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Our Beautiful Moon and its Mysterious Magnetism

A Long Voyage of Discovery

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To my dear Patricia, whose love, courage and strength have been an inspiration for me

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Contents

Introduction

Of all the millions, who have gazed at our beautiful moon over the millennia, those of us lucky enough to be alive in 1969, were the first to be able to witness human beings on the moon. Those grainy TV pictures are forever in our memories. Little did I know that the samples that Armstrong and Aldrin were collecting would play such a role in my life. At that time, my research group and I were busy trying to understand what happened when the geomagnetic field reversed its polarity and other aspects of the magnetic record of terrestrial samples. That was plenty to keep us busy.

When Armstrong, Aldrin and Collins returned safely to earth, NASA made their precious cargo of samples available to the world's scientists. It was then possible to start to answer the fundamental questions about our moon: What is it made of, how was it formed, how old is it, what was the difference between the dark Mare and the lighter regions, were those circular features volcanoes, or impact craters? Was the moon an evolved body like the earth with a crust, mantle and core? Its origin was totally mysterious. Capture was very unlikely because it was known that the probability of the necessary combination of orbits was so low. Trying to spin it off the earth faced other major difficulties. Evidently, we had lots to learn.

I was lucky enough to be involved in studies of lunar magnetism from the earliest Apollo days because Professor Nagata used to work in our laboratory in the University of Pittsburgh, so that when he was awarded some of the first samples to be studied, we helped with the measurements. In addition, I also had the good fortune to be on the lunar sample planning committee. This put me at the center of discussions of the early work on the samples and to hear the experts in other fields first hand and informally.

In the near half-century following the return of the samples, we have gone a long way to answering many of those fundamental questions. As is so often the case, the new work also raised more questions. One of the puzzles from the start was lunar magnetism, which still remains somewhat problematic, but may finally be reaching some resolution. Magnetic measurements on the lunar surface, from satellites in orbit around the moon, and on the returned samples all revealed this mysterious magnetization. Yet the moon has no planetary magnetic field actively generated as does earth. When rocks like the lavas of the Hawaiian Islands cool, they acquire what we call a paleomagnetic record of the geomagnetic field. A

remanent magnetization is stored in the rock from which we can recover the direction and strength of the field in which they cooled. On earth this field arises from the dynamo, in the fluid outer core of the earth. Was that what happened on the moon? Did the moon have a molten core giving a lunar dynamo field, or was lunar magnetism more exotic, perhaps related somehow to giant impacts on the moon?

This little book does not aspire to be a definitive scholarly text, but rather to tell, in as simple and entertaining a style as possible, the story of the great adventure of Apollo, of our new understanding of our moon, of the puzzle of lunar magnetism and of the fun of trying to find out what happened. As you will see this story is far from over for lunar magnetism, but we are making progress.

I have adopted an historical approach throughout, tracing the development of our ideas of the Earth–moon system, of the birth of the space age, of paleomagnetism and finally of lunar magnetism and its evidence for an early lunar dynamo. It is my hope that the book can be enjoyed by non-scientists, who like science and history, and by scientists not familiar with lunar science, if they skip some of the introductory material. In a further effort to serve these two masters, I have included in the notes for each chapter a few key references to the lunar scientific literature.

Before I begin the story, I would like to acknowledge the contributions of my colleagues in our research group over the years. It is one of the great joys of academic life to lead a research group. One is surrounded by bright young people to teach and from whom one constantly learns. In my group, first at the University of Pittsburgh and later at the University of California at Santa Barbara, I had the good fortune to work with outstanding colleagues. In particular, in the lunar efforts Stan Cisowski's contribution was pivotal and was the foundation of our work in the Apollo days. I also had equally outstanding senior colleagues in Bob Dunn and Vic Schmidt. Vic sadly died at far too young an age, but Bob continues to work with me nearly 50 years on.

Finally, to have worked on the lunar samples is a great honor. One only goes to the moon for the first time once! Let us hope our efforts are worthy of the opportunity. My thanks go to the many, many people, who made it all possible.

Chapter 1
The Moon in Antiquity and in the Development of Modern Science

To begin our journey to understand the puzzle of lunar magnetism, we first look at the long history of the development of our understanding of the earth moon system to set the stage for Apollo.

1.1 The Moon in the Greek World

Not surprisingly the moon plays a role in the mythology of ancient peoples. From the earliest civilizations in the near east onwards, all seem to have had lunar deities. The Greco-Roman tradition establishes female dominance in Western

Fig. 1.1 Selene visits Endymion in his eternal slumber

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Civilization lunar mythology. Selene, whose name is remembered in selenography, as studies of the moon are sometimes called, was a Greek goddess of the moon. She was a daughter of the Titans, was in love with Endymion, and asked her father Zeus to grant this beautiful mortal immortality. Zeus acquiesced, and Endymion was visited by Selene in his eternal slumber (Fig. 1.1).[1] Together, the pair had 50 daughters. Phoebe, another lunar goddess, was of the first generation born of the Titan deities of the Golden age. Her consort was Coeus her brother, who sired Leto and Asteria. The former mated with Zeus and bore Artemis (still another moon goddess) and Apollo. Let us leave this splendidly salacious world of Greek mythology and go to the first naturalist philosophers, who tried to understand the moon in a modern sense.

In turning to the earliest science of the moon in the west, it is natural to stay with the Greeks, but first let us try to imagine ourselves in their world about 2500 years ago. We are in Argos one of the many city states of ancient Greece. We are proud of the famous statues and the art of our city. We have history that goes back hundreds of years to the ancient glories of Homeric heroes. We are standing on the old land of these heroes, which is about as solid and unmovable as anything can be. In the day, we watch the sun rise in the east cross the sky and set in the west, followed at night by the moon, and all the stars of the night sky. We know the moon has phases (Fig. 1.2),[2] unlike the sun, or any of the other heavenly bodies, as far as we can see. The moon seems to keep time for us with its regular sequence of monthly changes. It follows the same procession across the night sky. Is it not natural to think the whole sky and everything in it rotates about the earth. This was the starting point for the earliest Greek philosopher naturalists, who sought to understand the world.

The first Greek philosopher we meet is Thales of Miletus ($\sim$620–546 BC), the first of the seven sages of ancient Greece named by Plato. What we know of his work was from others, for no writings of his have come to us. He appears to have been the first to ascribe natural causes to phenomena, rather than accepting them as the whims of the Gods. Recognizing the importance of Egyptian learning in his

[1] Selene (Diana) visits Endymion in his eternal slumber, Painted by Sir Edward Poynter (1836–1919), Victorian portrait and historical painter, President of the Royal Academy, educated Brighton College and Oxford University. This is one of several Victorian era paintings of the subject. Endymion was also immortalized in the poem by Keats with the opening line of the first stanza—"A thing of beauty is a joy for ever …" Some of the many books that may appeal: *The Library of Greek Mythology* (Oxford World's Classics), Apollodorus Translated by Robin Hard, 1997, Oxford University Press. This is the only mythology text to survive from the classical era. How much of it was written, or edited by Apollodorus is not clear. It covers myths from creation to the Trojan War; *The Complete World of Greek Mythology*, Richard Buxton, 2004, Thames and Hudson, this book gives helpful chronologies; *The Greek Myths*, Robert Graves, Penguin Books, 1992, First published in two volumes by Pelican books, 1955.

[2] Compiled with inclusions from various NASA figures.

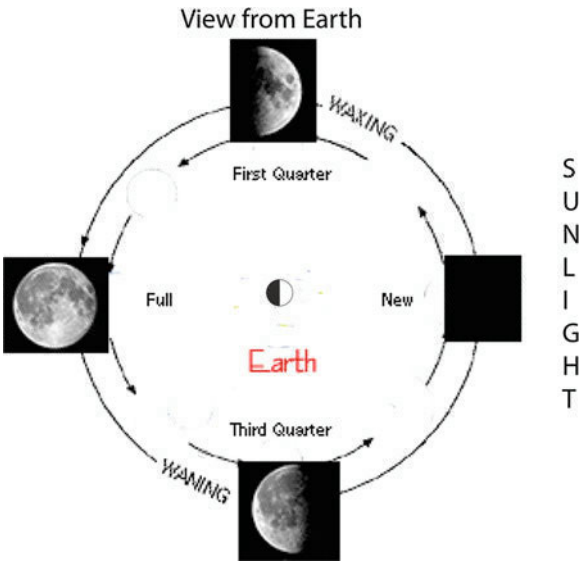

Fig. 1.2 The phases of the Moon—a modern version

time, Thales traveled there and brought geometry back to Greece. He knew that the earth was round and that the moon shone by reflected light from the sun. He realized that a solar eclipse took place when the moon passed in front of the face of the sun. He was also the first Greek to predict an eclipse successfully. How he made the prediction is not clear, but he may well have made use of the extensive Near Eastern records. One effect of the eclipse was remarkable; the Medes and Lydians had been fighting indecisively for about 5 years, but with day turning to night during a battle they decided it was time to try diplomacy.

From our viewpoint, his work on the orbits and diameters of the sun and moon is particularly interesting. Given the geocentric system with which Thales worked, the fraction of the sun's orbit corresponding to the sun's diameter, yielded the ratio of the sun's diameter to the length of its orbit around the earth. Here Thales was advocating that the sun was much larger than was generally thought at the time. He estimated the fraction of the solar orbit represented by the diameter of the sun and showed that given any reasonable orbit for the sun and its diameter must be very large. For the moon a similar ratio emerged, so a comparison of the two could be made. It was long way from solving the problem, but it was a start. For the solution to these problems of the size of the moon and its orbit, we will have to wait roughly three centuries.

Thales seems to have been aware of the power of certain iron ores from Magnesia to attract particles of iron—

> The magnet's name the observing Grecians drew
> From the magnetic region where it grew …,

as Lucretius wrote. At the very outset of our story, we find interest in magnetism.