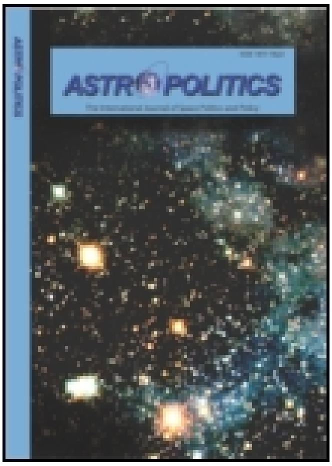

Astropolitics: The International Journal of Space Politics & Policy
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/fast20

Earth as Analog: The Disciplinary Debate and Astronaut Training that Took Geology to the Moon

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Published online: 27 Oct 2014.

Astropolitics, 12:196–209, 2014

ISSN: 1477-7622 print/1557-2943 online
DOI: 10.1080/14777622.2014.964131

Earth as Analog: The Disciplinary Debate and Astronaut Training that Took Geology to the Moon

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At the beginning of the twentieth century, geology was a terrestrial science, one that had no place making pronouncements on astronomical objects. Yet, by mid-century, this science was de rigueur in lunar studies. This article examines the heated debate, leading up to the Apollo missions, amongst geologists as to whether their discipline could tell scientists anything about the surface or composition of other celestial bodies. Precisely because the United States Geological Survey opened an Astrogeology Branch and geology education became a part of astronaut training, geologists gradually accepted the extraterrestrial application of their field and the prestige that came with it. In addition to recounting this disciplinary shift, this article considers how Earth itself became an analog for understanding the Moon. Before Neil Armstrong took his "one giant leap," astronauts traveled with trained geologists to sites that they thought would resemble the geologic composition of the Moon. There, astronauts were trained to identify different rock types and perform "analog fieldwork" that would prepare them for the science objectives of their lunar voyage. Upon landing on the Moon, several astronauts remarked at how much the Moon looked like the American Southwest, the landscape in which they were trained. Analogy is not just a cognitive heuristics used by scientists, but it is also a technique that can be embodied and enacted, as illustrated by this case of taking geology to the Moon.

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In 1895, Grove Karl Gilbert, the president of the Geological Society of Washington (and former president of the Geological Society of America), addressed its assembled members on the topic of the generation of scientific hypotheses. In "The Origin of Hypotheses," Gilbert took a philosophical tone and observed that new ideas are not generated out of nothing, but rather "hypotheses are always suggested through analogy . . . . Analogic reasoning suggests that the desired explanation is similar in character to the known, and this suggestion constitutes the production of a hypothesis."[1] Gilbert took as an example recent competing theories over the origin of a large crater located in Arizona. Scientists had developed four hypotheses to explain its origin, and for each, Gilbert conveyed to his audience the analogy that led to the hypothesis. To explain the analogy undergirding the hypothesis of a meteoric collision, he said, "A raindrop falling on soft ooze produces a miniature crater; so does a pebble thrown into a pool of pasty mud."[2] People regularly encounter the creation of such small-scale craters, and analogic thinking enlarges such an event, thus inviting a hypothesis that explains the origin through what he called "stellar impact."

Curiously, Gilbert went through his topographic analysis of the site in order to explain to the audience that a rival hypothesis, one that explains the crater as a result of volcanic activity, is more fitting. This is particularly surprising given that, two years earlier, Gilbert became one of the first advocates of the impact theory, as opposed to volcanic theory, to explain the craters on the Moon. The site near Arizona, which today is called Meteor Crater, was in fact formed through meteoric impact, and hence, in a similar fashion to most of the craters on the Moon. Sixty years after Gilbert's talk, Meteor Creator would serve not only as analogic inspiration for thinking about lunar geology, but also as a training ground for aspiring lunar geologists, known otherwise as astronauts, to experience this analogy.

This article considers two aspects of analogy in science: both how analogy, just as Gilbert suggests, structures written and spoken reasoning, and how people come to embody analogies; and how analogy becomes a lived experience. In this case study, I examine how geology became the dominant science used for lunar studies. Originally understood by scientists as an astronomical object—one knowable only through remote observation—by the time astronauts landed on the Moon's surface, it was thoroughly geological. The early disciplinary debate over whether geological reasoning could be extended beyond the Earth's surface is an example of analogic reasoning in its most traditional sense; of seeking to apply the familiar to the unfamiliar through means, as suggested earlier, of written and spoken comparisons. However, I argue that what solidified the logic that underlay geology's claim to lunar science came with the physical embodiment of the analogy: the training of astronauts to perform geological fieldwork on the Moon. This article shows how analogy travels out of the realm of the mind, structures material practice, and in so doing reinforces the initial analogic relationship.

Philosophers and historians of science have well considered the role of analogy in the service of knowledge production.[3] Mary Hesse, for example, was one of the first to discuss how analogies are heuristics that guide scientific studies of the unfamiliar.[4] Katherine Park, Lorraine Daston, and Peter Galison ask, in a collection of essays, about the role imagination played in constructing scientific analogies for early seventeenth-century thinkers. Daston considers some of the writing of Galileo to argue that while he drew on analogy as a way to describe the unfamiliar astronomical world, he was hesitant to use analogy to derive an explanation of the physical world (in the way Gilbert suggests scientists constantly do). The senses, not the imagination, were most reliable.[5]

And yet the Moon, one of Galileo's most famous objects of study, was long accessed only through the realm of the imagination. The Moon is unfamiliar, a tantalizing unknown looming large in the sky but, until recently, impossibly far away. It was not always imagined to be like the Earth. The Platonic Moon, for example, was a smooth orb of a divine quality. However, the naked eye sees the Moon not as a uniformly glowing sphere, but instead as spotted. The reason for these discolorations prompted much philosophical debate during the Middle Ages, with just as many people believing the spots were a sign of the pervasiveness of original sin across the heavens as those believing the spots were mountains and oceans.[6]

With his telescope, Galileo was able to bring the Moon closer to the world of sensory experience, thus distancing it from the realm of the imagination. However, even to see the magnified Moon as a landscaped surface like Earth was not an obvious interpretation. Historian Samuel Edgerton contrasts the telescope-aided drawings produced by Thomas Harriot in London, which lacked a sense of three dimensions and thus landscape, with Galileo's drawings published a few months later. Edgerton's argument is that because Galileo received artistic training in the new ways of Florentine perspectivism, he was able to interpret the dark spots on the moon as shadows cast by the sun.[7] Perhaps contrary to Daston's observation that Galileo was uneasy with using analogy as explanation, here he in fact did create a new hypothesis as to the nature of lunar features. Galileo might have thought he was merely drawing what he saw, but he was, at the same time, solidifying a hypothesis. This also serves to illustrate that seeing the Moon as mountainous was not simply a rational act, but also a physical act. Through the experience of drawing the lunar surface, Galileo was working out an analogy—connecting the phenomenon of shadows and landscapes on Earth with those on the Moon.[8] In describing one of his drawings of the Moon, Galileo articulated this analogy: "This same spot before the second quarter is seen to be walled round with boundaries of a deeper shade, which, just like very lofty mountain summits, appear darker on the side away from the Sun, and brighter on the side where they face the Sun."[9]

Analogy in science must be understood not only as ways of thinking, writing, and speaking, but also as embodied ways of being. In continuing to think about the analogy between the Earth and the Moon, I will first consider a debate that occurred in the geology community that began at the turn of the last century, but grew more fierce at the dawn of the Apollo program in the late 1950s and early 1960s over whether geology was a science that extended beyond the Earth. Throughout this debate, practitioners made rational, analogy-based appeals to the application of geology to the Moon and other planetary bodies. Even as this debate was being played out, the proponents of astrogeology, as it would be called, began enacting the analogy—making it a part of lived experience—by folding geological thought and practice into astronaut training. Ultimately, the rhetorical and embodied forms of analogy reinforced each other and firmly recast the Moon not as astronomical, but as geological.

RECASTING "GEO" AS EARTH

Modern geology, which emerged as a field in the beginning of the nineteenth century, was established as the study of Earth. Its founders did not foresee geology's application to the Moon or other planets and, when this possibility was broached, not all geologists were in favor of expanding the scope of their discipline. Geologists, astronomers, and thinkers from other fields discussed the question of what discipline was most appropriate for lunar study. These conversations reveal as much about ideas of the Moon as they do about the politics of science and its disciplines leading up to Project Apollo. Astronomy had long laid claim to studies of the Moon, so for geology to become not only relevant but indeed supersede astronomy as the preferred method of lunar study required a negotiation of the boundary between disciplines and ultimately an appeal to analogic thinking.

Fifty years prior to the core of this debate, in 1870, the British *Fortnightly Review* published an article concerning what constitutes "a science." In this article, the author made passing reference to selenology, or the study of the Moon. Primarily, the purpose of the article was to dismiss a previously published critique of Comte, which appeared in the same journal and argued that political economy deserved status as a science independent of sociology. To highlight the implications of such bifurcations, the author drew an analogy with the study of the Moon, stating that though selenology might be used to describe facts relating to the Moon, "There is no such science as selenology or heliology [the study of the sun], though astronomers may sometimes study the Moon and then the sun, *as* astronomers."[10] What is important in this quote is not the claim that selenology is not a science on its own,[11] but the broader idea that disciplinary positioning matters more than the object of study itself. Even before the Moon became a political object embroiled in the Cold War, arguments regarding how one should study the Moon served, at least in this one case, as an example of the structural importance of disciplines.

Also clear from this article is that astronomy was the presumed approach to selenology. It is perhaps unsurprising, then, that when the young upstart of a discipline geology began claiming that the Moon could be studied from its disciplinary perspective, astronomers were taken aback. Prior to the space program, the occasional geologist would gingerly dip a toe in the extraterrestrial waters. Early letters to the *Geological Magazine,* which was first published in 1864, would remark upon geologic formations spotted through telescopic lunar observations.[12] There were mountains and perhaps even glaciers on the Moon, structures that surely necessitated a geologist's expertise. Later, in 1938, Herman Fairchild, with apologies, suggested that geology might have something to offer the field of selenology.[13] More daringly, with breakthroughs in solar system science looming, Jack Green and Dael Wolfle suggested, in 1960, that distinguishing selenology from geology set a dangerous precedent of coining a field and associated terms for each planet in the solar system. Instead, "*Geology* and the *geo* terms can be extended from their earthly meaning to cover similar processes and features of other cosmic bodies . . . . Wherever they occur, a caldera is a caldera, sulfur is sulfur, and a reverse fault is a reverse fault."[14] Geology, they argued, was not tied to Earth, but was perhaps what tied Earth to other planets.[15]

One of the key mysteries that faced lunar studies was the origin of the thousands of craters on the Moon. The favored theory of astronomers and geologists through the eighteenth and nineteenth centuries was that of volcanic origin. Geologist Karl Gilbert, as noted at this article's outset, was an early proponent of the impact theory of crater formation, a theory that postulated that the pockmarked face of the Moon was created through a bombardment of its surface by space debris (though when this bombardment occurred was a point of debate). In his 1893 article, Gilbert noted that his discipline might help shed a new perspective on crater formation, and put forth a "plea" for astronomers to acknowledge that "the problem [of crater origin] is largely a problem of the interpretation of form, and is therefore not inappropriate to one who has given much thought to the origin of the forms of terrestrial topography."[16] Using such language, he carefully justified a geologist's utility on the matter. Despite Gilbert's paper, it took nearly 50 years for the impact theory to be accepted. Throughout the first half of the twentieth century, astronomers and geologists disputed whether impact or volcanic activity caused the Moon's pock-marked appearance. Remarking on the rival crater theories, the geologist William Morris Davis quipped in his 1926 biography of Gilbert:

> It has been remarked that the majority of astronomers explain the craters on the Moon by volcanic eruptions—that is, by an essentially geological process—while a considerable number of geologists are inclined to explain them by the impact of bodies falling upon the Moon—that is, by an essentially astronomical process. This suggests that each group of scientists finds the craters so difficult to explain by processes with which they are professionally familiar that they prefer recourse to a process belonging to a field other than their own, with which they are probably imperfectly acquainted and with which they therefore feel freer to take liberties.[17]

In this lighthearted manner, Davis highlighted the flexibility that came with a multi-disciplinary approach to the Moon. In taking geology's application to the moon seriously, terrestrial analogs were ready at hand to explain lunar phenomenon. A trained geologist like Gilbert, however, saw too many failings of the volcanic analogy to let that stand as the solution. As geology continued to mount its case that it was a useful science for studying the Moon and as geologists continued to challenge astronomical assumptions, tensions arose between the two disciplines.

In 1956, a young employee of the United States Geological Survey (USGS), Eugene Shoemaker, whose involvement in plutonium production had led him to study craters caused by underground nuclear detonations, approached the director to see if the Survey would support the production of the first geologic map of the Moon. Such an undertaking would give material credence to geology's claim to lunar studies, but it also required stretching the limits of analogy to create a geological map without physically being in the territory to be mapped. Shoemaker didn't begin this project until 1959 when, while working at the USGS branch in Menlo Park, California, he and a small team used detailed lunar photographs to sketch geologic maps of the Moon's surface, and thus, deduce its stratigraphy.[18] In 1960, Shoemaker became the first director of the Astrogeologic Studies Group, which would later become a branch of the USGS.[19] Once Shoemaker successfully secured his group as NASA's geologic brain trust and relocated to Flagstaff, Arizona, the newly named astrogeologists began refining their maps to aid in landing-site selection, first for robots and later for humans.

The geological community received the remote reconnaissance he was doing of the Moon with skepticism. Don Wilhelms, one of Shoemaker's early recruits, recalled giving a lecture at a French observatory in 1963. He explained to the audience that you can tell the age of craters through visual inspection. The reaction to this claim was simple disbelief—that you could geologically know a place without physically being there was a proposition his audience was unwilling to accept. Wilhelms retrospectively noted, "And that's been my experience through most of my career, especially in the sixties . . . in those days, it was like pulling teeth to get even a geologist to understand it."[20]

By the 1960s, whereas astronomers embraced the presence of a geological perspective in their studies of the Moon, some within the geological community continued to resist extending their jurisdiction beyond the Earth. Several geologists spoke out against the co-optation of geology by their rogue colleagues and attempted to reign in geology as a uniquely Earthly discipline. Kalvero Rankama of the University of Helsinki protested in 1962: "I, for one, am taking strong exception to the use of 'geology' in [planetary geology, lunar geology, and astrogeology]." He proposed "planetology" to be the description for these branches of study. Rankama went on to say, "Clearly, geology is restricted to the study of the Earth and of terrestrial phenomena and does not apply to extraterrestrial bodies and processes."[21] The retort to this, which came a few years later, was that geology is not about Earth with a capital E, but lower-case earth. In a short piece in *Geotimes*, American lunar scientist Luciana Ronca wrote, "It is the idea of the solidity, the stability of the land on which we can safely land after a travel through a more precarious medium, and it is the rock that composes this land." Ronca then extended the analogy from early explorers who traveled through the seas to new land to the astronaut explorers traveling through space to new, solid surfaces. Ronca argued, "Geology will be the study of the place where they land."[22]

As Shoemaker's team continued to make geology a part of both flight planning and astronaut training, a topic to which this article will shortly turn, and even though some geologists were slow to embrace their field as extraterrestrial, an astute astronomer noted the rising star of astrogeology. In a preface to a 1966 book entitled *An Introduction to the Study of the Moon*, the astronomer Zdeněk Kopal remarked, "As a result of these changing means of research [the direct exploration by spacecraft], the Moon may soon cease to be treated as an astronomical object, and be professionally annexed by other sciences more intimately connected with direct exploration. The present volume may, perhaps, be the last monograph devoted to our satellite to come out from the pen of an astronomer."[23] The application of geology to the Moon began by simply testing the limits of analogy; debating whether what we know about Earth's mountains and volcanoes had application to another cosmic surface. Now, though, the successfully drawn analogy had implications. Not only did it offer new hypotheses, but it also shifted the dominant approach to lunar studies—the Moon ceased to be an astronomical object and had become instead a geological object. Analogy shifted disciplinary domains.

After landing a man on the Moon and acknowledging the several million dollars that NASA diverted to the USGS during the Apollo Program, there was little hope for the dissenters to keep geology grounded on Earth. In a presidential address to the Geological Society of America in 1970, Morgan

Davis began by declaring the past year "the most momentous year the geological profession has ever known. I refer, of course, to the lunar landing."[24] He used the opportunity to chastise those who sought to limit the scope of geology, urging his colleagues to embrace the study of the ocean floor, the Moon, and other planets. And by 1973, a retrospective of scientific work accomplished during the concluded Apollo program was careful to state, "This article attempts to evaluate the effect of the Apollo program on geology (using the term in its broadest sense)."[25] Geology, successfully but perhaps a bit uncomfortably, was now a science applicable to the Earth, Moon, and the other planets NASA would hopefully continue to study and explore.

EMBRACING AND EMBODYING LUNAR GEOLOGY

If geology worked as an analogy to bridge the Earth and the Moon, astrogeologists wondered how to translate the more physical component of geology—fieldwork—from the terrestrial surface to lunar surface. Would learning how to do fieldwork on Earth translate to recognizing geologic formations on the moon? To figure this out, astrogeologists at NASA's Manned Spacecraft Center (MSC) worked with the USGS to turn some of the astronaut's "Right Stuff" into knowledge about "Rock Stuff." The astronauts had to embody the analogy that geologists had carefully drawn between the Earth and the Moon. That geology was so successfully incorporated into astronaut training shifted the question from whether geology was an appropriate science for lunar study to the limits of "analog training." Could one's training in terrestrial geology and fieldwork translate to the extraterrestrial?

The flourishing of the USGS's Astrogeology Branch helped legitimize geology as a multi-planetary science. In 1963, the branch moved from its original offices in Menlo Park, California, to Flagstaff, Arizona. There, staff had better access to telescopes and clearer seeing as they mapped the Moon. And, not insignificantly, it was near Meteor Crater. Geologists had been doing fieldwork there for some time to learn about impact geology as it might be applicable to the Moon. This same year, Shoemaker ran the first astronaut field camp, bringing the second class of astronauts (the nine selected in September 1962) to Meteor Crater for their first experience as geologists.[26]

An agreement between NASA and USGS led to formalizing the Astrogeology Branch's role in astronaut training. Preparing men to travel into space required not only a knowledge of science, but also familiarity with technological systems, the outer space environment, maneuvering in zero-G and low-G, and survival scenarios. In 1965, *National Geographic* magazine published an article by Robert Gilruth, the director of MSC located near Houston, on the rigorous training his center ran that prepared astronauts for space. Alongside Gilruth's text were large glossy photos which featured the astronauts training in many different surroundings. There were pictures of astronauts-in-training, dressed in orange flight suits, being fed boa constrictor by a traditionally dressed Choco Indian from Panama, as well as images of them in the American West, with field notebooks, pickaxes, leaning over to closely examine a rock structure. Was geologic training just as exotic (or perhaps just as farcical) as survival training in South American jungles? The article concluded by discussing the science training of the astronauts. One of the USGS scientists explained that, even though they bring astronomers to the telescope to look at the Moon, the atmosphere keeps the men from having a clear view:

> "What *would* be the best optical system for studying the moon?" [astronaut] Bill Anders asked. [Astronaut] Walter Cunningham offered an answer: "A hand-held magnifying glass—you just have to get close enough to use it."[27]

Astronauts were not entirely positive towards the amount of time they spent in the classroom, which took them away from their spaceships. Science training was one of 10 areas astronauts were expected to spend considerable time mastering. Alongside learning to fly their spacecraft and training for every conceivable malfunction, astronauts were required to participate in "Scientific and Technical Background Training." In his memoir, Michael Collins recalls his reaction to seeing his "NASA school" schedule in 1964. The 11 subjects they were expected to brush up on included 15 hours of astronomy, 12 hours of medical, 40 hours of flight mechanics, and the most time—58 hours—was assigned to geology.[28] Collins was not happy about the prospect of staring at rocks for long stretches of time. He was more dismayed when he realized that this was only training series one, and there were to be six more.[29]

Geology must not only be learned in the classroom, but also by seeing rocks *in situ*, in the field. The USGS training team faced a problem: How do you teach someone to be a geologist before they have set foot on the terrain they were going to be studying? To teach fighter pilots how to identify rocks and make sense of their lunar surroundings, the geology training included mini-fieldtrips. After all, as one member of the Astrogeology Branch put it, "fieldwork is the essence of geology, it really is. You know, you don't get any sense of the complexity of geology until you go out and try and do it."[30] And as Wilhelms has written, "How much geology a geologist knows depends very much on the amount he or she sees firsthand."[31] Shoemaker and his colleagues all received extensive fieldwork training in their geology education and wished to impart this to the astronauts. Shoemaker recalled his plan to "get scientist-astronauts away from their day to day involvement in the flight program and all the other activities the astronaut had, de-orbit them for a while, get them on the ground, give them three months of really solid training—which is what it takes. You have to go out and do fieldwork to learn how to do fieldwork!"[32]

The aspiration behind astronaut training was not only to get them to see like geologists, but also to teach them how to compare what they saw on Earth to what they would see on the Moon—to get them to think through analogy. Donald Beattie, in his memoir *Taking Science to the Moon*, writes, "On missions to the Moon some of the astronauts would comment on how much the Moon's surface looked like their memory of [their field-work sites]."[33] Similarly, Gilruth related in his *National Geographic* article that he hoped that the lunar training room they built in Houston, one meant to mimic the surface of the Moon, would be perfected "to the point that the first astronaut on the Moon will say, "Hey, this reminds me of Houston . . . ."[34] The analogy between Earth's surface and the Moon would be so secure that, upon finally coming into contact with the unfamiliar Moon, it was comprehended through the lens of our familiar Earth.

As training progressed, geologists accompanied astronauts all over the world to teach them different aspects of geology that they might encounter on the Moon. For example, Meteor Crater taught astronauts about impacts and Hawaii about lava flows. The geologists involved in selecting these fieldwork sites, both at USGS and NASA, were constantly in search of a perfect analog, the most lunar-like terrain. Unable to find the perfect site, partway through the Apollo training, USGS astrogeologists at the Flagstaff branch decided to craft their own ideal lunar landscape. After carefully studying a region of the Moon photographed by the Lunar Orbiter, they precisely placed explosives and produced, to the extent possible, a facsimile of the cratered lunar surface just outside of Flagstaff.[35] Geologic analogies, it seemed, worked in both directions: the Moon could be understood through a terrestrial landscape, but also a landscape on Earth could come to stand for the moon. Further, being in the field at such analog sites was made to be both a legitimate and necessary way of knowing other cosmological surfaces. It is through these embodied fieldwork practices that astronauts refashioned the Earth as the Moon, and the Moon as Earth, so that they could make scientific sense of the lunar surface.

Much of the astronaut field training took place in Arizona, Texas, California, and New Mexico. The astronaut's presence in these sites served to reinforce another analogy of the space age: that of the frontier. Though astronauts were fashioned to behave like geologists through their training, they much more identified as pioneers or cowboys, setting out into the untamed wild of their own accord. A poster from 1984 that celebrates the role Houston has played in the space program illustrates the enduring notion of the cowboy astronaut. The poster depicts an astronaut floating in space, with the traditional astronaut suit supplemented with a cowboy hat, boots, and a branding iron in the shape of the lone star. The caption of the poster reads, "Texas—Still in the Frontier Business." The seeds for this poster were planted 20 years earlier when, during geological training in the American West, astronauts were physically placed in and surrounded by the landscape most associated with the frontier.

In American history, the frontier was first synonymous with the American West and later, after this frontier was "closed," with scientific progress.[36] With the establishment of NASA and the goal of setting foot on the Moon, a new physical frontier was united with the scientific frontier.[37] Shoemaker, who found the frontier a compelling analogy for the growth of scientific research, recalled how this comparison ultimately unraveled:

> I tried to draw—at the AAAS [American Association for the Advancement of Science] meeting—an analogy between the early exploration of the American West and the Apollo program. The difference, of course, was the early exploration of the American West led to evolving, continuing, growing scientific enterprise. The Apollo program didn't. But at that stage it wasn't clear it was going to happen that way. I was trying to say what we wanted to do was just build on this early stage exploration and go on to a really deep, meaningful program of scientific exploration.[38]

Even while the Apollo program was still going on, Shoemaker began speaking out against NASA's vision of exploration. He rightly diagnosed NASA as an organization of engineers, more interested in "can" than "why." After landing on the Moon, he did not think NASA should move quickly to Mars, the next target.[39] Instead, the Moon should be refashioned as a scientific frontier and explored in that nature. To prove that a destination could be reached did not, for Shoemaker, fulfill the promise of the frontier.

The frontier and fieldwork were both central components of analogic relationships that positioned the Moon in certain social and scientific configurations. The physical, embodied act of being in the American West and studying the landscape from a geological perspective effectively silenced dissenters who, a decade earlier, might have questioned the validity of such preparatory work. Though no astrogeologist working in the 1960s and 1970s would claim to be satisfied with the amount of science that came back from Apollo, the astronauts were able to translate their terrestrial training to the lunar surface. There were a few golf swings and flag-raising ceremonies, but most extravehicular activities were devoted to examining, scraping, collecting, and describing geological formations. The astronauts were clearly doing geology, proving that the analogy that fueled their training was, after all, appropriate.

CONCLUSION

The moment of exploration discussed in this article has lasting implications that continue to shape today's planetary science community. There are no vestiges of the debate over whether or not geologic processes are the same on Earth and other planets. In some sense, geology is no longer an analogy; it simply is a science of many worlds. I suggest that it was the act of embodying this analogy, in the context of astronaut training, which provided the scaffolding for the seamless and ultimately uncontroversial integration of geology into the space sciences.

In fact, the analogic reasoning that underlay the astronaut training continues to strongly influence planetary scientists. To study other planets, particularly Mars, or think about astrobiology and extreme life more generally, many planetary scientists today participate in the very mainstream work of "analog fieldwork." There are dozens of sites around the world that scientists at NASA and universities travel to as part of their research activities. In going to these sites, scientists enact an analogy and connect to the unfamiliar by studying the familiar and close at hand. Analogy allowed the science of geology—a science premised on proximal encounters—to make epistemological sense even when what one is studying is remote. Analogy, as an embodied way of being and knowing, quite literally connects worlds.

NOTES

1. Grove Karl Gilbert, "The Origin of Hypotheses, Illustrated by the Discussion of a Topographic Problem," *Science* 3:53 (1896): 5.

2. Ibid., 8.

3. Max Black, *Models and Metaphors; Studies in Language and Philosophy* (Ithaca, NY: Cornell University Press, 1962); Fernand Hallyn, ed., *Metaphor and Analogy in the Sciences* (Dordrecht: Kluwer Academic Publishers, 2000); and Sabine Maasen and Peter Weingart, *Metaphors and the Dynamics of Knowledge* (New York: Routledge, 2000).

4. Mary B. Hesse, *Models and Analogies in Science* (London: Sheed and Ward Ltd., 1963).

5. Katherine Park, Lorraine J. Daston, and Peter L. Galison, "Bacon, Galileo, and Descartes on Imagination and Analogy," *Isis* 75:2 (1984): 287–289; and Lorraine J. Daston, "Galilean Analogies: Imagination at the Bounds of Sense," *Isis* 75:2 (1984): 302–310.

6. Scott L. Montgomery, *The Moon and The Western Imagination* (Tucson, AZ: University of Arizona Press, 1999), 20.

7. Samuel Edgerton, "Galileo, Florentine 'Disegno,' and the 'Strange Spottednesse' of the Moon," *Art Journal* 44:3 (1984): 225–232.

8. See William Shea, "Looking at the Moon as Another Earth: Terrestrial Analogies and Seventeenth-Century Telescopes," in Fernand Hallyn, ed., *Metaphor and Analogy in the Sciences* (Dordrecht: Kluwer Academic Publishers, 2000), 83–104.

9. Galileo Galilei, *Sidereus Nuncius*, trans. Peter Barker (Oklahoma City: Byzantium Press, 2004), 10.

10. Frederic Harrison, "Professor Cairnes on M. Comte and Political Economy," *Fortnightly Review* 8 (1870): 43.

11. I have no evidence that this was a matter of controversy in the scientific community; rather, this is an example of convenience meant to serve the larger debate concerning positivism.

12. See, for example, Volume III of this journal, January–December 1866, pages 91 and 141.

13. H.L. Fairchild, "Selenology and Cosmogeology: Cosmic and Geologic Import of the Lunar Features," *Science* 88:2294 (1938): 555–162.

14. J. Green and D. Wolfle, "Gea, Daughter of Chaos," *Science* 131:3407 (1960): 1071.

15. My thanks to one peer reviewer, when reading an early draft of this paper, who pointed out that while I focus here on examples of geologic interpretation of the Moon coming from geologists, astronomers during this same time period were forming their own hypothesis about the geological nature

of formations on the Moon. It would not be until the mid-twentieth century and the development of planetary science as a multidisciplinary pursuit that these parallel conversations in geology and astronomy would come together.

16. Grove Karl Gilbert, "The Moon's Face: A Study of the Origin of Its Features," *Bulletin of the Philosophical Society of Washington* XII:3 (1893): 242.

17. Quoted in Zdeněk Kopal, *An Introduction to the Study of the Moon* (Dordrecht: Astrophysics and Space Science Library, 1966), 267. There were, of course, geologists who favored the volcanic theory and astronomers who warmed to the impact theory. In a 1962 publication, one geologist, noting that "From an astronomical point of view, a lunar terrain heavily impacted with meteors appears the more reasonable; although from a geological standpoint, volcanism seems the more probable mechanism," chose to therefore favor the volcanic theory. Zdeněk Kopal and Zdenka Mikhailov, eds., *The Moon* (London: Academic Press, 1962), 169.

18. The first geologic map of the moon printed by the Survey was actually produced by another group that wasn't institutionally supported in the long run in the way Shoemaker's group was. Don E. Wilhelms, *To a Rocky Moon: A Geologist's History of Lunar Exploration* (Tucson, AZ: University of Arizona Press, 1993), 38–40.

19. David H. Levy, *Shoemaker by Levy: The Man Who Made an Impact* (Princeton, NJ: Princeton University Press, 2002), chapters 7 and 8.

20. Don E. Wilhelms, Niels Bohr Library & Archives, American Institute of Physics, interview by Ronald Doel, 22 June 1987, http://www.aip.org/history/ohilist/5064.html (accessed August 2014). This quote is a bit surprising, as applying the principle of superposition to the Moon was not a controversial move. Wilhelms gave this talk while he was a resident researcher at the Meudon Observatory to an audience of astronomers who were already inclined to doubt the qualitative approach of geology. In fact, the reason for Wilhelms' visit was to study a more quantitative observational technique, polarization, that Shoemaker believed would offer legitimacy to astrogeology.

21. K. Rankama, "Planetology and Geology," *Bulletin of the Geological Society of America* 73:4 (1962): 519.

22. L.B. Ronca, "Selenology vs. Geology of the Moon Etc," *GeoTimes* 9 (1965): 13. This exchange between Rankama and Ronca is also noted in Matthew Benjamin Shindell, "Domesticating the Planets: Instruments and Practices in the Development of Planetary Geology," *Spontaneous Generations: A Journal for the History and Philosophy of Science* 4:1 (2010): 204–205.

23. Kopal, *An Introduction to the Study of the Moon*, ix.

24. Morgan J. Davis, "The New Geology," *Bulletin of the Geological Society of America* 81:2 (1970): 331.

25. J.V. Smith and I.M. Steele, "How the Apollo Program Changed the Geology of the Moon," *Bulletin of the Atomic Scientists* 29:9 (1973): 11–15.

26. Wilhelms, *To a Rocky Moon*, 76.

27. Robert R. Gilruth, "The Making of an Astronaut," *National Geographic* 127 (1965): 144.

28. Moreover, the 1964 training document specified that, following the 58-hour course, geology training would continue on a frequent basis in preparation for the lunar landing. Additionally, geology, unlike many of the other academic training modules, was required by all astronauts. Raymond Zedekar, "Flight Crew Training Plan," *NASA General Working Paper No. 10,022*, 17 January (1964): 3-3.

29. Michael Collins, *Carrying the Fire: An Astronaut's Journey* (New York: First Cooper Square Press, 2001), 72.

30. Micheal H. Carr, Niels Bohr Library & Archives, American Institute of Physics, interview by Ronald Doel, 22 June 1987, http://www.aip.org/history/ohilist/5088.html (accessed August 2014).

31. Wilhelms, *To A Rocky Moon*, 122.

32. Eugene Shoemaker, Niels Bohr Library & Archives, American Institute of Physics, interview by Ronald Doel, 8 September 1988, http://www.aip.org/history/ohilist/5082_4.html (accessed August 2014).

33. Donald A. Beattie, *Taking Science to the Moon: Lunar Experiments and the Apollo Program* (Baltimore: Johns Hopkins University Press, 2001), 181.

34. Gilruth, "The Making of an Astronaut," 144.

35. Beattie, *Taking Science to the Moon*, 182.

36. Fredrick Turner famously argued that the frontier shaped American notions of individuality and democracy. There is a significant literature produced by U.S. historians revisiting, revising, and critiquing the Turner thesis. I will simply refer to Patricia Limerick's work, both because she offers a nuanced history of the American West and because she has elsewhere written against the use of the frontier

metaphor in the space program. In 1945, Vannevar Bush opened up another frontier when he dubbed science "the endless frontier." Frederick Jackson Turner, "The Significance of the Frontier in American History (1893)," in John Mack Faragher, ed., *Rereading Frederick Jackson Turner: "The Significance of the Frontier in American History" and Other Essays* (New Haven, CT: Yale University Press, 1893), 31–60; Patricia Limerick, *The Legacy of Conquest: The Unbroken Past of the American West* (New York: W. W. Norton & Company, 1988); Patricia Limerick, "Imagined Frontiers: Westward Expansion and the Future of the Space Program," in Radford Byerly, ed., *Space Policy Alternatives* (Boulder, CO: Westview Press, 1992), 249–262; and Vannevar Bush, *Science, the Endless Frontier: A Report to the President* (Washington, DC: U.S. Government Printing Office, 1945).

37. DeGroot shows how the frontier spirit animated NASA as early as the Mercury program. The first astronauts spoke of themselves as pioneers ready to explore the frontier of space. DeGroot nicely suggests that, in the wake of the atomic bomb and the shattering of the romance of war, the press and public welcomed the resurrection of the fantastical frontier explorer. Gerard DeGroot, *Dark Side of the Moon: The Magnificent Madness of the American Lunar Quest* (New York: New York University Press, 2006), 109. Also, see Martin Parker for a discussion on how capitalism intersects with the frontier narrative in the space program: Martin Parker, "Capitalists in Space," *Sociological Review* 57:1 (2009): 89–91.

38. Shoemaker, Niels Bohr Library & Archives (note 32).

39. Eugene Shoemaker, "Space: Where Now, and Why?," *Engineering and Science* 33:1 (1969): 9–12.