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The Geology of Mars: Evidence from Earth-Based Analogs

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The Surface of Mars

M. H. Carr
Cambridge University Press
Cambridge Planetary Science Series No. 6 (2007)
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The Geology of Mars: Evidence from Earth-Based Analogs

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Two recent books, in the Cambridge Planetary Science Series, published by Cambridge University Press, focus on the geology of Mars. This should not be surprising as we are in an unprecedented era of exploration of the Red Planet, and never before have there been so many robotic missions, either in orbit, or on the surface of Mars; this has resulted in exciting advances in our understanding of the geology of Mars. But what is the fascination with the Red Planet? Put simply, Mars is the most Earth-like planet in the solar system and is, geologically, one of the most complex. In addition, it is the only planetary body besides Earth, where water is known to have flowed across the surface – this is important because liquid H_2O is a requirement for life, as we understand it.

These two books take different approaches in their quest to understand Mars: one is an edited volume; the other is single-authored. The latter, although it was published 6 months earlier, is more up-to-date, in terms of the literature published and missions covered. As noted by Michael Carr in his preface, these books are "a snapshot of a moving picture". The amount of data being sent back from Mars is staggering and it seems that new discoveries are made almost daily. Any book about Mars will, therefore, represent a snapshot of our knowledge at the time of publication; however, I am convinced that both of these books will remain useful and relevant for some time to come.

In *The Surface of Mars*, Michael Carr provides an outstanding up-to-date thesis on the geology of Mars. In the author's own words, this is a "replacement" for an earlier book published in 1981 with the same title. Our understanding of Mars has, indeed, changed dramatically in the intervening years. This book opens with a very useful overview chapter that introduces and summarizes important "background" information, from orbital mechanics to the Martian atmosphere, and includes an important section on the stability of water, both at the present-day and in the past. The following 9 chapters deal with the various geological processes that have acted, or continue to act, to shape the surface of Mars.

The book begins in earnest with a chapter on impact cratering. As the author notes, meteorite impact craters are the most distinctive landforms on most planetary bodies in the Solar System that possess a solid surface – besides Earth. Martian impact craters possess some unique and unusual attributes that reflect the complex geology of the planet. This is followed by chapters on the more familiar endogenous geological processes of volcanism and tectonism. The author shows that Mars has had a long history of volcanic activity and that the planet is likely still active today. All the major volcanic provinces are introduced and the various volcano types and eruptions styles are discussed. A discussion on the implications of what the lack of plate tectonics means for volcanism on Mars leads to the following chapter on global structure and tectonics. Despite the lack of plate tectonics for at least the last ~ 4 Ga, the author notes that Mars displays a variety of tectonic features. Throughout these and subsequent chapters, the reader is provided with superb imagery from various missions including mosaics from the THEMIS instrument specially put together for this book.

In chapters 5 and 6, the author addresses the formation of a variety of landforms, which on Earth, are typically formed by water. The author presents imagery documenting canyons, channels, valleys and gullies on Mars, before moving on to a discussion of their origin, with particular attention paid to the possible involvement of liquid or solid H_2O. It is worth pointing out that despite his involvement in most of the past robotic Mars missions and countless publications on these and many other subjects, Michael Carr presents an unbiased discussion of the mechanisms of formation for these landforms. The reader is given the evidence but is left to decide for themselves the origin of particular landforms; this is a particularly nice aspect of this book.

The next chapter focuses on lakes and oceans. None currently exist on Mars, but the chapter summarizes the evidence for the presence of ancient lakes and even a northern ocean(s) that may once have covered much of the northern hemisphere. The latter, having been suggested and then dismissed in the past, appears to be gaining renewed attention and supported by a growing body of new evidence. The question as to the fate of such an ocean leads nicely into the following chapter on "Ice". H_2O ice is typically not stable on the Martian surface today, but there is abundant evidence for glacial and periglacial activity in the past, and sometimes very recent past. Indeed, in June 2008, the Phoenix lander – with the first Canadian Mars instrument onboard – discovered the presence of ice just a few centimetres below the surface, confirming earlier hypotheses based on remote-sensing data. Thus, ground-ice, glaciers, and ice caps have had, and may continue to have, an important role in shaping the surface of Mars.

Chapter 9 deals with wind as an agent of erosion. The author notes that aeolian erosion is an active process at present as evidenced by images of dust devils and dust storms, some of which have been global in extent. In the following chapter, the book returns to ice, but this time in the context of the Martian poles. Although superficially similar to the north and south polar terrains on Earth, this chapter highlights the unusual aspects of Mars' poles. Many features, such as the so-called "swiss cheese" terrain continue to baffle scientists to this day. Chapter 11 – the view from the surface – would not have been possible without the success of the twin Mars Exploration Rovers (MER's) that landed in January 2004 and which are still active today. These missions represent a major advance, allowing geologists to "roam" the surface of Mars and to see and analyze rocks for the first time, albeit through the eyes of a rover. When coupled with high-resolution remote-sensing imagery it is now possible, for the first time, to link detailed surface observations with satellite data.

The final chapters bring together a vast amount of data, much of it presented in the previous chapters, to address two of the most important topics in Mars science. In Chapter 12, the author discusses climate change throughout Mars' history. Understanding the past climate and history of H_2O is critical for assessing the potential for past and even present-day life on Mars – this is addressed in the penultimate chapter. As the author shows, despite strong evidence for wetter and potentially warmer conditions on early Mars, there still remains no satisfactory explanation as to what caused these more clement conditions. In the more recent past, large shifts in Mars' obliquity are likely to have played an important role in changing the stability of H_2O and allowing more active surface processes to occur, but even here there are still considerable gaps in our knowledge.

The second book, edited by Mary Chapman, comprises 17 chapters addressing various topics on the geology of Mars, based, to a large extent, on the study of terrestrial analogues. Until now, there has not been a book that draws together research conducted on the comparative study of Mars and Earth-based analogues. In contrast to *The Surface of Mars*, this book is more a collection of manuscripts brought together as chapters. As with any edited volume, the chapters are variable in terms of length, style and approach to the subject, reflecting the individual authors' writing style(s). As is apparent from reading the table of contents, certain aspects of Mars' geology are covered in considerable detail, while others are missing. This book will be of particular interest for those interested in volcanic processes, where several chapters compare and contrast different aspects of volcanism on Earth and Mars. It is unfortunate that there are no chapters dealing with polar, glacial or periglacial processes, which are important given Mars' past and present "polar desert" climate. A further minor shortcoming is that most of the referenced literature is pre-2001; hence findings from the more recent missions are not included. A particularly useful aspect of this book is the emphasis on describing outstanding issues, which should prove valuable for directing and stimulating future work.

This book begins with an excellent overview by J. W. Head, summarizing the various geological processes that have acted to shape the Martian surface. This is a thorough and excellent summary of Martian surficial processes and what we have learned from terrestrial analogues. With its 14 pages of references, this chapter would make an excellent introduction to Martian surface processes for new students**.** I particularly like the attention to highlighting what we do not know, as well as what we do know. This introduction is followed by a chapter on impact cratering by N. G. Barlow and coauthors. They provide a summary of impact cratering processes and the similarities and differences between impact structures on Earth and Mars.

The next 6 chapters deal with various aspects of volcanism and volcanic deposits. In the first of these, P. J. Mouginis-Mark and coauthors focus on terrestrial analogues to the calderas of the Tharsis volcanoes on Mars. An excellent introduction to calderas is followed by detailed descriptions of several examples, with particular attention given to what types of terrestrial analogues are instructive for understanding specific aspects of Martian calderas. In Chapter 4, L.S. Crumpler and coauthors take a different approach by focusing on the New Mexico volcanic region. The following chapter, by L. Keszthelyi and A. McEwen, provides a detailed overview of Martian flood-lava occurrences and emphasises specific similarities and differences to terrestrial Large Igneous Province flood basalts. In Chapter 6, S. A. Fagents and T. Thordarson present a comparative study of rootless volcanic cones on Iceland and on Mars. These authors also highlight an interesting "spin-off" of terrestrial analogue studies, namely that many geological processes and features on Earth are still poorly understood, so by studying the geology of these terrestrial analogues, we not only increase our understanding of Mars but also our understanding of outstanding scientific problems here on Earth. A further important aspect of terrestrial analogue studies, highlighted by these authors, is that differences in scale, weathering rates and the overall environment (e.g. pressure, temperature, precipitation) must be considered. The next chapter, by M. G. Chapman and J. L. Smellie, documents similarities between Mars' interior layered deposits and terrestrial sub-ice volcanoes. As with the previous chapter, the authors note the paucity of terrestrial data. In Chapter 8, T. Gregg continues in a similar vein by exploring the evidence for lava–sediment interaction on Mars, drawing upon terrestrial analogue studies involving the emplacement of lava into wet and dry sediments.

Chapter 9 is the only chapter on aeolian processes. In this work, J. R. Zimbelman and S. H. Williams present a concise but detailed description of 22 sites in the western United States followed by a discussion of the evidence for aeolian processes and dunes on Mars. The authors note that the effects of the thin atmosphere and lack of a hydrological cycle on Mars complicates the use of terrestrial analogues.

In Chapter 10, F. Costard and coauthors discuss the origin of recent gullies on Mars and provide insight from terrestrial examples in Greenland. Their work suggests that the presence of ground-ice may be important in gully formation on Earth and possibly Mars. The following two chapters focus on the origin of channels and valleys on Mars. In chapter 11, F. Costard and E. Gautier suggest that periglacial regions of Earth provide good analogues for Mars. They focus on several Siberian rivers and draw comparisons with Martian outflow channels. In the subsequent chapter, G. Komatsu and V. R. Baker highlight the strength of comparative planetology, noting that our current understanding of Martian outflow channels would not have been possible without the study of terrestrial analogues, such as the Channelled Scabland in the United States.

The remaining chapters of this book focus on several different unrelated topics. Chapter 13 examines the potential for playa environments in Mars' past. G. Komatsu and co-authors also include a discussion on the identification of terrestrial evaporite deposits by remote sensing, drawing attention to the difficulties in interpreting similar data from Mars. In Chapter 14, N. A. Cabrol and coauthors discuss how terrestrial analogue sites are important for understanding the limits of life on Earth, which is important in identifying potential habitats for life on Mars. Their specific example is the astrobiological potential of high-altitude lakes in South America. The next chapter focuses on a completely different subject; namely the "canyonlands model" for the formation of simple planetary grabens. The penultimate chapter by H. E. Newsom is on geochemical analogues and Martian meteorites. As the author notes, the physical properties (e.g. strength, density, thermal conductivity, etc.) of rocks and minerals affect the efficiency, rate, and outcome of many geological processes, so having an understanding of the physical properties of Martian materials is critical.

The final chapter discusses the use of terrestrial analogues for instrument testing and development, astronaut training, and other exploration-related activities that will become increasingly important. In this chapter, K. Snook and coauthors present a case for carrying out simulated missions in analogue environments on Earth in preparation for human missions to the Moon and Mars. This is particularly timely given the current emphasis on the return of humans to the Moon, and eventually on to Mars.

In summary, despite a quantum leap in our understanding of Mars, there is still much that we do not understand and there is still much science to be done. The *Geology of Mars* provides an excellent introduction to the field of comparative planetology and should be a welcome addition to the bookshelf of planetary scientists. *The Surface of Mars* is also an outstanding up-to-date synthesis of our understanding of the geology of Mars. This book should be the first read for anyone interested in the study of the Red Planet. The target audience for both these books is broad, and they should be of interest to students and more experienced researchers alike.

Impact Structures of Canada

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This book makes a timely appearance in the general scope of Earth and Planetary Science thinking. The last quarter century has witnessed a quiet, post-plate tectonic revolution in the geosciences, with a growing realization that our planet has not magically escaped the consequences of bombardment by asteroids and comets. As so well demonstrated by the Moon's thoroughly cratered surface, Earth was impacted as much as any other planet, especially in the period before 3.8 Ga during the elusive Hadean times. The relative paucity of impact structures on Earth (174 versus, for example, more than 40 000 named on Mars) is due to the dynamic nature of our planet (like that of Venus), with subduction, volcanic activity, weathering and sedimentation leading to the relatively rapid destruction, or burial, of most impact features. Nevertheless, we have come to realize that these impacts not only contributed to forming our planet (through planetesimal collision and accretion), but also by modifying it through time, and even punctuating the path of life's evolution. A critical contribution to our recognition of the impact process as a global environment modifier was made by physicist Luis Alvarez and geological colleagues in 1980 (Alvarez et al. 1980). This seminal publication linked the mass extinction at the Cretaceous–Tertiary (K/T) boundary to the impact of a large projectile at 65 Ma (with the resultant formation of the Chicxulub Structure in Mexico). Although controversial, the Alvarez team's research drew attention