maximum dimensions are quoted, but when cropped pictures include only part of a specimen, there may be some ambiguity: a visual scale would have served better.

Finally, a Selected Bibliography is provided as a resource for browsing. It is remarkably extensive, yet few of these references appear in the text. This is one of several aspects of linking in the book that could have been implemented better. Another would be better connection between the text and the colour plates: easily possible by reference to plate numbers. An omission is the absence of any significant reference to mineral compositions and chemistry. While the inclusion of mineral formulae in the text or in captions can be repetitive, and possibly distracting, a glossary of mineral species with formulae would enable readers to appreciate better chemical associations and relationships.

Nevertheless, the strengths of this excellent book far outweigh its shortcomings. I thoroughly recommend it as a source of reference and I am sure it would be a welcome asset for any mineral enthusiast.

PETER WEBB

Bethke, C.M. *Geochemical and Biogeochemical Reaction Modeling* Second Edition, 2007, Cambridge University Press, Cambridge, UK. 564pp., Price £45, ISBN 978 0 521 87554 7

The geochemical modelling package 'Geochemist's Workbench' is well known as a powerful tool for the interpretation and understanding of water–rock reactions. Craig Bethke, who developed the software, has a deep understanding of aqueous geochemistry combined with mathematical and computational skills. This book has to be an essential companion to *The Geochemist's Workbench*, as it explains so much concerning what the software does, why it does it, and how the operator can develop the skills of modelling by interacting with it.

Teaching 'thermodynamics' or theoretical geochemistry is a challenge. Bethke appears to have overcome that challenge, because the book is structured and written in ways that genuinely encourage the reader to progress. Typically, chapters are introduced with fairly simple concepts, often illustrated with interesting, quirky, and familiar examples drawn from everyday life that illustrate theoretical principles. Individual chapters are short, easily digestible, and readily adopted as teaching packages.

After an introduction to modelling that sets out basic conceptual principles in a very accessible way, the book is divided into three parts. First, equilibrium in natural waters is considered, introducing the reader to understanding the modelling of equilibrium (including technical issues relating to the mathematical description of equilibrium) before discussing complications: redox equilibria, the need to consider activity coefficients and how to model brines, sorption, ion exchange and surface complexation. This section takes up almost half of the book, and culminates in discussion of the modelling technicalities of automatic reaction balancing and uniqueness. The text occupies 12 chapters up to this point, and in each case very clear links are made to Geochemist's Workbench to the extent that it is impossible, practically, to use the book without having the software running alongside.

Once the reader has mastered the art of equilibrium modelling, he (or she) is led into the domain of reaction process modelling. This second major section of the book considers mass transfer and reaction path modelling (with varying temperature, activity and fugacity paths), buffers, and then kinetic modelling of mineral dissolution/precipitation and redox. There are substantial chapters on the modelling of microbially-mediated kinetics, and stable isotope fractionation. The section culminates with chapters describing the modelling of flowing groundwater systems, in which dispersion and advection are considered as well as water–rock reaction, and reactive transport.

Having established the theoretical framework for the discipline of geochemical modelling, Bethke devotes the third section of the book to examples of the application to specific scientific and engineering problems. Using familiar starting points, he illustrates the use of modelling to understand hydrothermal fluids, then geothermometry and the evaporation of seawater. He then moves into sediment diagenesis and the kinetics of water–rock interaction in an aquifer. Weathering however, defeats the modeller, and identifies a challenge for the future (3^{rd} edition perhaps?). Becoming increasingly applied to problems of commercial interest, there are chapters on oxidation and reduction (uranium and organic aquifer contaminants), waste injection wells (how modelling could have prevented industrial disasters), petroleum reservoirs and acid mine drainage. The final two chapters address groundwater contamination and modelling of microbially-mediated systems. So there really is something for everyone.

As with many books of this type, the appendices are particularly useful. Very brief details are given of 17 geochemical modelling software packages that have been used over the last 30 years or so, including key publications describing each package and web sources of the software. A second appendix paces the reader through the Harvie Møller and Weare activity model, and a third appendix lists the mineral species in the Lawrence Livermore National Laboratory database. A final appendix briefly discusses non-linear rate laws. Finally, there is an extensive list of references (~350), containing a portrait of the 'great and the good' of experimental and aqueous geochemistry from the last four decades.

As stated earlier in this review, the book is best used alongside an operational version of *The Geochemist's Workbench*. It is designed well as an instructional book, well suited to geochemistry courses at Masters level or to support PhD students in their work. Individuals who lack a strong mathematical foundation will struggle with large parts of the text. They will however be able to use *The Geochemist's Workbench* mechanically without necessarily understanding the mathematical basis that underpins the software, and will be able to work through the book, skipping the difficult bits. In contrast, students who have taken appropriate mathematics courses at university level (undergraduate and postgraduate) will find their use of geochemical modelling enriched, becoming competent in the use of software by virtue of understanding its mathematical limitations as well as limitations imposed by analytical chemistry.

Assuming that the reader is able to grapple with the theory, this book is an extremely valuable resource. It provides an essential basis for understanding the chemical behaviour of waters in natural systems. It is very easily accessible to a mathematically literate reader, and demonstrates the breadth of application of modelling to a range of geological and engineering problems. Those lacking a strong maths background will find this book challenging but rewarding given its diversity of application and clarity of explanation.

DAVID MANNING

REVIEWS

Geochemical Reaction Modeling. By Craig M. Bethke. New York and Oxford: Oxford University Press, 1996. 397 pages. $50.00 cloth.

This book definitively demystifies geochemical modeling of water-rock reactions and makes it a breeze. The modeling approach described is the equilibrium and reaction path approach developed by Helgeson and perfected by Reed and Bethke himself. Principles and concepts of the approach, mathematical methods used, and numerous applications of it are described with economy, an original light touch, and insight. The egg whites needed as ingredients for a cake can be made up with whole eggs plus negative amounts of egg yokes as components—a sparkling illustration of the differences between component and phase, crucial for modeling. The explanation of the need for aqueous-solute activity coefficients is typical of the insight and conciseness that characterize this book. Quantitative applications are described in many short direct chapters with excellent figures and geological sense. Isotopes, hydrothermal fluids and ores, black and white smokers, carbonates, water chemical divides upon evaporation, scaling of wells, increased oil recovery, carbonates, diagenesis, surface reactions, kinetic and equilibrium reaction paths, inferring the ''overall'' reaction, Ostwald ripening, acid drainage, heterogeneous buffering, and non-uniqueness and uncertainty of geochemical modeling predictions, are all here, among others. (On the other hand, weathering, authigenic zonations, and other cases of the geochemical interpretation of the geometry of authigenic textures and structures, are not here—inevitably, because the reaction path approach, being space-blind, is unsuited for such ''spatial'' subjects or for modeling geochemical feedbacks. The continuity-based reaction-transport modeling approach, which by contrast is space-sensitive, is cited but not included.) This is an outstanding book for students, teachers, researchers, and professionals (including environmental ones) interested in any low-temperature geochemical endeavor, applied or not yet applied. Combining the pragmatism, flexibility, and insight displayed here with use of the author's own software (not reviewed), will lead to new applications of geochemical modeling.

ENRIQUE MERINO
Department of Geological Sciences
Indiana University, Bloomington

Introduction to Geochemical Modeling. By Francis Albarede. Cambridge: Cambridge University Press, 1995. 543 pages, 132 figs.

This book is a hybrid which bridges the worlds of applied mathematics and geochemistry. The first chapter, entitled Mass Balance, Mixing, and Fractionation, looks like a geochemistry book, taught in the language of isotope and elemental ratios within the framework of open and closed system distillations. The next four chapters, devoted to linear algebra, numerical analysis, probability and statistics, and inverse methods, come straight from the world of applied mathematics, but are supplemented with examples, applications, and sample problems from the geochemical literature. Examples include a matrix expression for the evolution of U-Th decay series nuclides with time (chapter 2), the calculation of a multivariate confidence ellipse for Pb isotopes from replicate data, and error propagation of a Sm-Nd determination of a sediment crustal residence age (chapter 4), and isocrons as non-linear least squares inverse problems (chapter 5). The final chapters justify the existence of the first half of the book, as the conceptual and notational vocabulary of applied mathematics is used to describe equilibrium calculations (chapter 6), dynamical systems (chapter 7, ranging from simple box models and residence times to a daunting-looking treatment of the evolution of the mantle and crust according to Nd isotopes), transport, advection, and diffusion (chapter 8, with an analytical treatment of diffusion to complement the numerical methods relegated to chapter 3), and finally, a detailed treatment of trace elements in magnatic processes (chapter 9). The book is polished and professional, the writing style is clear, and the figures are very nice. Some of the problems derive from aqueous and other low-temperature environments, but the author is clearly in his element as he describes the high-temperature side of geochemistry. The generally high intellectual level of the book, coupled with the sample problems throughout, would make it ideal for a graduate level text in a Geochemical Modeling class, or as a reference/refresher book for practicing geochemists. This book contains a wealth of good stuff, and I recommend it highly.

DAVID ARCHER
Department of the Geophysical Sciences
University of Chicago

JOURNAL OF PETROLOGY | VOLUME 38 | NUMBER 7 | PAGES 971–973 | 1997

Book Reviews

Geochemical Reaction Modeling: Concepts and Applications, by Craig M. Bethke. Oxford University Press, New York, 1996. ISBN 0 19 5094751. 414 pp. Hardback. £37.95.

It is over a quarter of a century since Harold Helgeson pioneered computer modelling of what happens when minerals interact with the sort of fluids that occur in nature, but *Geochemical Reaction Modeling* is the first text book to attempt to strip away some of the arcane mysteries that surround the subject and explain how, and of course why, geochemical modelling of fluid–rock interactions is carried out.

The aims of the book are essentially two-fold. Much of it is devoted to working through the various steps involved in geochemical modelling, from the simple equilibrium aspects of speciation and solubility calculations to reaction progress calculations, well illustrated with examples. Along the way, however, the author demonstrates the specifics of how problems are solved using his Geochemists Workbench software package. The way in which these two themes are interleaved is sometimes idiosyncratic, and can get in the way of the clear development of the main themes. For example, an early chapter entitled 'Changing the Basis' is a little premature for people who have yet to run an equilibrium model.

For the reader with some previous exposure to the subject, this book does a marvellous job of putting things in their place, and includes some clear explanations of some potentially difficult topics, such as uniqueness or the workings of Newton–Raphson iteration. However, a reasonable working knowledge of the thermodynamics of geochemical fluids is an essential prerequisite. The examples used cover a wide range of applications and in general the author has been careful to point out limitations and problems that can trip the unwary. Nevertheless, although the examples range from water-rich to rock-rich systems, the text does not emphasize that the type of reaction progress modelling used in Geochemists Workbench (and most other codes) is based on the conceptual experiment of dropping mineral grains into buckets of water, rather than the reverse. Inevitably, this can lead to difficulties in interpreting the implications of a model for rock-dominated processes. Although the book rightly sells the value of geochemical modelling for understanding a wide range of problems, this is not matched by information about the need for, and creation of, databases for P–T conditions other than along the boiling curve. Furthermore, there are limitation to the use of the HKF activity coefficient model for fluids which are not dominated by NaCl, which the user should be aware of.

The quibbles notwithstanding, this is a unique book with many valuable insights. Mathematical derivations are balanced by clear, qualitative descriptions of what is going on, and the overall theme is developed logically through a large number of easily assimilated chapters. It must be essential reading for anyone starting off in the study of water–rock interactions, as well as being an extremely valuable reference for people already wrestling with such problems.

Bruce Yardley

Microtectonics, by C. W. Passchier and R. A. J. Trouw. Springer-Verlag, Berlin 1996. ISBN 3540587136. 289 pp. Hardback. DM 64.00.

This is a beautifully crafted book which is sure to find a place next to the microscope of any practising metamorphic petrologist or structural geologist working on metamorphic rocks. Over 160 black and white photomicrographs, including superb examples of snowball garnets, shear criteria in mylonites and kelyphitic reaction rims, give the book almost a coffee-table quality. It really is a delight just to flick through the series of superb microstructural illustrations, or to test your opinion against those of the authors in the problems set in Chapter 11. Unfortunately, part of the attraction of this book for a traditionally instructed geologist such as me is its nostalgic quality; most undergraduates these days have difficulty distinguishing quartz from feldspar under the microscope, and there is simply not the scope for systematic teaching of inclusion patterns in porphyroblasts and other metamorphic microstructures. For this reason, I doubt if this book will be widely purchased by undergraduates, who are likely to prefer the much briefer treatment of the subject in standard texts such as Yardley (1989).

Meteoritics & Planetary Science 32, 439–440 (1997)

Book and Multimedia Reviews

Skywatchers, Shamans & Kings: Astronomy and the Archaeology of Power by E. C. Krupp. John Wiley, New York, New York 1997, 364 pp., $27.95 (cloth, ISBN 0-471-04863-1).

Skywatching is practiced by only a few specialists in modern society, but in more ancient times knowledge of the celestial sphere was not only important but often critical to the community's well-being. Understanding current events or predicting future ones required a personal link to the astronomical realm. This established link not only conferred special knowledge but also power by virtue of that knowledge. Kings and rulers often legitimized their authority by claiming celestial gods as ancestors; shamans tapped into cosmic power by using trances to travel supernaturally to power havens located throughout the cosmos. This is the world into which E. C. Krupp takes us with *Skywatchers, Shamans & Kings*.

Although the book is subtitled with a reference to astronomy, the text is really concerned with the anthropology of astronomical symbolism. Krupp leads the reader around the world on a search for the relationship between the acquisition of power and its celestial connotations. We visit well-known examples of Egyptian pharaohs, Chinese astronomy, Mayan pyramids, and the royal Japanese celestial lineage. Krupp balances these with lesser-known illustrations from ancient Malta, California Chumash, !Kung Bushmen, and neolithic Turkey. The geographic scope is large and benefits greatly from Krupp's first-hand knowledge of the locations he describes.

The introduction provides the reader with several examples of ancient and more modern connections with the sky and lays the groundwork for the rest of the book between these connections and the power they bring. Chapter one describes the notion of cardinal directions and local world centers. The second and third chapters discuss how individuals can connect with cosmic power and why each group creates their own unique center of creation. Chapters four and five relate the symbolism used for fertility and cyclical renewal. The remaining chapters (six through ten) deal more directly with the link between cosmic forces and power. Sprinkled throughout the text are examples of modern cosmic symbolism that remind the reader of the importance of such symbols in popular culture. Two such examples are the cosmic power transferred to superheroes such as Superman and Captain Marvel and the celestial notions of kingship demonstrated by the movie *The Lion King*.

The only real problems I had with the book are very minor points. Krupp occasionally goes into so much detail the reader may lose track of the point being made. However, the end of chapter summaries reinforce the important themes very well. Also, Krupp does not always relate noncelestial interpretations. For example, he spends several pages discussing the cosmic placement of earthen mounds and the circular arrangement of timber postholes at the prehistoric Cahokia site near St. Louis, Missouri. Although there is probably some solstitial and equinox alignments involved, some archaeologists contend that the "Woodhenges" may have more to do with community planning than astronomical alignments and cosmic order.

Skywatchers, Shamans & Kings is a very interesting read. The authoritative nature of the discussion and the broad coverage of societies make this book useful as a handy reference work. Krupp does an excellent job of combining the rituals of diverse cultures into a common theme. I would highly recommend this book to anyone interested in how human cultures rely upon and draw strength from their celestial surroundings.

Glen Akridge
Cosmochemistry Group
Department of Chemistry and Biochemistry
University of Arkansas
Fayetteville, Arkansas 72701, USA

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Comet Hale-Bopp: Find and Enjoy the Great Comet by Robert Burnham. Cambridge University Press, New York, New York, 1997, 60 pp., $12.95 (paper, ISBN 0-521-58636-4).

By the time *Meteoritics & Planetary Science* readers see this review, the Great Comet of 1997 will have begun its long journey out of the solar system, with its two bright tails fading into the blackness and memory. But Robert Burnham's book will still be a valuable resource for following the comet as it heads out, as well as for looking at other comets that may find their way into Earth's sky over the next few years.

An experienced amateur astronomer and former editor of *Astronomy* magazine, Burnham has brought his own observing experience and knowledge to bear in writing a clear and understandable guide for observing comets.

Even though the book is aimed specifically at Hale-Bopp, its wisdom should work for other comets and other types of skywatching. The book begins with the delightful story of how two observers working independently with simple telescopes, one in a back yard and the other at a star party, discovered the comet in 1995 July and discusses how the orbit was calculated.

The next chapter explains comets as "dirty snowballs" orbiting the Sun and explores how comets develop their comae and tails. The third chapter presents a list of viewing conditions for the comet through the end of 1997. A chapter on how to photograph the comet contains useful tips for anyone trying to take good shots of the night sky. The final chapter considers how comets are discovered and reported.

This book was published by Cambridge University Press, one of the oldest presses in the world; a press that, I believe, even counts Edmond Halley as one of its writers. The press may be old, but its book is young: it has a lively style that young readers will especially enjoy. Get the book and enjoy the comet!

David H. Levy
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721, USA

—♦♦♦—

Geochemical Reaction Modeling by Craig M. Bethke. Oxford University Press, New York, New York, 1996, 397 pp., US$50.00 (cloth, ISBN 0-19-509475-1).

This book is timely because geochemists increasingly use computer models to understand a variety of processes, including diagenesis, hydrothermal alteration, formation of ore deposits, and laboratory experiments, among many examples. Of great importance to public policy, geochemical models are used to predict the behavior of toxic and radioactive contaminants in existing and proposed waste-disposal sites. For the readers of *Meteoritics & Planetary Science*, in particular, the book is relevant to those exploring the implications of liquid-water on Mars in the past. The book focuses on conditions near Earth's surface but includes conditions up to ~300 °C. Extreme hydrothermal, metamorphic, and anhydrous systems are not considered.

The book presents the theory and application of computer methods for chemical-reaction modeling using the program The Geochemists' Workbench, a polygenetic program developed by the author. The program is oriented to describing the chemical state of natural waters and how waters react with minerals and gases. The book is not, however, a reference manual for the program, nor does it serve as an introduction to aqueous chemistry and mineral equilibria. Rather the authors stated purpose was "...to present in one place both the concepts that underpin modeling studies and the ways in which geochemical models can be applied." Bethke met his objectives admirably: the book is well organized, the concepts are rigorously and clearly explained, and the range of examples are relevant and interesting. The writing style is lucid and concise, and I found the book a pleasure to read. The author also takes a refreshingly balanced view of the role and limitations of modeling, cautioning at one point that "...our calculations are a considerable simplification of reality."

After rehearsing the development of the various modeling approaches that went before and defining the fundamental concepts used in geochemical modeling in the introductory first two chapters, Part 1, "Equilibrium in Natural Waters," (chapters 3–10) begins with defining the equilibrium state and then presents the mathematical underpinnings of the computational methods. Concepts of chemical thermodynamics here and in later chapters are only lightly rehearsed and serve more as review than as a primary explanation. The philosophical and mathematical bases of the computational methods using matrix algebra to solve simultaneous nonlinear equations are developed in great detail but will be of interest primarily to those specialists devising their own modeling codes. Fundamental concepts are progressively introduced, each accompanied by real life examples. In chapter 6 ("Equilibrium Models of Natural Waters"), the chemical model of seawater is used as an example. The program calculates the chemical speciation of seawater from a given chemical analysis and evaluates the saturation state of the water with the universe of possible minerals. In a pattern that is followed in later chapters, the common-sense constraints are explained, and the steps required to carry out the calculation are listed in the form of specific Geochemists' Workbench computer commands. Part 1 is completed with a chapter addressing "Activity Coefficients" (expanded Debye Hückel model for dilute solutions and the Pitzer ion-interaction for brines are accommodated), "Surface Complexation," "Automatic Reaction Balancing," and a discussion of "Uniqueness." Part 2, "Reaction Processes," addresses the topics of "Mass Transfer," "Geochemical Buffers," "Geochemical Kinetics," and "Stable Isotopes." An impressive feature of The Geochemists' Workbench is that it combines all the above concepts and can bring them together to bear on any given problem.

Part 3, "Applied Reaction Modeling," consists of eight chapters presenting case studies of model applications: "Hydrothermal Fluids," "Geothermometry," "Evaporation," "Sediment Diagenesis," "Kinetic Reaction Paths," "Waste Injection Wells," "Petroleum Reservoirs," and "Acid Drainage." Each of these chapters draws on examples from the literature and demonstrates where modeling can yield insight. The examples illustrate geochemical processes in water-rock interactions and show how to make the necessary simplifying assumptions. In chapter 16, for example, the mixing of a "black smoker" fluid with cold seawater is modeled. The model predicted the observed mineral precipitates rather well and revealed the counter-intuitive phenomenon that oxygen fugacity of the mixture actually decreases during mixing for up to 100 kg seawater to 1 kg hydrothermal fluid. The model revealed the reasons for this decrease and provided an explanation for the observation that sulfide minerals in the "smoke" show no evidence under the electron microscope of beginning to redissolve. Chapter 22 examines another interesting application, "Alkali Flooding." In this process, a caustic solution is injected into a clastic reservoir rock to enhance petroleum production. The results were presented in terms of relative volumes of dissolving and precipitating minerals, and they showed that formation damage would likely be caused by massive precipitation of zeolites near the well bore. This kind of modeling, in particular, can prevent potentially costly field experiments.

The production quality of the book is excellent and the illustrations are clearly made and relevant to the immediate text. I found no typographic errors. The price is very reasonable, in part because the author did the layout himself to keep the price affordable for students. The book will be most useful to a wide spectrum of students and researchers with interest in, and some prior familiarity with, aqueous chemistry, mineral equilibria, and water-rock interactions.

James L. Bischoff
U. S. Geological Survey
Menlo Park, California 94025, USA

BOOK REVIEWS

Bethke, C. M. *Geochemical Reaction Modeling*. New York, Oxford (Oxford University Press). 1996, xvii + 397 pp. Price £37.95. ISBN 0-19-509475-1.

Craig Bethke's book *Geochemical Reaction Modeling* is about how natural waters and their dissolved masses behave when they react with the minerals, fluids and gases of the earth's crust and hydrosphere. Natural hydrous systems are dynamic hence any description of their behaviour will show a change in composition with time. They are also normally multicomponent solutions. Thus any attempt to describe their behaviour in a realistic way presents a mathematical problem of some complexity. Whilst early workers sought to solve problems of this type 'by hand' it is only with the advent of computer modelling that quantitative solutions can be tested in systems of any complexity. Hence this book is an exposition of a particular approach to geochemical reaction modelling built around a specific suite of computer programs known as 'The Geochemist's Workbench®' produced by the author and co-workers in the hydrogeology group at the University of Illinois.

The author seeks to illustrate the principles of geochemical reaction modelling by describing the concepts that underpin modelling studies and by showing how geochemical modelling studies can be applied to quantitative geochemistry. Throughout the book theory is illuminated by reference to a large number of examples chosen to reflect the practical needs of workers in petroleum geology and environmental geochemistry. These case studies not only show the results but also the limitations and uncertainties that are encountered in geochemical reaction modelling.

The book is divided into three main sections. In the first part 'Equilibrium in Natural Waters' the author describes how the equilibrium equations for hydrothermal systems are derived, and then modified for their application to reaction pathways. This leads into a discussion of the mathematics necessary to solve for the equilibrium state and a discussion of the vagaries of activity coefficients, surface complexation and automatic reaction balancing. In the following section 'Reaction Processes' the reader is shown how geochemical reaction modelling can be applied to problems involving mass transfer, polythermal reaction paths, geochemical buffers geochemical kinetics and how changes in stable isotope ratios can be integrated into the modelling approach. The final section shows how reaction modelling is applied to problems in low-temperature geochemistry. The range of applications is impressive, illustrating the huge power in the methods described. Examples are drawn from the study of low-temperature mineral deposits, the geothermometry of natural waters, the evaporation of natural waters, sediment diagenesis, kinetic reaction paths, the prediction of scaling in geothermal wells, the outcome of steam flooding of oil reservoirs, the management of injection wells and the study of acid drainage.

This volume is an excellent introduction to the power of geochemical modelling. The reader is given a thorough grounding in the appropriate theory, is made aware of the complexities involved and given a wide choice of practical applications. However, it is my guess that for many readers this is not enough and they will want to become users of the methods outlined. For such readers this book is inadequate for they must then follow-up the information presented in one of the appendices and select an appropriate software package for their use. This book is not a 'user manual' although with each case study the author has chosen to outline the appropriate commands necessary to execute the software. For me this was somewhat obtrusive in an otherwise very well written text, and I would have preferred to have taken the results presented 'on trust' and seen the computer commands relegated to an addendum to each chapter. Such a presentation style has the effect of making the reader wish that he/she was sitting at a terminal running the software. Maybe that is what the author intended.

In many ways this is a highly technical and very specialised volume but for organisations working in any area of low-temperature geochemistry this is an essential addition to the library. For those working either in industry or academia in the areas of petroleum geology, environmental geochemistry and the geology of low-temperature hydrothermal mineral deposits this book is invaluable and full of stimulating ideas. It is also a book for graduate students and final year undergraduates specializing in low-temperature chemistry.

Oxford University Press have produced this book to a very high standard and for a volume in hardback, the price is fair. For some, however, the purchase of this book is but the beginning and the price of a license for the software is in a different league.

H. ROLLINSON

The Manson Impact Structure, Iowa: Anatomy of an Impact Crater. Geological Society of America Special Paper 302. Paperback, vi + 468 pp. Price US$99.50, ISBN 0-8137-2302-7. Edited by Christian Koeberl and Raymond R. Anderson.

The Manson impact structure (north-central Iowa, USA), at ~38 km in diameter is one of the largest impact structures in the United States. The crater is filled with a thick layer of sediments and breccias, and for many years following its recognition as an impact structure, its age was put at between 60 and 90 Myr., (i.e., spanning the Cretaceous-Tertiary (K-T) boundary), on the basis of sediment stratigraphy, fission track- and argon age-dating. After the proposal by Alvarez *et al.* (*Science*, 1980) that the extinction at the end of the Cretaceous was a consequence of a giant impact, the search commenced for the site of the impact. The apparent age of the Manson structure indicated that it was a possible candidate for the K-T impact site. On this basis, in 1991 the Iowa Geological Survey Bureau, with the US Geological Survey, conducted an intensive drilling programme across the structure, resulting in the production of over 1000 m of well-characterized drill core from a dozen locations across the feature. The cores were made available for study, and it is the results from these materials that are collected in this Geological Society of America Special Paper.

The book consists of a series of 22 papers, covering all aspects of the Manson impact structure, including historical, stratigraphic, structural, geochemical, isotopic, mineralogical and petrographic descriptions and interpretations. The occurrence and distribution of shock-produced mineral polymorphs and impact melt breccias receive due recognition. There is discussion of the dynamics of crater formation, and comparisons with craters on the moon and Venus. An introductory chapter contains an overview of other impact craters in the US, for comparison, along with a valuable discussion of the characteristics by which a crater and associated shock features might be recognized, on both macro and micro levels. A major irony of the study has been the precise dating of the Manson structure, at 74 Myr., too old to be implicated as the site of the K-T event. Notwithstanding this disappointment, the comprehensive nature of the investigation has ensured that the Manson structure is now one of the best understood features in the US. The publication is riddled with maps of the Manson structure: geological, geophysical, cross-sections, location, diagrammatic, schematic etc., etc. However (and this is a very minor carp on an otherwise excellent book), I couldn't find a single picture of what the Manson feature actually looks like from the ground (or air) today. I know that the crater is buried in glacial drift and has a town built on it – but surely there must be some giveaway that it is there?

There is an increasing perception of the role impacts have played in shaping the Earth's history. The relatively low number of well-studied craters has hampered interpretation of the cratering record. This publication, co-ordinated, logically organised and comprehensively indexed by the editors Koeberl and Anderson, provides a valuable insight into just one feature on the Earth's surface. The only other craters studied in similar detail are at Chicxulub (Mexico), now known to be the K-T impact site, and at Sudbury (Canada), where major mineral deposits are located. It is too much to hope that other craters not associated with 'newsworthy' features such as extinctions or precious mineral deposits can be studied in such detail, but this exercise on Manson has certainly provided a wealth of detail of immense use to impact and cratering specialists.

As usual, the GSA Special Paper Series has produced a scholarly body of work which will be the baseline reference material in this field for many years to come. It is an excellent publication, for which the editors must be congratulated.

M. M. GRADY

Mathematical Geology, Vol. 32, No. 1, 2000

Book Review

Geochemical Reaction Modeling
Edited by By Craig M. Bethke
Oxford University Press, New York, 1996, 397 p, $50.00 (U.S. hard cover) ISBN 0-19-509475-1.

When I took aqueous geochemistry as a graduate student in 1964, no textbooks were available so we had to rely on notes and problem sets provided by Professor Hugh Barnes. Then in 1965 the now famous text, *Solutions, Minerals and Equilibria*, by Garrels and Christ was published. I adopted this as a text when I began to teach aqueous geochemistry in 1969 as it had a good selection of problems for my students to work on. I have always believed that the best way to master this subject and to develop chemical intuition is by working on many problems covering a wide variety of topics. This textbook, however, had some shortcomings as its focus was largely on mineral stability diagrams and to a lesser extent on carbonate equilibria and sea water chemistry. Then in 1970 Stumm and Morgan published *Aquatic Chemistry*, which unlike Garrels and Christ focused entirely on low temperature aqueous chemistry and was geared toward aquatic ecologists as well as geochemist. This book touched on kinetics and expanded the kinds of problems that students could work on. However, I noticed that most of the students had difficulty following the more complex development of equilibrium theory presented therein. Eventually in 1982 Drever published *The Chemistry of Natural Waters*, which I adopted because it covered in a more intuitive and straightforward way much of the material covered in Garrels and Christ and in Stumm and Morgan. I also liked this book because it was organized around geochemical topics such as weathering, watershed chemistry, acid rain, and carbonate geochemistry, and had numerous case histories and real world problems.

In the past few years several new texts have appeared, including *Aqueous Environmental Geochemistry* (1997) by D. Langmuir, *Geochemistry, Groundwater, and Pollution* (1993) by C. A. Appelo and D. Postma, and *Geochemical Reaction Modeling* (1996) by C. M. Bethke, which is the subject of this review. The first two of these recent offerings are similar to Drever's text but are a bit more rigorous and comprehensive. The latter is also quite rigorous and comprehensive, but demands a much higher level of mathematical skills (including matrix algebra, Jacobians, and attendant tedious notation), which might make it appealing to the readers of this journal but will defeat all but the most gifted geoscience graduate students. As a result of the dense mathematics and absence of pencil and paper type problems, students are unlikely to develop the intuition they need. *Geochemical Reaction Modeling* does in fact present and discuss many interesting geochemical problems. These, however, are solved by means of Bethke's proprietary software, The Geochemist's Workbench, which unfortunately is not included with the text. Without access to this software and its user's manual, some of the code presented in the text is not very meaningful. Even if this software was included I would not be inclined to rely on it as a pedological tool for this subject because of its black box character. Perhaps I am old-fashioned but I feel one should thoroughly learn to do arithmetic by hand before resorting to a calculator. Besides, one could probably do most of the problems presented by Bethke using the USGS public domain code PHREEQC, although perhaps not as easily as with Bethke's software. Accordingly, I do not recommend this book as a text for a beginning course in aqueous geochemistry. However, for an experienced practicing geochemist who is willing to invest in Bethke' software, this could be a useful tool to have at hand.

The book contains 23 chapters and 5 appendices. After two introductory and overview chapters, the book is divided into three parts devoted to equilibrium concepts and calculations, reaction processes, and applied reaction modeling. Much of the material in the first two parts will be familiar to experienced geochemists, but as noted above is presented in a rather abstract and mathematically tedious fashion. In Part 1, I found new material on and/or novel presentations of surface complexation and viral methods for determining activity coefficients in brines. Chapters on uniqueness and uncertainty in geochemical models also caught my attention because these issues invariably come up in using inverse modeling codes such as NETPATH, although Bethke does not present them in this context. Part 2 on reaction processes contains interesting chapters on geochemical buffers and stable isotopes, but a far too brief chapter on kinetics. Part 3 covers applied reaction modeling with chapters and case histories on hydrothermal fluids, geothermometry, evaporation, sediment diagenesis, kinetic reaction paths, waste injection wells, petroleum reservoirs, and acid drainage. I particularly liked the chapter on geothermometry, wherein methods for inferring the origin and equilibration temperature of hydrothermal fluids are given, a topic not covered in the other texts. Also presented are interesting case histories and analyses of the effects injecting fluids such as caustic wastes and alkali floods into aquifers and petroleum reservoirs.

In summary, this is a book that could be useful to an experienced geochemist, particularly if he is interested in using the modeling software associated with it.

However, it is too abstract and mathematical to be used as a text in an introductory aqueous geochemistry course.

L. R. Gardner
Department of Geological Sciences
University of South Carolina
Columbia, South Carolina 29208, USA