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BOOK REVIEWS

MIND OVER MAGMA. by Davis A. Young. Princeton Universtity Press, Princeton and Oxford, 2003, 686 pp, $69.96.

Although magmatic processes directly or indirectly impact all or nearly all facets of earth science, few historians of science have devoted themselves to describing the evolution of our understanding of igneous rocks. *Mind over Magma* provides one of the first records of many of the important people, institutions, and events that have had major impact on this discipline. As pointed out in the preface, this subject cannot, however, realistically be covered to everybody's satisfaction within a book of about 600 pages. Those restrictions notwithstanding, a reader will leave the book with at least a flavor of the many important events that influenced our science and the context in which these events took place. The book also points to how discoveries in other sciences such as chemistry and physics as well as technological advances affected this process.

Mind over Magma is organized into 6 separate "eras," each characterized by particularly important events or developments. Although in broad terms these eras are chronological, they are not meant to imply that the topics are isolated from what occurred before and what may have happened subsequently. Each section (era) contains from 3 to 7 chapters resulting in a total of 30 chapters and 613 pages of text, 58 figures or diagrams, and 9 tables. There is a comprehensive and very useful 50-page bibliography that includes both scientific and historical literature, a subject index, and an author index. The subject index is comparatively short and not as useful as might be desired.

The first 5 chapters comprise the "Foundational Era." Chapter 1 covers the record of volcanology in ancient Greek and Roman literature and in the Old Testament, the extent of survival of this literature through the Middle Ages, and the evolution of knowledge in the 16th, 17th, and to a certain extent, 18th centuries. Up to and including the 16th and 17th centuries, most writing was by Italian authors whose interests understandably were active regions and volcanoes such as Mt. Vesuvius, Mt. Etna, and the Phlegraean Fields. In the 18th century, the knowledge base was expanded to include information on volcanism in Iceland, the Azores, and the Canary Islands as well as volcanism in Mexico, the West Indies, and the Andes.

Chapters 2 and 3 introduce the early discussion of whether igneous rocks resulted from deposition in a global ocean ("neptunism") or from heating and cooling of subterranean rocks ("plutonism"). Chapter 4 contains highlights of the discussion leading to general acceptance that basalt, at least, could not have an aqueous origin. Chapter 5 introduces granite and describes the first great granite debate.

The debate on the origin of basalt, occurring for the most part in the 18th and 19th centuries, is chronicled in Chapters 3 and 4. Observations of extinct volcanic terranes in both France and Germany led many participants in this debate, in particular in France, to come down on the side of plutonism, whereas in Germany and for some time, England, the neptunist view dominated. Neptunists such as Abraham G. Werner and others argued that many old basaltic terranes showed no evidence of typical volcanic products and exhibited structures and mineral contents consistent with precipitation from aqueous solutions (ocean). Plutonists such as James Hutton took a broader view and argued that textures such as columnar jointing, for example, clearly were the result of cooling. The plutonists also suggested that volcanic processes should not be viewed as events isolated from their larger environments, but should incorporate consideration of land elevation and erosion. This discussion, which also introduced the first use of the term "magma," ended in the first few decades of the 19th century with general acceptance that basalt was of igneous origin.

The first debate on the origin of granite is chronicled in Chapters 5 and 6 (Hutton, Playfair, Kirwan, Werner and others). The basis of this discussion was for the most part field observations of granites in Central Europe, but this discussion also, interestingly, brings in the earliest attempts on laboratory experimentation at high temperature by James Hall.

The second of Young's eras, the "Primitive Era," follows with a total of 3 chapters (Chapters 6-8). Chapter 6 is entitled "The Origin of Granite." In addition to arguments over field relationships, this debate introduced the concept of relative fusibility of individual minerals in granitic rocks. Neptunists supported their position by repeatedly pointing to the apparent inconsistency between experimentally determined fusibility and textural relations in granite. Further, experimentalists in the neptunist camp pointed to the solubility of quartz in aqueous fluids and to quartz precipitation from hot water in the laboratory (Scheerer). Proponents of dry fusion such as Joseph Durocher and Robert Bunsen suggested that crystallization of melts should be treated as a problem of solution chemistry and suggested, therefore, that melting temperatures of individual mineral constituents (fusibility) did not provide an accurate description of the situation. Interestingly, the compromise conclusion in this debate was that granite formation likely involved H_2O-rich magma.

A major problem evident in debates on the origin of basalt and granite was the lack of a proper classification scheme for igneous rocks. This matter is taken in up in Chapter 7. After tracing the origin of certain terms such as tephra, pumice, and basalt to antiquity (in particular Pliny the Elder), this chapter focuses on the classification debate in the 18th – 19th century. That debate suffered from the fact that it was difficult to agree on what type of information should play a role in classification. In particular, whether or not geological origin should be incorporated remained a major problem. Chemical compositions also began to become available at that time and some suggested that these data should be incorporated. The most comprehensive classification schemes, however, were based on new mineralogical data being obtained with the petrographic microscope.

The "Primitive Era" ends with Chapter 8, which draws attention to the considerable diversity among igneous rocks, with one school of thought (Bunsen, von Waltershausen, Durocher and others) arguing for two sources of magma within the Earth. One was felsic in character and the source of rhyolite and granite, whereas the other was more basic and the source of basaltic rocks. The other school of thought, which included luminaries such as Scrope, Dana, and Darwin, suggested only one magma source. For this group, diversity in igneous rocks resulted from differentiation processes governed by temperature, pressure, and cooling history.

The third of Young's eras, termed "the Microscope Era," comprises 7 chapters. Chapter 9 traces the origin and evolution of microscope methods beginning in the 17th century with studies of petrified wood and continuing into the 18th century, where the petrographic microscope was employed in examination of minerals (Brewster, Nicol, and Biot) and eventually igneous rocks (Zirkel, Rosenbusch, Michél-Levy and others). Many of the fundamental principles of igneous petrology were developed with the aid of this technology as chronicled in several other chapters (10-15) in this section. Diversity of igneous rocks is discussed further in Chapter 10. The question of whether or not plutonic and volcanic rocks might be related to each other became a topic of major discussion. Whether or not all minerals observed in the rocks were formed during crystallization and the role of alteration processes became important. The concept of igneous provinces and their relations in time and space are discussed in Chapter 11 (Harker and others). Such thinking led to geometric and volume considerations pertaining to large bodies of intrusive rocks. This, in turn, led to discussion of emplacement mechanisms. These principles and discussions provided the foundations for many a heated discussion between practitioners of igneous petrology in the 20th century.

In hindsight, it follows naturally that once the order of crystallization in igneous rocks could be inferred from petrographic examination, possible differentiation mechanisms became an important topic (Chapter 12). It was suggested that differentiation might be accomplished by gravitational separation of heavy and light components in a magma chamber or by settling of crystals (King, Darwin, Dutton, Iddings, Rosenbusch and others). During this discussion, basalt was first proposed as a primary magma (Dutton) rather than granite. Chapter 13 details possible mechanisms of differentiation in more detail as these ideas developed in the second half of the 19th century. Early concepts of differentiation in the liquid state (diffusion processes) driven by thermal energy eventually were discarded as unrealistic or unlikely toward the end of the century (Backström, Harker, Michel-Lévy, Brögger and others). Other means of differentiation in the liquid state were also proposed but generally found insufficient to account for the diversity of igneous rocks. The ideas developed in this period led to early concepts of differentiation by crystal fractionation (Chapter 15).

Before proceeding with a description of the differentiation-crystallization theory, there is first another discussion of rock classification (Chapter 14). This chapter brings the reader through early attempts to quantify petrographic analysis and how results from such analysis were used as a basis for classification. The origin and evolution of the CIPW classification scheme at the beginning of the 20th century is detailed here.

Chapter 15 chronicles early experimental petrology dating back to the first experiments with granitic rocks by James Hall through a long list of minerals synthesized in the laboratory in the 19th century. The main rock-forming minerals were synthesized in this period, although this was accomplished not only at high temperatures relevant to igneous processes, but also via aqueous chemistry. Experimental needs led to better methods for measuring high temperatures. The concept of "fusibility," which played a major role in the first granite debate, was clearly inadequate. Experimentalists began, therefore, to use gas thermometry (first reported by Prinsep in 1828) and thermoelectrics (developed by Seebeck in 1821) to measure temperature. Accurate measurement of high temperature became one of the most important aspects of early experiments at the Geophysical Laboratory of the Carnegie Institution of Washington, the early history in which is described in the last few pages in Chapter 15.

The concluding pages of Chapter 15 lead naturally to the fourth of Young's eras, "the Experimental Era." This section consists of 6 chapters (16-21). After a brief summary of our understanding of rock-forming processes at the beginning of the 20th century, Chapter 16 focuses on Norman L. Bowen and the theory of crystallization and differentiation. The first part introduces the theory and experimental data available to Bowen at that time. In the second part, the discussions that arose from this theory are presented. Bowen argued that all igneous processes could be understood in terms of fractional crystallization of minerals, whereas others argued that other processes such as assimilation and liquid immiscibility are also important (Day and others). The problem with iron enrichment in magmatic evolution (Fenner), not easily accommodated in Bowen's theory, is also discussed.

Chemical and mineralogical data from differentiated sills and layered intrusions, discussed in Chapter 17, formed the principal battleground for Bowen's theory of differentiation and crystallization. The Palisades Sill, for example, was considered a prime example of differentiation by crystallization resulting from a single magma (Lewis), whereas in other cases, multiple injections made such conclusions less obvious (Tyrrell). The Skaergaard Intrusion is discussed in some detail. Although this intrusion offered pervasive evidence of fractionation, the fractionation trend for the most part was toward Fe-enrichment, a feature also noted for Karoo basalt (Wager and Deer). Such a trend was, of course, difficult to rationalize with Bowen's original theory, which could did not accommodate the role of iron in fractionation processes.

The recognition of large layered intrusions in the Earth's crust led to extensive discussions of the mechanics of intrusion during the early 20th century (Chapter 18). The two principal modes of intrusion proposed were forceful injection and injection by stoping. These matters led naturally to a return to the controversial modes of formation of granite (Chapter 19). This debate in many ways resembled the first debate (Chapter 6) although the recognition by many (including, of course, Bowen) that there now existed laboratory evidence consistent with fractional crystallization of basalt to form magmas resembling granite became a hot topic.

That new experimental information notwithstanding, granitization mechanisms via injections of fluids or solid-state diffusion (Sederholm, Michel-Levy, Lacroix, Read, and Reynolds among others) were also advocated. This granite debate is summarized in greater detail in Chapter 20. This chapter discusses the various arguments that eventually led to the confrontation between granitizers, most vocally presented by Read, and the magmatists, represented by Bowen, at a meeting of the Geological Society of America, in Ottawa in December 1947. Although that debate by itself did not resolve the issues, *Mind over Magma* suggests that resolution of the problem arrived with the publication by Tuttle and Bowen in 1958 of their experimental data in the $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O system. Interestingly, this paper, published after Bowen's death, offered a persuasive case for formation of granitic magma by melting of crustal materials, a concept not necessary consistent with Bowen's thinking.

The last chapter (Chapter 21) of the section on the "Experimental Era" returns to the classification problems in the mid-20th century. This remained an unresolved issue.

The fifth of Young's eras is entitled "The Geochemical Era" and consists of 6 chapters (Chapters 22-27). Chapter 22 is divided into three main sections that cover topics such as "Early Quantitative Chemical Analysis of Rocks," "X-Ray Diffractometry and Crystal Structure," and "Application of Emission Spectrography to Petrology." The first section points to the fact that many early chemical analyses of rocks had significant, yet unknown, errors. Even so, a few large compilations of rock analyses appeared in the early parts of the 20th century (Daly). The crystal structure section traces the earliest studies of crystallography followed by a summary of Goldschmidt's contribution to crystal chemistry. The section on emission spectrography describes the development and use of this technique, primarily at MIT, Oxford, and, to lesser extent, Cambridge.

Chapter 23 first offers some thoughts on changes affecting petrologic research around the mid-20th century. The author points to changes in funding structure, the expansion of petrologic research in North America and elsewhere, the rapid increase in student population (primarily reporting the situation at MIT), and the introduction of journals devoted specifically to petrology. The chapter also chronicles the evolution of studies of igneous rocks on the seafloor starting with early dredging around mid-century and ending with the development of the concepts of sea-floor spreading about 15 years later. A short section (4 pages) on lunar petrology is included at the end of this chapter.

Chapter 24 is devoted to stable and radiogenic isotopes. About 60% of the text traces the oxygen isotope geochemistry studies of igneous rocks by Hugh Taylor and colleagues. The remainder of this chapter is devoted to radiogenic isotopes with emphasis on the $^{86}Sr/^{87}Sr$ system in petrogenesis and age dating (Faure and Hurley). The remainder of chapter 24 describes contributions to the U-Th-Pb system by Doe and coworkers and the Sm-Nd system by DePaolo and coworkers. Chapter 25 chronicles trace element systematics in igneous petrogenesis. The chapter includes a section on developments in analytical techniques in the latter half of the 20th century, a brief discussion of some models used to model trace element behavior during petrogenesis, a separate section on the behavior of rare earth elements, and, finally, a discussion of some of the work used to relate trace element characteristics of igneous rocks in various tectonic settings. The relatively recent experimental and modeling studies of trace elements in magmatic processes at Bristol University (Wood, Blundy, and others), viewed by many as the most important breakthrough in this area during the last decade, is ignored. Further, the groundbreaking studies at CalTech (Wasserburg and others), at the Institute de Physique du Globe (Allegre and others), at Woods Hole/MIT (Hart, Shimizu, Frey, and others), and Mainz (Hofmann and others) are barely mentioned or not mentioned at all. In Chapter 26, *Mind over Magma* returns to experimental petrology after Bowen ("Bombs and Buffers"). The chapter begins with a 7-page section on "Ongoing Work at the Geophysical Laboratory." Here, the reader is introduced to some of the high-pressure work by Yoder and Boyd and their developments, respectively, of the internally-heated, high-pressure apparatus, and the solid-media-high-pressure apparatus. There is also a brief section on the development of oxygen buffers (Eugster). A more appropriate title of this section might be "Some Aspects of Ongoing Work at the Geophysical Laboratory" because major efforts during this period involving, for example, mantle melting (Kushiro and coworkers) are not mentioned. The chapter continues with an incomplete summary of how experimental petrology spread to other parts of the world. Surprisingly, the groundbreaking studies of mantle melting at CalTech (Stolper and others), at the Institute for the Study of the Earth's Interior (ISEI, Takahashi, Kushiro, Ito, and others), and at the Bayerisches Geoinstitut (BGI, Walter, Rubie, Dingwell, and others) are barely mentioned or not mentioned at all. Nowhere is there a mention of the proposed role of a deep and extensive magma ocean during the early history of the Earth and the experimental work devoted to this at Harvard, LPI, the University of Arizona, the Geophysical Laboratory, ISEI, Tokyo Tech, and BGI (Agee, Li, Drake, Fei, Walter, Takahashi, Rubie, and others).

The last chapter in this section (Chapter 27) returns to classification of igneous rocks and chronicles the work done on classification of intrusive and extrusive rocks under the auspices of the IUGS.

The sixth and last era in *Mind over Magma*, the "Fluid Dynamical Era," is covered in 3 chapters (Chapters 28-30). Chapter 28 describes for the most part the modeling work at Cambridge University and at the Australian National University and the discussions between theoreticians and modelers in those organizations (Turner, Huppert, Campbell and others) and others (Marsh and others) who repeatedly reminded modelers that they did not appreciate what one might infer by actually studying the rocks. Chapter 29 returns to interpretation of the natural record in light of our understanding of fluid dynamics. Here, we return to layered intrusions with a detailed discussion of recent thinking on crystal settling and resultant cumulate layers in such rock complexes. The reader is introduced to several classic studies of intrusions such as the Stillwater, Bushveld, and Muskox, as well as yet another discussion of the Skaergaard intrusion.

The last chapter (Chapter 30) briefly summarizes what the author did not discuss in *Mind over Magma* and where igneous petrology goes from here. The author obviously had to make several decisions as to what should or should not be included in the book. Modern students of igneous petrology might be surprised that very little space is devoted to melting and crystallization processes in the mantle, for example. Further, despite numerous discussions of magma emplacement throughout the book, the author does not devote space to the vast literature on physics and chemistry of silicate melts. Aside from the discussion of the role of H_2O in granite petrogenesis, the wider role of H_2O in the Earth as such is not discussed. Inter-relationships between magmatism and the formation and evolution of the oceans and the atmosphere in the Earth's early history are not mentioned. Also, practitioners of isotope and trace element geochemistry will be disappointed at the limited discussion of this work.

There will, therefore, undoubtedly be readers of *Mind over Magma* who will feel that many important aspects of magma genesis are not mentioned or have been given insufficient space. *Mind over Magma* does not provide a balanced and comprehensive summary in this regard.

Despite its shortcomings, *Mind over Magma* is interesting reading. To my knowledge, it is the first, or among the very first attempts to cover this topic in a historical context. Obviously, the book reflects the author's own views of the important events in this history. Those views are not, however, likely shared by all readers. That notwithstanding, *Mind over Magma* serves as a starting point for others who wish to study the history of our knowledge of magmas and the processes that govern their formation and evolution.

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TOURMALINE. extraLapis English No. 3: A Gemstone Spectrum. Alexander Falster and Günter Neumeier (translators). Christian Weise Verlag, Munich, and Lapis International, East Hampton, Connecticut (2002) 106 pp. $28.50 (includes shipping).

This book on tourmalines is another in the series of magnificent tomes on minerals, which is especially full of beautiful specimen photographs. However, the editors don't state a specific goal for this specialty mineral book, and unfortunately the topics seem too wide-ranging and disjointed to provide a coherent coverage. The random nature of the monograph is evidenced by the following topics: History of the mineral group, mineralogy, crystallography, worldwide locales summary section, and multiple (5) historic notes. I believe this volume would have benefited from a tighter focus, whatever direction the editors had decided to choose.

The 20 major chapters in the Table of Contents are: (1) Tourmaline History, (2) New From Sludyanka, (3) Mineralogy of the Tourmaline Group, (4) Crystal Structure of Tourmaline, (5) Species by Species- The Tourmaline Group Minerals, (6) The Crystals of Mr. Vorobiev and His Search for the Positive End, (7) Is there Really Black Tourmaline, (8) Cut Longitudinally with Drafting Pen and Paintbrush, (9) News from the Star, (10) Dravite from Qarusulik, Ameralik Fjord in Southwestern Greenland, (11) Cuprian Tourmaline from Paraiba, Brazil, (12) Tourmaline from Bolivia's Tropical Rainforest, (13) Burmese Tourmaline — An Historical Perspective, (14) The Kremlin's Carbuncle, (15) Inclusions in Elbaite Crystals, (16) News from the Origin of the Crystal: Solution Associates and Stress, (17) If Icarus had a Tourmaline, (18) Pegmatites — An Overview, (19) From Paris in America to Amerika in Saxony — A Survey of the Worlds Tourmaline Deposits, and (20) References. Unfortunately, what I list above as chapters 4, 5, and 16 are not listed in the Table of Contents. There are two other minor issues with the Table of Contents. First, the title of Chapter 11 varies from the Table of Contents to the actual chapter heading. Second, the Table of Contents mixes chapter titles and side bars all as chapter headings, but forgets to list "The Saint Wenceslas Crown," which is actually embedded right in the Table of Contents pages. The dedication to Eugene Foord is touching and appreciated but could have discussed in more depth his long involvement in pegmatite and tourmaline research. Even with these minor complaints, some of the chapters themselves are absolute marvels aimed at the lay mineralogist.

Chapter 1, a history in brief of tourmalines, is a well-written time line of the discovery of the various species. This chapter makes good use of abundant references throughout. Chapter 2, titled "New from Sludyanka," provides a fascinating insight into the relentless search for and work on new minerals by Irkutsk's Institute of the Earth's Crust. However, this chapter dealt little with vanadiumdravite, the tourmaline whose type locality is Sludyanka.

The third through fifth chapters deal very effectively with the crystal chemistry, structure and mineralogy of the tourmaline group. Chapter 3 is a very tight, strong and comprehensive article dealing with the crystal chemical and basic physical property complexities of this mineral family. It is especially well written for the level of this manuscript's interested readers. Chapter 4 is a succinct, well-written discussion of the crystal structure of this cyclosilicate. The illustrations are very useful in explaining structural concepts. Chapter 5 discusses the various tourmaline-group minerals. Each description includes a history of the mineral name, provides detailed mineralogy of each species, and includes the more famous localities. Important references and photographs of the species truly enhance this chapter.

The next four chapters, 6 through 9, cover a variety of topics. Chapter 6, "The Crystals of Mr. Vorobiev," contains wonderful photographs and drawings. This chapter touches on a great piece of mineralogic history, but Vorobiev's hunt for tourmalines is relegated to only one page of the article. Chapter7 is a nice and well-referenced discussion related to the colors found in tourmalines, with Table 2 laying out the causes of color. Chapter 8, "Cut Longitudinally with Pen and Paint Brush," is a whimsical and informative discussion of the longitudinal reconstruction of a series of beautiful cross sections from a Madagascar tourmaline. Chapter 9, "News about the Star," discusses the origin of pink star-shaped zones in Malagasy liddicoatite specimens. The authors provide some fascinating theories, but state that more research is needed to pin down an explanation.

Chapters Ten through Thirteen take in various tourmaline localities. "Dravite from Qarusulik" (Chapter 10) is a wonderful article with a superb, succinct section on the geology of the deposit and the species crystal chemistry. This chapter also contains a good discussion of the history of the deposit with accompanying photographs. “Tourmaline of Paraiba, Brazil,” is an extraordinary Chapter (11), which describes the history of the deposit, the local geology, and the role of Cu^{2+} as a chromophore. This chapter uses photos of variously colored tourmalines and inclusions to drive its points home. Chapter 12, “Tourmaline from Bolivia’s Tropical Rainforest,” takes the reader down the trail with a field/research collector in search of an elusive type locality. Chapter 13, written about Burmese tourmalines, is a nice historic description of major tourmaline collecting tracts in Myanmar.

The chapter on the “Kremlin’s Carbuncle” is written about a gemstone that legends are truly made of. This chapter does an admirable job of tracing the fortune of a 250-carat rubellite crystal from 1570 to the present. Chapter 15 explores “Inclusions in Elbaite Crystals.” Beautiful photos accompany text that describes various samples of tourmaline inclusions. Chapter 16 titled “News from the Origin of the Crystal” may actually be part of the previous chapter, but carries a title all its own. The material described, however, fits nicely with the microphotographs on the previous pages. A short informative article on accelerometers (“If Icarus had had a Tourmaline”) is presented as Chapter 17.

Chapter 18, “Pegmatites, An Overview,” is an excellent overview of pegmatites for the lay geologist. A more advanced article on myriolitic pocket formation would have been a welcome addition to this manuscript. Chapter 19, “From Paris in America to Amerika in Saxony” is a phenomenal compilation of all the major (and many minor) tourmaline occurrences worldwide. The descriptions herein make one just drool about the potential for new finds out in the field. The final chapter of references is quite comprehensive.

In summary, although there are quite a few minor flaws with this book, there is enough worthwhile information to make it well worth the price. Tourmaline collecting aficionados are sure to enjoy this special issue of Lapis for all it has to offer in the way of crystal chemistry, locality information, and world-class photography.

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