PETROGRAPHY

An Introduction to the Study of Rocks in Thin Sections

Second Edition

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Preface

Our aims in this book are much the same as they were in the first edition: We are concerned primarily with the description of common rocks as they appear in thin section beneath the petrographic microscope. We have assumed that our readers have already learned how to identify rocks within broad limits by use of a hand lens; indeed, it is most desirable that observers have available the hand specimens from which the thin sections have been cut. Readers must already be acquainted with the principles of optical mineralogy, for this is the very basis of petrographic technique. We devote considerable, but, we hope, not undue attention to two unifying themes, each treated at an elementary level, both of which contribute geological significance to purely descriptive study. First, the relevant aspects of the modes of origin of igneous, sedimentary, and metamorphic rocks are treated in a manner consistent with modern concepts of petrogenesis.* This topic requires an elementary knowledge of chemistry and, preferably, an inkling of the nature of the thermodynamic assessment of phase equilibria and the possible interactions between the mineral components of rocks, the concrete evidence of which exists in textural detail observed through the microscope. As an aid to thinking in thermodynamic terms, we offer Appendix A, written in the simplest possible terms and illustrated with plots of specific data

*These concepts are elaborated in standard petrology texts.

for albite and for water. The second thematic topic is the field occurrence and global distribution of principal classes of common rocks, with special emphasis on the context of tectonics and time.

With proper selection of rock types, *Petrography* provides the basis for a one-semester introductory course involving six hours of laboratory work and such explanatory lectures as meet the requirements of any specific class. This book will also furnish the descriptive background for more advanced courses in any of the three main branches of petrology. Of course, we hope that it will continue its usefulness as a reference for professional work in most fields of geology.

We completely omit discussion of some of the most fruitful techniques practiced today in the laboratory investigation of rocks, for example, microscopic oil-immersion, x rays, electron-microprobe, and electron-microphotography. The main difference between these complementary methods is the scale of observation. However, their goals are the same: understanding the mineralogical make-up of rocks, the particle-to-particle textural relations of component phases on every scale (in both space and time), and the evaluation of mineral and rock chemistry within the limits of each approach.

No new rock names have been coined, though a few, pertaining to rocks that have recently assumed new significance in geology, have been added to the list appearing in the first edition. On the contrary, we have striven to limit the number of terms, especially in igneous petrology, a subject area in which terminology appears to have proliferated needlessly. Alternate terms that we consider superfluous have been relegated to footnotes marked:°. Each of these terms has a page reference in the index; in this way, students will always be able to find information on a particular rock, despite vagaries of terminology in the technical literature.

Some rock types, of course, are much more abundant on a global scale and some are of greater genetic significance than others; among igneous rocks, basalts and granites are notable examples. However, description of rare but significant rocks may demand at least as much text as is devoted to more voluminous or more common rocks. Chapters treating, respectively, siliceous plutonic rocks (including granites) and silica-deficient feldspathoidal plutonic rocks (including nepheline syenites) are of comparable length. Greenschists, widespread in both space and time, and blueschists, whose distribution in both respects is much more limited, receive comparable discussion. In brief, neither the abundance nor the geological significance of a rock is to be measured by the pages devoted to its description.

Many students and teachers would prefer to see rock types neatly arranged in tables and charts, since such graphic devices aid memory and tend to satisfy the desire for regularity and order in nature (the very impulse that leads scientists to stipulate natural laws). A few such aids are included here; but we feel that "pigeonhole classifications," however satisfying to the order-minded pedagogue or student, may convey a false impression of exactitude where none exists. Our aim is to stress the gradational relationships among individual rocks within any natural or artificially designated group of rocks. This topic is elaborated especially in the chapters on igneous petrography.

The thirty years since the first edition have seen spectacular advances in all branches of petrology and in relevant peripheral aspects of geology: theoretical and experimental geochemistry, chemical composition and spatial relationships of phases identified and analyzed on the submicroscopic scale, geochronology, and plate tectonics. Of course, the composition and texture of rocks have not changed within this period, but they are seen in a different and more revealing perspective than they were three decades ago. In response to such changes, we found it necessary to extensively revise the content and arrangement of the original text, while retaining the approach and general coverage. Chapters 1, 2, 9, 14, and 16 where much attention is devoted to petrogenesis and the tectonic backgrounds of common rocks, have been completely revised; many parts were entirely rewritten. More attention is now paid to certain rocks whose geological significance has become much more fully understood during these last thirty years, including: basalts, carbonatites, limestones, the three lithologic ingredients of ophiolites (serpentinites, spilites, cherts), blueschists, rocks affected regionally by incipient metamorphism (clay sediments, graywackes, basalts), and a group of rocks that appears to have been transported virtually unchanged from the upper mantle. Tectonic environments of specific rock groups receive somewhat greater emphasis than previously.

This revised edition, like its predecessor, has not been easy to write, and as before, we hope that it will not be difficult to read. The preparation of any introductory text presents particular difficulties, especially with respect to classification, selection of material, mode of presentation, and relevant references. Few instructors will agree on the naming and grouping of rocks, the order in which they should be taken up, or the relative emphasis to be placed on each type or class. Each instructor will be guided by his or her own predilections, the demands of the course, and the role of petrography courses in any individual geological curriculum. References are confined to a few easily accessible, classic, comprehensive works and a few specialized works (written in English) that are helpful in illustrating or elaborating specific details relevant to the petrography of some particular type or group of rocks.

Principal responsibility for writing and revising this edition was divided as follows: Part One, igneous rocks, Turner and Gilbert; Part Two, sedimentary rocks, Gilbert; Part Three, metamorphic rocks, and Appendix A, Turner. To avoid confusing the reader with regard to cross-references, the usage and petrogenic approach adopted in Parts One and Three are consistent, as far as possible, with recent petrological texts by Turner.

All petrographic microdrawings, except two (Figure 15-8 by C. O. Hutton and Figure 14-4 by R. S. Creely), are by our late coauthor Howel Williams and, except for Figure 4-1, have been retained from the previous edition. About half of them depict rocks from well-known localities within the United States. The remaining half refer to classic provinces elsewhere (especially those designated as type localites by the European founders of petrography) or to areas of special interest to one or the other of the three original authors.

We cannot adequately acknowledge the encouragement we have received over the years from so many colleagues and former students who have provided material and support in the preparation of both editions of *Petrography*. It is particularly appropriate, however, to acknowledge our special indebtedness to A. V. Cox, R. V. Dietrich, W. G. Ernst, and R. M. Gates for critical assistance in the preparation of the present edition; and to Amy Einsohn and Judith Wilson for skill and tolerance in copy editing.

Finally we, the two surviving authors, wish to pay tribute to the two men who conceived the original project, spiritedly persuaded us into coauthorship, and brought the complete project to fruition as the original edition: Howel Williams, geologist, and William H. Freeman, publisher. It was with the active encouragement of the former that this revision was undertaken. Accordingly, and in affectionate memory of a stimulating, critical, and generously forbearing colleague and friend, we dedicate this work to the late Howel Williams.

Charles M. Gilbert
Francis J. Turner
March 1982

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1

Magma and Igneous Crystallization

NATURE AND SOURCES OF MAGMAS

Igneous rocks are formed by cooling and solidification of *magma*—hot mobile rock matter made up wholly or in appreciable part of a liquid phase having the composition of a silicate melt. The chemistry of this melt, by analogy with chemical analyses of igneous rocks, is usually expressed by weight percentages of a dozen principal component oxides—SiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, K_2O, and others—and parts per million of a host of trace elements (Mn, Ni, Sr, Ba, Rb, U, S, Cl, F, etc.). There is an important group of minor constituents, totaling no more than a small percentage by weight, that because of their capacity to escape from the crystallizing magma can be termed (following the usage of S. J. Shand and others) the *fugitive* components—commonly loosely referred to as "volatiles"—of the magma. Chief among these are H_2O and CO_2. The actual chemical species that can be identified in the melt phase are of a different nature. They include metallic ions (Fe^{2+}, Fe^{3+}, Mg^{2+}, Na^{+} . . .), $(OH)^-$, $(HCO_3)^-$, and Cl^- held within a discontinuous, fluctuating matrix of variously linked Si, Al, and O atoms analogous to embryonic and imperfect crystalline structures. At the time of emplacement within the crust or eruption on the surface, magmas commonly are to some degree heterogeneous; swimming in the melt phase are suspended crystals and even bubbles of gas generated as the melt, on release from pressure, becomes oversaturated in its fugitive components.