HYDROMAGMATIC PROCESSES AND PLATINUM-GROUP ELEMENT DEPOSITS IN LAYERED INTRUSIONS

The role that hydrothermal fluids may have played during the crystallization of layered intrusions and the formation of the ore deposits they contain has long been debated. This book summarizes the evidence for fluid-crystal-liquid (hydromagmatic) interactions and their importance for the understanding of the formation of platinum-group deposits in layered intrusions. It discusses the composition of igneous fluids in mafic magmatic systems, the generation and movement of these fluids in layered intrusions, their impact in altering the mineralogy and composition of the originally precipitated assemblages, and their role in the transport of the platinum-group elements (PGE). Using examples from the Bushveld complex of South Africa and other intrusions, this book provides a comprehensive overview of the hydromagmatic model for the origin of various features of layered intrusions. It is a useful reference for academic researchers and professional geologists working on economic mineral exploration, layered igneous intrusions and hydrothermal metallogenesis.

ALAN BOUDREAU is Professor of Geology at Duke University and an expert on the origins of layered intrusions. He has worked on numerical modelling of crystallization processes such as crystal aging and compaction, and how they give rise to the variety of features observed in these intrusions. He is also interested in the role of igneous fluids in the petrogenesis of platinum-group element (PGE) deposits in layered intrusions, including the understanding of the interaction of igneous fluids with liquid-crystal assemblages to produce the observed features.

HYDROMAGMATIC PROCESSES AND PLATINUM-GROUP ELEMENT DEPOSITS IN LAYERED INTRUSIONS

ALAN BOUDREAU
Duke University

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108416009
DOI: 10.1017/9781108235617

First published 2019

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Boudreau, Alan, 1953- author.
Title: Hydromagmatic processes and platinum-group element deposits in layered intrusions / Alan Boudreau (Duke University, North Carolina).
Description: Cambridge ; New York, NY : Cambridge University Press, 2019. | Includes bibliographical references and index.
Identifiers: LCCN 2018036907 | ISBN 9781108416009 (hardback : alk. paper)
Subjects: LCSH: Platinum ores. | Ore deposits. | Folds (Geology) | Hydrothermal deposits. | Intrusions (Geology)
Classification: LCC QE390.2.P56 B68 2019 | DDC 553.4/22–dc23
LC record available at https://lccn.loc.gov/2018036907

ISBN 978-1-108-41600-9 Hardback

For Kathleen, and the kids

Contents

Preface

The idea for this book originally began as a description of the hydrothermal model for the concentration of platinum-group elements (PGE) in layered intrusions. This is a model that is contrary to the majority opinion of those who work in layered intrusions, and acceptance requires overcoming a certain amount of cognitive dissonance with longstanding interpretations. However, much of the supporting evidence has grown stronger over time and the need to present a full and detailed description of the model is long overdue. Previous work by the author had shown that the evidence for hydrothermal petrogenetic models had grown beyond the ability of single papers and even extended review articles to cover the supporting evidence in a complete manner. Equally important is to answer some common criticisms of the model; it is common for the idea that the PGE were concentrated by magmatic fluids to be discounted in as little as one sentence. Thus, the idea for this book was conceived.

However, it soon became evident that such a book would need to include related evidence on the effect of volatiles on the crystallization of magmas. This includes growing evidence for re-melting of pre-existing minerals and metasomatic reactions involving fluids and the crystal pile. In many cases this also includes the role of crustal fluids and their effects on the isotopic character of the rocks in general and the growing evidence for isotopic disequilibrium. Indeed, one of the ideas expressed in this book is that large layered intrusions, and particularly the Bushveld Complex, are an excellent analogue for subduction zone hydrothermal systems. Both involve fluids derived from dehydrating underlying sediments that manage to preserve their isotopic character as they move through thick sequence of ultramafic rock to reach hotter rock where they may induce melting. These factors and more led to the expanded scope of this book.

It is common for many review books to be a collection of papers whose chapters are authored by perhaps several authors but the overall content of which is largely determined by one or more editors. This book is instead the product of a single author to present a unified view of the subject. In part, this is because the main ideas presented are very much a minority viewpoint. It is by no means meant to be the last word nor even to be correct in some details. However, it is felt that without a strong description of the hypothesis, future advancement will be haphazard at best.

An overview of the hydrothermal systems in layered intrusions and how it differs from well-known hydrothermal systems in porphyry systems is presented in Chapter 1, along with an overview of orthomagmatic and hydromagmatic models for the concentration of the PGE in layered intrusions. Chapter 2 discusses some of the problems of cumulate terminology with examples of how an originally precipitated crystal assemblage can be modified. Because many of the examples used in this book are from the Stillwater, Bushveld and Skaergaard intrusions, a brief overview of these three intrusions is also presented. Those who are not familiar with these intrusions may want to start here. Chapter 3 presents a summary of volatiles in mafic magmas, but also discusses igneous fluids as hydrothermal solutions and mineral solubility considerations. Chapter 4 covers the geochemistry of the PGE in both magmas and hydrothermal fluids, the latter of which is still poorly known in high temperature solutions. Chapter 5 looks at bubble formation and the phenomenon of three phase flow in crystal-silicate liquid-volatile fluid systems. Chapters 6 and 7 summarize the halogen geochemistry evidence for fluid involvement and the evidence from silicate liquid and fluid inclusions, respectively.

The remaining chapters largely look at evidence for the role of fluids in the formation of specific features in layered intrusions. Chapter 8 discusses the formation of discordant features such as pegmatoids and PGE-bearing pipes. Chapter 9 looks at the role of fluids in altering the crystallization behaviour of magmas and volatile fluxing. Chapter 10 considers chromatographic theory and the origin of ore metal offsets. Chapter 11 discusses the role of compaction in forming stratigraphic traps for migrating fluids and the formation of Great-Dyke type deposits at ultramafic-mafic boundaries, and Chapter 12 discusses the potential role of fluids in the formation of chromitites and their associated PGE mineralization. Chapter 13 looks at isotopic evidence and compares examples of isotopic disequilibrium with that observed in mantle samples. Finally the last chapter looks at some common objections of the hydromagmatic interpretation and a response to these criticisms.

A note on the terminology and format of this book. Ideas or terms that may be unfamiliar with students or even some professionals are generally defined with *italic* font. Because a silicate liquid and a supercritical volatile fluid are both fluids in the physical sense, this report will reserve the terms *silicate liquid* or *liquid* to denote a silicate liquid (magma) in general and the terms *melt* or *silicate melt* to denote a silicate liquid produced specifically by the local melting of pre-existing crystals. The terms *volatile fluid*, *fluid* and *vapour* will be used interchangeably to define a volatile-rich fluid phase. If need, the term *transitional fluid* will be used to define those volatile-rich silicate liquids that can evolve into solute-rich volatile fluids without a phase transition. Finally, cumulate terminology (Wager et al., 1960) is not used in rock descriptions. As noted by a number of authors (Hunter, 1987; Higgins; 1991, 1998, 2002; McBirney and Hunter, 1995; McBirney, 2009) layered intrusion have undergone extensive recrystallization and cumulate terminology has interpretive implications that can have a pernicious effect on the understanding of the processes which formed the rocks. This is particularly true for understanding those rock whose compositions may have be influence by volatile fluids. Thus, this report will use

respectable but model-neural rock names with modifiers as necessary (e.g., granular harzburgite, melanorite).

This book required more than just the labour of the author. In particular, many thanks go out to reviewers of individual chapters: Steve Prevec, Edmond Mathez, Rais Latypov, James Mungall, James Webster and Jacob Hanley. Errors of fact, omission or conclusion are otherwise those of the author. Editorial assistance and support by Cambridge University Press editors and staff, including Sarah Lambert, Zoë Pruce, Harsha Vardhanan and Emma Kiddle, are much appreciated.