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BOOK REVIEWS

Clay Mineralogy: Spectroscopic and Chemical Determinative Methods. Edited by M.J. Wilson. Chapman & Hall, 29 West 35th Street, New York, N.Y. 10001, U.S.A. 1994, 367 pages. CDN$179.95 hardbound (ISBN 0-412-53380-4).

Over the last two decades, research into clay mineralogy has been strongly influenced by the development and application of a number of spectroscopic techniques. Since researchers in the field of clay science are not necessarily familiar with spectroscopy in general, essential developments applicable to clay research have not always been fully appreciated. The editor states in the preface that the aim of the book is to bring together in a compilation many of these spectroscopic techniques in a way which would make them more accessible to the non-specialist.

The book consists of nine chapters, written by eleven authors. Chapter 1, by B.A. Goodman, gives a concise introduction and general principles of molecular spectroscopy. Chapter 2, by J.D. Russell and A.R. Fraser, provides basic principles of infrared spectroscopy, instrumental methodology, typical spectra of standard minerals, and examples of how spectra may be used to assess constituent minerals by analysis of a few representative soil clays. Chapter 3, by B.A. Goodman, presents principles of Mössbauer spectroscopy, instrumentation and experimental techniques, spectra of iron oxide minerals, with analytical examples for the identification of these minerals, spectra of phyllosilicates, with special reference to the effect of structural configurations of Fe on the spectra, and brief applications to archeology and art. Chapter 4, by B.A. Goodman and J.A. Chudek, offers principles of nuclear magnetic resonance (NMR) spectroscopy, experimental techniques, general features of magic-angle spinning NMR of minerals having nuclei such as ^{29}Si, ^{27}Al, ^{17}O and ^{31}P, high-resolution NMR spectroscopy of clay minerals with a few examples, and applications to clay-surface studies. Chapter 5, by B.A. Goodman and P.L. Hall, gives a general background of electron paramagnetic resonance (EPR) spectroscopy, spectrum acquisition and display, electronic configurations in transition-metal ions fundamental to crystal-field theory, EPR spectra of Fe^{3+} for the case of ions with two or more unpaired electrons, nuclear hyperfine coupling, experimental procedures for obtaining EPR spectra from which information concerning hyperfine coupling can be unfolded, and applications to phyllosilicate studies from various aspects. Chapter 6, by E. Paterson and R. Swaffield, deals with X-ray photoelectron spectroscopy under four headings: fundamental principles, experimental aspects, information content, and applications in clay mineralogy. Chapter 7, by D.C. Bain, W.J. McHardy and E.E. Lachowski, provides general principles of X-ray fluorescence (XRF) spectroscopy and X-ray microanalysis (XMA), instrumentation and sample preparation for XRF analysis, XMA with scanning electron microscope and analytical electron microscopy, and practical examples regarding clay minerals. Chapter 8, by D.C. Bain and B.F.L. Smith, outlines the approach required to carry out a reliable and complete chemical analysis, which is still necessary for the comprehensive study of any clay mineral despite sophisticated spectroscopic techniques available for the study of clays. Chapter 9, by B.F.L. Smith, provides selective chemical methods for the characterization of poorly ordered minerals in soils. The methods include alkali dissolution, extractions with sodium dithionite and ammonium oxalate, hydroxyl release by the reaction with sodium fluoride, trimethylsilylation and pyrophosphate extraction. The last two chapters, which describe a purely chemical approach, are included because that approach is still a prerequisite to a successful application of the spectroscopic techniques.

Each chapter ends with a list of references cited. The references mostly cover papers published until 1992, although this varies depending on the chapter. This book is a companion volume to "A Handbook of Determinative Methods in Clay Mineralogy", also edited by M.J. Wilson (Blackie, Glasgow, 1987), but now out of print. All chapters except 2, 8 and 9 in the book under review are updated versions from the previous book. Nowadays, it is clearly evident that a multi-technique approach is indispensable to the characterization of the complex nature of clays. This book is particularly useful for those who are familiar with the problems of investigating clay minerals, but need a quick and fresh review on appropriate spectroscopic or chemical analytical methods.

This book is very well organized, and the quality of printing is excellent. Unfortunately, the high price-tag may hinder purchase by individual investigators. However, institutional libraries ought to have a copy on hand.

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Petrography to Petrogenesis. By M.J. Hibbard. Prentice Hall, Englewood Cliffs, New Jersey 07632, U.S.A., 1995, 587 pages. CDN$90.95, hardbound (ISBN 0-02-354145-8).

This is a big (22 × 29 cm) book that covers a lot of ground. Presumably it is intended for use as a text in one or more subjects, though nowhere is its audience identified clearly. Ten parts, beginning with optical mineralogy and ending with sedimentary rocks, make up the core of the text, some 520 pages long. Each of the parts opens with a useful one- or two-page overview of the material to be covered.

Part I, "Optical mineralogy", presents basic theory. It is followed by bare-bones descriptions of 85 rock-forming minerals. Next, no less than 19 pages are devoted to the determination of plagioclase compositions, but without mentioning dispersion methods, even in passing. Point-count analyses and the U-stage round off this part. Part II, "The anatomy of rocks", introduces some new terminology: eustructural, astructural, graphicgrain, and so on. I found particularly useful a series of illustrations of real and apparent textural relations between and within rock-forming mineral grains as controlled by location and direction of thin sectioning (Figs. 8.1 to 8.3). This topic is rarely touched upon. Part III, "The classification of rocks", opens with "traditional" rock classifications, but emphasizes the utility of a "unified" classification (published in detail elsewhere) that requires comparison with a rock data-base using appropriate software. Just how useful this would be to the beginner or to the field geologist is doubtful. Part IV, "Fundamental processes of rock formation", deals with aqueous solutions, silicate phase diagrams, deformation, and so on. Part V, "Rocks formed by magmatic processes", covers most igneous rocks of more conventional books. These magmatic rocks are divided into homogeneous, cumulate, mixed, and assimilation-hybrid. Others are left to parts VII through IX (see below). Part VI, "Rocks formed by solid-state processes", covers chiefly the metamorphic rocks. The author chooses five key reactions to illustrate basic relationships and to define four grades (very low-T, low-T, medium-T, and high-T). The significance of textures is then discussed in some detail. This part closes with treatments of low-T recrystallized rocks (glacial ice and salt diapirs), cataclasites, impactites, and a pot-pourri of "Low-T deformed rocks". Part VII is a wastebasket, "Rocks formed by magmatic and solid-state processes." Included are magmatic breccias, "dynamomagmatic" (= protoclastic to us old-timers) gneisses, anatexites, restites and injection migmatites. The shortest part, VIII, bears the imposing title "Rocks formed by the mechanical interaction of high-temperature fluids or gases with rocks or magma." It treats pyroclastic rocks and hydrothermal breccias. Part IX, "Rocks formed by precipitation and reactive crystallization involving high-temperature fluids", impinges on the realm of economic geology in its coverage of "magmagenic" pegmatites, hydrothermal rocks, and fumarolites. The final part, X, "Rocks formed by mechanical and chemical processes involving low-temperature aqueous fluids", is fundamentally about sedimentary rocks. It closes with weathered rocks, including "roll-front" U deposits and supergene enrichment. Three appendices (conversion factors, atomic properties, and geological time-scale) and about 800 references spread over 41 pages conclude the book.

Several weaknesses deflect from the effectiveness of this book. Does a section on optical mineralogy belong? If it does, in the broad scope of the text it might have been preceeded by an elementary discussion of the rock-forming minerals, including their classification. Then in the petrography sections, no mention is made of the roles and significance of trace elements or isotopes. No results of major-element analyses are offered. Also, I found the separations of pyroclastic rocks from magmatic rocks, and cataclasites from metamorphic rocks, too drastic. Most of the photomicrographs are muddy, and for the illustration of the Becke line (Fig. 2.3), the same photomicrograph is printed twice. Some mineral names now rejected are used: barkevikite, salite, and sphene are three that caught my eye. In concentration (p. 525), 0.001% is not 1 ppm. The values of $2V$ on the left-hand side of Figure 3.3 are values of $2E$. Some mineral names are massacred: melelite (p. 67), acapolite (Fig. 2.25), and phologopite (p. 69). On page 77, Figure 5 should read Figure 5.2. A "fi" has replaced the reaction arrow in chemical equations in chapters 28 and 34. And there are other errors.

Would I use this book as a text? I think not, but to be fair, I admit to 18 years having passed since I last taught rock-forming minerals, optical mineralogy, or petrography. Someone currently in academe could offer a better opinion.

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Ultrahigh Pressure Metamorphism. Edited by Robert G. Coleman and Xiaomin Wang. Cambridge University Press, Cambridge, U.K., 1995, 528 pages, CDN$111 (ISBN 0-521-43214-6).

Many geologists have on their shelves textbooks on metamorphism which treat pressure as a comparatively unimportant variable. Winkler, for example, considered that temperature was the dominant variable, and that the maximum metamorphic pressures reached by crustal rocks did not much exceed 1 GPa. This book takes as a *lower* boundary 2.8 GPa (28 kilobars), and concludes that significant volumes (>10^6 km^3) of continental crust have been metamorphosed at pressures as high as 4.0 GPa. The first evidence for such high values (of which the reviewer is aware) came from eclogite inclusions, which could be interpreted as tectonically transported chunks of the mantle and hence not relevant to crustal rocks (compare the classic debate among Krogh and Carswell on one side and D.G. Smith on the other, which is reprised in this volume). However, Chopin's discovery of coesite in quartzite boudins of the Dora–Maira massif in 1984 could not be so interpreted, nor could the subsequent identification of coesite and diamond in the Dabie Shan orogen of China by Wang and others. This book discusses the distribution and characteristics of ultra-high-pressure metamorphism (UHPM), and the metamorphic history and tectonic processes which make it possible.

The initial overview by Coleman and Wang includes five documented areas of UHPM, all in the eastern hemisphere (western Norway, western Alps, Bohemian massif, southern Kazakkhstan and the Dabie Shan of China). All developed from old, cold, dehydrated crust that had undergone metamorphism and anatexis long before the variable Paleozoic to Mesozoic age of UHPM. All lie in zones of continental collision, with evidence of both thrusting and crustal thickening. All contain boudins of mafic to ultramafic rocks (eclogite, garnet peridotite) possibly derived from the mantle. Anatexis during UHPM was minor to absent, despite peak temperatures of 700 to 1000°C, indicating that uplift must have been extremely rapid (1.5–2.5 mm/year) by some combination of stretching, thrusting and buoyancy.

The thermodynamics and mineralogy of UHPM are discussed in successive chapters by Masonne and by Chopin and Sobolev. Massonne's chapter is of particular interest since he calculates coesite stability for parts of the Franciscan Complex of California and the Sifnos ophiolite of Greece, where these relics have not yet been found. He uses some extensions to the well-known data set of Berman, which will hardly convince everyone, especially since he posits some curious end-members, for example $Mg_6Al_{20}Si_20_{40}$ for aluminous sapphirine, rather than the better documented $Mg_7Al_{18}Si_30_{40}$. Chopin and Sobolev get down to the basics of how to find UHPM – painstaking petrography and sophisticated mineralogy. Relics are most commonly found in garnet and pyroxene, although Sobolev concludes that zircon is probably the most reliable carrier! The following three contributions consider the vexed problem of how crustal rocks got down to such depths (definitely subduction), and even more difficult, how they got back up quickly enough to preserve relics. Paradoxically, the answer seems to involve continued subduction, indicated by decreasing temperatures after peak pressures, accompanied by extrusion along complex systems of faults. The (hypothetical) thick ophiolite sections above the UHPM rocks have been reduced to thin serpentinite mélanges by this process. Although the rocks were apparently dry going down, water seeped in near the pressure maximum, leading to such bizarre metamorphic tectonites as magnesian whiteschists. Post-orogenic collapse and extension may have finally brought the rocks to the surface, but only from crustal depths.

Five contributions consider in detail the western Alps, western Norway, the Dabie Shan and related regions, and the Kokchetav massif of Kazakhstan. These contributions give the present state of knowledge on these regions by leading researchers, and emphasize that UHPM is a rapidly developing field, still beset by fundamental problems. There is still no agreement in Norway, for example, whether the UHPM minerals refer to an extensive terrane (Smith) or only to tiny inclusions (Krogh and Carswell). The mechanisms by which the rocks are returned to the surface remain tentative, confused, and mainly incomprehensible to the outsider. A final chapter in the book considers diamond-facies ultramafic rocks of orogenic belts, a topic of current commercial interest.

As a researcher in a collisional orogen in Newfoundland, I found the book fascinating. I experienced a shock of recognition at several points, and found myself uncomfortable with the feeling that perhaps I had walked over some of these rocks. All experienced geologists and postgraduate students who work in or model collisional orogens will find something of interest in this book, and metamorphic petrologists will clearly have to expand their horizons to take in UHPM. The book is written by experts in the field as a reference work for such experienced geologists, and contains magnificent, current bibliographies. It would be heavy going for undergraduates, but I found the book a pleasure to read, and read all 500+ pages in a weekend, a tribute to the care with which the book has been written and edited. "Typos" are rare (I found only three), and despite the number of authors whose native language is not English, the grammar, syntax and flow of the text are very good, with a minimum of neologisms [for example "dubitatively" on p. 247 (= dubiously)]. For a personal library, there are several drawbacks to the volume. Few geologists will find all chapters of equal interest. There is a considerable amount of repetition between chapters. Perhaps the most irritating is a four-fold repetition of an indifferent geological map of the western Alps. Indeed, the illustrations are the weakest part of this otherwise excellent volume. Too heavy line-weights have been used on the maps, making them hard to read, and the editing of the maps is not up to the standard of the text. Several have discrepancies between map and caption, although none is critical. The photographs are barely adequate, since the publishers did not make them into plates. This is particularly unfortunate, since some of the most crucial criteria for identification depend on textures that are not well presented. According to a foreword, this volume is the first in a series, Cambridge Topics in Petrology. Ideally, future volumes will be of equal merit and without the shortcomings. Despite the few shortcomings, I highly recommend this volume. All geologists and geophysicists who ponder the metamorphism and kinematics of collisional orogens should have access to a copy. The price is not extreme for a current textbook, but if you cannot afford your own copy, make sure that your library gets one.

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Mineralogy of Hyperagpaitic Alkaline Rocks. By A.P. Khomyakov. Oxford University Press, 70 Wynford Drive, Don Mills, Ontario M3C 1J9. 1995, 223 pages, CDN$162, hardbound (ISBN 0 19 854836 2).

With the end of the cold war, there has been a steady stream of scientific information coming from the former Eastern Bloc countries. One of the more interesting works that has been recently published is a book on the mineralogy of the world-famous nepheline syenite pegmatites in the Kola Peninsula of northern Russia. The title of the book might be somewhat misleading since the book deals almost exclusively with the mineralogy of the Khibina–Lovozero complex from this area. This Hercynian complex, which consists of two massifs – Khibina with an area of 1327 km^2 and Lovozero, 650 km^2 – is a classic mineralogical locality. It has been extensively investigated for more than one hundred years; notable contributions include studies by A.E. Fersman, K.A. Vlasov, and E.I. Semenov, to name a few. However, for many years there were few comprehensive and current English-language publications on this complex. The book of A.P. Khomyakov, a timely contribution that attempts to fill some gaps in our knowledge of the complex, is a revised version of the Russian edition published in 1990. It is a culmination of about 20 years of research by the author and his associates, using samples from drill-cores, mine workings and outcrops.

Hyperagpaitic alkaline rocks, as defined by the author, refer to agpaitic pegmatitoid rocks related to nepheline syenites, which contain significant amounts of rare minerals such as "hackmanite", ussingite, analcime, cancrinite, natrolite, feldspathoids, aegirine, arfvedsonite, natrosilite, alkali carbonates and villiaumite, some of which are readily soluble in water. These rocks occur mainly in the pegmatitic bodies within both the Khibina and Lovozero massifs.

The book starts with a brief description of the geology and petrography of the two massifs and the nature of the occurrences of hyperagpaitic rocks. It is followed by a description of minerals that are water soluble and unstable under normal atmospheric conditions and are major constituents of the hyperagpaitic rocks. Primary sodium-carbonate-group minerals in the deeper part of the complex are interpreted to be of magmatic endogenic origin.

The bulk of the book presents a description of about 500 mineral species and varieties from the Khibina–Lovozero complex. The minerals are grouped into major classes as follows: oxides (60), carbonates (58), silicates (291), phosphates (29), sulfates (7), halides (5), sulfides and arsenides (30), native elements (4) and carbon compounds (11). For each mineral, the type and frequency of occurrences and chemical formula are listed. The book also gives a more detailed description, mainly of diagnostic properties, of about a third of the minerals; for some, results of chemical analyses are given.

In the second to last chapter, Khomyakov discusses the use of hyperagpaitic rocks as exploration tools for rare metals and phosphate deposits. The book concludes with a short summary of the preceeding chapters. A handy five-page mineral index, an appendix giving the origin of the names of the new minerals from the massif, and extensive up-to-date references on the mineralogy of the complex, also are provided.

The book is reasonably well edited, although there are some glaring omissions; for example, scales are missing in a few figures. In places the text is difficult to read. As an up-to-date book on the mineralogy of the Khibina–Lovozero complex, the publication is appropriate for university and research libraries and the libraries of mineralogists and others specializing in nepheline syenites and related alkaline rocks.

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Kimberlites, Orangeites and Related Rocks. By Roger H. Mitchell. Plenum Publishing Corporation, New York, 1995, 410 pages. US$89.50 (hardback) (ISBN 0-306-45022-4).

Although diamonds had been recovered from alluvial deposits for several centuries, diamond was first found in its volcanic parent-rock in 1872 in a vent intruding sediments of the Carboniferous–Jurassic Karroo system on the South African highveldt. The rock within this vent, around which grew the diamond-mining town of Kimberley, was recognized and described as a distinctive rock-type termed "kimberlite" by Carvill Lewis in 1887. As exploration for diamonds spread across South Africa, other diamondiferous, post-Karroo intrusive bodies were gratuitously and conveniently named as being of "kimberlite", although some, mainly small dykes, were quite distinct petrographically from the diamondiferous host-rock at the type locality. Thus arose a terminological confusion that has lasted for over a century.

P.A. Wagner (1914) recognized a fundamental distinction between two different types of kimberlite, one that he termed "basaltic" kimberlite (a term no longer in use), and a second called "lamprophyric or micaceous" kimberlite in view of its high proportion of groundmass mica; other mineralogical distinctions were the presence of augite, but an absence or rarity of macrocysts of garnet and ilmenite, in the micaceous kimberlites. Considerably later, Smith (1983) distinguished two groups of kimberlite on the basis of Sr, Nd and Pb isotope compositions, his group I coinciding with Wagner's "basaltic" kimberlites, and his group II, with the micaceous kimberlites. Concomitant with these isotopic distinctions was the recognition of different source-areas, in the asthenosphere and the lithosphere, respectively. A further complication, arising from the discovery of diamonds in lamproites and the consequent intensive comparative studies on them, is the more recent appreciation that group-II kimberlites are probably more similar to lamproite than to group-I kimberlite.

The time is clearly ripe for a clear and authoritative statement on kimberlite–lamproite distinctions, and this is certainly provided by Mitchell in this, his third book on kimberlites and lamproites. This volume, centering on group-II or micaceous kimberlites, makes detailed comparisons with kimberlites and lamproites from the following points of view: field geology, means of emplacement, petrography, mineralogy, major-, trace-element and isotope geochemistry, and experimental evidence for their differing modes of origin. It is inevitable with such a comprehensive review that much of the material is drawn from other authors, but Mitchell himself has a major input, with numerous hitherto-unpublished results of mineral analyses. Mitchell makes his comparisons with the acerbic commentary typical of his earlier books, and his objective analysis makes a clear case for the distinctiveness of group-II micaceous kimberlites. So much so that he resurrects the term "orangeite", a name first used informally by Wagner (1928) for micaceous kimberlite from the Lion Hill dyke in the eastern Orange Free State, but one that, owing to Wagner's death shortly afterward, was never proposed formally and hence never entered the literature. In Mitchell, Wagner has an enthusiastic and persuasive advocate.

Chapter 1 starts with a commentary on the etymology of kimberlites, and continues through a review of rock-clan relationships, to age and distribution, field relationships and petrography of orangeites. It should be noted that orangeites appear to have a very limited geographical and time distribution, having been confined to the Kaapvaal craton over a period from about 200 to 110 Ma. This geologically short event is unlike that of the "archetypal" kimberlites, as Mitchell chooses to call the "real" kimberlites, that occur worldwide and have erupted since at least the Archean. The following Chapter 2, on the mineralogy of orangeites, is the weightiest part of the book (157 pages of the total 410); approximately half is devoted to mica chemistry, together with major sections on pyroxene, olivine, spinel and perovskite, and smaller sections on phosphates, amphibole, ilmenite, rutile, carbonates, and various exotic zirconium silicates. The detail is thorough to the extent of being encyclopedic. A comprehensive review of the geochemistry is given in Chapter 3, ending with the conclusions that, in addition to the general conclusions of Smith (1983) for the isotopic distinctiveness of orangeites and derivation from ancient enriched mantle, a sequence can be recognized from relatively unevolved orangeites to more evolved varieties containing higher silica and that are peralkaline. The book ends with an exhaustive discussion of the petrogenesis of orangeites and kimberlites, at the end of which the conclusion is that no single model to date can adequately explain the genesis of orangeites, and the postscript gives a list of suggested topics for orangeite research.

The book has an excellent bibliography and index, is well illustrated, and I didn't find any typos. Introduction (or, in this case, the resurrection) of a further rock name inevitably jars, and I can see the International Sub-Commission on Rock Nomenclature throwing its collective hands up in horror at the arrival of "orangeite", specially when isotopic data are desirable for classification in addition to a petrographic mode. However, I believe that Mitchell has made a clear case for "orangeite", and we have precedents for multiple criteria for rock classification – carbonatites are a good case in point. For myself, even following the short acquaintance necessary for the writing of this review, I feel comfortable with the term.

In view of the apparently rather limited part of the petrological spectrum covered by the volume, should you buy it? Anyone concerned with diamond exploration should have access to a copy, if only to keep up to date with the latest thinking on kimberlite genesis. For the academics, the rather high price will inevitably mean that only the ultramafic enthusiast will be persuaded to indulge, though every self-respecting earth science library should have a copy on its shelves.

REFERENCES

SMITH, C.B. (1983): Pb, Sr and Nd isotopic evidence for sources of African Cretaceous kimberlites. *Nature* **304**, 51-54.

WAGNER, P.A. (1914): *The Diamond Fields of Southern Africa.* Transvaal Leader, Johannesburg, South Africa.

———— (1928): The evidence of the kimberlite pipes on the constitution of the outer part of the Earth. *S. Afr. J. Sci.* **25**, 127-148.

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Perfect Symmetry: The Accidental Discovery of Buckminsterfullerene. By Jim Baggott. Oxford University Press, 70 Wynford Drive, Don Mills, Ontario M3C 1J9. 1994, 315 pages. CAN$44.95 hardbound (ISBN 0-19-855790-6).

In setting out to popularize this intriguing scientific story, Jim Baggott, himself an accomplished scientist, succeeds admirably. No question about it, as carbon-based life forms, we intelligent beings ought to be aware through the story of buckminsterfullerene (BMF) of our celestial link to stardust! Why? Well, you see, the discovery of BMF began as a search for a particulate form of long- chain carbon molecules that could explain the mysteriously diffuse 217-nanometer absorption band observed in the spectrum from the carbon-rich red giant stars. As matters turned out, a near-match for the mysterious band is provided by C_{60}, a molecule produced by a team of American and British chemists by vaporizing graphite with laser irradiation; subsequently, C_{60} was deduced to be a perfectly spherical molecule shaped like a soccer ball, and the name assigned in tribute to the architectural vision of Buckminster Fuller (Kroto *et al.* 1985). However, it was several years later that a team of physicists discovered quite accidentally that BMF also forms spontaneously, and in large amounts, simply by heating graphite rods electrically in an atmosphere of inert gas (Krätschmar *et al.* 1991).

The serendipitous discovery of BMF heralds an entirely new series of all-carbon molecules (in addition to graphite and diamond), and it stands as a classic example of how blind chance rather than planned paradigm can promote a revolution in thinking and a new world view. However, as Baggott reminds us, the step from symmetry to substance required time. By 1989, BMF had yet to be purified. Even in 1990, when tiny orange-brown hexagonal rods, platelets and star-shaped crystals of BMF were at long last produced, it took an agonizingly long time to get on with the definitive single-crystal study required for unambiguous proof of the "soccer ball" structure. How curious that the absurdly commonplace and perfectly spherical modern soccer ball (with its 12 pentagons and 20 hexagons) was not appreciated earlier. Eureka! A whole new concept in molecular architecture and an entirely new branch of "round" chemistry.

Follow-up NMR studies revealed that there is a whole family of fullerenes, although the closed cage structure of C_{60} makes it the most stable of all. Evidently, a revolution in materials science is on the way. For example, BMF has important applications in polymer chemistry; the soccer ball structure can be linked to metal atoms outside or shrink-wrapped onto individual metal atoms; fulleride superconductors are a reality; higher fullerenes grown in tubular structures are probably the strongest materials known, the list goes on and on. Even so, the translation of these developments into commercial propositions will doubtless take several years.

This is a book full of surprises. Under the right conditions BMF occurs naturally (provided there is soot, there are fullerenes). Yet, since C_{60} is chemically reactive, its preservation should be largely a matter of chance. Or should it? BMF has been found in soot at the K/T boundary, in shungite (a carbonaceous substance) in Precambrian rocks near St. Petersburg, Russia, and in fulgurite from Colorado. And what about those mysterious diffuse interstellar bands? The match with BMF is evidently not exact. Is BMF just too perfect? Could ionized C_{60} be a possible explanation? Fullerenes are present in space. Diamonds have been found in meteorites. Has Superman been at work here?

Baggott has done an absolutely splendid job. *Perfect Symmetry* provides an in-depth case study with object lessons for all of us concerning organization, research and development, self perception, and real insight into how scientific progress is made.

REFERENCES

KROTO, H.W., HEATH, J.R., O'BRIEN, S.C., CURL, R.F. & SMALLEY, R.E. (1985): C_{60}: buckminsterfullerene. *Nature* **318**, 162-163.

KRÄTSCHMER, W., LAMB, L.D., FOSTIROPOULOS, K. & HUFFMAN, D.R. (1990): Solid C_{60}: a new form of carbon. *Nature* **347**, 354-358.

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