

the remaining elements, the described deposits are located, and map references are given relative to latitude and longitude, and to the nearest minute of arc.

Professor Smirnov deserves warm congratulations for producing this notable addition to the literature of ore deposits and of mineral paragenesis; and due credit should also go to his translator, Professor D. A. Brown of the Australian National University for the faultless English of this lengthy work.

KINGSLEY DUNHAM

Bowen (R.) and Gunatilaka (A.). *Copper: its Geology and Economics*. London (Applied Science Publishers Ltd.), 1977. 366 pp., 33 tables. Price £25.00.

This is a welcome review of all aspects of copper from its prehistory, through geochemistry, global tectonics, structure, petrology, and stratigraphical control of natural concentrations to the economics of exploitation. In his introduction, Professor Paul Bartholomé of Liège remarks that economic geology requires a better comprehension of the physico-chemical and biological processes that together build its framework, and justly claims that this book emphasizes processes rather than descriptions. The authors, both in the Geology Department of the University of Zambia, Lusaka, are in one of the great producing areas of the world, but their data, drawn from a very wide range of sources, gives a balanced picture of all the principal types of copper deposit, without unduly stressing the controversial stratiform ores of the Central African Copper Belt. Chapter 1, 'The World of Copper', is a concise summary, almost an abstract, of the subject-matter. In their discussion of the relationship between copper mineralization and plate tectonics, the authors take a more sophisticated view than some, and do not rely on subducted oceanic crust as the sole or even the principal source of the metal. This is wise, for the great deposits of the western U.S.A. can hardly be explained in this way; nor, of course, can those of Africa. There are four long chapters devoted to (i) the plutonic association (most space properly goes to the 'porphyry' type here); (ii) the hydrothermal vein association, including breccia pipes; (iii) the stratiform mode; and (iv) the volcanogenic-sedimentary (island arc) type. Useful check lists of the major deposits in the western literature are given for each association and the bibliographies, though omitting many works of historical interest in the evolution of ideas, are comprehensive for the past decade. One curious effect of this is the absence of much reference to secondary enrichment; perhaps this is no longer so important in the mass-mining of

low-grade ores. The chapters dealing with the copper industry will be useful in widening the horizons of geologists. They contain extended reference, in addition to describing present day copper technology from the ore to the metal, to the proposed ocean-floor mining of cupriferous manganese nodules, and the attendant problems of international law. There is an appendix listing 156 copper-bearing minerals, of which only ten are regarded as of great economic significance; tenanite should not be included in this latter list and is, incidentally, incorrectly spelled. The chief interest of this book to the mineralogist is not, of course, this list; it is the excellent view that it gives of the state of thought in the mid 1970s about the processes that have concentrated copper in the earth's crust into workable deposits.

KINGSLEY DUNHAM

Guarascio (M.), David (M.), and Huijbregts (C.), editors. *Advanced Geostatistics in the Mining Industry*. Dordrecht, Holland (D. Reidel Publishing Co.), 1976. xvi + 461 pp., 126 figs. Price Dfl. 105.00 (\$39.50).

This book is a collection of twenty-eight papers presented at the NATO Advanced Study Institute held at the Instituto di Geologia Applicata of the University of Rome, Italy, 13-25 October 1975, some ten years after the publication of Professor G. Matheron's doctoral thesis *Les variables Régionalisées et leur estimation*. Since that time, Matheron and his co-workers at the Centre de Morphologie Mathématique, Fontainebleau, continue to extend the theory of geostatistics and have educated very many mining engineers and geologists in the techniques that they have developed. The papers in this volume<sup>1</sup> represent an excellent state-of-the-art review of work in this field drawn mainly from the experiences of the French school of geostatistics.

'Geostatistics' has a special meaning in this field, and should not be confused with the usage of the term frequently encountered in the Anglo-American geological literature where it usually stands for the use of conventional statistical methods in geology, except in the context of ore-reserve evaluation. Matheron's theory of Regionalized Variables is concerned with the behaviour of random variables (e.g. ore grade) where this behaviour is itself a function of spatial position. Classical statistics do not take the spatial location into account. The most important areas of application of the geostatistical theory have been in ore-reserve estimation, the miner being concerned with

<sup>1</sup> A full list has already appeared in *Mineralogical Abstracts*, 78-126.

estimation of the most likely values of blocks of ore, or of the whole deposit, and the prediction of the errors of such estimates. Classical techniques for ore-reserve estimation by the methods of isolines, triangles, or polygons are not only subject to bias, but it is also extremely difficult to determine the reliability of the final estimate. Geostatistical methods allow these difficulties to be overcome.

The collection of papers in this volume is without doubt of fundamental importance in this field, particularly those in the first four sections (Basic Concepts, Kriging, Ore-waste discrimination, and Theoretical new developments) concerned mainly with the theoretical aspects. These expository papers, mainly from the Fontainebleau school or its ex-students, present a formidable arsenal of new geostatistical techniques. Already methods introduced only a few years ago, and still to see widespread use in the mining industry (e.g. Universal kriging) are being discarded and replaced by Transitive kriging, Disjunctive kriging, and Transfer functions. However, the mathematical techniques involved are highly complex, and will prove a considerable barrier to comprehension in most cases. Perhaps what is now required is a large number of *comparative* case histories to demonstrate to the mining world the advantages of both the old and new approaches in terms of reliability of estimation and computational cost. Some papers in the Kriging, Ore-waste discrimination, Industrial applications, and Case studies sections include practical examples. Applications of interest outside the mining field include optimal interpolation methods for contouring using kriging (A. Hass; M. Alfaro and F. Miguez), petroleum reservoir estimation (A. Hass), and the spatial distribution of ore deposits (F. P. Agterberg).

It is a pity that the organizers of the meeting did not feel that an elementary review of the principles of geostatistics might have a place in this volume in order to make it more understandable to a wider audience. With the exception of a 'Tentative glossary of geostatistical terms and notations' (rather curiously worded in places) included after the meeting as a result of suggestions from the participants, the volume consists solely of the papers as presented, with the exception of three papers by M. W. Clark and J. B. Thornes; P. Delfiner; and F. Muge, H. Pereira, and L. Cortez; whose absence is not explained. It is also to be greatly regretted that no record of the discussions appears as these were often most informative.

The volume is published with English as the major language and some papers in French. This should considerably help its dissemination to the international geological and mining community.

The style of the book is adequate and as would be

expected when reproduced from 'camera-ready' typed material, and the illustrations are clear. Very few misprints were encountered.

In summary, this book is a collection of papers of fundamental importance to geostatistics, and as such will be invaluable to advanced students of the subject and to practitioners in the field. It is not suitable as an introductory text (nor was it intended to be that) but could easily have had more widespread appeal by the inclusion of additional introductory material.

R. J. HOWARTH

Beus (A. A.) and Grigorian (S. V.). *Geochemical Exploration Methods for Mineral Deposits* (transl. from Russian; technical editor A. A. Levinson). Wilmette, Illinois (Applied Publishing Ltd.), 1977. x + 287 pp., 94 figs. Price \$32.00.

The development of exploration geochemistry in the 1930s in Russia and Scandinavia followed the establishment of strong schools of geochemistry and it was Fersman, a student of Vernadsky, who was the first modern exploration geochemist to recognize the importance of primary and secondary halos associated with ore deposits. In Russia theoretical geochemistry has remained the basis of exploration geochemistry, whereas in the West geochemical prospecting is more dependent on sophisticated analytical and computer technology, exploration criteria being derived empirically from large amounts of data.

As the more readily detectable surface deposits are discovered, a change of emphasis will be required from extensive to intensive methods such as the use of conceptual models; the impact of the porphyry copper model on discovery rates being the best-known example of this approach. The publication of a text that places particular emphasis on primary geochemical halos for mineral exploration is thus timely and it will provide a useful reference for those investigating mineral deposits or following up anomalies identified on geochemical maps.

The title, which suggests that the book is a general text on exploration geochemistry, is misleading. The most important chapters to the exploration geochemist are the first five in which theoretical concepts (Chapters 1-3) are developed into practical criteria in Chapter 4—geochemical specialization of rocks—and Chapter 5—primary geochemical halos. Much of this discussion provides a new viewpoint on rock geochemistry for mineral exploration to the Western geochemist and it should be recognized that Soviet geochemists have claimed success in discovering buried ore deposits as deep as 'some hundreds of metres';