points (See Fig 4).

Mare Crisium was imaged by Walter Elias (AEA) on 2021 Sep 12 under similar illumination to a curious TLP report from the early nineteenth century:

Mare Crisium 1826 Apr 13 UT 20:00 Observed by Emmett (England?) "Black moving haze or cloud" NASA catalog weight=2. NASA catalog ID = 109. ALPO/BAA weight=1.

Figure 5. *Mare Crisium as imaged by alter Elias (AEA) on 2021 Sep 12 UT 22:57 and orientated with north towards the top.*

As we can see from Fig 5 there is nothing resembling a dark cloud on the floor of Mare Crisium unless one looks at the slightly darker areas between the gaps in Tycho's rays, but these certainly wouldn't have moved. Examining the contents of Cameron's card index system, which went into the catalog, Emmett sees a dark cloud on two nights, 1828 Apr 12 and 13th. The report from the 12th is of a "Black moving haze or cloud". The report on the 13th is of a less intense cloud. Cameron estimates the UT of each observation as 20:00 which is her default for when actual time is not reported by the observer concerned. This was published in the RAS Astronomical Register in 1882 and also mentioned by Webb (1962 edition) p105. She also has a "?" next to Emmett's name. The Apr 12 report is referenced to Emmett, R.B. in 1826, Ann. Phil. 12, 81. So if anybody has access to any of these publications, please let me know what you find? Myself and Cameron's cards suspect terrestrial atmospheric phenomenon. We have checked out repeat illumination of the Apr 12 and 13 events before in the 2016 Mar newsletter. On the plus side, at least, we have a reference image of what Mare Crisium would have looked like on the night concerned, assuming the estimated 20:00 UT was correct.

Gassendi was captured in a whole Moon image mosaic by Maurice Collins (ALPO/BAA/RASNZ) under similar illumination and topocentric libration on 2021 Sep 18 UT 10:37-10:44.to the following TLP report:

Gassendi 1973 Jun 12 UT 20:50-21:15 observed by Baumeister(48.83N, 9.25E, 240mm reflector, T=2, S=3) "Bright point at the NNE slope of the central peak" - Hilbrecht and Kuveler, Earth, Moon & Planets, 30 (1984), p53-61. ALPO/BAA weight=1.

Figure 6. *Gassendi as imaged by Maurice Collins on and orientated with north towards the top.*

As you can see from Maurice's image (Fig 6) the NE most once of the central peaks has a sunward sloping side that is bright compared to the other peaks. I think probably agrees with the Beumeister description from 1973, so we can set the weight to 0 and remove the observation from the ALPO/BAA catalog of TLP.

Mare Crisium: On 2021 Sep 21 UT 23:15-23:35 Trevor Smith (BAA), using a 16" Newtonian, under Antoniadi IV seeing, observed this flooded impact basin under similar illumination to the following report:

Mare Crisium 1948 Jul 21/22 UT 22:00?-01:00? Observed by Moore (England, 12" reflector) "Almost featureless except for Peirce & Picard" NASA catalog weight=3. NASA catalog ID #506. ALPO/BAA weight=2.

He found Mare Crisium to be full of detail. Other craters e.g., Swift, Yerkes, Greaves and Lick could all be easily seen. Lots of white streaks across the floor of the mare were also visible. His final comment was that the whole of the mare looked normal. We shall leave the weight as it is.

Gassendi: On 2021 Oct 22 UT 20:47-21:07 Valerio Fontani (UAI) imaged the crater under similar illumination to the following report:

2004 Aug 31 UT 22:30-22:35 C. Brook (Plymouth, UK) looked at Gassendi and noted a slight chestnut brown colouration in the dark area on the crater floor to the north of the central mountain leading to Gassendi A. It lasted for about two minutes during 22-30 hrs UT to about 22-35 hrs UT (observer unable be more precise). Used 60mm OG x120. Seeing quite steady trans good. Checked Gassendi again at 23hrs UT to 23-05. No sign of colour. Also, area mentioned earlier seemed lighter now. No colour on Aristarchus. Plato floor dark - no sign of craterlets. Seeing good with just slight tremor. Trans good 60mm OG x120 used. The ALPO/BAA weight=2.

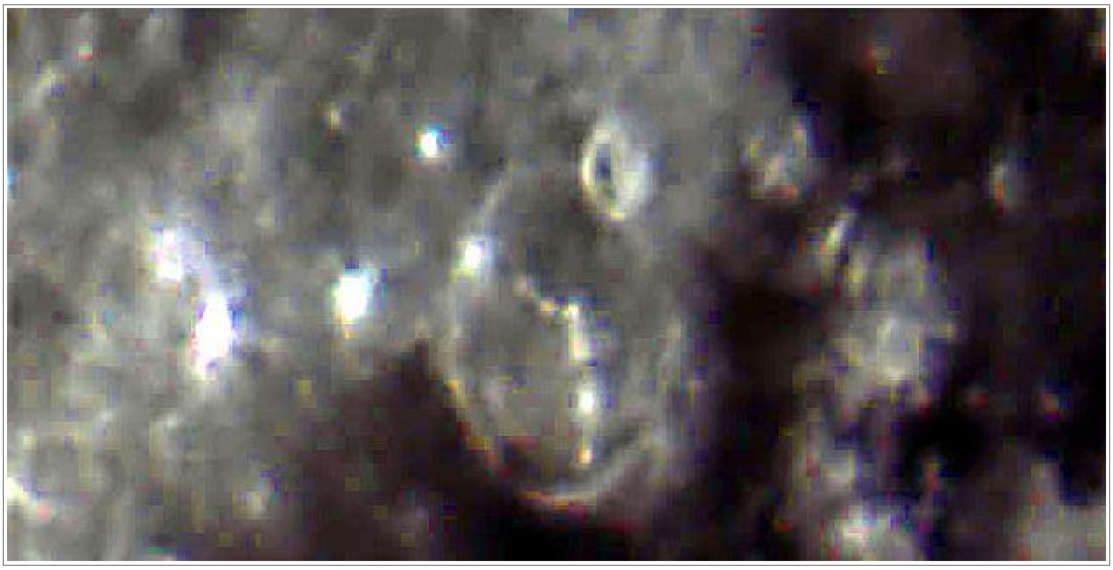

Figure 7. *Gassendi as imaged by Valerio Fontani (UAI) on 2021 Sep 22 UT 21:01 after colour normalisation and colour saturation increased to 70%. Image orientated with north towards the top.*

Valerio's image (Fig 7) was taken under almost Full Moon conditions, and so lacks normal shadows, texture and contrast. Ray and high albedo material dominate the scene. There is perhaps a slight brownish colour on the northern floor, however I can also see brown on the mare. So, it's very difficult to confirm Clive Brook's observation. Examining Valerio's four submitted images I certainly cannot see any variation in the lightness on the northern floor. We shall therefore leave the weight as it is i.e., 2.

Theophilus: On 2021 Oct 24 UT 22:49, whilst imaging other features, Ivan Walton (BAA) capture Theophilus in monochrome under similar illumination to the following report:

On 1981 Oct 26 UT 20:44-21:14 M. Mobberley (Bury St Edmunds, UK, 14" Cassegrain, seeing III) noticed an ~100deg wide fan on the floor of Theophilus, radiating on the central peak up to the surrounding base of the wall next to Cyrillus crater. This fan had a hint of yellow/red. The observer did not consider this to be abnormal - there was certainly no loss of focus here as far as the observer was concerned, and no mention is made of this effect in later observations that night. Plenty of spurious colour was reported. The ALPO/BAA weight=1.

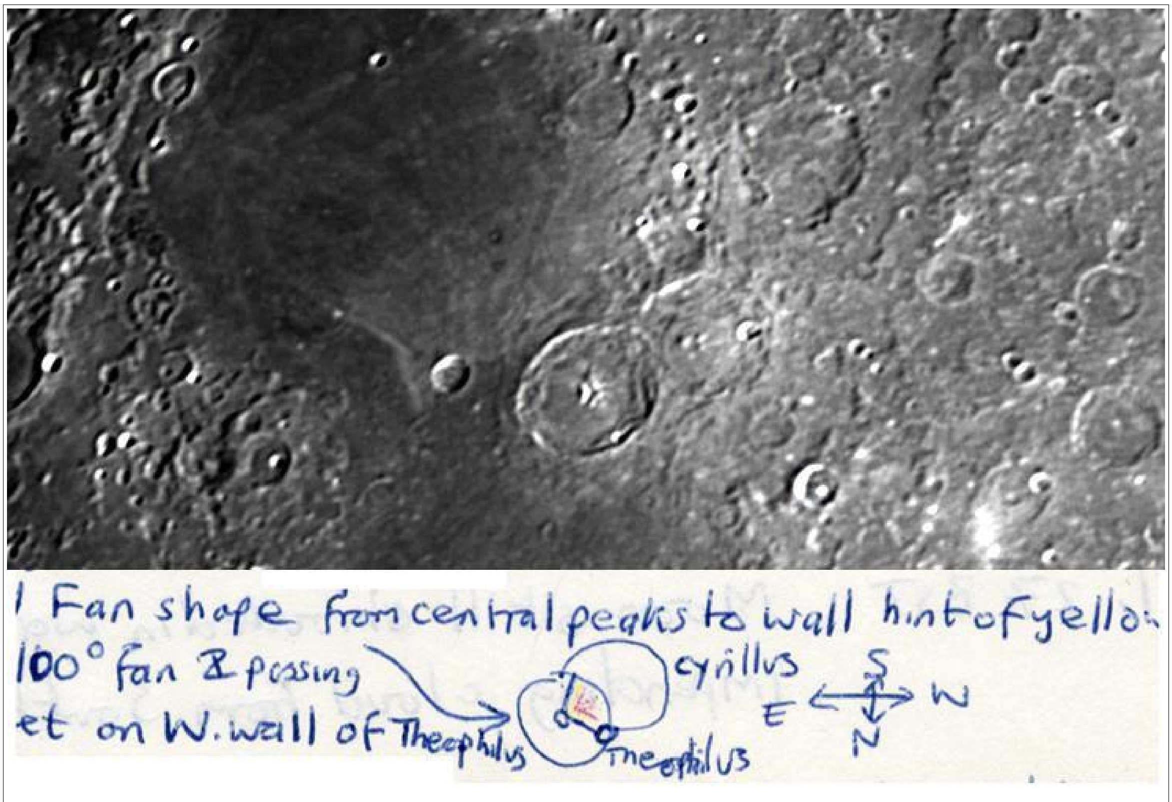

Figure 8. *Theophilus crater* ***(Top)*** *2021 Sep 24 UT 22:29 as imaged by Ivan Walton (BAA) and orientated with north towards the top.* ***(Bottom)*** *A sketch by Martin Mobberley made on 1981 Oct 16 UT 20:44.*

Although Ivan's image was in monochrome it can be used to check out Martin's description of a 100° fan-like formation on the craters floor, from the central peak towards Cyrillus. I can certainly see some terraces in the wall but am not sure I can say for sure I can see a fan. Martin noted that there was atmospheric spectral dispersion present on the Moon, "Blue, yellow red" from E to W on craters. It maybe this explained the yellow colour seen in the SE quadrant. He also saw no loss of focus inside the fan area. It is probably worth leaving this TLP at a weight of 1 for now even though Martin did not regard what he saw as abnormal at the time.

General Information: For repeat illumination (and a few repeat libration) observations for the coming month - these can be found on the following web site: http://users.aber.ac.uk/atc/lunar_schedule.htm . By re-observing and submitting your observations, only this way can we fully resolve past observational puzzles. To keep yourself busy on cloudy nights, why not try "Spot the Difference" between spacecraft imagery taken on different dates? If you would like your observations to be considered for mention in the next newsletter, then they should be submitted by 17:00UT on the 24th of July, covering observations for June. Please send observations in, even if older than this as they are still very useful for future repeat illumination studies. This can be found on: http://users.aber.ac.uk/atc/tlp/spot_the_difference.htm . If in the unlikely event you do ever see a TLP, firstly read the TLP checklist on http://users.aber.ac.uk/atc/alpo/ltp.htm , and if this does not explain what you are seeing, please give me a call on my cell phone: +44 (0)798 505 5681 and I will alert other observers. Note when telephoning from outside the UK you must not use the (0). When phoning from within the UK please do not use the +44! Twitter TLP alerts can be accessed on https://twitter.com/lunarnaut .

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