

INTRODUCTION

1.1. USING THE MOON: AVAILABLE DATA

This book was written to provide a single, complete, and annotated description of our present knowledge of the Moon. It is intended for a wide range of readers, including scientists who are studying the Moon and trying to understand its place in the solar system, designers now planning missions to return to the Moon, and engineers and astronauts who may participate in the future exploration of the Moon. We dedicate this book to all of them, because their wide range of thoughts and activities will be essential to the intelligent future use of the Moon.

During the last 20 years, the Moon has developed a dual role in human thought. As the Apollo explorations have shown, the Moon is a scientifically important planet. It preserves a unique history of planetary formation and early development, and also serves as a probe that has recorded the space environment and cosmic radiation for billions of years. Because of its closeness to Earth, the Moon is also an obvious target for long-term human exploration beyond Earth. Knowledge of the Moon's characteristics, especially its potential usefulness and resources, has become critical for planning the human future in space.

Many conceptual designs for lunar bases have already been prepared by Americans as well as by European and Japanese engineers. The National Aeronautics and Space Administration (NASA) now receives a steady flow of requests from engineers, student groups, and others involved in such planning.

These groups want detailed information about the Moon, and their requests have not been easy to answer. Most handbooks containing data about the Moon were written in the 1960s for the Apollo missions and are therefore out of date; they are also out of print. Much of their information was intended for spacecraft design and is not useful for planning long-term surface activities or a permanent outpost on the Moon.

To address these problems, the authors of this book have attempted to combine their aggregate experience in different areas of lunar research in order to summarize, in one place, the currently available data about the Moon and its environment.

The great accumulation of post-Apollo lunar science information, although rich in details, is an inconvenient database. This information is scattered through dozens of technical journals, making the search difficult. Many data are found only in government publications, contractor reports, and abstract volumes that are now virtually unobtainable. In addition, complete information on specific matters is not easily collected. For example, a particular lunar parameter, such as soil density or radiation exposure, may have been measured by several scientific groups over several years. Published values of that parameter may be valid only for a specific set of conditions or for specific sample materials, and these limitations are not obvious in a casual literature search. The most current or best

available measurement may have been published in a journal that is not readily accessible. It is not uncommon for errors to be found years after the original data appear, but the corrections are difficult to discover, even if they were formally published.

The data are separated into individual chapters by topic, and the goal has been to make each chapter independent, so that a minimum of cross-referencing is required to extract the data. Within each chapter the data are presented in their scientific context, and the limitations are described so that the reader can make the best use of the data. Extensive references have been included for access to the original scientific and technical literature. Finally, much remains to be discovered about the Moon, and the authors have tried to identify areas where data are lacking, rather than to leave such subjects unmentioned.

1.2. THE CONTENTS OF THIS BOOK

The substantive parts of this sourcebook begin in Chapter 2 with a summary of lunar exploration, a description of the sample collections that have resulted from this exploration, and a brief summary of the new ideas on lunar origin and evolution that have resulted from exploration and sampling.

Chapter 3 focuses on the lunar environment as a set of boundary conditions for the designer. Values for physical parameters of the lunar surface are presented. The critical data on radiation and temperature are also covered. This information is adequate for planning a wide variety of surface operations.

Chapter 4 discusses the large-scale geologic processes that have shaped the surface of the Moon. Foremost are the impact craters that cover the face of the Moon. Every piece of lunar real estate has been affected by cratering, whether it is part of a crater or has been blanketed by impact ejecta. Another major mechanism of terrain formation is volcanic eruption. Lava flows tend to occur in the gigantic impact basins excavated much earlier in the history of the Moon. In many of the maria there are ridges and domes of apparent tectonic origin, formed by compressive stresses associated with cooling and settling of the vast volcanic plains.

Careful study of lunar minerals, rocks, and soils is a primary tool for deciphering the history and structure of the Moon, and Chapters 5 through 7 summarize the great body of data that has been collected on lunar materials. Lunar minerals are discussed in Chapter 5. Chapter 6 begins with the description of lunar igneous rocks that crystallized from magmas (a process also common on Earth) and then covers the many rocks created by impacts, such as impact breccias and impact melt rocks.

Sedimentary rocks and water-bearing minerals are absent on the Moon because of the total absence of water. On the other hand, the fragmentary debris (regolith) blanketing the Moon is an impact-formed "physical weathering" product unknown on the Earth, having its own set of physical and chemical properties. These are described in Chapter 7.

Chapter 8 first relates the well-studied chemistry of the Apollo samples to the important primordial processes of planetary accretion and the subsequent differentiation of the lunar crust to produce the lunar highlands. In a concise format, this chapter then illustrates where each chemical element of interest can be found on the Moon, as well as the range of its abundance. The rarity of volatile elements in lunar materials exacerbates the problem of supporting life and industry there. However, the Apollo missions sampled only a small part of the lunar surface and it is possible that isolated concentrations of volatile elements or ores do occur somewhere on the Moon. Insights gained from our partial knowledge of lunar geochemistry can direct the exploration needed to find important resources.

Although most studies of the Moon have been carried out for purely scientific objectives, ongoing lunar operations will require engineering data. Such data will be necessary for planning lunar bases. Chapter 9 reviews the physical quantities that characterize the lunar surface environment. The geotechnical information comes from the work of the few civil engineers who participated in lunar exploration. These data come both from measurements made on the lunar surface and from measurements made on returned samples. The collection of engineering measurements was overshadowed by exciting scientific discoveries, but the engineering studies now assume new importance. The thermal, optical, and electromagnetic parameters come from astronomical and remote-sensing investigations coupled with a few lunar surface experiments and many laboratory studies of returned samples. The values derived from very-large-scale remote measurements do not always agree with data taken on specific samples because the techniques differ and the lunar environment cannot be reproduced exactly in the laboratory. Therefore, the experimental conditions and constraints are described in the text to aid the reader in interpreting the data properly for any given application.

Exploration produces maps; development requires them. Chapter 10 summarizes the lunar maps derived from quantitative spectral imaging, astronomical measurements, and orbital remote sensing. Even the casual reader will note the startling lack of completeness in the information. Mars is more completely photomapped than the Moon, and the

global cartographic control for Mars is better than that for the Moon. Very important geochemical remote-sensing data are limited to narrow strips in the equatorial regions of the Moon, along the ground tracks of the brief Apollo missions. Some of the data are presented as geologic maps that interpret photographic or remotely-sensed data. While these maps are often easier for the nonspecialist to understand, they sometimes embody data interpretations that are still controversial in the scientific community. The geologic cross-sections shown in Chapter 10 are most speculative. Planners must keep an open mind and utilize this information carefully.

Chapter 11 looks to the future. Many gaps in this book's data can be filled with relatively modest unmanned spacecraft placed in lunar orbit. Plans for

such missions are discussed, and the significance of new findings is placed in the context of future manned explorations as well as advancement of our understanding of the planets, Earth included.

The authors intend this publication to be a succinct but quantitative summary of what is known about the Moon. In most chapters the quantitative aspect has been emphasized, because numerical data are needed to bridge the gap between speculation and planning. The information has been organized to be accessible and has been discussed in enough detail to make it useful even when incomplete. Inevitably, condensation of much knowledge and opinion into one volume has its price. We trust the compromises have been the right ones and that the users of the book are not frustrated by omissions.