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Summary

Did We Really Land on the Moon?
Suggestions for Science Teachers

On Feb. 15, 2001, the FOX network broadcast a one hour TV program claiming that the Apollo lunar landings had all been staged in a studio set in Nevada, and that astronauts had never landed on the Moon. This claim can be refuted on many points, focussed on the supposed photographic evidence indicating studio lighting or other aspects of the Apollo missions.

The TV program ignored the returned lunar samples. Science teachers have been swamped with questions about the program, and this paper has been written to suggest how they can use it to stimulate interest in lunar geology. The article shows how the NASA Lunar Disk kits, available on loan to schools, can be studied by students. These samples are visibly different from terrestrial soils and rocks in several ways. There is no quartz in the lunar soil; there are no true reds and browns resulting from ferric oxides; and the textures of the soil (agglutinates and glass beads) can only be formed on an airless planet.

The article has several pictures of the lunar surface and the Apollo samples, and a short bibliography for background reading.

Did We Really Land on the Moon?
Suggestions for Science Teachers

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Introduction

The claim has been made, in supermarket tabloids and on television (Feb. 15, 2001), that American missions to the Moon were faked, and that no one really landed on the Moon. A sizable fraction of the general public reportedly believes this claim. Children can be forgiven for this, but they will undoubtedly ask science teachers: Did we really land on the Moon? How do we know?

The purpose of this note is to suggest an approach to this question, making use of material and observations students themselves can have access to, in particular actual samples of lunar rock and soil. The "conspiracy theory"TV program was largely based on photographic evidence. All the arguments presented can be refuted directly, but such refutation involves detailed study of the pictures and knowledge of the lunar surface optical environment. An excellent Web site, **http://www.badastronomy.com,** is maintained by astronomer Phil Plait, who gives specific explanations of all the supposed optical evidence that the lunar surface TV was faked.

My refutation will be instead based on evidence that teachers can present to their students: actual samples brought back from the Moon, now in the Lunar Sample Disks kits (**Fig. 1**). These disks can be borrowed from NASA centers, such as Goddard Space Flight Center, with instructional material on their use. Information can be obtained from **gsfcerc@pop900.gsfc.nasa.gov.**, or **(301) 286-8570**.

Is This Material Really From the Moon?

This is the question students should ask, and can be used by the teachers to open a discussion. Here are some suggested responses.

First, it is not widely known that we actually have **three** totally independent sets of rock and soil samples from the Moon: the Apollo samples themselves (382 kg: 840 pounds); several meteorites from the Moon collected in Antarctica; and three small samples (total about one kg.) returned from the Moon by Russian robotic spacecraft. All three sets have been studied by scientists from dozens of countries, and they are agreed to be genuine material from the Moon. Conspiracy theorists might claim that the Apollo samples are fakes, produced in a laboratory, but the lunar meteorites and the Russian returned samples are essentially similar in chemistry and mineralogy, thus giving an independent check on the authenticity of the Apollo samples.

Meteorites have only been known to come from the Moon since the early 1980s, when they were first discovered on the blue ice in Antarctica. McSween's "Meteorites and Their Parent Planet" gives an up to date review of this subject. Several of the lunar meteorites are similar in all respects to mare basalts or breccias derived therefrom. Others are plagioclase-rich breccias similar to highland samples, although with chemical differences suggesting that they may be from the lunar far side.

The rock and soil samples returned by the Apollo missions have been analyzed over the last three decades by thousands of highly-qualified scientists in many countries. None of these scientists has raised the slightest question about their lunar origin. One can imagine an American mineralogist supported by NASA funding agreeing to take part in a conspiracy, but not the dozens of other mineralogists from Canada, Britain, France, Germany, Japan, and other countries.

The characteristics of the Apollo samples themselves point firmly to a lunar origin. Here are a few of them, based on my personal experience as a co-investigator for Apollo 11 and 12 samples, later independent study at Goddard Space Flight Center, and many years of using the sample disks.

Lunar Soil

The lunar soil, or regolith, is fundamentally **different in texture** from any terrestrial soil with the possible exceptions of fresh volcanic ash or ejecta from a young impact crater. As teachers can show, with the lunar sample disk, the lunar soil under the microscope consists of extremely angular agglutinates and glass beads (impact melts or volcanic glasses). Soil like this can form in quantity only on an airless body, such as the Moon or an asteroid. Teachers may wish to have students bring in a handful of silty or sandy soil for comparison. They will find it, under a magnifying glass, to be chiefly rounded grains.

The mineralogy of the lunar soil is different from that of any terrestrial soil with, again, the possible exception of some volcanic ash. Most important is the **nearly total absence of quartz** from the lunar soil, reflecting its rarity on the Moon. Quartz is the most common simple mineral on the surface of the Earth, making up most sands and sandstones, and is a major constitutent of granites and similar igneous rocks. There is apparently no true granite on the Moon, and hence very little quartz. Any handful of silt will consist at least partly and possibly wholly of quartz. This test should help convince students that the lunar sample disk soil is from the Moon.

The main minerals visible in the sample disk are plagioclase feldspar (white), pyroxene and olivine (various shades of greenish or yellowish brown), and ilmenite (black, opaque). Glass beads are common, but glass is not a mineral. Terrestrial soils are as previously mentioned very rich in quartz in most areas. However, in areas of, for example, Precambrian igneous and metamorphic rock, soils may be rich in feldspar, pyroxene, or even garnet. Mica is common in many terrestrial soils, and easily identified by students. However, there is apparently no mica on the Moon, primarily because lunar lavas were totally dry. Mica contains water of crystallization: no water, no mica.

The chemistry of the lunar soil is also different from that of terrestrial soil. Like all lunar rocks, the soil shows **no evidence of oxidation**. Students know what oxidation produces: rust. With the important exception of the Apollo 17 orange soil - to be discussed later - there is no reddish brown or red material in the lunar sample disk. There are occasional crystals of pyroxene or olivine, yellow-brown, greenish-brown, or similar colors, but these are easily distinguished under the microscope from the iron oxides such as limonite or hematite common on the Earth. Another exercise for students in this connection is simply to examine some brownish mud, clay, or sandstone, depending on local geology. Reddish colors encountered in terrestrial rocks are almost always the expression of ferric oxides reflecting formation or alteration in an oxidizing environment.

Lunar Rocks

Proper study of lunar rocks requires at the very least use of a petrographic microscope with lunar thin sections 30 micrometers thick. Obviously far more advanced instruments are used by professional scientists. However, characteristics of lunar thin sections visible in good photomicrographs (**Fig. 2**), especially in color, can also be used to demonstrate the lunar origin of the Apollo samples. Some of the most obvious ones are the following.

The **absence of hydrothermal alteration** is the most obvious proof that Apollo samples of basalt or anorthosite are from the Moon. Terrestrial basalts in thin section are almost invariably altered to some extent by water in the magma or lava, which produces greenish minerals such as chlorite (a form of mica). Many basalts in older terrains may be almost completely altered to chlorite or hornblende, and many metamorphic rocks, such as amphibolites, are actually completely altered basalts. Lunar anorthosites and related rocks, consisting largely of plagioclase feldspar, similarly show no hydrothermal alteration, which would produce mica or clay. The appearance of crystalline lunar rock in thin section (**Fig. 2**) is notable for the sharp outlines and clarity of the minerals, in contrast to most comparable terrestrial rocks.

The **absence of oxidation**, already discussed for lunar soils, shows up in the color of lunar rocks and for that matter the terrain of the Moon itself. Teachers should ask the students what color the Moon is, as seen from the Earth when high in the sky, and then contrast it with the browns, yellows, and reds so common on the Earth. This contrast is ultimately the result of the apparent absence of water on or in the Moon. (There is probably water ice at the north and south poles, but this may be from comets.) The orange soil of the lunar sample disks was collected by the Apollo 17 astronaut Harrison Schmitt, the only geologist to land on the Moon. He noticed it because of its striking color (**Fig.3**), which he at first thought might indicate oxidation. Analysis back on Earth showed that it was instead a deposit of orange glass beads, apparently formed in a volcanic fire fountain, with an orange color produced not by oxidation but by an unusual chemical composition.

The **widespread occurrence of breccia** (**Fig. 4**),samples of which are in the lunar sample disk, strongly suggests a lunar origin. Any photo of the lunar surface, even from the Earth, will show that the face of the Moon is intensely cratered . Students are now familiar with the concept of meteoritic or cometary impact from recent disaster movies and television. A close-up picture of the lunar surface, from orbit or from the ground, will show that the terrain is saturated with craters (**Fig.5**). The lunar soil, or regolith, in fact covers the bedrock almost everywhere, and the Apollo astronauts never did sample an undisturbed bedrock outcrop. This is why breccias are among the most common type of rock sample collected by the astronauts. There are of course breccias on the Earth, as in fault zones or volcanic areas. However, these are relatively restricted occurrences. Breccias are in contrast almost everywhere on the Moon.

Evidence of **shock metamorphism** is common in lunar rocks, especially those from the lunar highlands. The most obvious such evidence is, first, intense brecciation and granulation. Some crystals show planar deformation features distinct from cleavage. Glass formed by shock waves, sometimes preserving the shape of crystals, occurs in some lunar samples. This criterion for a lunar origin requires use of a petrographic microscope and familiarity with shock metamorphism, and may not be useful for most classes.

This summary has touched on only the most obvious characteristics of lunar rocks, those of possible use in classrooms. There are many others pointing to a lunar origin: extremely great radiometric ages (as high as 4.5 billion years), cosmic-ray induced radioactivity, isotopic chemistry, and many more. These are described in any one of several textbooks and may be worth mentioning in class.

Summary

Absurd though it is, the conspiracy theory for the Apollo landings can be used as an effective teaching device. Most fundamentally, it can encourage students to think things through for themselves, to test the "theory." The Moon itself is easily visible; students can see its colors, such as they are, for themselves. More exciting is the possibility of studying samples returned from the Moon. The lunar sample disks have been used successfully for years; the students can make their own scientific evaluations of the conpiracy theory.

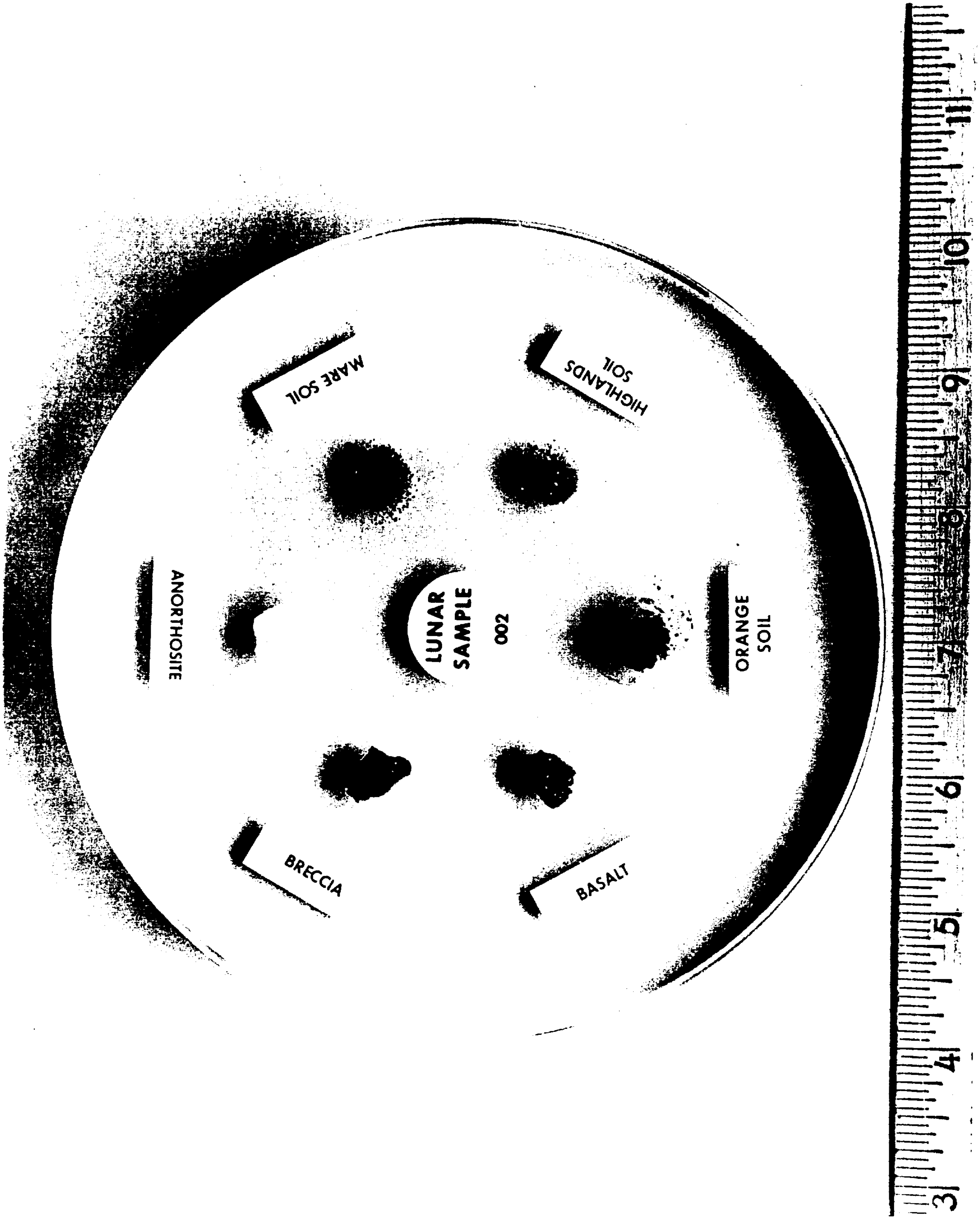
References

The New Solar System (3rd ed.); J.K. Beatty,B. O'Leary, and A. Chaikin, Cambridge University Press, 1997. *Includes an excellent chapter on the Moon by B.M. French, with good color pictures of lunar rocks in thin section.*

Lunar Sourcebook: A User's Guide to the Moon, G. Heiken, D. Vaniman, B.M. French, Cambridge University Press, 1991. *Encyclopedic volume with technical information on all aspects of the Moon, especially mineralogy, petrology, and regolith properties.*
McSween, H.Y. Jr., Meteorites and Their Parent Planets, Second Edition, Cambridge University Press, 1999.

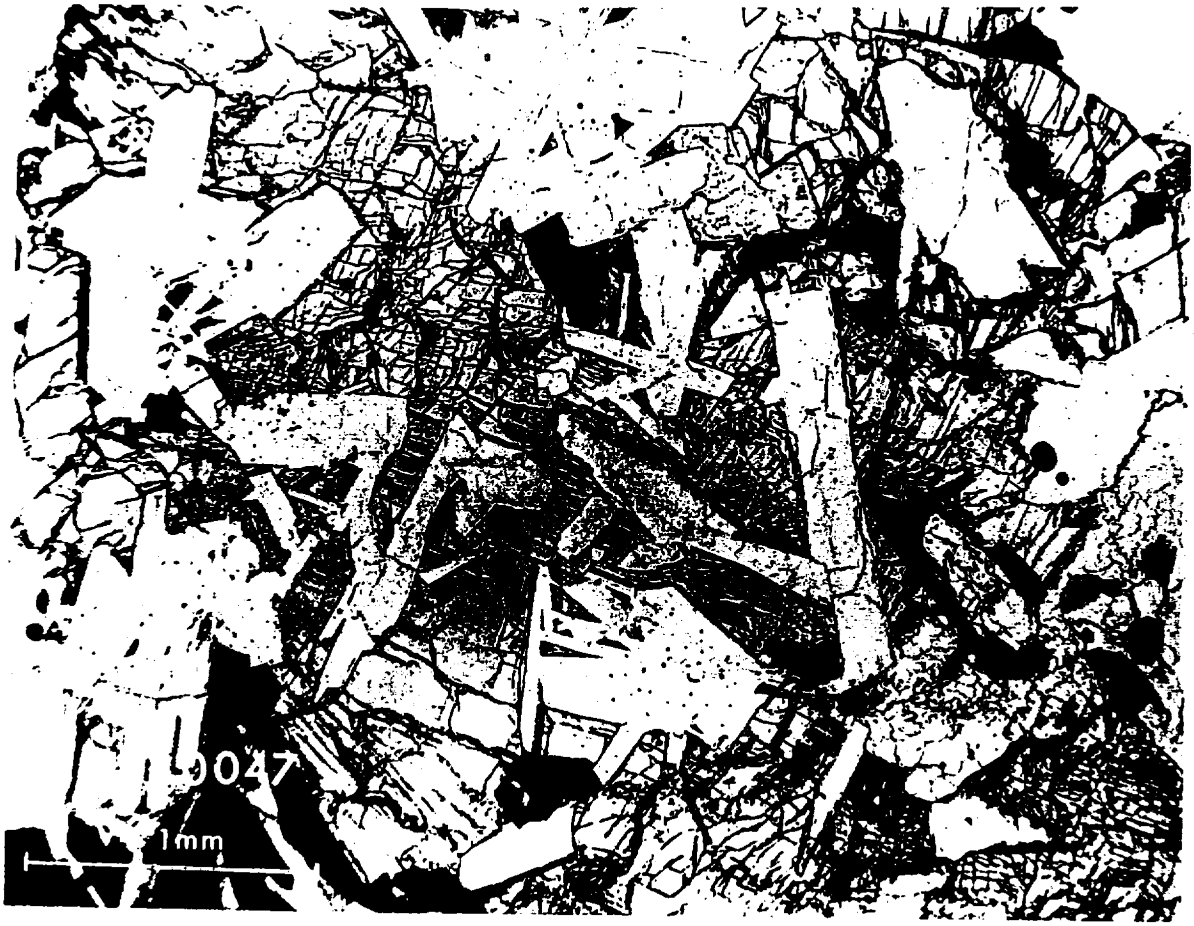
Figures

1. Lunar sample disk; lunar materials embedded in plastic. "Orange soil" is from the Apollo 17 mission; see text.
2. Thin section of Apollo 11 basalt 10047, viewed in plane-polarized light. White crystals are plagioclase feldspar, gray are pyroxene, black are ilmenite. Note sharp crystal and lack of alteration.
3. Exposure of orange soil at Apollo 17 landing site. Gnomon gives local vertical and color bars give standard colors. Boot prints indicate size of features. Photograph by Apollo 17 astronaut Harrison Schmitt.
4. Thin section of breccia (BRECHea) from Apollo 12 landing site. Rock and mineral fragments and some glass beads in opaque fine-grained matrix.
5. Lunar Orbiter III photograph of Oceanus Procellarum near Apollo 12 landing site, showing typical mare terrain and dense crater population. Fresh crater at center is about 130 m wide; concentric structure shows penetration of 5 -15 meters of regolith to bedrock.



LUNAR SAMPLE
002
ANORTHOSITE
MARE SOIL
HIGHLANDS SOIL
ORANGE SOIL
BRECCIA
BASALT
3
4
5
6
7
8
9
10
11

Fig. 1



Thin section of Apollo 11 basalt 10047, plane-polarized light. Note sharp crystal outlines and lack of alteration. White crystals are plagioclase, gray pyroxene, black ilmenite.

Fig. 2

NASA
S17-137-20990

Fig. 3

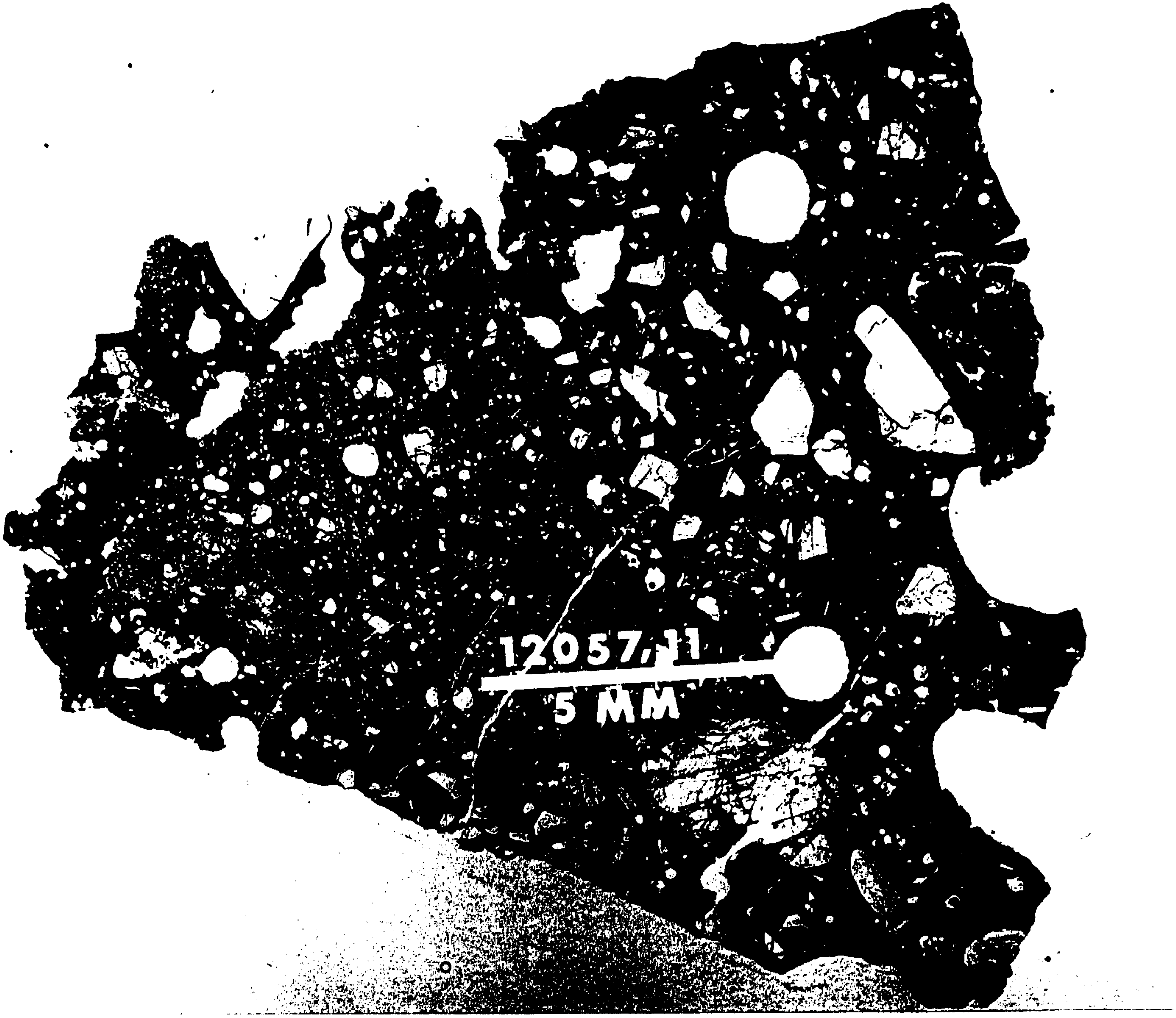


Fig. 4

Lunar Orbiter III photograph of Oceanus Procellarum, showing typical mare terrain and crater population. Fresh crater at center about 130 m. wide; concentric structure shows penetration of 5 -15 m. regolith to bedrock.

Reference: P. D. Lowman, Lunar Panorama, Weltflugbild, 1969

Fig. 5