

BOOK REVIEWS

STABLE MINERAL ASSEMBLAGES OF IGNEOUS ROCKS—A METHOD OF CALCULATION. By Alfred Rittmann, with contribution by V. Gottini, W. Hewers, H. Pichler, and R. Stengelin. Springer-Verlag, 1973. 262 pages. \$31.20.

For more than thirty years Alfred Rittmann has been concerned with the nomenclature and classification of igneous rocks, and especially with the relationship between the mode and the chemical composition of volcanic rocks. In this book he proposes a system for calculating realistic assemblages of complex minerals whose compositions and proportions closely approach those actually found in igneous rocks that have crystallized slowly enough to maintain chemical equilibrium. One may calculate, in Rittmann's terms, a "dry" or "wet" volcanic facies, a "dry" or "wet" plutonic facies, a carbonatite facies, and even various mixed facies. Calculated assemblages for each facies are expressed in volume percent and are intended for use in any modal scheme of classification, although the QAPF double triangle of A. Streckeisen is obviously preferred. Rittmann feels strongly, however, that magma types should be designated by names of volcanic rocks only, rather than by those of plutonics, the magmatic origin of which may be in doubt. The system is not intended for strongly altered rocks or for certain ultramafic rocks such as dunites, pyroxenites, and peridotites, for which no volcanic equivalents are known. Rittmann does suggest, however, some "probable" assemblages for these rocks.

In Th. G. Sahama's preface and in three short contributions by Rittmann's coworkers, the term *Rittmann norm* is frequently used. Nowhere in the book, however, does Rittmann, himself, refer to his method of calculation as a norm. Indeed, the system he proposes is more nearly akin to the apportioning of cations to a mode, but with fixed rules arrived at empirically. In other words, the intent of the calculation scheme is to closely approach what the mode should be for a given stable assemblage; hopefully the calculation will indicate accurately the proportions of the various phases, if not their precise compositions. Instead of generating only simple stoichiometric compounds the system uses average compositions of actual minerals, in large part from Deer, Howie, and Zussman. The mineral compositions, however, do not necessarily remain constant for all rocks, but may vary with the rock type according to various proportionality and discriminatory factors determined from "statistical evaluation" of petrographic and chemical data. Thus, while olivines, sillimanite, and minerals of the sodalite group remain stoichiometric throughout the calculation, clinopyroxenes, amphiboles, and biotites are variable, depending on such rock factors as silica saturation, alkali ratio, magnesium to iron ratio, and titanium content. Feldspars are dependent on constituents remaining after formation of clinopyroxene or amphibole and biotite; some potassium may enter plagioclase and some calcium

may enter sanidine or anorthoclase, again depending on empirically derived factors.

To facilitate the calculations, the oxide weight percentages given in a rock analysis are transformed into numbers of atoms in the manner proposed by Niggli (1936) and elaborated by Barth (1952) and Eskola (1954); *i.e.*, the oxides are divided by molecular or half molecular weights depending on whether an oxide contains one or two positive ions. Following the sequence of the C.I.P.W. norm, the positive atoms are then distributed among saturated silicates and accessory minerals without regard to the available amount of Si; hence $\Delta Q = Si - Si^*$. This "saturated norm" serves as the basis for the Rittmann calculation of the stable assemblages for all facies of igneous rocks. Clinopyroxenes and hornblendes, for example, are expressed as various proportions of the normative minerals Il, Or, Ab, An, Wo, Hy, ΔQ ; these have no fixed ratios, but instead are apportioned according to various discriminatory factors. Rittmann's approach has been to plot data in diagrams and, by a kind of trial and error method, find approximate relations between the composition of the rock and the corresponding clinopyroxene or amphibole. While the real compositions of the minerals cannot be obtained accurately in this way, he feels the approximation obtained from the plots is sufficient to distinguish between augite, pigeonite, and titanite, for example, or between common hornblende, hastingsite, and kaersutite.

Biotite is expressed by one of three partially fixed ratios of normative constituents, depending on whether the saturated norm of the rock contains sillimanite, (An + Wo), or acmite. Muscovite is expressed by a single, fixed formula, *i.e.*, $100 Ms = 61 Or + 12 Ab + 40 Sil - 13Q$, as is melanite, *i.e.*, $11 Melanite = Il + An + 8 Wo + 3 Hy - 2Q$. The components of melilites are looked upon as desilicated components of pyroxene; hence, the calculation of melilite is based on the conversion of already calculated clinopyroxene.

While most of the factors and field boundaries used in the calculations are supposedly derived from statistically evaluated data, much of the statistical treatment and most of the data sources are not revealed in the text. Commonly the author merely states that "the best relation found is the following . . .", or "available data have shown . . .", or ". . . can be expressed with sufficient approximation by . . .", or simply, "on average." In attempting to perform actual calculations, I found this lack of substantiation rather disconcerting. It shows up even in minor aspects of the calculation, such as how the factors for converting atoms to volume percent were determined. Why, for example, is the same factor used for all plagioclases, and for all pyroxenes, when in reality these minerals can have a wide range in specific gravity which should be reflected in the volume factor?

The book contains 57 pages of *Keys for Calculation*

of the various facies, and 42 pages are devoted to sample calculations of 12 analyses representing a wide range of rock types. An additional 12 pages are devoted to the calculation of "Probable Mineral Assemblages of Ultramafic Rocks" in the "wet" and "dry" plutonic and eclogite facies. An appendix lists some 50 operational symbols and their definitions; unfortunately the listing is not complete, and at least three of the definitions are in error. The appendix also contains a listing of equations of field boundaries shown on the 27 diagrams and graphs used in the *Keys for Calculation*. These equations were used by Stengelin and Hewers in computerizing the calculation scheme.

Unfortunately, there are numerous errors throughout the book that should have been caught in proof stage. In fact, errors are so glaring and so numerous that it seems unlikely that any serious review of a galley proof was undertaken. Some of the errors have almost certainly been carried over from the manuscript stage. A few of the errors that could cause confusion should be mentioned. On p. 23, under *Basic Principles*, the composition of a clinopyroxene has been expressed by structural formula, by oxide components, and by mineral symbols; the latter two are in error, both numerically and by the omission of ilmenite. On p. 32 the expression for alkaline rocks should read Al less than $(Na + K)$, and $(Fe + Na + K - Al - Ti)$ should read $(Fe + Al - Na - K - Ti)$; the factor a used in this section should not be confused with $a = Ac/Ac + Hy + Wo$; this last expression is commonly used in figure captions and in the text and *Keys for Calculation* with Wo omitted. On p. 50 the ilmenite component has been omitted from two of the three biotite formulae, and on the same page the expression for v should show An rather than ΔQ in the numerator; this same error appears throughout the text and even in the list of symbols in the appendix, but fortunately not in the *Keys for Calculation*. On p. 52, Table 13, the value ΔQ is in error for all 24 of the calcium amphiboles; this could prove most disconcerting to one working with cation norms for the first time. On p. 54 the three "less than" and "greater than" symbols pertaining to 0.75 Hy should be reversed, and the saturated norm for Ca-amphiboles should show $-Q$ rather than $+Q$. Skipping to the first sample calculation under *Examples* on pages 141 and 142, at least eight errors have been found, six of which are probably typographic. The symbol H , used in calculating hornblendes, appears in three of the sample calculations, but nowhere is H discussed in the text, nor is it in the list of symbols. The symbol H does appear in the *Keys for Calculation* (Key 3, Step 18), but is defined as $H = 5 Wo$, which is obviously incorrect.

A listing of errors from some 50 pages of the book has been sent to the author. To those who have already purchased the book, I suggest they write to Rittmann for a list of corrections.

Some of the minerals that result from the sample calculations appear to be questionable. In example 8 on p. 165, a rock whose chemical composition is that of a nepheline basanite has been calculated in the "wet" plutonic facies to produce a hornblendite containing 81 percent hastingsite and almost 4 percent quartz. A structural formula of the hastingsite, based on 16 cations, shows only 5.88 Si , which

seems rather low for a rock with free silica. The structural formula also shows only 1.58 Ca but 1.22 $(Na + K)$. The Ca seems low for a hornblende in a theoretically stable assemblage containing both sphene and hypersthene; it seems more likely the hornblende would contain an actinolite component, *i.e.*, $6 Tn + 14 Hy \rightarrow 15 Act + 4 Il + Q$, with excess alkali apportioned to a more albitic plagioclase.

An even more questionable result appears in example 9 on page 171. Here a leucite tephrite has been calculated for the plutonic facies, producing a hornblende melanite monzosyenite. A structural formula of the hornblende (hastingsite) shows only 1.26 Ca , but 0.87 K , and 0.55 Na —a rather unusual hastingsite. I would suggest that melanite be reduced to add Ca to the hornblende, and biotite be increased to reduce K in the hornblende.

I found the calculation scheme to be rather cumbersome, chiefly because of the need to constantly refer to nomograms to determine the next step. Almost certainly the scheme could be simplified for use with modern electronic calculators.

An example of computer print-out is shown on page 222; only the volume percentages of the phases are printed. As most of the calculated constituents are not stoichiometric, I feel it is imperative that the print-out show the cation percentages of the phases as well as the cation distribution among the phases; otherwise it is impossible to determine the validity of the calculations or to think intelligently about the results.

References

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DONALD B. TATLOCK
U.S. Geological Survey,
Anchorage, Alaska

PETROGENESIS OF METAMORPHIC ROCKS. By Helmut G. F. Winkler. Springer-Verlag, New York, 1974. x + 320 pages. \$9.80, paperback.

The third edition of Winkler's already classic work on metamorphism is 35 percent longer, extensively revised and considerably improved. Among major changes, the use of metamorphic facies for purposes of classification has been abandoned as obsolete and the descriptive aspects of metamorphic rocks and reactions are instead developed using groups of rocks related by common bulk composition.

The book begins with two chapters of definitions and limitations on the concepts of metamorphism (diagenesis is excluded; anatexis is included) and a chapter each on the controlling factors of metamorphism, mineral parageneses, and their graphical representation. Included is an extensive and well-done section on the AFM projection, an almost word-for-word repetition from the second edition,

and a revised and improved explanation of ACF diagrams. Two entirely new chapters are devoted to a full account of Winkler's concept of the "isoreaction-grad" and arguments for the use of grade and against the use of facies for purposes of classification. Here grade refers to one of four divisions of P - T space defined rigorously by mineral reactions but which are largely functions of temperature (very low, low, medium, and high). An "isoreaction-grad" is an "isograd based on a specific reaction," rather than on the appearance of a key mineral or mineral assemblage. A short chapter barely touches on the physical and geologic setting of metamorphic terrains and the following six chapters deal sequentially with the metamorphism of rocks grouped by composition: carbonates, marls, ultramafics, mafics, graywackes, and pelites. Chapter 15 summarizes key isoreaction-grads using three P - T diagrams, one for each of the three grades. One updated chapter each is given to granulites (redefined as "granolite" with no grain size restrictions) and eclogites. A final chapter, in my opinion the best in the book, covers partial melting, migmatites, and the origin of granite.

The treatment of anatexis has for the past four years been required reading in my metamorphic and igneous petrology classes as the clearest single exposition of the solution to "the granite problem" and an excellent example of the application of experimental techniques to real rocks. The six chapters on metamorphism of rocks grouped by composition represent a major contribution as a succinct and up-to-date summary of important metamorphic reactions treated in a logical and useful way. Winkler has also done much to establish the central importance of the experimentally-derived petrogenetic grid and its field application to determine conditions of formation. This reviewer is, however, somewhat less sanguine concerning some simplifications introduced, no doubt, for pedagogical reasons. Real rock systems consisting of multicomponent phases with complicated histories of time-varying conditions stubbornly resist reduction to 2-dimensional diagrams that must ignore some solutions and independent variables. Too facile an application of experimental data can lead to a comforting but false feeling of precision, and I retain some misgivings about my own students' likely response to advice like ". . . only rocks having certain compositions need be examined in detail." Detailed single-mineral analyses, field and textural studies, and consideration of time and scale parameters will still ultimately be necessary for complete understanding.

The single mention of plate tectonics (p. 108) will disappoint enthusiasts: "These ideas (paired metamorphic belts and Benioff zone underthrusting) are in agreement with the hypothesis of plate tectonics (*sic*), which undertakes to explain worldwide relationships between metamorphism, magmatism and orogeny." Miyashiro's new book, *Metamorphism and Metamorphic Rocks*, is a more complete pedagogical tool, dealing with the causative geological framework of metamorphism as well as the result. Winkler's book suffers from a lack of proofreading, but the relatively low price almost makes up for it. The type in the newest edition is easiest to read by far.

The book is a good standard reference and, supplemented by some thermodynamics, would make an excellent gradu-

ate text. In my opinion, undergraduates would be better served by judiciously chosen readings from Winkler supplemented by material from the books by Miyashiro and Turner. The profession is fortunate to have three texts of this quality from which to choose, and an added benefit comes from exposure to petrology as an international discipline. Despite the minor criticisms above, the book is an important one and deserves to be read carefully by anyone seriously studying metamorphic petrology.

DAVID J. HALL
Gulf Research and Development
Company

THE CHEMISTRY OF CLAY MINERALS. By Charles E. Weaver and Lin D. Pollard. American Elsevier Publishing Co., Inc., New York, 1973. viii + 213 pages, 75 tables, 32 illustrations. \$22.50.

This book is both a comprehensive and a critical review of the chemical composition of phyllosilicate clays, allophane, and the chain-structures attapulgite and sepiolite. For the more common clays, the composition mean and range, standard deviation, histograms, and correlation coefficients are presented for common and rare specimens of clay minerals, as percentage oxides, structural formulas, and compositional plots. An enormous effort has gone into compiling elemental analyses of clays from the world-wide literature. Many new calculations and interpretations are included.

The chemical data are interpreted in terms of cation size, charge, and sums as to the effects on how the tetrahedral and octahedral sheets fit together and what parameters determine mineral stability. Low temperature synthesis is briefly reviewed. For example, the apparent role of Mg in getting Al into 6-coordination in neutral to basic media is pointed out. The nature of hydroxy interlayers, cation exchange capacity, and degree of mixed-layering of clays are discussed. Analytical criteria and properties are briefly discussed.

The chapter titles, which show that the book is organized by mineral groups and species, include: Introduction. Illite. Glauconite. Celadonite. Smectite. Chlorite. Vermiculite. Mixed-layer clay minerals. Attapulgite and palygorskite. Sepiolite. Kaolinite. Dickite and nacrite. Halloysite. Allophane. Tri-octahedral 1:1 clay minerals. Low-temperature synthesis. Relations of composition to structure. References. Index.

Few faults or criticisms come to mind. One that should be mentioned is the use of one-half unit cell formulas— $\text{Si}_4\text{O}_{10}(\text{OH})_2$ —instead of the almost universally textbook-adopted whole unit cell basis— $\text{Si}_8\text{O}_{20}(\text{OH})_4$. Another is incomplete use of nomenclature of the International Nomenclature Committee, but little or no ambiguity arises from this.

Research workers, both pre- and post-doctoral, as well as college and M.S. students in mineralogy, soil science, ceramics, and chemistry, will find this book to be an indispensable reference book and to some extent a textbook for a specialized course.

M. L. JACKSON
University of Wisconsin, Madison

NENDO-KOBUTSU-GAKU (CLAY MINERALOGY).

By Toshio Sudo, published by Iwanami-Shoten, Mitotsu-bashi Kanda-ku, Tokyo, Japan. xxi + 498 pages. 4000 Yen.

This nicely produced, and obviously comprehensive, treatise on clay mineralogy by the leader of clay science in Japan will unfortunately remain a closed book to all who cannot read Japanese. The numerous figures and tables regrettably do not carry captions in both English and Japanese, as one often finds in Japanese publications. From the detailed table of contents, supplied separately in English, we see that there is indeed a detailed coverage of the structures and chemical formulae of clay minerals, their study by microscopic, electron-optical and X-ray diffraction techniques, their infrared absorption spectra and their thermal behavior. Other topics include ion-exchange reactions, clay mineral synthesis, clay-water relations and clay-organic complexes. The mode of occurrence of clay minerals in different geologic environments and the concept of the intermediate clay mineral are topics to which Professor Sudo has made many personal contributions. To all of us who cannot read Japanese it is very frustrating that this mine of information is barred to our exploration. Although Professor Sudo is now approaching retirement from his position of Professor of Mineralogy in the Tokyo University of Education, it is to be hoped that he will not retire from further study of the subject to which he has made major contributions for very many years.

G. W. BRINDLEY
Pennsylvania State University

LABORATORY HANDBOOK OF PETROGRAPHIC TECHNIQUES. By Charles S. Hutchison. John Wiley and Sons, 1974. xxvii + 527 pages, 148 illustrations. \$19.95.

Dr. Hutchison has compiled the many special petrographic techniques commonly used in detailed studies of igneous and metamorphic rocks and describes each method using a detailed, step-by-step format. Although he has excluded standard thin-section description on the one hand, and electron microprobe and electron microscope techniques on the other, he has included that vast array of techniques which fall between these extremes. The book is designed for those studying crystalline rocks, but, of course, many methods used in the study of crystalline rocks are equally useful in the study of sedimentary rocks; thus, the book should also be of interest to the sedimentary petrologist.

The techniques discussed are indicated by the chapter headings. Thin-section Preparation; Aids in Thin-Section Study; Grain Size, Modal Analysis, and Photomicrography; Rotation Methods for the Polarizing Microscope; Mineral Separation; Powder Methods of X-ray Diffraction; Application of X-ray Powder Data to Specific Mineral Groups; Specific Gravity Determination; Refractive Index Determination; X-Ray Fluorescence Spectrometry; Atomic Absorption Spectrophotometry; Determination of Chemical Components Not Attainable by the Foregoing Methods; Display of Data; and Thermal Analysis Techniques. A list

of 337 references and an Appendix listing companies that supply the necessary equipment and materials are also given.

Each chapter is subdivided into "exercises." Each exercise describes, in a step-by-step fashion, the method (or most often several methods) used to attain whatever result is being considered. In general, the how-to-do-it descriptions are complete, and Hutchison has pointed out at the appropriate step what kinds of things will happen, what pitfalls may arise, and where special care must be taken. He also has included, in capital letters, safety warnings where appropriate. If special equipment or material is called for, the suggested manufacturer's or supplier's name and address are given along with the model or stock number. References are cited for each of the methods. A discussion follows the methodology and generally consists of hints or comments based on the author's own experience. Little or no theory is given with each exercise, and thus the book is in many ways a "cookbook" of petrographic techniques.

Space does not permit a complete listing of the techniques described in each chapter, but to give the reader a better idea of the contents, I have selected several chapters to describe in more detail.

Chapter 2, Aids in Thin-section Study, for example, includes standard staining techniques used to aid in the identification of certain minerals, the use of ultraviolet light (including a list of fluorescent minerals and their colors), and opaque mineral identification (reflectivity and microhardness determination, but not microchemical and other optical techniques).

Chapter 6, Powder Methods of X-ray Diffraction, consists of two parts, Camera Techniques and Diffractometer Techniques. Some of the camera techniques discussed are alignment, choice of collimator and X-ray tube, and film development and measurement. The section on diffractometer techniques discusses such things as alignment and calibration procedures, choice of slits, pulse height discriminator settings, and the general procedure for running an X-ray diffractometer. Use of a standard, identification of an unknown, line indexing, and deductions regarding the lattice type are also considered. It should be mentioned that all sections in this and other chapters dealing specifically with equipment (*e.g.*, alignment of the diffractometer) are written for specific instruments and need to be modified or, in some cases, disregarded if other models are used. Hutchison, however, has taken pains to describe what he feels are the most frequently used brands and models.

Chapter 13, Display of Data, contains descriptions under three subheadings: graphical, norm calculations, and statistical analysis of data. Some of the things included under graphical are: variation diagrams; ACF, A'KF and AFM diagrams; the solidification, crystallization, differentiation, and weathering indexes; the alkalinity ratio; calculation of pyroxene analyses; classification and display of amphibole structural formulas; and relationship between garnet chemistry and metamorphic grade. The complete rules for calculating the C.I.P.W. norm, the Niggli Molecular Norm, and the mesonorm are given. The section on statistical analysis, although brief, covers frequency distribution (histograms, populations and samples, mean, variance, standard deviation, coefficient of variation and interval estimation) and simple linear regression.

There are a number of minor points for which the book can be criticized. Safety warnings have been omitted in some instances; for example, no warning is given about the danger of X-rays nor has care been taken to specify X-rays "ON" or "OFF" while making certain alignment adjustments. The descriptions of methods generally assume that the laboratory is very well equipped, and few "make-do" hints are offered. For example, to center a specimen in a Debye-Scherrer powder camera, the author describes the "specimen centering device bracket," which, in my experience, is unnecessary and is not used in many laboratories. In some exercises helpful information has been omitted. For example, Hutchison discusses crushing rock samples for chemical analysis by means of a jaw crusher and a steel mortar and pestle, but does not comment on the possibility of contaminating the sample.

In addition, there are a few points with which this writer disagrees, but may be a matter of personal preference. Hutchison, for example, states that a line-focus X-ray beam should be used with a Debye-Scherrer camera; it has been my experience that a spot-focus beam is more widely used because the X-ray beam produced more nearly coincides in shape with the specimen and the opening in the collimator and beam intensity is greater. In a discussion of optical studies of uniaxial minerals, Hutchison directs the reader to seek a grain yielding a centered optic axis figure to enable him to determine ω . This, of course, is not necessary because, as Hutchison points out himself, ω may be obtained from any grain. Finally, there are a very few inconsistencies and mistakes. For example, he suggests (on p. 161) that peaks on a diffractogram be located at the peak apex and that the "mid-point of the $\frac{2}{3}$ peak height" method be abandoned. Yet, on p. 182, he states that the peak position should be determined at the mid-point of the $\frac{2}{3}$ peak height. One figure is referred to by the wrong number, and one reference, although spelled correctly in the text, is misspelled in the Reference section and in the Index.

I feel that, on the whole, the book is well done and should become a welcome and useful addition to a "hard-rocker's" (or even a "soft-rocker's") library. Although somewhat similar to *Physical Methods in Determinative Mineralogy*, edited by J. Zussman (1967, Academic Press, London, 514 p.), this book covers more ground and has a more practical approach. The reader should be able to use much of the book without having to consult the original references for more detail. Hutchison suggests that the book will find use as a text in an undergraduate course on petrographic methods, and it would be a good text if such a course is offered. I feel, however, that it will be used more by graduate students and other researchers who need to use some of the methods discussed but do not really need to know all of the theoretical considerations behind these methods. In short, it is a good "cookbook" on petrographic techniques.

NORRIS W. JONES
University of Wisconsin-Oshkosh

STONE, PROPERTIES, DURABILITY IN MAN'S ENVIRONMENT. By Erhard M. Winkler. Vol. 4, *Applied Mineralogy*. Springer-Verlag, New York, 1973. xiii + 230 pages. \$33.70.

Texts on nonmetallic minerals commonly include tabular listings of the physical properties of building stone and monumental stone, collectively known as dimension stone. Some texts give only average values of the properties. Similarly, these texts contain purely descriptive accounts of the durability of stone and methods of preserving its surfaces. Rarely do the authors of these treatises attempt to interpret the data analytically.

This book, on the other hand, excels in the originality of its presentation. The author treats the subject—stone—by interpreting the physical and chemical properties of rock in terms of the basic theories of physics, chemistry, and biochemistry. The table of contents makes evident the new development of the data and the manner of evaluating their significance: 1. Rock and Stone; 2. Properties of Stone; 3. Natural Deformation of Rock and Stone; 4. Color and Color Stability of Structural and Monumental Stone; 5. Decay of Stone; 6. Moisture and Salts in Stone; 7. Chemical Weathering; 8. Stone Decay by Plants and Animals; 9. Natural Rust on Stone; 10. Fire Resistance of Minerals and Rocks; 11. Frost Action on Stone; 12. Silicosis; 13. Stone Conservation on Buildings and Monuments; Appendix: Properties of Some Rock-Forming Minerals, Stone Specifications (ASTM), Conversion Tables, Glossary of Geological and Technical Terms, Exclusive of Minerals and Architectural Terms.

Winkler has selected pertinent data from the literature, combined it with his own observations, and prepared a unified treatment of each topic. The text contains 280 references which make possible further study in the original sources.

The text contains many applications of physical chemical principles, but I found their use in chapters 6, 10, and 11 particularly interesting. The chapter on stone decay by plants and animals is based on biochemical considerations, and the subject matter will be new to most readers.

The author is well prepared to write this book, for he has been active in both research and application in the stone industry in America; in addition, he is familiar with the extensive research and practice in European centers. It is also apparent from this text that Professor Winkler has made many observations on stone used in buildings, monuments, and gravestones and has extracted from these observations valuable inferences on the stability of stone. The reader will be impressed with the author's strong aesthetic appreciation of stone.

The book is introduced by an apt foreword by Richard H. Jahns. I recommend this book unqualifiedly to mineralogists, petrologists, and general geologists; those who read it will not only profit thereby but will find that the author's crisp style will command their continued attention.

GEORGE T. FAUST
*U.S. Geological Survey,
Reston, Virginia*

AN ATLAS OF VOLCANIC ASH. By Grant Heiken. Smithsonian Contributions to the Earth Sciences, No. 12, 1974. 101 pages, 33 plates. Superintendent of Documents, \$2.00.

This brief collection of scanning electron micrographs

(SEM) and photomicrographs of volcanic ash shards is a moderately extended version of the author's recent paper, "Morphology and petrography of volcanic ashes," published in *Geological Society of America Bulletin*, **83**, 1961–1988 (1973). Although much of the text is taken verbatim from that publication, the number of localities sampled has been about doubled, with a corresponding increase in the number and quality of the photo reproductions. The coverage is still far short of what one might expect from an atlas that seeks to "enable a worker to infer the genesis and possibly the source of isolated volcanic ash samples from stratigraphic sections or deep-sea cores," and it may be hoped that these promising first steps in the desired direction will be followed by subsequent editions to extend the range of eruptive and petrochemical types, with continued emphasis on SEM techniques.

RAY WILCOX
U.S. Geological Survey,
Denver

PROCEEDINGS OF THE FOURTH LUNAR SCIENCE CONFERENCE. Supplement 4, *Geochimica et Cosmochimica Acta*. Wülf A. Gose, Managing Editor. New York, Pergamon Press, 1973. Vol. I, xi + 1079 + xiv pages; Vol. II, xii + pages 1081–2274; Vol. III, xii + pages 2275–3290 + xlvii. \$100.00 for three-volume set.

Before the first Apollo landing it was hoped that the lunar surface would yield samples of primitive material to supplement that from meteorites. The recognition that all lunar samples so far recovered are relatively simple differentiates of basaltic magmas produced at different but comparatively early stages in the Moon's history, adds little to what has been deduced already about creation; it does however tell us a very great deal about the development of the lunar surface and its provinces, and reveals still more about the early stages in the evolution of a relatively simple planetary body, comparable evidence having been long since erased on Earth. Convincing evidence for quite early stages in lunar history comes from the samples recovered by the Apollo 16 mission to the Descartes site in the lunar highlands, from the geophysical data now reported, and from the first results of the remote sensing geochemical experiments of Apollo 15 and 16.

The Fourth Lunar Science Conference was held at Houston, Texas, from March 5–8, 1973. Its timing less than four months after the successful completion of the final Apollo mission was prescient, for preliminary analysis of the Apollo 17 samples had just become available and fuller reports on the Russian Luna 16 and 20 missions had appeared, enabling us for the first time to build up a coherent and reasonably convincing picture of the whole body of the Moon. This conference therefore may be regarded as marking an important turning point in the development of lunar science, and a convenient stage at which to review our state of knowledge in this field. Hitherto efforts had concentrated on reconnaissance of the unknown, on frantic efforts at sample description and analysis, and on rapid developments of technology in preparation for the next mission. Future research will permit

more time for contemplative thought, for problem-oriented investigations, and for a more critical appreciation of the vast mass of data now pouring in. This in turn should help even more in unravelling the very complex geological history of our own planet.

These three beautifully produced volumes sponsored by NASA seem to contain almost a lifetime of fascinating reading, but the mass effect presented by so many individually written papers is to render difficult an overall appreciation of just what has been achieved. The volumes contain a total of 228 papers from those presented at the conference by some 180 Principal Investigators and their associates from 14 countries, supplemented by 4 papers from Soviet scientists on the Luna 16 and 20 samples. It is claimed that less than 5 percent of the results reported have appeared elsewhere. The publication follows the pattern of previous issues, Volume 1 being devoted to general geology and to mineralogy and petrology, Volume 2 to chemical and isotope studies, and Volume 3 to physical properties. Each volume is self-contained and carries its own full lunar sample and author index; each paper has a full bibliography. Most are concerned with Apollo 16 samples, but some early Apollo 17 results, such as the investigation of the orange soils, and some of the physical experiments are included.

It is shown that the overwhelming majority of highland rocks are plagioclase-rich cataclastic breccias; a small number of genuine igneous rocks were also collected, but as nothing was found *in situ* their origins must remain speculative. Breccia samples differ mainly in the nature and size of the clasts (calcic plagioclase, olivine, hypersthene, pink spinel, lithic fragments), glass content, and degree of compaction and recrystallization. Although the Moon's age is believed to be the same as that of the rest of the solar system, 4.6×10^9 years, the apparent radiometric ages of the highland breccias produced a major surprise. All seem to lie in the range $3.85\text{--}4.05 \times 10^9$ years, presumably indicating some major group of cataclysms at about that time. Light colored formations like the Cayley, which are widespread, seem to have been produced by ejecta from the excavations of the Nectaris, Imbrium, and Orientale ringed basins. Only in the vicinity of the young North Ray Crater at the Descartes site does deeper material seem to have been sampled. This contains a higher content of light matrix breccias and here, significantly a small soil fragment produced an age of 4.2×10^9 years, the greatest yet determined from the Moon. The breccias appear to have been derived from anorthositic gabbro which may well represent the original lunar crust. It seems to have been generated mostly by upward flotation of plagioclase at a very early stage when large-scale magmatic activity was rife. The igneous rocks seem to belong to two main types, a fairly homogeneous group of KREEP-rich and relatively alumina-poor micronorites, and a more diverse group of KREEP-poor norites and troctolites quite high in alumina. The former seem to represent low-melting fractions that may have been produced by partial melting of gabbroic anorthosite by some as yet unexplained process and subsequently erupted; the low-KREEP norites, *etc.*, seem to be complementary differentiates to the anorthosites.

Age determinations of basalts from 5 maria reveal that

all lie in the relatively narrow time range $3.15\text{-}3.85 \times 10^9$ years; all the basaltic rocks have proved to be relatively enriched in Fe and Ti, the Apollo 17 suite being virtually identical to the extremely Ti-rich compositions encountered in Apollo 11. High resolution photographs reveal numerous long flows up to and exceeding 350 km in length sloping at less than 1° towards the centers of the maria. It is suggested that a very high rate of extrusion rather than low viscosity is the dominant factor in producing such long flows. Geophysical data indicate basalt thicknesses of about 20 km at the centers of the maria, thinning towards the edges: these are not fully compensated isostatically, thereby accounting for the mascons. It is thought that the maria basalts owe their origins to radioactive heating of an olivine-clinopyroxene region located at a depth of some 300 km. Partial melting here was presumably effected by sudden relief of pressure. The orange soils encountered in the Taurus-Littrow region owe their color not to the presence of ferric iron but to an unusual abundance of very small Fe- and Ti-rich golden glass spheres which are virtually transparent. Since larger spheres in the same soil are partly crystalline it is thought that the deposit owes its origin to lava fountaining. It seems to have been covered by basalt shortly after it was formed and was exhumed only 30 million years ago when Shorty crater was produced.

Geophysical data indicate a rigid, non-dynamic lithosphere extending down to about 1,000 km with a gradual transition to a hot weak asthenosphere. Internally generated moonquakes, which seem to be set off by tidal forces, arise from the vicinity of this boundary. The crust appears to be about 60 km thick, perhaps rather more on the far side, and there may be two layers beneath the maria. Anorthositic gabbro appears to be the favored crustal material while a pyroxene-olivine mantle is suggested by the 7.7 km/sec *P*-wave velocity of the upper mantle, but other solutions are also possible. Magnetic properties are something of an enigma, for the breccias which are randomly magnetized have a much greater field intensity than the mare basalts but they contain significantly more free iron and kamacite produced by severe thermal metamorphism in a strongly reducing environment. Clearly the moon at an early stage possessed a substantial magnetic field which is no longer present. The substantial heat flow measurements of about 30 ergs/cm²/sec, if representative, indicate a uranium content averaging 50-70 ppb which is consistent with achondritic bulk compositions between howardites and eucrites. All this evidence indicates that extensive differentiation with a very high degree of melting occurred at a very early stage and this may have produced a small liquid metallic core.

These volumes record a very substantial and impressive advance in lunar science, but it is clear that still more problems remain unexplained. The evidence that the Moon is a layered body with a still hot interior is of fundamental importance, and we may confidently anticipate that Mars, Venus, and Mercury are similar. The editor and his associates deserve to be congratulated for producing these excellent volumes so quickly.

I. D. MUIR
University of Cambridge

GEMSTONES AND MINERALS: A GUIDE FOR THE AMATEUR COLLECTOR AND CUTTER. By Paul Villiard. Winchester Press, New York, 1974. 228 pages. \$7.95.

Today's marketplace is deluged with a profusion of introductory books on rocks, minerals, and gems. The rapid rise of interest in earth science hobbies, especially in the U.S., has created many niches to be filled with specific types of books. As in the case of natural selection, the creation of a particular-niche is often short-lived as several competing works rapidly fill the gap. In such an environment competition is pronounced, and a newcomer's major chance for survival is a fresh approach, a new insight, or the introduction of new information or a format not already available. Unfortunately, this new book has few such advantages, and contains many erroneous statements that will do little to help the uninformed amateur.

The basic concept of the book is fine—a general overview of the mineral and gem hobby, with some detail on mineral and rock origins, occurrences, and collecting, and chapters on various lapidary arts and jewelry making. The photos, all by the author, are generally good and well illustrate their intended points. The 28 color photos are acceptable but undistinguished. The text, however, leaves much to be desired.

Early in the first chapter are some eloquently worded descriptions of rock formation, crystallization pressure, and crystal growth. The fact that growth pressure exists has been well demonstrated by crystallographers and theoreticians. But, alas, here we are told that such pressure explains the formation of twinned crystals! That is, a twin forms by the action of one crystal slowly forcing its way through another as it grows.

On the next page is a discussion of basic physical laws. "Rocks possess attraction for everything else. This attraction, probably magnetic in origin, we call gravity. Weight and gravity are sometimes thought of as being synonymous." And why is the earth round? "It is the fact, however, that rocks are rigid and stiff that makes it possible for our planet to maintain its shape. If rocks were plastic like clay, for example, the rotation of the earth would in time force the globe to expand at the equator. . . ." Thus, a basic geodesic fact is presented as a false hypothesis.

The explanation of the origin of mineral deposits is equally disappointing. "In a magma there are very rich hydrothermal deposits where certain minerals are carried out in solution. Hydrothermal deposits are superheated water under such enormous pressure that it remains liquid and does not turn into steam."

The chapter on metamorphic rocks leads quickly into a discussion of pseudomorphs, which are treated as metamorphic products of chemical attack (rather than of heat and pressure). Petrified wood is discussed in the same terms.

Chapter 2 deals with the characteristics of rocks and minerals. The author states "Rocks are identified by several different qualities or physical properties. Among these are hardness, color, luster, streak, specific gravity or weight, and cleavage." No discussion of physical properties that started out this way would be complete without a mistreatment (so prevalent in literature of this type) of the name

of that poor, abused savant, Friedrich Mohs. So we read . . . "This is called the Moh scale, and it is graduated in steps from 1 to 10." This shakes the reader's confidence in the author's scientific accuracy.

With the above in mind, mineral recognition presents no problems. For example . . . "Malachite and azurite . . . are always deep green or blue, opaque, and are easily recognized as copper minerals." This should be welcome news to Kennecott and Anaconda.

Luster is another valuable recognition aid, but the author confounds the definition. Thus, "Metallic luster appears like metal, sometimes with a color overlaying the surface, usually yellow or yellowish, since the luster is usually due to the inclusion of sulfides in the specimen." This explanation is insufficient, so he adds: "The non-metallic luster is further broken down into several categories: . . . adamantine, if it has a hard, somewhat greasy look, as seen in diamond, mercury, lead, and other elements." Mineralogists would be wise to note that mercury and lead can be easily recognized by their distinctive adamantine, nonmetallic luster.

At this point we are on page 24. All hope is not to be lost, however, for the remaining 204 pages. There is a remarkably concise and accurate explanation of the mechanism of fluorescence, except for very minor inconsistencies. Most of the book deals in a conversational style with

mineral collecting, cutting, and jewelry making. However, the chapter on collecting sites is superficial (New Mexico and Colorado are granted only one site each). The mineral descriptions (100 species listed, alphabetically) are so brief as to be useless for recognition. The two color plates of mineral specimens look fine, but several of the photos are misplaced on both pages, leading to added confusion.

If a person doesn't know better, and he reads a statement such as: "The earth's matter, as we know it, is composed of over one hundred elements," he is very likely to accept it as fact. It sounds "about right" to the layman. Considering the number of serious inaccuracies in the early chapters of this book, the hapless reader (for whom the book was intended) may well come away with a "knowledge" of earth science that will have to be unlearned later. When this factor is combined with the dearth of new information presented, the lack of imagination and originality in format, and the cover price, the total is balanced heavily against ownership. Perhaps there is still room in the marketplace for books of this type. If there is, such books will have to be considerably more laden with assets than this current attempt.

JOEL AREM

Arem Multifacet Investments, Ltd.

List of Books Received

ANALYTICAL CALORIMETRY. Volume 2. *Proceedings of the Symposium on Analytical Calorimetry at the Meeting of the American Chemical Society, Chicago, September 13-18, 1970.* Edited by Roger S. Porter and Julian F. Johnson. Plenum Press, New York, 1970. xvi + 460 pages. \$25.00.

ANALYTICAL METHODS IN PLANETARY BOUNDARY-LAYER MODELLING. By R. A. Brown. Halstead Press, New York, 1974. xii + 148 pages. \$24.00.

APPLIED GEOPHYSICS: INTRODUCTION TO GEOPHYSICAL PROSPECTING. By Gerhard Dohr. Translated by George H. Kirby. Vol. 1, Geology of Petroleum, Edited by Heinz Beckmann. Halstead Press, New York, 1974. viii + 272 pages. \$6.95 (paper).

CYCLES OF ESSENTIAL ELEMENTS. Edited by Lawrence R. Pomeroy. Benchmark Papers in Ecology, Vol. 1. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania, 1974. xv + 373 pages. \$22.00.

EIN NEUES HOBBY: KLEINMINERALIEN. SAMMELN UND PRAPARIEREN. By Alex Kipfer. Kosmos, Gesellschaft der Naturfreunde, Franckh'sche Verlagshandlung, Stuttgart. 64 pages. DM 4.80.

THE GEOMETRY OF ROTATIONS ABOUT A POINT: A PRACTICAL TREATISE. By Milton Felstein. Milton Felstein, Rte 1, Box 126, Albany, Ohio 45710. 1974. 69 pages. \$7.25.

MINERALOGY, GEOCHEMISTRY, AND GENESIS OF RARE EARTH PEGMATITES OF ALKALINE GRANITES IN THE NORTHWEST PART OF THE USSR. By A. Y. Luntz. All-Union Research Institute of Submarine Geology and Geophysics, Riga, USSR, Moscow, 1972. 176 pages. (in Russian).

MOSSBAUER EFFECT METHODOLOGY, Vol. 8. PROCEEDINGS OF THE EIGHTH SYMPOSIUM ON MOSSBAUER EFFECT METHODOLOGY, New York City, January 28, 1973. Edited by Irwin J. Gruverman and Carl W. Seidel. Plenum Press, New York, 1973. xii + 281 pages. \$22.50.

STATISTICAL METHODS FOR THE EARTH SCIENTIST: AN INTRODUCTION. By Roger Till. Halstead Press, New York, 1974. vi + 154 pages. \$11.75.

VOLCANOES. AN INTRODUCTION TO SYSTEMATIC GEOMORPHOLOGY, Vol. 6. By Cliff Ollier. The MIT Press, Cambridge, Massachusetts, 1969. xiv + 177 pages, 63 figures, 44 plates. \$3.45 (paper).

WORLD DIRECTORY OF MINERAL COLLECTIONS. By Commission on Museums of the International Mineralogical Association, 1974. \$4.00. Order from Dr. O. V. Petersen, Mineralogical Museum, Øster Voldgade 5-7, DK-1350, Copenhagen, Denmark. (reviewed, *Am. Mineral.* **59**, 1149).