

Chapter 2

Lunar and Earth Sciences at the Time of the Apollo Landings

We will now focus in on the moon itself in particular on the origin of its surface features. If they are indeed giant impact craters they might account for lunar magnetism. We will also introduce the topic of paleomagnetism some other relevant ideas from mid 20th century geophysics and geochemistry which are key to our story.

2.1 Early Modern Studies of the Moon and Impact Cratering

If we are looking for a founding father of modern lunar science, a good candidate is Ralph Baldwin (1912–2010). He was, a gentleman scientist, representative of a past era, with a full time job as a Vice-President of the family business and did his science because he loved it. He had however been well trained as an astronomer. He was no amateur, as far as his knowledge and skills were concerned. In the 1940s he became interested in the moon and the origin of the features on its surface. The current view was that they were of volcanic origin, but one gets the impression that the moon was very much on the back burner of the science of the day. Astronomers were not too much concerned with such local objects as the moon and planets, and geologists had not yet become very interested in them.

Ralph Baldwin's "The Face of the Moon" published in 1949¹ may not have attracted much attention then, but it is a beautiful book. In the preface he lays out its structure, which leads after a historical introduction to his observations and to his thesis, which is that,

¹ Baldwin (1949). This book covers a mass of interesting material with much more detailed treatment of work in the 19th and 20th centuries than given here. Another source, which may prove useful is "Shock Waves & Man" by I.I.Glass. It covers the broad field of shock effects in a similar style to that I have aspired to in this book.

The single process which offers promise of being the one which actually operated to build the moon's surface structures is that of meteorite impact. Meteorites travel very fast and have great kinetic energy. When one strikes the moon, this energy must be released suddenly and thus an explosion occurs. If the meteorite is large enough and moving fast enough, it will carry sufficient energy to produce the equal of any crater now found on the moon.

The book presents detailed data on craters, comparing for example features of bomb craters and terrestrial impact craters with lunar craters. He also emphasizes that in comparison with scale of volcanic activity and the calderas seen on earth, the lunar phenomena is far grander and could not possibly be caused by volcanic activity. In this, he was following in the footsteps of the geologist Grove Karl Gilbert (1843–1918), who had come to the same conclusion.

The history of the recognition of impact craters on earth followed a somewhat similar course. In the 1920s Walter Bucher studied a number of features, which he called cryptovolcanic.² He realized that they must have originated in a massive explosive event, but he thought that it was internal, or volcanic in origin. The geologists John D. Boon and Claude C. Albritton, visited Bucher's sites but interpreted them as impact craters.³

Bob Dietz (1946) also argued for an external origin for the features that Bucher had described and gave them the name astroblemes. Long before this, at least one crater on earth had been recognized as an impact feature. This was Meteor Crater in Arizona, which is about 50,000 years old (Fig. 2.1). In 1903, Daniel Barringer identified this as an impact crater. Pretty conclusive evidence had already been seen by the first Europeans to pass by, when they saw tons of oxidized iron meteorite fragments in the surrounding area. Barringer had thought that he would be able to recover large amounts of very valuable iron from the crater itself, but had not realized that most of the meteorite had in fact been vaporized, as Boon and Albritton had previously suggested.

A key player in the early modern studies of terrestrial impacts was Eugene Shoemaker and in Chao and Shoemaker (1960) demonstrated the presence of coesite in Meteor Crater. Coesite is a form of silica that could only be formed by the level of shock associated with impacts, or nuclear explosions. This then was the critical observation, the test, which proved the extraterrestrial origin of the feature. No volcanic event could provide the necessary shock level to generate this mineral.

At this time, the Moon was emerging from astronomical semi-obscurity “to claim renewed interest and attention”.⁴ Lunar observations and theoretical discussions were coming to the fore and the moon was ceasing to be on the back

² Bucher (1933). I remember reading this book as an undergraduate, but was not smart enough to see that the scale of meteoritic impact was so much greater than volcanic events of the type that Bucher envisioned.

³ Boon and Albritton (1936). This paper was presented at a meeting in Chicago, but the authors do not seem to have received much credit for their idea in the recent literature.

⁴ Kopal (1962). This book is a convenient starting point for a picture of the state of lunar science at the beginning of the 1960s.

Fig. 2.1 Meteor crater
Arizona



burner. A common view expressed by Harold Urey was that “The moon accumulated independently of the Earth and represents a more primitive object than the terrestrial planets”. Following this line of thought he assumes that the moon was captured. However, he was quick to recognize that these ideas may be changed by direct exploration. By 1960, the Russians had already landed Luna 2 on the surface of the moon and Kopal notes it “will soon be followed by others carrying instruments and eventually men to the moon”.

2.2 Geology and Geophysics in the 1960s

We also need to remember how the geological and geophysical sciences stood in the 1960s, for they were to be critically relevant to lunar exploration. It was a time of great turmoil with the birth pangs of plate tectonics and the growing introduction into geology of the methods of modern physics and chemistry.

The queen of the geophysical sciences is seismology, the study of earthquakes and the analysis of the passage of seismic waves through the earth to yield its internal structure. In about 150 years, we have learnt exquisite details about our earth from seismology. This is not to say that there was no seismology before then. There was. The Chinese had an operational seismograph millennia ago, but modern seismology of the past 150 years has given us the key results that allowed us to determine the internal structure of the earth. In the early years of the last century sufficient seismograms were available to record the arrival times of seismic waves from earthquakes on a worldwide basis. At this time, R. Oldham recognized the different types of seismic waves that propagated away from the earthquake source: (1) P-waves, which are pressure waves, analogous to sound waves, with particle motion parallel to the velocity direction, (Fig. 2.2a), (2) S-waves, which are shear waves with their particle motion perpendicular to direction of motion (Fig. 2.2b), are unable to pass through liquid and (3) Surface waves—the waves which propagate along the earth’s surface and do most of the damage in earthquakes.

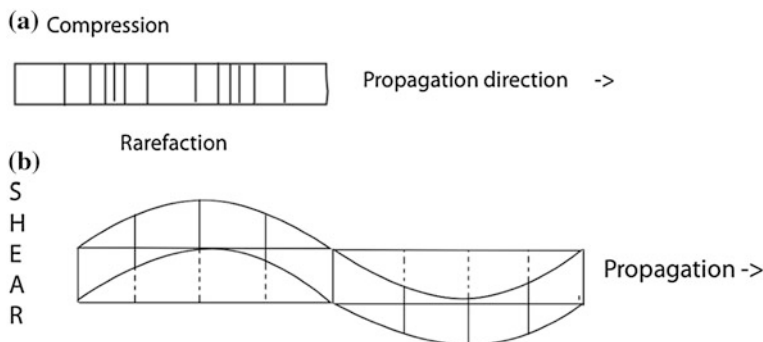


Fig. 2.2 Particle motion (a) in P-wave is parallel to the propagation direction giving regions of compression and rarefaction (b) in S-waves particle motion is perpendicular to the propagation direction

When it was found that S-waves disappeared at some angular distance on the earth's surface from the earthquake source, Oldham recognized that this must be due to the presence of a liquid core through which S-waves could not pass. Assume an earthquake at the north pole in Fig. 2.3,⁵ and consider only the simplest trajectories of P and S-waves that travel southward in the mantle. Both P and S-waves will curve to shallower paths as the velocities increase as they go deeper into the mantle. The P-waves whose trajectory takes them into the fluid outer core will be refracted at the core mantle boundary (CMB) to take up a deeper trajectory because of the decrease in P-wave velocity in the outer core compared with the mantle. When the P-wave leaves the fluid outer core and reenters the mantle it will be refracted again, as is shown in the figure, so that there will be a gap in which P-waves are not seen—a shadow zone. The S-waves that stay in the mantle will follow a similar path to the P-waves, but no S-waves can enter the fluid outer core, so S-waves will not be seen beyond the grazing path similar to where the P-wave shadow starts. The last part of the deep earth structure puzzle was solved by Inge Lehmann in 1936, when she discovered the solid inner core.

The crust on which we live is separated from the mantle by the Moho, which is roughly 5–10 km down under the oceans and 35–90 km under the continents. The Moho is named for Mohorovicic the Croatian, who discovered it. He found that there were double sets of arrivals of P and S waves in shallow earthquakes, one of which had propagated entirely in the crust and the other had entered the upper mantle before returning to be observed at the surface. The boundary separates regions of P-wave velocities of 6 km/sec in the crust and 7 km/sec in the mantle. There are outcrops of the mantle rocks in ophiolites, which are sections of ocean floor that have been thrust up to the surface by tectonics, so we have seen the nature of the upper mantle under the oceans.

⁵ Combination of NASA images Cosmos.

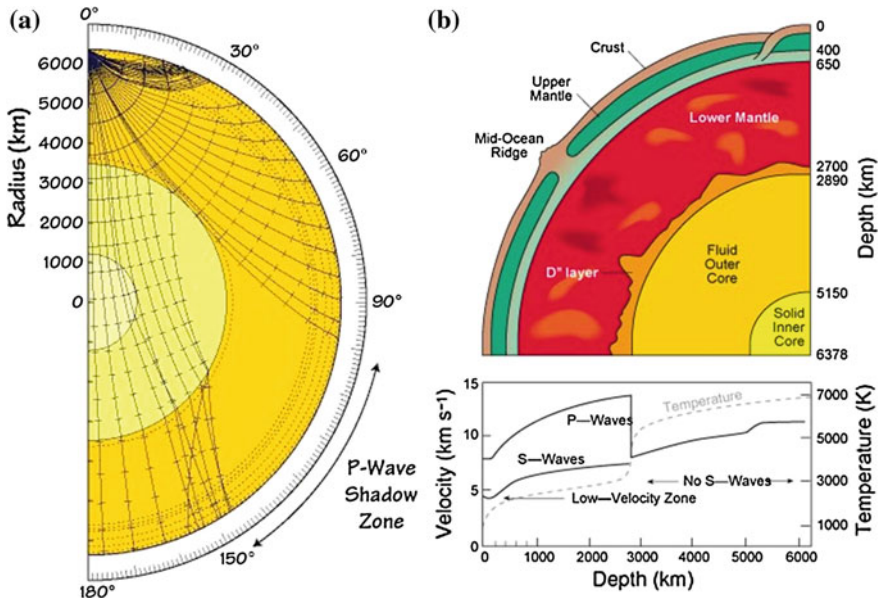


Fig. 2.3 Internal structure of the earth (a) P-waves and P-wave shadow zone and (b) summary figure

Radioactive age determination had matured and produced key results by the 1960s, such as the age of the earth of at 4.55 Ga by Claire Patterson and of 4.95 Ga for the solar system by John Reynolds. This method of radioactive age determination would be key in establishing the history of the moon. Rapid progress had followed Rutherford's initial work. The method depended upon knowing the decay rate of particular atomic species and measuring parent and daughter masses in a rock considered it as a closed system, from which nothing escaped and into which nothing went. From the remaining mass of the parent, the generated mass of the daughter product and knowing the decay rate of parent to daughter one can determine how long the system has been closed, although as usual it turns out to be not quite as simple as this might seem.

From Rutherford comes a classic anecdote. It concerns a formal presentation of his work, which happened to be in the presence of Lord Kelvin. That great man was famous for his opposition to an age of the earth that gave the long periods of time required by geologists and biologists. He maintained eventually from his cooling model that the age of earth could not be more than 20 million years. This was nowhere near enough time for Darwin, whose theory of evolution required at a minimum a far longer earth history, or indeed for contemporary geologists, who needed far more time for geology to work its ways. Lord Kelvin was not very charitable to his geological and biological colleagues calling their methods of determining the passage of time from phenomena such as the erosion rates of chalk absurd. However, while these geological estimates of the passage of time were

certainly not very accurate, they turned out to be better than the ages from Lord Kelvin's method with its impeccable mathematics, based upon an incorrect model for the cooling of the earth. To return to our anecdote Rutherford said,

I came into the room, which was half dark, and presently spotted Lord Kelvin in the audience and realized that I was in trouble at the last part of my speech dealing with the age of the earth, where my views conflicted with his. To my relief, Kelvin fell fast asleep, but as I came to the important point, I saw the old bird sit up, open an eye, and cock a baleful glance at me! Then a sudden inspiration came, and I said, 'Lord Kelvin had limited the age of the earth, provided no new source was discovered. That prophetic utterance refers to what we are now considering tonight, radium! Behold! The old boy beamed upon me (Rutherford 1904).

As usual there are many lesser known heroes in these studies, who made key contributions. One such is Boltwood, who traced sequences of decay products including the uranium lead decay series, which is the basis of so much radioactive age determination. A geologist whose contributions have perhaps been underestimated is Arthur Holmes. He initially did major work in radioactivity and established the first quantitative geological time scale. He also suggested that convection in the mantle provided a mechanism to explain Wegener's theory of continental drift. His text "Principles of Physical Geology" was very popular among physicists coming into geology to test continental drift with paleomagnetism (Holmes 1944). It gave them a quick, but thorough introduction to modern geology.

The relatively new technique of paleomagnetism took advantage of the ability of rocks to record the geomagnetic field at the time of their formation, as we shall see in much more detail later. When I was a student at Cambridge in the 1950s, I attended lectures by Keith Runcorn, who was advocating the exciting possibility that Wegener's continental drift could be tested with paleomagnetism. At that time, it was generally accepted that given a roomful of geologists about 50 % would be strong advocates of drift and the other 50 % equally strong opponents of the idea. Runcorn's research group, first at Cambridge and subsequently at Newcastle, included Ted Irving and Ken Creer, whose contributions were to be pivotal. A second group, first at Manchester and subsequently at Imperial College led by Patrick Blackett and John Clegg also set out to use the geologic fossil compasses to navigate the continents back in time and to test the idea of continental drift. I was more familiar with this group because I had the good fortune to be John Clegg's nephew. He had taught me about the joys of working in science and largely decided the course of my life. Both groups found that many rocks recorded a magnetic field inconsistent with their present location and orientation: they must have moved over the face of the planet. For a while it seemed that the data might be explained by polar wander, whereby the earth as a whole moves in relation to the rotation axis. Critical data, particularly from Irving in the Newcastle group and from the London group eventually made it clear that the answer was continental drift.⁶

⁶ Frankel (2012). This exhaustive study written with benefit of help from the central characters is an excellent presentation of the story.

In those days I had an opportunity to see how strongly scientists hold their views and how emotionally tied to them they can be. It seemed sometimes that adherents of different camps were near to coming to blows. However, out of this was to come the revolution in the earth sciences. Perhaps such strong interactions between scientists are an accompaniment of times of paradigm shift, as we would now say. Indeed, it has often been noted that opponents of the new ideas never change, they simply die unconvinced. For the most part, interactions between geophysicists are much more congenial now and so we may be in a period of consolidation and less excitement. Yet to some extent, in the magnetism of the moon, meteorites and asteroids, and in the events in the early solar system I sense some of the same passions as newer ideas upset the old order.

2.3 Summary

In this chapter, we have traced the growing understanding of the impact cratering on the earth and moon and taken a brief glimpse at the deep structure of the earth, age determination and paleomagnetism in the 1960s. They will all be central to our story.

References

- Baldwin R (1949) The face of the Moon. University of Chicago Press
- Boon JD, Albritton CC (1936) Meteorite craters and their possible relationship to cryptovolcanic structures. *Field Lab* 5
- Bucher WH (1933) The deformation of the Earth's crust, Princeton University Press, Princeton
- Chao ECT, Shoemaker EM, Madsen BM (1960) First natural occurrence of coesite. *Science* 132(3421):220–222
- Dietz RS (1946) Geological structures possibly related to lunar craters. *Popular Astron* 54:465
- Frankel HR (2012) The continental drift controversy: paleomagnetism and confirmation of drift. Cambridge University Press
- Holmes A (1944) Principles of physical geology. Thomas Nelson and Sons, Edinburgh
- Kopal Z (1962) Physics and astronomy of the Moon. Academic Press
- Rutherford E (1904) Speech at the royal institution. Quoted in E.N. da C. Andrade, 1964, Rutherford and the nature of the atom. Anchor Books, Doubleday, p 80

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