The color of the Moon in visible light through a review of published photographs. A paradox?

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Abstract: - Photographs are information sources and, as such, are used to provide evidence for many historical events. Such events were the lunar landing missions of the USA Apollo program in the end of 1960s and early 1970s. Many reels of film and video recordings have been made public to attest to the case, where in all the evidence provided, the moon surface is nearly devoid of strong colors and gray predominates. The present article addresses this issue by presenting images of the Apollo missions and assessing them through scientific knowledge that was available before or accumulated after the missions. Before the Apollo landings, observations from the Earth showed a red-brown color, agreeing with photographic evidence from orbits performed just before or just after the first Moon landing mission. New Moon missions provide contradicting evidence, as many photographs – in visible color – show a rather brown to red surface, not matching the Apollo observations. Particularly, three recent Chinese landing missions (2013-2020) show a consistent strong red brown color for the surface of the Moon, while missions from Japan and India show the gray surface of the Apollo missions. With the advancement of digital photography and relevant software, it is today easy to photograph the lunar color in visible light using relatively cheap equipment. Unfortunately, the result of using digital photography does not give a clear answer It is hence up to the space agencies that own the original photographic data to clarify the matter.

Key-Words: - Lunar surface color, Moon, Lunar soil, Apollo missions' photography, Visible color

1 Introduction

It is well understood that photographs are sources of information, which may influence the public opinion. As such, photographs have been used as legal evidence in trials in the USA, since the early days of the invention of photography around the time of the Civil War [1]. Nowadays, the quality of information conveyed by photographs cannot always be accepted as evidence, because there are photographic and electronic means by which the information can be changed.

Photographs can also serve as historical evidence, with notable examples being the depiction of significant events for a country, such as the activities in wartime, the Olympic games and so on. They can also help one keep a record of important events in their lives, such as tracking the children's growing up and keeping memories alive about all sorts of things of the past.

Photography, as it is generally known, records electromagnetic radiation coming from the objects being imaged at a certain frequency range (visible light). However, there are though film and electronic camera sensors that can record in many other bands of the electromagnetic spectrum such as gamma rays, X-rays, ultraviolet radiation, infrared radiation, radar and radio waves [2] and which are used in many disciplines such as astronomy, medicine, geology, engineering, and so on.

Historically, a major leap in photography was made with the Kodachrome film, introduced to amateurs in 1935, and used by professionals in 1938 [3]. By the 1960s, color photography was cheap enough to be widely used around the world. The amount of information present in color images is much larger than that in black and white. In addition to the aesthetic aspect of a better image, color photography allows one to recognize shapes and objects much more easily. Fig. 1 shows two cases of color photos that can be compared to their black and white counterparts of the same content.

Regarding the color reproduction quality of photographs, studies (for example, [4], [5], [6]) have shown that the main perceptual attribute depends on both the average chroma and its variability. The perceptual quality of the images was found to be closely related to the naturalness of the images. Naturalness means that an image is as close as possible to the observer's ideas and expectations for

the original scene at the time of capture. It follows that, for natural images, the impression of naturalness reflects the degree of correspondence with the memorized reality and should not necessarily be equal to the optimal physical reproduction of an image.

Fig. 1. Comparison of color photos (left column) to black and white (right column). Much more information can be gathered from the color images. Observing only the black and white photos, one can come to completely wrong conclusions especially about the existence of life.

Moreover, to give the required colorfulness, a camera must produce a pleasant balance of brightness, hue, and color saturation. This balance depends entirely on the film and development chemistry [7] or on camera's light- sensitive sensor [8].

The present article examines how accurately photographs were used to historically depict the Lunar landing missions of the NASA Apollo program. The Apollo Project achieved the objective of sending humans to the Moon and back, in July 1969 with the Apollo 11 mission and expanded to five more successful lunar landing missions by 1972 [9].

2 Method

The present study examines the lunar surface color of the USA Apollo program and compares it to the color of the surface shown in other sources. The evidence and data come directly from the official NASA suppositories and online libraries, published books and official websites of other countries and organizations, as referred in detail for each case. In general, official suppositories and online libraries from the Apollo era, are maintained in (a) the Apollo Image Atlas (70mm Hasselblad Image Catalog), Universities Space Research Association (URSA), Lunar and Planetary Institute (LPI) [10] and (b) the Apollo Lunar Surface Journal, copyright 1995-2018 by Eric M. Jones [11].

Newer scans of the Apollo missions are kept online at (a) Flickr.com Project Apollo Archive Apollo Image Gallery [12] and (b) March to the Moon [13].

A visual analysis of images and commenting are performed in parallel to the presentation of relevant data. The current study also presents actual verbal descriptions of the surface color of the Moon by the astronauts that walked on it, paintings and comments by the astronaut/artist Alan Bean and Photos of the Moon received by NASA after the Apollo era. A comparison is made with photos received by other countries and institutions like the Soviet Union's space program, the Japanese Aerospace Exploration Agency, The Indian Space Research Organization, the Israeli SpaceIL and the China National Space Administration. Based on the above information our analysis and conclusions are drawn.

3 On the Moon color

At night we observe the Moon and see a bright silvery-white celestial body traveling in the sky. When seen during the day the color of the Moon is also white although it is not as bright because of the high illumination of the day sky. From the above observations we get the impression that the actual color of the Moon must be white or at worst a light gray color.

The moon receives the same solar irradiance as the Earth (1361.0 W/m^2), but its Geometric Albedo is 0.12 (see Table 1) [14]. Simply put, this means that, in visible light, the ratio of its actual brightness, as seen from the light source, to that of an idealized flat, fully reflecting, diffusively scattering disk of the same cross-section is 0.12. Given that 0 corresponds to a black body absorbing all incident radiation and 1 corresponds to a body reflecting all incident radiation, this means that the Moon reflects only a small amount of radiation back into space, although it looks very bright in the night sky.

4 Moon surface color before the Apollo era

One of the first astronomers to describe the color of the Moon's surface is the Soviet N.N. Suetinskaya, in her book "Nature of the Moon" [15]. On page 123 it is stated that "… the lunar surface is not just dark, but also slightly reddish. A substance with such a reflective ability is normally perceived by vision as brown. Therefore, it can be argued that if it were possible to place a piece of the lunar surface among the objects around us, it would look dark grayish-brown or brownish-dark gray". She also reproduces in the book, a photo of the moon showing its true color (Fig. 2).

Table 1. Basic properties of the Moon compared to those of Earth [14].

	Moon	Earth	Ratio (Moon/Earth)
Volumetric mean radius (km)	1737.4	6371.0	0.2727
Mass (10^{24}kg)	0.07346	5.9724	0.0123
Mean density (kg/m^3)	3344	5514	0.606
Surface gravity (m/s^2)	1.62	9.80	0.165
Bond albedo	0.11	0.306	0.360
Geometric albedo	0.12	0.434	0.28
Black-body temperature (K)	270.4	254.0	1.065

According to NASA records, Apollo 8 was the first manned spacecraft to orbit the Moon without landing. The mission took place between 21-27 December, 1968 [16], during which several color photos were captured. A complete set of the original scans can be found in the libraries of the Lunar and Planetary Institute [17]. Fig. 3 shows two of the photos taken during the mission. It is clear then that the NASA scientists knew – at least immediately after the return of the actual photos of the Apollo 8 mission – the correct color of the Moon.

Also, shortly after the first Apollo landing mission on July 20, 1969, the Soviet unmanned spacecraft Zond-7 photographed the Moon on August 11, 1969. Two of the photos taken by the spacecraft are shown in Fig. 4 [18], where a brown-reddish color of the Moon surface can be seen.

A literature search also shows that a lot of papers exist with professionals explaining how the color of the Moon should appear and what it means in geological terms [19], [20], [21], [22], [23]. Some books also refer to the color of the Moon, such as "Strange World of the Moon: An Enquiry into Lunar Physics" [24]. The author of this book refers to D.P. Avigliano, a USA researcher of the Lunar color, who recommends the use of a reflective telescope that is free of chromatic aberration and therefore preferable to a refractor in color work.

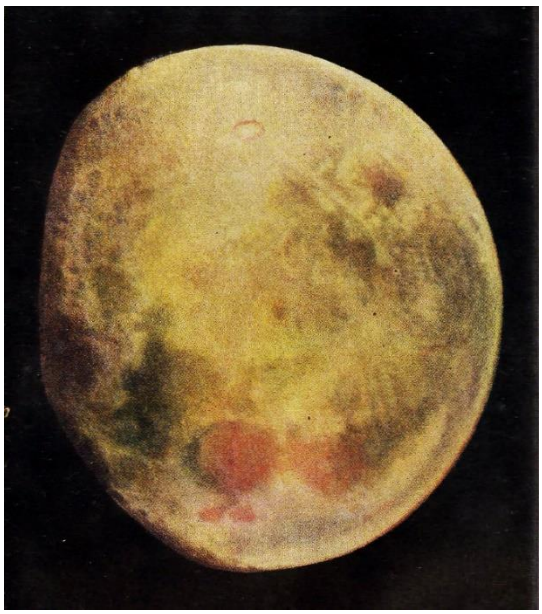


Fig. 2. Color photo of the Moon, obtained by N. P. Barabashev [15].

5 The Apollo program exploration and the gray Moon

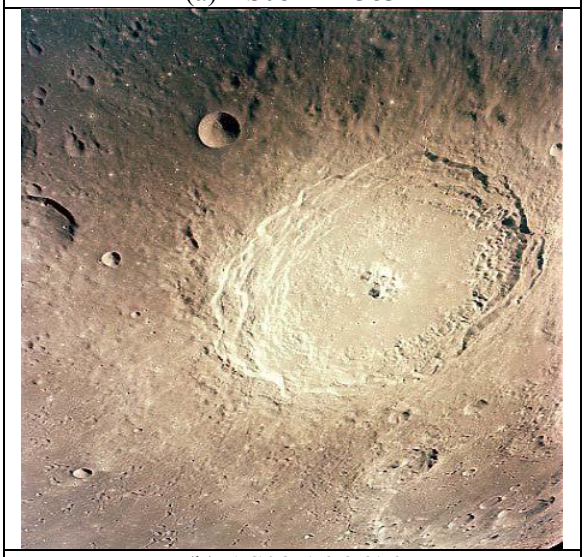
To find out the true color of the Moon one needs to observe the color of the soil in real photos taken during the Apollo landing missions to the Moon. In this way one will be able to confirm the everyday visual observation and detect any discrepancies. Fig. 5 shows four color images from the landing sides from Apollo 11, 14, 16 and 17 [25].

Unquestionably the color of the Moon in the Apollo photos is grayish-white in all landing sites and it is understandable that the white color seen from Earth is an illusion, because the light reflection on the Moon is seen in contrast to an absolutely black background that gives a false impression. The soil color shown in the photos is the correct color, as the overall color balance is correct, a fact attested by the color of the American flag, which is very well illustrated.

Additionally, a lot of photos taken during the Apollo missions are in black and white, despite the availability of color films at that time period. As explained in the introduction, color photos could

deliver images with more information and could preserve a better-quality historical record of the events.

(a) AS08-14-2383



(b) AS08-16-2616

Fig. 3. Color photos of the Lunar surface taken by the Apollo 8 mission, as kept in the libraries of the Lunar and Planetary Institute [16]. (a) AS08-14-2383; (b) AS08-16-2616.

One can even see the actual soil and rocks of the Moon as exhibited in science museums. An example are images from the Science Museum in Houston, USA, shown in Fig. 6. The images show soil and rocks brought back to Earth, and a reproduction of a landing site. The color of soil and rocks is grayish-white and no other color stains the samples and presentations.

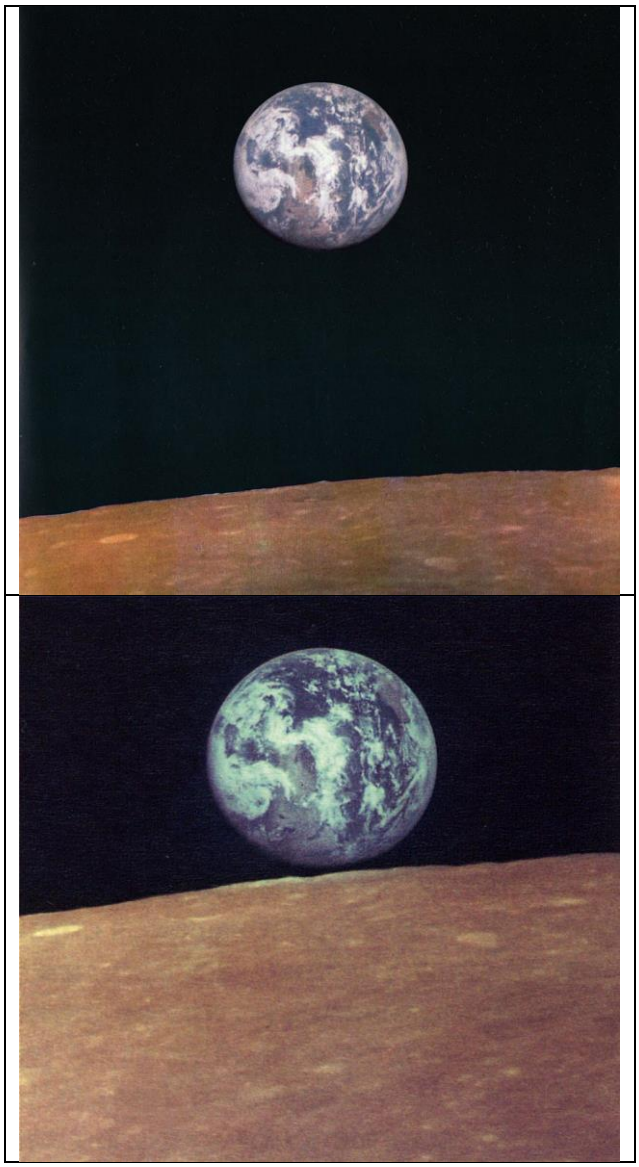
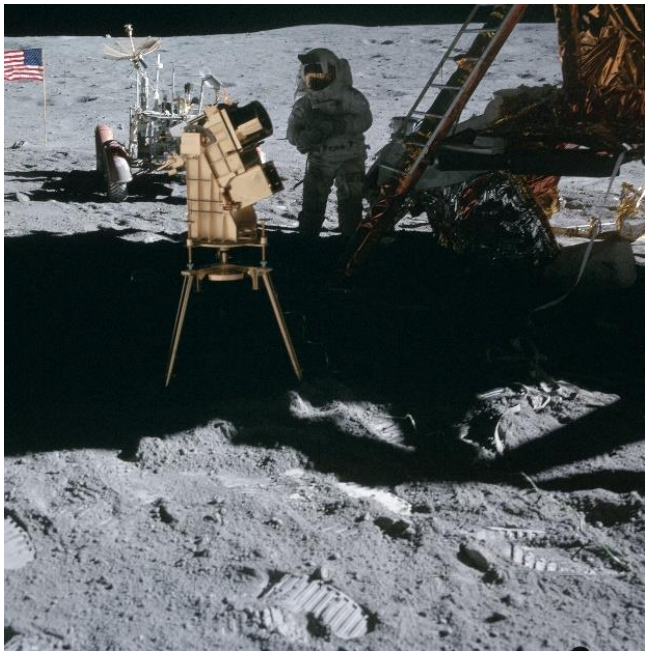


Fig. 4. Color photos of the Lunar surface as taken by the Zond-7 spacecraft in 1969 [17].

Michael Light, the man responsible for reproducing the Apollo photos kept on NASA pages in the Apollo Lunar Surface Journal, comments on Apollo Photography and the color of the Moon [25]. A summary of his comments is the following. The color on the Moon is a very subjective phenomenon; the color changes depending on the angle of the Sun; the old master films had gone magenta, because they were not stored in very cold conditions, and Light worked on his exhibition by printing to a neutral gray isolating what he felt to be filmic issues and eliminating them.

(a) AS11-40-5905 [25]
https://www.hq.nasa.gov/alsj/a11/AS11-40-5905.jpg

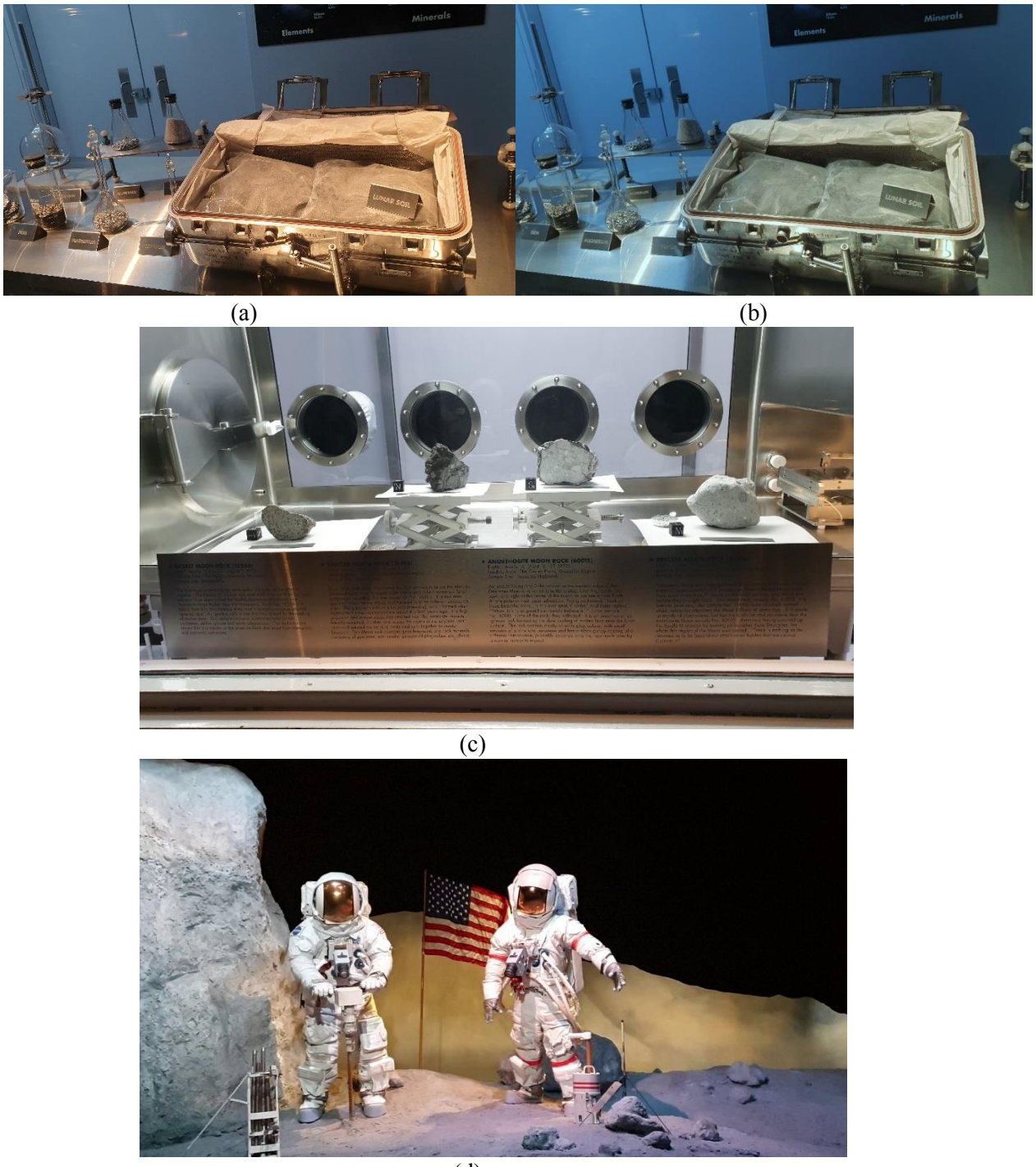
(b) AS14-66-9232 [25]
https://www.hq.nasa.gov/alsj/a14/AS14-66-9232HR.jpg



(c) AS16-114-18439 [25]
https://www.hq.nasa.gov/alsj/a16/AS16-114-18439HR.jpg

(d) AS17-140-21386 [25]
https://www.hq.nasa.gov/alsj/a17/AS17-140-21386HR.jpg

Fig. 5. Images from four landing sides, from Apollo 11, 14, 16 and 17, showing the color of the Moon soil that is grayish-white [25]. Observe and compare to the color of the flags that are shown in the correct colors. (a) AS11-40-5905 (b) AS14-66-9232 (c) AS16-114-18439 (d) AS17-140-21386.



(a) (b)

(c)

(d)

Fig. 6. Moon samples and landing site as presented in the Science Museum in Houston. Gray soil, rocks and scenes are exhibited. A brownish lighting was added, perhaps to give life to the gloomy color. (a) Soil brought back to Earth with brownish illumination; (b) color normalized by removing the brownish tint of the lighting, yielding a gray soil; (c) various types of rocks showing gray colors; (d) reproduction of a landing site with grayish-white rocks and soil (with brownish lighting at the back).

The above explanation indicates that the color of the Moon surface is portrayed as best as the film could allow, because any change in the film could not affect only the color of the soil but also the rest of the photo. Therefore, if the known object colors, such as the flag, the astronaut helmets, space suit etc. appear in the correct color, then the rest should also show good matching.

Of course, the most appropriate answer to the moon surface color could only be given by the astronauts themselves who landed there and knew it firsthand. Fortunately, one of them, Alan Bean, who

was the lunar module pilot of Apollo 12 and the fourth man to set foot on the Moon, published the book "Apollo, an Eyewitness account by Astronaut/Explorer Artist / Moonwalker Alan Bean" [26]. Bean was an excellent eyewitness and observer to describe the color because as an artist, he could also reproduce it in paintings. In the book, he presented his paintings on his experience with the moon's missions along with his comments. Here are three examples:

(1) Apollo 12; Cernan, Gnomon and Crater, Fig. 7(a); "The sun was low in a shiny black sky… I knew that the lunar rocks and dust were dark gray. But as I stood in that intense sunlight, the landscape appeared a light grayish tan. The shadows were black … But if I stood in the only available shadow, that of the lunar module Intrepid, the dust, rocks, and craters within the shadow looked dark gray, almost black. … When I first began painting the moon, I painted it exactly as I remembered it as an astronaut, and much the way it looks in photographs."

(2) Apollo 15; Mountains of the Moon with the Lunar Module Falcon, Fig. 7(b); "With him (Monet) in mind, I have not painted the moon the neutral gray I saw with my astronaut-geologist's eye, but rather a more beautiful combination of hues that I saw in my explorer astronaut artist's eye."

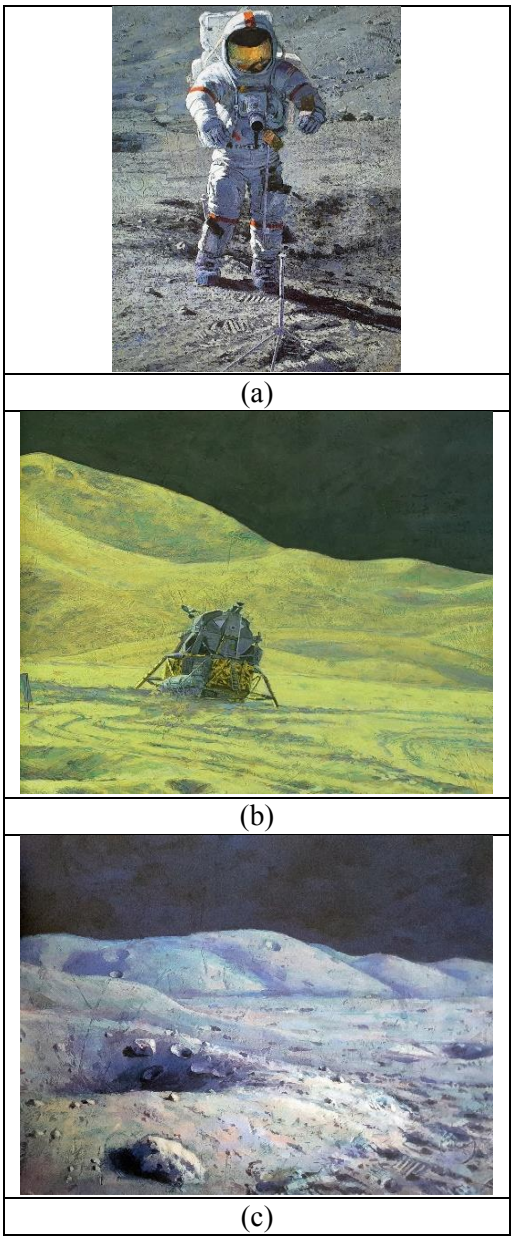
(3) Apollo 17; Portrait of a Crater, Fig. 7(c); "Ballet Crater is in the Taurus-Littrow' Valley of the moon. As an astronaut, I would observe that the rocks and surface material were dense fine-grained basalts ranging between a light and a dark gray, but as an artist I created a painting that is slightly warm green in the sun with cool, colorful, violet shadows."

There also exist detailed descriptions of the moon color by the astronauts themselves. These descriptions can be found in the following records:

(1) During the Apollo 11 Post Flight Press Conference (August 12th, 1969) at 17:16/1:23:01 astronaut Buzz Aldrin [27], describes the landing area as "… the general color of the terrain looking down sun was a very light tarnish color, this blended as we look more across sun to a more sharper well defined features and more of a grey color ..."

(2) Neil Armstrong interview, BBC 1970 with Patrick Moore at 1:30-3:54/7:12min [28]:

"**Moore:** Looking at the photographs that you brought back, the color photographs of the moon surface, it seems that the color of the surface actually varies according to the angle from which you see it. Is this so does it, does it do this?



(a)

(b)

(c)

Fig. 7. Alan Bean paintings [26] (permission obtained from the CFO of The Greenwich Workshop, Inc.). (a) Cernan, Gnomon and Crater (Apollo 12); (b) mountains of the Moon with the lunar module Falcon in "Monet" style (only part of painting is shown); (c) portrait of a Crater (only part of the painting is shown) in false color, with added slightly warm green in the Sun, and cool, colorful, violet shadows instead of light and dark gray hews.

Armstrong: Yes it certainly does it's a characteristic that we observe first while traveling around the moon in orbit you could see that at the Terminator at the boundary between the black part of the moon and the lighted part of the moon it was this if you were looking at a television set with the contrast turned to full contrast very black and very

white, as you moved further into the light there were more and more shades of gray but as you moved further such the Sun was higher above the horizon you actually start to see the tans and browns appear although at a very low level, similarly on the surface of the Moon the same characteristic is evident you can see Browns if the Sun is high enough. Apollo 12 for example landed while the Sun was only 5 degrees above the horizon so when they arrived they saw no Browns or tans anywhere only fairly high contrast grays

Moore: But you did

Armstrong: Yes, I did. The Sun was 11 degrees and Apollo 12 did. Also, the next day when they arose from their sleeping period and the Sun was higher of course then the Browns were observable to them

Moore: When you were actually walking about on the moon's surface and kicking about a certain amount of dust, did you notice any local color and also were you at all subconsciously worried about the possibility of unsafe areas

Armstrong: Well the color is as a puzzling phenomenon on the, on the moon, aside from the characteristics that I've already mentioned, you generally have the impression of being on a desert like surface with rather light colored hues, yet when you look at the material at close range as if in your hand, you find it's a charcoal gray in fact and we were never able to find any things that were very different from that color. I suspect that as we get more and more samples with future flights we will see that there is in fact some color but the optical properties on the moon are most peculiar.

(3) Scholastic students interviewed Buzz Aldrin, the second man to walk on the moon, on November 17, 1998 [29]:

Q. What did it feel like to walk on the moon? Is its surface different from that of Earth?

A. The surface of the moon is like nothing here on Earth! It's totally lacking any evidence of life. It has lots of fine, talcum-powder-like dust mixed with a complete variety of pebbles, rocks, and boulders. Many pebbles, fewer rocks, and even fewer boulders naturally make up its surface. The dust is a very fine, overall dark gray. And with no air molecules to separate the dust, it clings together like cement. If you examine it under a microscope, you can see it's made up of tiny, solidified droplets of vaporized rock resulting from extreme velocity impacts, like an asteroid from outer space hitting the surface over millions of years.

(4) Featured in: Gene Cernan Quotes [30]: Gene Cernan of Apollo 17: "The moon is bland in color. I call it shades of gray. You know, the only color we see is what we bring or the Earth, which is looking down upon us all the time. And to find orange soil on the moon was a surprise."

(5) In a Deutsche Welle Documentary with title "Surviving on the Moon" by Felix Kohler and Gabriel Stoukalov (ZDF 2018, English version DW 2019) [31], in 4:46/42:25, Charles Duke of Apollo 16 describes the Moon landing area as "It was like one of the most beautiful deserts I'd ever seen. GREY, very rough topography up and down hilly craters, rocks, hills everywhere."

Based on the many photos and testimonies of the astronauts, the famous Discovery Channel MythBusters series in their episode "Moon Landing Hoax (2008)" reproduces the dust that covers the moon in a gray color [32] (Fig. 8).

They mention that: "The dust that covers the Moon is called regolith… / the albedo of moon dust is between 7 and 10 percent, according to our sources at NASA. / To make our version of Regolith, we used Portland cement and charcoal powder. / Now, to measure the albedo or reflected light coming off of it, we used a light meter and our fake sun eight percent. / That is perfect for what we just showed with this test is that our sample regolith has a reflective index of about eight percent, which makes it ideal for us to test with."

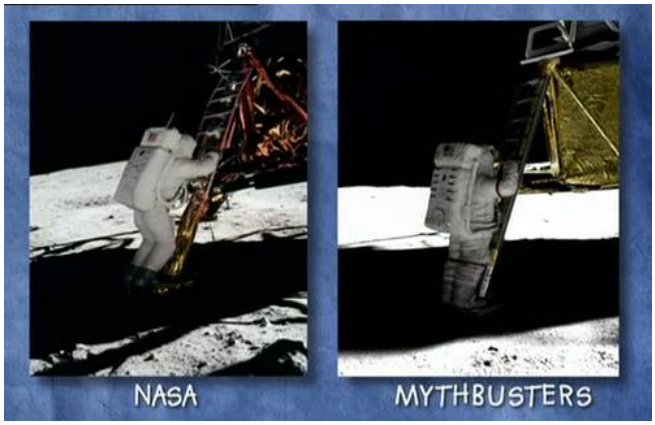


Fig. 8. Replication of NASA photo (MythBusters Moon Landing Hoax 2008 [32].

Moreover, the well-respected Life Unbounded, Scientific American, in an online article on the color of the Moon by C. A. Scharf, director of Columbia University's multidisciplinary Astrobiology Center [33], assures the reader that the surface of the Moon

is nearly devoid of strong colors and refers to Apollo images (that have now been removed) that show that the lunar soil looks gray. Going back to the original page as published in 2013 and preserved [34], one can still see the original article with the Apollo photos in place and understand why Scharf had this opinion (Fig. 9).

Fig. 9. The Moon is nearly devoid of strong colors and the lunar soil looks grey on Internet Archive-Wayback Machine [34].

6 USA Lunar exploration after the Apollo program

After the Apollo era, there were many missions of robotic spacecraft sent to the Moon to explore the lunar surface. A complete archive can be found on the Lunar and Planetary Institute webpages [35]. The following are the results of two of those missions:

(1) Clementine, 1994 [36]. On these pages many black and white pictures as well as false color images are displayed. Some real color images are also published. Two of these images are reproduced in Fig. 10.

(2) Lunar Reconnenses Orbiter (LROC), 2009. In this orbiter there was a wide-angle camera (WAC) that could map the Moon at 7 UV and visible wavelengths (320 nm through 689 nm) [37] (Fig. 11). In October, 2017, NASA/Goddard/Arizona State University published a true color composite mosaic showing most of the Moon's surface, based on images from NASA's Lunar Reconnaissance Orbiter [38] (Fig. 12).

The above figures display a rather brown color of the surface in contrast to what it was shown in the photos of the Apollo era.

7 Lunar Exploration by other countries

In line with NASA, other countries space agencies that sent spacecraft to photograph the Moon and published their photos are the following:

(1) The Japanese Aerospace Exploration Agency (JAXA) spacecraft began its voyage in 2007 and remained in orbit until 2009. JAXA released the pictures and videos taken by its Kaguya spacecraft in 2016. The image collection includes more than 450 photos in HD [39]. All the photographic evidence undoubtedly shows a grey Moon (Fig. 13).

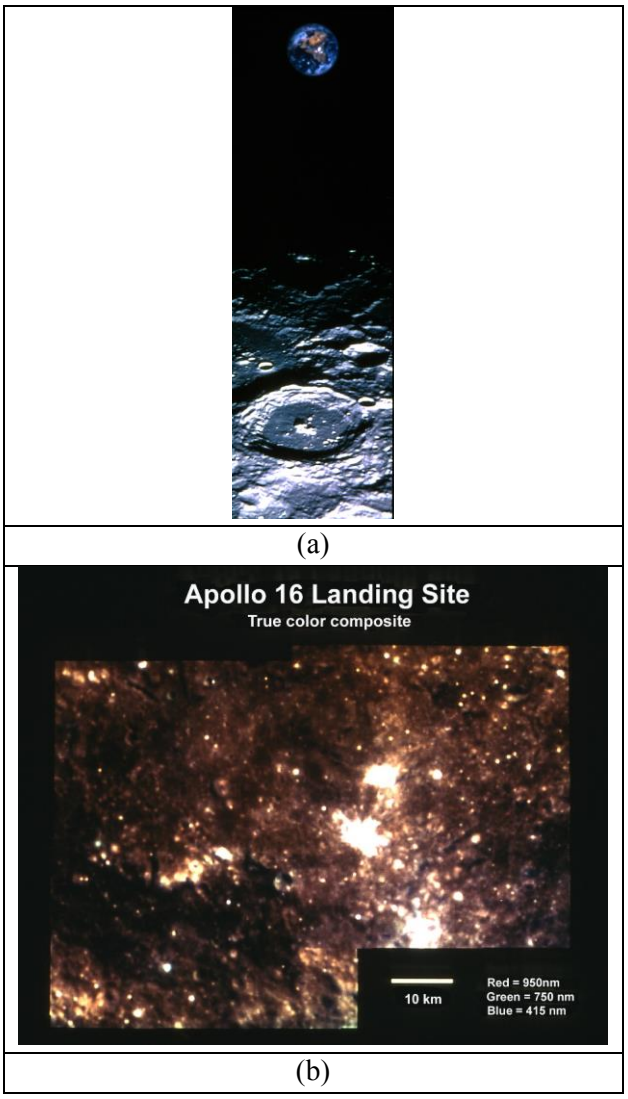


Fig. 10. Clementine, 1994 [36]. (a) Earthrise – view from Clementine of the full Earth over the north pole of the Moon in 1994; (b) natural color rendition of the Apollo 16 landing site as seen from the orbiting Clementine spacecraft. Clementine images were deliberately taken at high Sun angles to emphasize color differences.

Some videos have also been released, with one video still shown in Fig. 14 [40].

(2) The Indian Space Research Organization [41], also sent spacecraft to the Moon. On September 8, 2019, Chandrayaan 2 orbiter released its Vikram lander on the Moon. Minutes into its descent onto the lunar surface, the lander lost contact with Earth. ISRO released the last image of Vikram that was relayed to the communication center shortly before the loss of communication (see Fig. 15) [42]. In this case the surface of the moon is shown in a rather gray color.

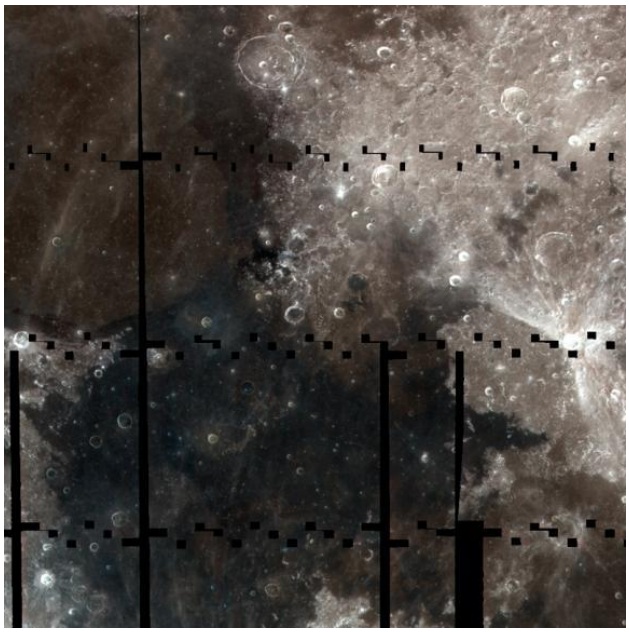


Fig. 11. Lunar Reconnaissance Orbiter. Color composite in visible wavelength colors on the Moon are dominantly controlled by variations in iron and titanium content. Iron oxide in the mare regions has lower reflectance. Titanium oxide shifts the color of the mare from red to blue (NASA/GSFC/Arizona State University [37].

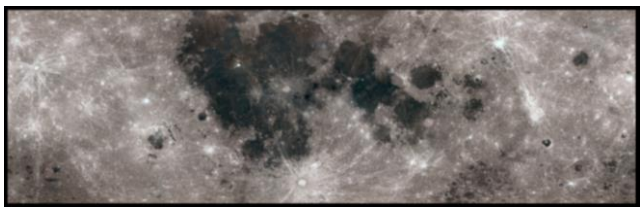


Fig. 12. Lunar Reconnaissance Orbiter. Wide Angle Camera (WAC) color composite mosaic of the Moon, photometrically normalized using new Hapke parameter maps [38].

(3) The Israeli spacecraft Beresheet was the first privately funded mission of SpaceIL [43] to the Moon. On April 11, 2019, it attempted a soft touchdown, but suffered technical problems during its descent to the lunar surface. The aim of the mission was to take pictures and conduct experiments, but the end-result was that Beresheet sent back only a few images showing a heavily colored Moon (Fig. 16).

(4) Chinese missions to the Moon. The publication of some of the photos of the Chinese missions to the Moon showed that the color of the soil in all the landing places was red-brown.

Chang'e 3 was a robotic spacecraft operated by the China National Space Administration, incorporating a robotic lander and China's first lunar rover. It landed on the Moon in December 2013 and released some photos in 2014 that show that the surface of the moon has a brown-reddish color [44] (see Fig. 17).

Fig. 13. One of the photos taken by Kaguya spacecraft of the Japanese Aerospace Exploration Agency [39].

Fig. 14. Video still by Kaguya (Selene) taking "Full Earth-rise" by HDTV on Apr. 5, 2008 [40].

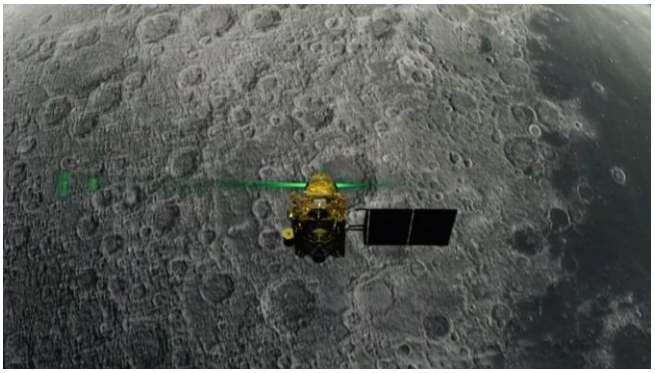


Fig. 15. ISRO released the last image of Vikram that was relayed to the communication center shortly before the loss of communication [42].

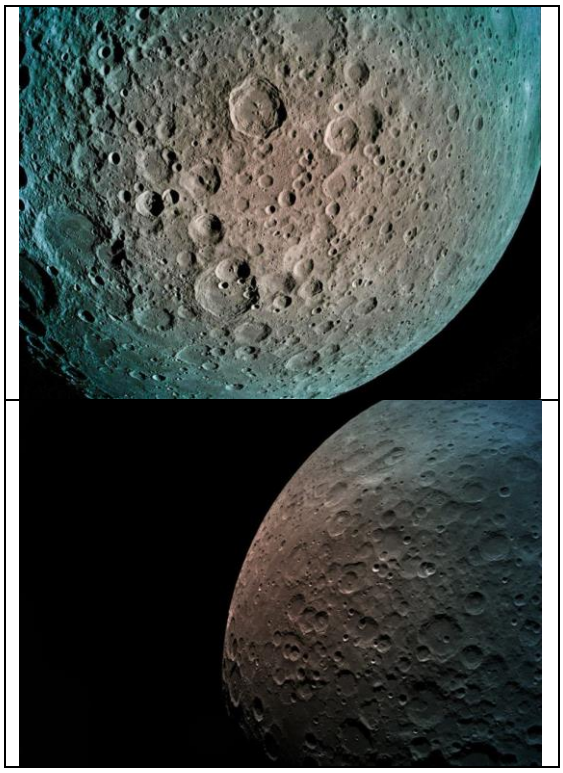


Fig. 16. Images captured by the Israeli spacecraft SpaceIL [43].

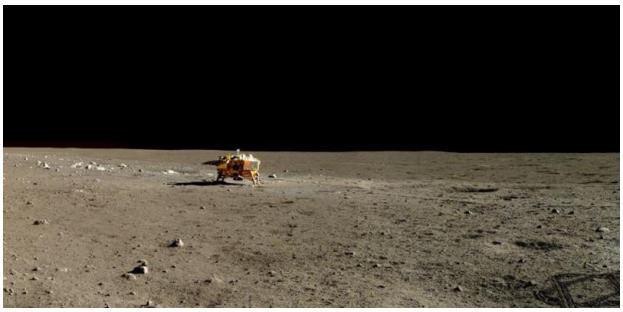


Fig. 17. Image of the Chinese Chang'e 3 probe, taken by the Yutu rover carried by Chang'e 3 [44].

Chang'e 4 was a robotic spacecraft of the Chinese Lunar Exploration Program. China made its first soft landing on the far side of the Moon, on January 3, 2019. The Chang'e 4 lander carried a rover, Yutu-2 (Jade Rabbit-2) that traveled in the Moon and conducted scientific exploration [45]. The photos released clearly show brown soil (see Fig. 18).

Chang'e-5 probe comprised an orbiter, a lander, an ascender and a returner. Launched on November 24, 2020, it landed on the near side of the moon, collected samples and returned to Earth on December 17, 2020 [46] (see Fig. 19).

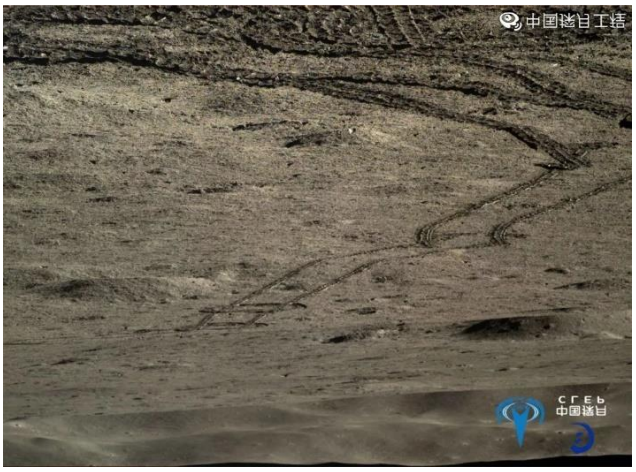


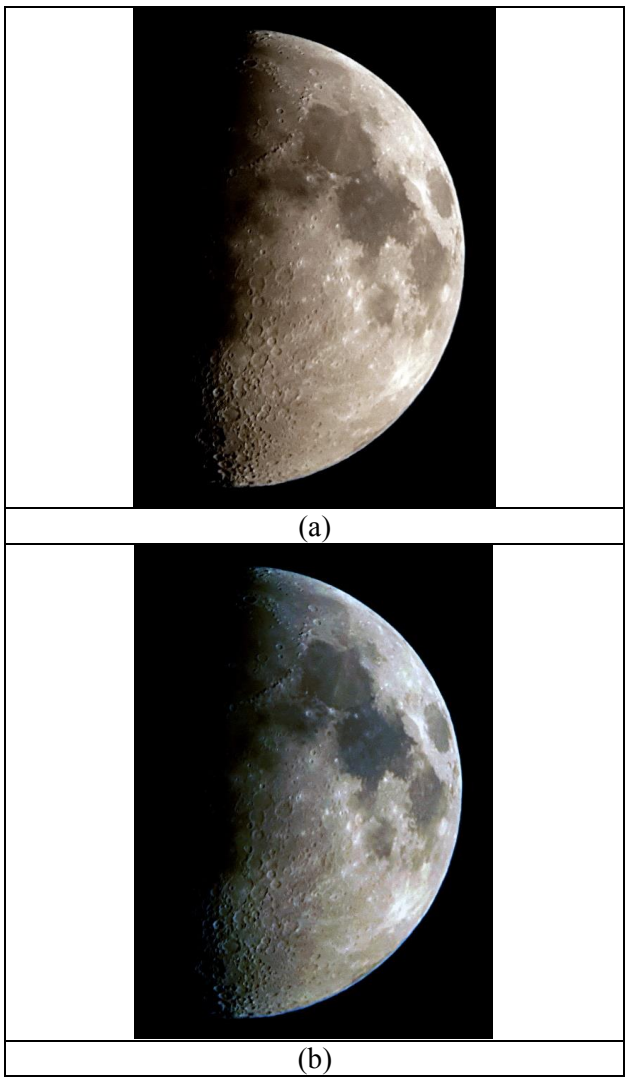
Fig. 18. Traces of Yutu-2 on the moon [45].

Fig. 19. The lander-ascender combination of Chang'e 5 robotic lunar probe finished gathering lunar samples and packed them in a vacuum container on December 2, 2020 [46].

The photographic data presented above shows that agencies cooperating with NASA, like the Japanese Aerospace Exploration Agency and the Indian Space Research Organization, show images displaying a rather grayish moon. Images from other countries (the Soviet Union, Israel (private company) and China display a brown-reddish Moon surface.

8 Direct observations with digital photography

Today, with the advancement of digital photography and computer software, it is quite easy to capture the Moon in visible color (Fig. 20). To take a good lunar photo, just a camera with a good magnifying mirror lens (500×-1000×) is more than adequate. The advantage of a mirror lens is that, due to its design, the images produced are free of chromatic and off-axis aberrations (i.e., failure of rays to converge in a focus because of a defect of a lens or mirror) so common with traditional refractive telephoto lenses.



(a)

(b)

Fig. 20. The Moon captured with a digital camera and a Mak60 Reflector (Maksutov-Cassegrain) Telescope with 750mm Focal Length. (a) Without any enhancement. (b) Digitally enhanced.

The interested person can refer to books (for instance, [47]) that explain to amateur astronomers how to take quality pictures with a cheap camera and a small telescope, or alternatively to internet sides that describe how to get a good true color photo of the Moon and enhance it [48], [49], [50], [51].

Given the above results, one is really confused. Do the Apollo era photos, with which generations of people had grown with, give the true color of the Moon in specific areas that were gray in color? And,

why was this matter not clarified? Why do black and white, or false color, photos still appear in public and not photos of the Moon in its visible color? Currently, NASA informs the public [52], that from outside the Earth's atmosphere, the dark Moon appears a magnificent brown-tinged gray. Still, official sites give the wrong impression by presenting the famous foot print color from gray to brown (see Fig. 20).

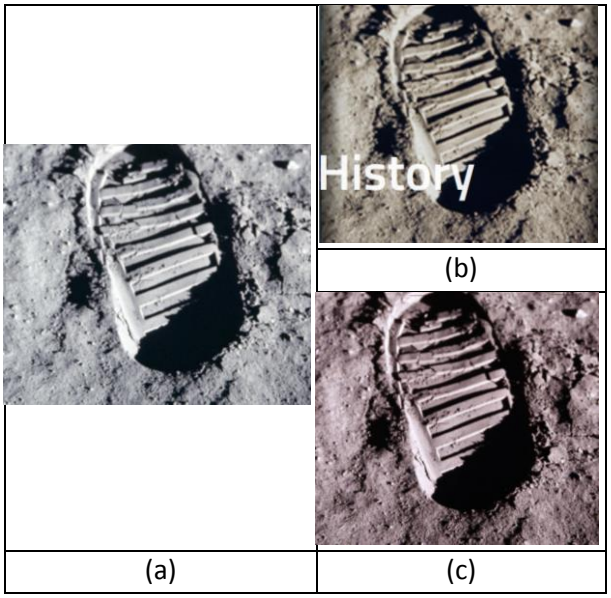


Fig. 20. "Foot print" in color: (a) Original Apollo 11 image, AS11-40-5877 image [53]. (b) AS11-40-5877 [9]. (c) AS11-40-5877 [54].

9 Conclusion

It is a fact that in the photos of all the landing sites of the Apollo missions, the soil color appears gray, with other items from the Earth appearing in their true color. Hence, the conclusion resulting from the Apollo missions' information is inevitable: the color of the Moon's surface is gray and the NASA scientists and the astronauts who were on the Moon could not have failed to recognize the color at the landing sites. This is also attested by photographic evidence of the Japanese and the Indian Space Agencies.

On the other hand, in older observations before the Apollo era, but also in recent photos, the color of the soil appears to be generally red-brown, with the color of the mare shifting from red to blue.

It is clear that there is a contradicting evidence coming from various sources about the visible color of the Moon surface. One would logically expect that different colors characterize various areas on the Moon, as is the case on Earth.

Hopefully the space agencies that have released the relevant photographic data will eventually clarify the matter. Or, alternatively, it is time that the expert scientists informed the public about this "paradox".

References:

[1] Meskin, A., and J. Cohen. Photographs as evidence. *Photography and Philosophy: Essays on the pencil of nature*, 2008, pp. 70–90.

[2] Alfano, R.A. Photography and Imagery. In *Van Nostrand's Scientific Encyclopedia*, 2006.

[3] Pope, N. Kodachrome and the Rise of 16mm Professional Film Production in America, 1938–1950. *Film History*, 28(4), 2016, pp. 58–99.

[4] Silverstein, D.A. and J.E. Farrell. The relationship between image fidelity and image quality. In *Proceedings of 3rd IEEE International Conference on Image Processing*, Vol. 1, September 1996, pp. 881-884, IEEE.

[5] Fedorovskaya, E.A., H. de Ridder and F.J. Blommaert. Chroma variations and perceived quality of color images of natural scenes. *Color Research & Application: Endorsed by Inter-Society Color Council, The Color Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Color Centre Foundation, Color Society of Australia, Centre Français de la Couleur*, 22(2), 1997, pp. 96–110.

[6] Yendrikhovski, S.N., F.J. Blommaert and H. de Ridder. Perceptually optimal color reproduction. In *Human Vision and Electronic Imaging III* Vol. 3299, July 1998, pp. 274-281, International Society for Optics and Photonics.

[7] Kapecki, J. and J. Rodgers. Color Photography. In *Kirk- Othmer Encyclopedia of Chemical Technology*, 2001.

[8] Kapecki, J. and J. Rodgers. Color Photography. In *Encyclopedia of Imaging Science and Technology*, 2002.

[9] NASA History Overview. 2021. https://www.nasa.gov/content/nasa-history-overview. Accessed 17 March 2021.

[10] Lunar and Planetary Institute. 2021. https://www.lpi.usra.edu/resources/apollo/. Accessed 17 March 2021.

[11] Apollo Lunar Surface Journal. Copyright 1995-2018 by Eric M. Jones, 2021. At https://www.hq.nasa.gov/alsj/. Accessed 17 March 2021.

[12] Flickr.com Project Apollo Archive Apollo Image Gallery, 2021. At:

https://www.flickr.com/photos/projectapolloarchive/albums. Accessed 17 March 2021.
[13] March to the Moon. 2021. At http://tothemoon.ser.asu.edu/gallery/Apollo. Accessed 17 March 2021.
[14] Moon Fact Sheet. Moon/Earth Comparison, 2021. At: https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html. Accessed 17 March 2021.
[15] Suetinskaya, N.N. *Nature of the Moon*, p. 123. pdf, 1959. At: N.N._Suetinskaya_Priroda_Lunue(BookZa.org).pdf - Google Drive: https://docs.google.com/file/d/0B7JibVG2qFnoS1hqWGJrUnd5SVU/edit?pli=1. Accessed 17 March 2021.
[16] NASA History Apollo 8 The Second Mission. 2021. https://history.nasa.gov/SP-4029/Apollo_08a_Summary.htm. Accessed 17 March 2021.
[17] Apollo Image Atlas Apollo 8. 70mm Hasselblad Image Catalog, Universities Space Research Association (URSA), Lunar and Planetary Institute (LPI), 2021. At https://www.lpi.usra.edu/resources/apollo/catalog/70mm/mission/?8. Accessed 17 March 2021.
[18] Larry Gerstman – Soviet Lunar Photos. Zond spacecraft 1969, 2021. At https://sites.google.com/site/larrygerstman/soviet-lunar-photos. Accessed 17 March 2021.
[19] Hargreaves, F.J. An attempt to determine the color of the lunar surface by direct color photography. *J. Brit. Astron. Assoc.*, 34, 1924, pp. 243–5.
[20] Hapke, B. and H. van Hoen. Photometric studies of complex surfaces, with applications to the moon. *Journal of Geophysical Research*, 68(15), 1963, pp. 4545–4570.
[21] Oetking, P. Photometric studies of diffusely reflecting surfaces with applications to the brightness of the Moon. *Journal of Geophysical Research*, 71(10), 1966, pp. 2505–2513.
[22] Adams, J.B. and A.L. Filice. Spectral reflectance 0.4 to 2.0 microns of silicate rock powders. *Journal of Geophysical Research* 72(22), 1967, pp. 5705–5715.
[23] McCord, T. B. Color differences on the lunar surface. *Journal of Geophysical Research*, 74(12), 1969, pp. 3131–3142.
[24] Firsoff, V.A. *Strange World of the Moon: An Enquiry into Lunar Physics*. Hutchinson, 1959.
[25] Apollo Lunar Surface Journal, Apollo Photography and the Color of the Moon. Copyright 2000 by M. Light and E. M. Jones, 2021. At https://www.hq.nasa.gov/alsj/apollocolor.html. Accessed 17 March 2021.
[26] Bean, A. *Apollo, an Eyewitness account by Astronaut/ Explorer Artist/ Moonwalker Alan Bean*. The Greenwich Workshop Inc., 1998. ISBN 0-86713-050-4.
[27] Apollo 11 Post Flight Press Conference. 1969. At: https://www.youtube.com/watch?v=Yz6nzutr7RU. Accessed 17 March 2021.
[28] Neil Armstrong interview, BBC. 1970. At: https://www.youtube.com/watch?v=W1R5uquFJjs&t=249s. Accessed 17 March 2021.
[29] Buzz Aldrin Interview. 1998. At: http://teacher.scholastic.com/space/apollo11/interview.htm. Accessed 17 March 2021.
[30] Gene Cernan Quotes. 2021. At: https://quotefancy.com/quote/1127529/Gene-Cernan-The-moon-is-bland-in-color-I-call-it-shades-of-gray-You-know-the-only-color). Accessed 17 March 2021.
[31] Kohler, F., and G. Stoukalov. Surviving on the Moon. ZDF, 2018, (English version DW 2019).
[32] MythBusters Moon Landing Hoax. Episode of the MythBusters series of the Discovery Channel, Beyond Entertainment Ltd, 2008. At https://www.dailymotion.com/video/x2m7k1z. Accessed 17 March 2021.
[33] Scharf, C.A. *The Moon Is Not Black and White, It Just Looks That Way*. Life Unbounded, Scientific American, 2013a. At https://blogs.scientificamerican.com/life-unbounded/the-moon-is-not-black-and-white-it-just-looks-that-way/. Accessed 17 March 2021.
[34] Scharf, C.A. *The Moon Is Not Black and White, It Just Looks That Way*. Life Unbounded, Scientific American, 2013b. At the Internet Archive-Wayback Machine: https://web.archive.org/web/20150524043102/https://blogs.scientificamerican.com/life-unbounded/the-moon-is-not-black-and-white-it-just-looks-that-way/. Accessed 17 March 2021.
[35] Lunar and Planetary Institute. Lunar Exploration Timeline, 2021. At https://www.lpi.usra.edu/lunar/missions/. Accessed 17 March 2021.
[36] Clementine Explores the Moon. Clementine, 1994, 2021. At https://www.lpi.usra.edu/publications/slidesets/clem2nd/clementine_index.shtml. Accessed 17 March 2021.
[37] PhotoJournal. Lunar Reconnaissance Orbiter (LRO)-Jet Propalsion Laboratory, NASA/

GSFC/ Arizona State University, 2021. At https://photojournal.jpl.nasa.gov/catalog/PIA13517. Accessed 17 March 2021.

[38] LROC. Wide Angle Camera (WAC) color composite mosaic of the Moon, photometrically normalized using new Hapke parameter maps, 2021. At http://lroc.sese.asu.edu/posts/801. Accessed 17 March 2021..

[39] JAXA PDAP. The Japanese Aerospace Exploration Agency (JAXA) spacecraft, Kaguya (Selene), 2021. At https://www.darts.isas.jaxa.jp/planet/project/selene/hdtv/pdap/?RESOURCE_CLASS=HDTV_OBJECT&RETURN_TYPE=HTML&PARENT_PRODUCT_ID=sh_20071030T190702_wm8&DISPLAY_ORDER=PRODUCT_ID. Accessed 17 March 2021.

[40] YouTube-KAGUYA (SELENE). Video still of Apr. 5, 2008. At https://www.youtube.com/watch?v=H1KWtG66lEQ. Accessed 17 March 2021.

[41] ISRO. The Indian Space Research Organization (ISRO), 2021. At https://www.isro.gov.in/chandrayaan2-home-0. Accessed 17 March 2021.

[42] YouTube-ISRO Official. 2021. At https://www.youtube.com/watch?v=7iqNTeZAq-c. Accessed 17 March 2021.

[43] SpaceIL. SpaceIL - The Israeli spacecraft Beresheet, 2021. At https://www.spaceil.com/home-page. Accessed 17 March 2021.

[44] XinhuaNet-China Focus. Photo provided by National Astronomical Observatories of Chinese Academy of Sciences, 2018. At http://www.xinhuanet.com/english/2018-04/12/c_137106440.htm. Accessed 17 March 2021.

[45] ChinaDaily-Chang'e 4. Weibo account of China's Lunar Exploration Project, 2019. At http://chinadailyglobal.com/a/201911/04/WS5dbf9b2ba310cf3e35575428.html. Accessed 17 March 2021.

[46] ChinaDaily-Chang'e 5. Photo provided by China Daily, 2020. At https://www.chinadaily.com.cn/a/202012/18/WS5fdbf893a31024ad0ba9c846.html. Accessed 17 March 2021.

[47] Buick, T. *How to Photograph the Moon and Planets with Your Digital Camera*. Springer-Verlag London Limited, 2006. ISBN-10: 1-85233-990-X, ISBN-13: 978-1-85233-990-6.

[48] YouTube-Astrofarsography. Video by R. Farsad, 2018. At https://www.youtube.com/watch?app=desktop&v=ncPJY5CRi-Q. Accessed 17 March 2021.

[49] Argerich, L. *How to Photograph the Real Colors of the Moon*, 2021. At http://photographyblogger.net/how-to-photograph-the-real-colors-of-the-moon/. Accessed 17 March 2021.

[50] Schmitz, C. *Photographing Space: How to Find the Secret and Subtle Color in the Moon*, 2021. At https://photographingspace.com/find-the-secret-and-subtle-color-in-moon-photos/. Accessed 17 March 2021.

[51] Vandevenne, P. *Shooting the Moon in colours - the RAW vs Jpeg lunar experiment*, 2021. At https://www.datarescue.com/life/kepler/moontests/raw_vs_jpeg.html. Accessed 17 March 2021.

[52] APOD. Astronomy Picture of the Day, 2020. Image Credit & Copyright: Marcella Giulia Pace at https://apod.nasa.gov/apod/ap201111.html. Accessed 17 March 2021.

[53] Apollo Image Atlas Apollo 11. 70mm Hasselblad Image Catalog. Lunar and Planetary Institute, 2021. At https://www.lpi.usra.edu/resources/apollo/images/print/AS11/40/5877.jpg. Accessed 17 March 2021.

[54] Hasselblad Photo in March to the Moon. 2021. At http://tothemoon.ser.asu.edu/gallery/Apollo/11/Hasselblad%20500EL%20Data%20Camera%2070%20mm#AS11-40-5877. Accessed 19 August 2021.