KOMATIITE

Komatiites erupted billions of years ago as pulsating streams of white-hot lava. Their unusual chemical compositions and exceptionally high formation temperatures produced highly fluid lava that crystallized as spectacular layered flows. Investigation of the extreme conditions in which komatiites formed provides important evidence about the thermal and chemical evolution of the planet, and the nature of the Precambrian mantle.

This monograph, written by three experts with long experience in the field, presents a complete account of the characteristics of komatiites including their volcanic structures, textures, mineralogy and chemical compositions. Models for their formation and eruption are evaluated, including discussion of the controversial issue of whether komatiites originated from anhydrous or hydrous magmas. A chapter is also devoted to the valuable nickel and copper ore deposits found in some komatiites.

Komatiite is a key reference for researchers and advanced students interested in petrology, Archean geology, economic geology, and broader questions about the evolution of the Earth's crust and mantle.

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To Catherine, Greg and Ben

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Preface

The time traveller was becoming despondent. Here she was, 2.7 billion years back in time, and she had spent most of the day flying over a flat, featureless plane. True, some hours back, she had passed over a chain of fiery stratovolcanoes strung out along the margin of the continent, no doubt marking the trace of an active subduction zone. She had marvelled at the spectacle of the thick mat of floating pumice blanketing a vast area of blue-green sea. There was a long mountain range with lofty snow-covered peaks. Imposing, yes, but duller than modern mountains because of their total lack of vegetation. But now all she saw was this dreary plain, feebly lit by a pale yellow sun glinting in the reddish sky. She'd seen it all before, this enormous flow of basaltic lava, so like the flat, monotonous uppermost flows of the Deccan plateau.

Then, far to the north, she saw a small plume of rising vapour. The plume was not large but, as she got closer, she saw in the dull twilight that it was illuminated from below, as if by a powerful flickering searchlight. She reached the plume, circled slowly around it, and realized that she was witnessing, for the very first time, an eruption of komatiite.

The plume shot forth several hundred metres into the air, streaming steadily skyward, like the jet from an enormous fire hose. There was none of the pulsing agitation of the lava fountains she had seen on Hawaii and Iceland. It had to be driven by the density difference between the magma and a thick underlying column of crust rather than being propelled by the expanding gases that drive modern lava fountains. Most remarkable was its colour – not the reddish-orange of basaltic lava but an intense bluish white. Her optical pyrometer gave a reading of 1620 °C! The fountain fed a river of lava that flowed to the north as far as she could see, moving rapidly, jostling and splashing, at close to 40 kilometres per hour. Occasionally, a thin, dark elastic crust formed on the surface, temporarily masking the brilliant whiteness of the lava. But quickly the crust would be destroyed by the turbulence of the flow.

Several kilometres downstream, the lava was noticeably more viscous and the flowage was less agitated and probably laminar. The colour of the lava had shifted to a brilliant yellowish white due to a slight change in temperature. The increase in viscosity must be due to the combined effect of phenocryst growth with a small decrease in temperature, thought the time traveller. She noticed a solid crust was forming at the surface and the lava continued to flow beneath, gradually inflating the roof of the flow so that, a few kilometres farther downstream, the thickness of the flow had doubled.

She started turning over in her mind how she would present this evidence for the eruption of hot, anhydrous, mobile komatiite during her invited talk at the upcoming EGU meeting, three weeks after she got back to the 21st century.

Komatiite is a rare rock type. If we ignore for the moment the glaring anomaly of the Tertiary Gorgona flows, all true komatiites so far discovered are Archean in age. Archean rocks cover only about 10% of the surface of the globe and in these regions komatiite constitutes less than 10% of the volcanic successions or 1% of the entire Archean rock assemblage. Overall, komatiite is no more common than rocks like phonolite, mugearite and other unusual alkaline rocks that excite a few specialists but are of little or no interest to most geologists. Yet, as Bob Thompson pointed out some 24 years ago when he reviewed the first komatiite book (Arndt and Nisbet, 1982a; Thompson, 1983), these rocks have always interested the average geologist, and, when described by a skilled journalist, will capture the attention of the general public. The reasons for this interest are not difficult to find. Komatiite contains spinifex, arguably the most beautiful and intriguing of all igneous textures. Komatiites contain valuable ore deposits, which add economic interest. But above all, komatiite is an extreme magma type with highly unusual physical and chemical characteristics. Komatiites must have formed under conditions quite different from those that yield other types of magma and they provide one of very few tools we have for understanding how the Earth operated 2–3 billion years ago.

Komatiites were far hotter than any other magma that ever erupted on the Earth's surface. Lewis and Williams (1973) developed a series of intriguing arguments to support their conclusion that a komatiite flow in Western Australia erupted as a superheated liquid whose temperature was at least 400 °C higher than that of Hawaiian basalt. We have since realized that komatiite magma forms through partial melting deep in the mantle, at depths far greater than those that yield the modern basaltic magmas. Was this always the case? An idea that pervades the current literature is that the Archean mantle was far hotter than the modern mantle; if true, it is perfectly logical that hot magmas like komatiite were more abundant then than now. All this

seems eminently reasonable, yet, for the past decade, a team of petrologists has argued that komatiites do not form deep and hot but shallow, wet and tepid. The long series of papers published by Tim Grove, Stephen Parman, Maarten de Wit and Jesse Dann has done much to stimulate interest in komatiites and, although I agree with very few of their conclusions, I readily acknowledge the contribution they have made to komatiite research. The debate between proponents of wet or dry komatiites has now rumbled on for over a decade and has stimulated a large number of research projects that have greatly improved our knowledge of all aspects of the nature and probable origin of these remarkable magmas.

In this volume I have attempted to provide a complete and comprehensive account of komatiite. I discuss all aspects of the rock type – how and where they occur, their field characteristics, their petrology and geochemistry, and with the addition of two chapters by Mike Lesher and Steve Barnes, their volcanological aspects and their ore deposits. The first part of the book, Chapters 1–7, is mainly descriptive. After a brief chapter dealing with terminology, I illustrate the main features of komatiites by way of summaries of the characteristics of six type examples. Then follow chapters on the field characteristics, mineralogy, geochemistry experimental studies and finally, the physical characteristics of komatiite lavas. My coauthors contributed the lithofacies section in Chapter 1, the Kambalda section in Chapter 3, and part or all of the descriptions of the dimensions of komatiites, of thick dunitic units and of volcanoclastic komatiites in Chapter 4.

The second part of the book opens with the chapters by Lesher and Barnes on ore deposits and volcanology. Then comes a chapter in which I address directly the issue of whether komatiites are wet or dry, and finally there are three chapters that relate current ideas about the origin of komatiite. Chapter 12 deals with the composition of komatiite liquids, Chapter 13 focusses on petrogenesis and finally, in Chapter 14, I discuss the tectonic setting in which they erupt.

Komatiites are beautiful rocks, particularly in thin section, and their textures deserve to be celebrated. I have therefore included a large number of photos of komatiite, particularly in the opening chapters. I have included only a few tables of geochemical data because this information is readily available in on-line databases such as GEOROC http://georoc.mpch-mainz.gwdg.de/georoc/. I tried to keep the book brief and readable, and this has meant that I have avoided going too deeply into discussions of the more arcane aspects of the subject, particularly when these aspects were well treated in published papers. The reference list includes over 600 entries and provides the sources of more detailed information.

During the preparation of the book, which started two decades ago, I received substantial support from the funding agencies first in Germany (DFG) then in France (CNRS) and from the Max-Planck-Institut, the Université de Rennes and most recently the Université de Grenoble. I thank my friends and colleagues in each location for the help and encouragement they provided. Special thanks go to Martine LeFloche, who helped with the figures, and to Rob Hill, Tony Fowler, Claude Herzberg, Tony Naldrett, Allan Wilson, Stephane Guillot, Rich Walker, Phil Thurston and Euan Nisbet, who provided comments on selected chapters, and to Mike Bickle and Bob Nesbitt, who had the patience to read through large portions of the book. Mike Lesher and Steve Barnes thank all the students, postdoctoral researchers and colleagues who worked with them and Steve Beresford and Caroline Perring for reading their chapters. They also acknowledge support from NSERC and CSIRO and mining companies. ... Finally, we all thank Susan Francis, Maureen Storey, Annette Cooper and Jeanette Alfoldi of Cambridge University Press and Devi Rajasundaram of Integra for their patience and encouragement during the long and difficult gestation of the book.