APOLLO 11 LUNAR REGOLITH (10084-47) REVISITED – A NOVEL OPTICAL MICROSCOPY STUDY

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Introduction: Forty years of research has provided a lot of information about the chemical and physical properties of lunar regolith [*e.g.*1]. Even though monochrome light micrographs of lunar soil particles can be found throughout the literature [*e.g.* 2,3], surprisingly few high magnification color micrographs have been published. The quality of the image obtained with an optical microscope is typically limited by the depth of field of the objective lens. This means that when trying to take a photograph of a particle, only a small part of it is in sharp focus at any one time; the foreground and background is often blurred. The greater the magnification, the worse this problem becomes. This limitation can now be overcome by collecting a systematic series of images moving the focal plane step-wise from the top to the bottom of the particle. A computer software program then analyzes each image and selects only the in-focus regions, discarding the out-of-focus parts. The in-focus portions are then seamlessly joined into a single image that is totally in focus. This feature is available on some of today's more specialized computer controlled microscopes [4].

In addition, as any photographer will tell you, the way in which you light a subject is crucial to obtaining a good photograph. The same is true for taking a light micrograph through a microscope. Conventional microscopes have two basic light geometries: one that passes light through the sample (transmission) and the other where a beam of light is reflecting off it. This is not the best way to bring out the detail in a picture – the lighting is too 'flat'. It has been revealed [5,6] that oblique lighting has the strange effect of making the sample appear tilted in the microscope, as if you were looking at it from an angle: the more oblique the angle, the greater the degree of tilt. Oblique lighting from two different sources (one from the left and one from the right) can be passed through the sample producing a left eye and right eye view of the sample simultaneously resulting in a dramatic 3-D image. In other words, both eyes would receive a 2-D image but from a slightly different angle; the human brain then naturally creates the third dimension. This approach has been used in a wide variety of applications, for example, in cancer screening [7] and to compare the morphology of sand grains from around the world [8]. Using oblique lighting in conjunction with the collection and subsequent processing of a through-focal series of frames has allowed us to obtain high resolution color micrographs of lunar regolith particles showing detail never thought possible with an optical microscope.

Results and Discussion: The light micrographs shown in Figure 1 reveal some of the diversity of particles that exist in the Apollo 11 lunar soil. One of the most interesting types of particles are the glassy spherules. They come in a variety of colors – off-white, orange, red, brown, and dark gray. The darker particles contain more iron and titanium – a basaltic composition - whereas the lighter particles tend to contain more calcium and aluminum – closer to an anorthositic composition. The orange glassy spheroid shown in Figure 1(a) is thought to have originated from an ancient fire-fountain volcano [1]. The tiny bubbles present at the surface are thought to be due to the release of implanted solar wind gases in the molten droplet. The vast majority of glass globules found in Apollo 11 lunar soil, however, are thought to be ejecta from primary micro-meteor impacts. The energy associated with such impacts causes the regolith to melt (and vaporize) and solidification occurs before the droplet returns to lunar surface [9,10]. Many of these spheres are opaque and possess bud-like protruberances [*e.g.*11], an example of which is shown in Figure 1(b). Such spheroids have a much higher Fe and Ti content and are less homogeneous than the orange spheres. While many are perfect spheres, one can also find ellipsoids, tear-drops, rods and dumb-bells [12]. An example of a glassy dumb-bell particle is shown in Figure 1(c).

The ring structure of the particle in Figure 1(d) is a common feature of many agglutinates and indicative of localized melting associated with a single micro-meteor impact [12]. In this case, the glassy matrix is almost black suggesting it contains relatively large amounts of iron and titanium. There are also several mineral fragments that have not been totally enclosed in the matrix but are simply adhering to the outer surface of the particle. The large concave glassy agglutinate shown in Figure 1(e) most likely started its existence as an expanding bubble in a very viscous piece of molten regolith. The pressure inside bubble may soon have become too great causing fracture rather than further expansion in the bubble diameter. The ejected fragment was presumably still exposed to intense heat which induced further viscous flow causing its surface to smooth out before solidifying. There is also clear evidence of surface melting in the micrograph of the off-white anorthosite particle shown in Figure 1(f). This type of particle is thought to have originated from the highlands and to have been transported down onto the maria during successive meteor impacts.

Although these light micrographs illustrate the fascinating diversity of lunar regolith particles, they can sometimes give rise to misleading conclusions because they are just 2-D images. A three-dimensional visualization makes it easier to see the variety and spatial distribution of different components within the agglutinates. While it is not possible within this abstract to present high resolution 3-D light micrographs, a collection of 3-D images can be found, together with a more extensive gallery of 2-D images, at www.sandgrains.com.

Summary: Using oblique lighting conditions in conjunction with the collection and subsequent processing of a through-focal series of frames, has allowed us to obtain high resolution color micrographs of lunar regolith particles showing detail never thought possible with an optical microscope. These images may prove very useful in providing evidence to descriminate between competing models on the structural evolution of lunar regolith.

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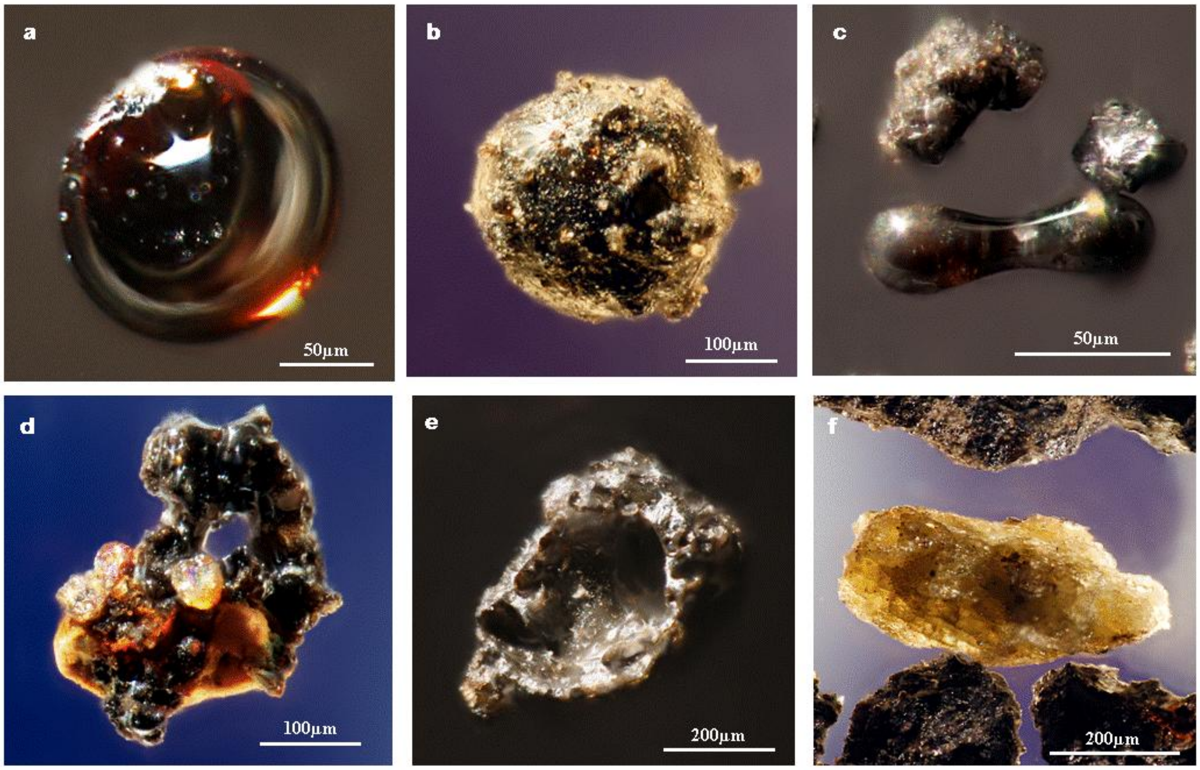

Fig. 1 A selection of light micrographs of Apollo 11 lunar regolith particles.