Precambrian Geology of the Tobacco Root Mountains, Montana

Edited by

John B. Brady
Department of Geology
Smith College
Northampton, Massachusetts 01063
USA

H. Robert Burger
Department of Geology
Smith College
Northampton, Massachusetts 01063
USA

John T. Cheney
Department of Geology
Amherst College
Amherst, Massachusetts 01002
USA

Tekla A. Harms
Department of Geology
Amherst College
Amherst, Massachusetts 01002
USA

THE GEOLOGICAL SOCIETY OF AMERICA

Special Paper 377
3300 Penrose Place, P.O. Box 9140 • Boulder, Colorado 80301-9140 USA
2004
Cover: Metamorphosed mafic dikes and sills (MMDS) that have intruded quartzofeldspathic gneisses of the Pony–Middle Mountain Metamorphic Suite are visible as nearly horizontal bands in a cliff face in the central Tobacco Root Mountains. The middle of the three prominent MMDS in the photo thins dramatically, as if caught in the act of intrusion. The photograph is taken from the northeast ridge of Spuhler Peak looking northwest toward previously unnamed, flat-topped, 10,080 foot Keck Mountain. In the foreground on the left are rocks of the Spuhler Peak Metamorphic Suite, which are typically more brown in color than the gray-weathering gneisses of the Pony–Middle Mountain Metamorphic Suite. The absence of the MMDS in the Spuhler Peak Metamorphic Suite suggest that the rocks of this suite were not in their present position at the time of intrusion of the MMDS.


Contents

Preface ................................................................. v
Overview .............................................................. v
Dedication ............................................................. v
Acknowledgments ..................................................... v

1. General geology and tectonic setting of the Tobacco Root Mountains ............... 1
   H. Robert Burger

Geochemistry and Petrology

2. Geochemistry of quartzofeldspathic gneisses and metamorphic mafic rocks of the Indian Creek and Pony–Middle Mountain Metamorphic Suites, Tobacco Root Mountains, Montana .......... 15

3. Geology and geochemistry of the Spuhler Peak Metamorphic Suite .................. 47

4. Precambrian meta-ultramafic rocks from the Tobacco Root Mountains, Montana ........ 71
   Kathleen E. Johnson, John B. Brady, William A. MacFarlane, Rebecca B. Thomas, Chris J. Poulsen, and M. Jennifer Sincock

5. General geology and geochemistry of metamorphosed Proterozoic mafic dikes and sills, Tobacco Root Mountains, Montana ................................................................. 89
   John B. Brady, Heidi K. Mohlman, Caroline Harris, Sarah K. Carmichael, Lisa J. Jacob, and Wilfredo R. Chaparro

6. Proterozoic metamorphism of the Tobacco Root Mountains, Montana .................. 105

Geochronology

7. 40Ar/39Ar ages of metamorphic rocks from the Tobacco Root Mountains region, Montana ... 131
   John B. Brady, Dana N. Kovaric, John T. Cheney, Lisa J. Jacob, and J. Toby King
8. In situ ion microprobe $^{207}\text{Pb}/^{206}\text{Pb}$ dating of monazite from Precambrian metamorphic suites, Tobacco Root Mountains, Montana ........................................... 151
   John T. Cheney, A. Alexander G. Webb, Chris D. Coath, and Kevin D. McKeegan

9. Age and evolution of the Precambrian crust of the Tobacco Root Mountains, Montana .... 181
   Paul A. Mueller, H. Robert Burger, Joseph L. Wooden, Ann L. Heatherington, David W. Mogk,
   and Kimberly D’Arcy

Structural Geology and Tectonics

10. Character and origin of Precambrian fabrics and structures in the Tobacco Root Mountains,
    Montana ................................................................. 203
    Tekla A. Harms, H. Robert Burger, Daniel G. Blednick, Jacob M. Cooper, J. Toby King,
    David R. Owen, Josh Lowell, M. Jennifer Sincock, Steven R. Kranenburg, Ann Pufall, and
    Carlos M. Picornell

11. Advances in the geology of the Tobacco Root Mountains, Montana, and their implications
    for the history of the northern Wyoming province ................................. 227
    Tekla A. Harms, John B. Brady, H. Robert Burger, and John T. Cheney

Index of Keywords ................................................................. 245

Explanatory text to accompany geologic map of southern Tobacco Root Mountains,
Madison County, Montana (reprinted) ............................................. 247
   Charles J. Vitaliano, H. Robert Burger III, William S. Cordua, Thomas B. Hanley, David F. Hess,
   and Forrest K. Root
OVERVIEW

The Tobacco Root Mountains occupy a unique niche in the Wyoming province of North America. Located near the northwestern margin of the province, the Precambrian rocks of the Tobacco Roots were subjected to an intense tectonothermal event during the collision of the Wyoming province with the Hearne province in the Early Proterozoic. This event overprinted earlier periods of deformation and metamorphism, but the unique lithologic packages present in the Tobacco Root Mountains aid in unraveling early from later events and in detailing many results stemming from this Early Proterozoic collision.

This Geological Society of America Special Paper is organized into three separate parts. In Chapters 2–6, an effort is made to review the geochemistry and petrology of the four major Precambrian rock sequences present in the Tobacco Root Mountains: the Indian Creek Metamorphic Suite, the Pony–Middle Mountain Metamorphic Suite, the Spuhler Peak Metamorphic Suite, and metamorphosed mafic dikes and sills. Each of these suites, or sequences, plays an important role in understanding the Precambrian geology of this region. This section focuses on what each rock suite represents in terms of original protolith and provides the foundation for understanding the extensive petrological and geochronological information that follows. In addition, Chapter 4 considers the meta-ultramafic rocks that are dispersed throughout all Precambrian exposures in the Tobacco Root Mountains. Chapter 6 presents petrologic observations and interprets them in terms of a metamorphic history and a pressure-temperature path for the four rock suites.

The second section (Chapters 7–9) presents the results of numerous and extensive radiometric age determinations from all four major rock suites. Each chapter details the results of a different approach; taken together, they provide a solid base for understanding the timing of the tectonothermal events that affected these rock suites and for separating the effects of the last major event in the Early Proterozoic. The final chapters (Chapters 10 and 11), comprising the third section, examine the structures and fabrics present in these Precambrian rocks and propose a sequence of events that correlates observed field relations and structures with age determinations and metamorphic history.

Included with this volume is a reprinted version of the Geologic Map of Southern Tobacco Root Mountains, Madison County, Montana, that was compiled by Charles J. Vitaliano and William S. Cordua and published by the Geological Society of America in 1979 as MC-31. The map is included as a pocket insert, and the text that accompanied the map is appended at the end of this volume. As this map was the foundation upon which our research was based and as it currently is out of print, we are pleased that it can be included here. This reprinting of MC-31 is made possible by a generous donation from a former student of Dr. Charles J. Vitaliano.

DEDICATION

The editors dedicate this volume to Sandra Glass, former program vice-president of the W.M. Keck Foundation. It was largely through the wisdom and foresight of Sandra Glass that the Keck Geology Consortium was born. Her insights into science education and research, especially (in our case) at undergraduate liberal arts colleges, provided the support that ultimately made possible our field seasons in Montana and, by extension, this volume.

ACKNOWLEDGMENTS

This volume is an outgrowth of three Keck Geology Consortium undergraduate summer research projects in the Tobacco Root Mountains and the resulting 32 undergraduate theses. Special thanks are due to the advisors of those theses for their careful supervision and guidance. We are grateful to the W.M. Keck
Foundation of Los Angeles and to the 12 colleges of the Keck Geology Consortium (Amherst College, Beloit College, Carleton College, Colorado College, College of Wooster, Franklin & Marshall College, Pomona College, Smith College, Trinity University, Washington and Lee University, Whitman College, and Williams College) for financial support of our field and laboratory work. We also wish to thank Henry H. Woodard and Cathryn A. Manduca, who served as Keck Geology Consortium coordinators during the time of our work in Montana. Their support and flexibility contributed substantially to the success of our project. We are very grateful for the generous assistance of the many reviewers, who are individually acknowledged in each chapter. Finally, we wish to thank GSA Science Editor Abhijit Basu and the GSA publications staff for their patience and assistance in making this publication a reality.

John B. Brady  
H. Robert Burger  
Northampton, Massachusetts

John T. Cheney  
Tekla A. Harms  
Amherst, Massachusetts