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Impact Structures of Canada

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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 to our vulnerability to extraterrestrial causes of major catastrophe. We clearly needed to understand our planet's history in the context of the solar system and not in isolation. Since the early 1980s there has been an increase in research on impact structures and the projectiles that generate them. Stronger interaction has occurred between geologists, planetary scientists, physicists and biologists, complemented by the more recent planetary programs of NASA and ESA (e.g. the Mars Exploration Rovers, Spirit and Opportunity, which have functioned as robot geologists). Impact is clearly on the "map", although it is yet to be taught in a systematic way at the undergraduate level at most institutions.

Of the currently known 174 proven impact structures on Earth (Earth Impact Database 2008), 29 of them are located in Canada and this book presents a summary of each, essentially giving us a snapshot of where our current knowledge lies. As a reference work it is an excellent entry into impact cratering studies. It starts with an introductory chapter on the impact process, which details the effects, from field to microscopic scale, of the energy transfer from projectile to target. This documents a "fast", non-uniformitarian type of geology, where the shock wave and related momentum pulse exist for just parts of a second or minutes. It is a far cry from typical endogenic geological processes, some of which can take thousands or millions of years to reach completion. The remaining chapters detail each of the known Canadian craters in alphabetical order. Surprisingly, few of the Canadian impact structures have been documented beyond the original discovery paper. They are commonly found in remote northern locations that make it difficult, and hence expensive, to stage comprehensive field surveys. This statement is also true of the global inventory of impact structures – few have been investigated by more than one generation of researchers. Thirteen of the twenty-nine Canadian structures are completely or predominantly buried. Those structures that have yielded economic benefit due to an impact-associated accumulation of mineral or hydrocarbon resources have, understandably, received the greatest scrutiny (e.g. Sudbury, Ontario).

So far, only six of the twenty-nine structures have been studied in any real detail (i.e. by more than one generation of researchers). These are Brent (Ontario), Clearwater East and West (Québec), Haughton (Nunavut), Manicouagan (Québec) and Sudbury (Ontario), each of which merits over 8 or more pages of text. Some of the others have only 2 pages allocated to them (e.g. Presqu'île, Québec), usually due to their poor exposure, highly eroded nature and/or limited accessibility. Much remains to be done – detailed geological mapping of the exposed examples is an outstanding need. Finding resources for this can be problematic – field work is all too frequently not seen as cutting edge science by funding agencies, yet there are many exciting discoveries to be made through the careful sampling and mapping of impact structures. Nevertheless, foundation work has been done on all 29 structures and this short book (210 pages) documents it all.

This book is a legacy to the Canadian foresight that, over 50 years ago, heralded the impact revolution. The astronomer Carlyle Beals (1899-1979) of the Dominion Astronomical Observatory in Victoria, and subsequently Ottawa, is to be credited with initiating a comprehensive investigation of Canadian craters in the 1950s, and realizing a vision well ahead of its time. After hiring geologists and geophysicists to assist him, a systematic search of the Canadian Shield was made using aerial photographs and Royal Canadian Air Force maps. This was supplemented by extensive field work and drilling. Numerous new craters were discovered. This work laid the foundation for continued research into impact structures from the late 1960s onwards, with individuals such as Michael Dence, Blythe Robertson and Richard Grieve taking the lead in terms of field activities, data gathering and expertise. In many ways, this book is a testament to the contributions made by Canadian impact researchers and it represents a summary of our knowledge to date. It provides a foundation for future field operations, which should aspire to better understand the fundamental mechanisms associated with impact (e.g. shock wave – materials interaction), and to resolve disparities between computational models and field observations of the cratering process.

At a time when many scientific texts cost more than $100, the author is to be congratulated on publishing with the Geological Association of Canada, where prices have been kept low. The production, printing and paper quality, though published in black and white only, is good. The book will make a worthy contribution to any science library and is a 'must' for anyone interested in impact cratering.

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