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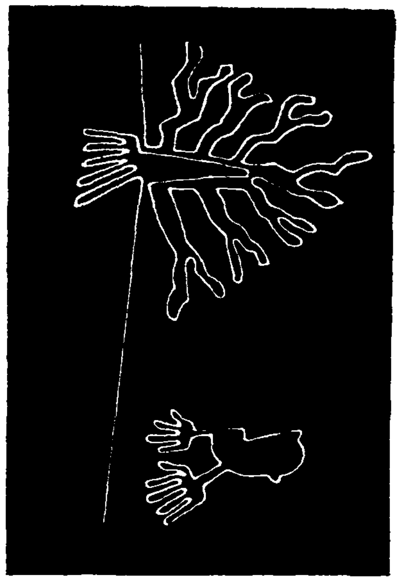
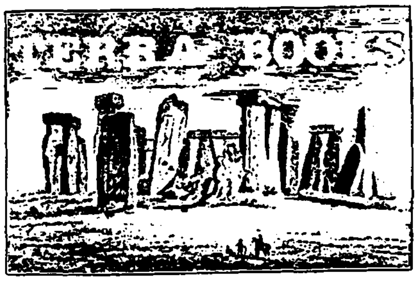




STATISTICS FOR SPATIAL DATA

Noel Cressie

John Wiley, London, UK,
Wiley Series in Probability and Mathematical Statistics,
1991, £71.00 (hbk), xvii +900 pp.

A short time ago, I began sorting through the mount of original documentation, dating from 1967, concerning the launching of the International Association for Mathematical Geology, to prepare this material for despatch to Professor D.F. Merriam, custodian of the I.A.M.G. archives in Kansas. This enforced stroll down memory lane brought back vividly the heroic days of the I.A.M.G. and the need, even battle, to convince colleagues that an association really was necessary. Among the positive and friendly replies received to the call I put out, there were the boorish, sometimes insulting, responses generated by a misanthropic few, some of whom believed me to be involved in sciamachy. Such is life.

The overriding reason for wanting to found a society to house quantitative workers in the Earth Sciences was that although there was a wide interest in the sixties in computing, enthusiasm greatly outweighed knowledge and, for that matter, good judgment. There was a risk of deluging the geological journals with poor, or just plain wrong, work. After a rather shaky start and slow progress in the beginning, the I.A.M.G. is now an established success. My initial desire was to try to bring about an amalgamation of professional statisticians and mathematicians with geologists, in much the same manner has been achieved by the *Biometric Society*. (In passing I record that John Tukey, in his letter of support in 1967, thought we could call ourselves the *Geometric Society*, a suggestion that was still a consideration at the dramatic founding meeting in Prague in 1968).

Our first Vice President was G.S. Watson, an important figure in applying statistical theory to the Earth Sciences, an early user of tensor calculus in geology and known to me from my days as a student in the Mathematics Department at the University of Melbourne (I knew Geof, he didn't know me). His work on distributions on the circle and sphere are of fundamental significance in geostatistics. Our first President was A.B. Vistelius, St. Petersburg, who will go to history as the real founder of the concept of geostatistics (during the mid-forties).

The book by Noel Cressie is just the kind of production I hoped and dreamt would appear from the collaboration between statisticians and geoscientists. It is massive, perhaps too overpowering for your average PC-buff, but the sort of thing that is now starting to appear thanks to the catalysing influence of the I.A.M.G. (It is worth noting, that Cressie was a postdoctoral student of Watson at Princeton.)

More sashaying down memory lane. Long before any plans for the I.A.M.G. were conceived, I attended a doctoral dissertation by Bertil Matérn in the Department founded by Harald Cramér at the University of Stockholm. This was in 1960 and the subject was *spatial statistics*, one that virtually nobody in the auditorium had even the vaguest idea of.
It became clear to us as the public

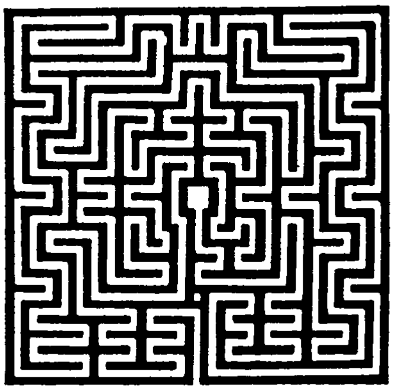
defence went on that a subject of major importance was being ventilated before us. Matérn, a forestry statistician, was using spatial statistics to estimate everything from coverage of species of economically useful trees, based on a few traverses, to the number of elks in a region (a serious problem for road traffic in a country vastly over-populated with wild animals). Was this possible? It was, and the work of the thesis could be backed up by actual measurements obtained by the foot-slogging zeal of Bertil's students at the Forestry College.

In 1969, Geof Watson was invited to work in my Department in Uppsala by the Swedish Natural Science Research Council. The first thing he asked for was an interesting and non-trivial problem. After some looking around and a few dry runs, I gave him a book I had just been sent by Georges Matheron, whose acquaintance I had made a few months earlier in connection with a meeting of CODATA held in Fontainebleau. Geof went off with the book, skepsis all over his face. A few days later he had a handwritten paper ready on aspects of the results presented by Matheron which led to Watson receiving an invitation to work for several months with Matheron in 1970. This seems to be the point of fusion between the anglophone and francophone views on 'Geostatistics', at least as regards the main breakthrough.

Cressie's book, monographic in its proportions (and hence price), gives us a modern synthesis of mainly application and theory of spatial statistics in the Earth Sciences and many other domains, with a rather pronounced bias towards the theoretical situation represented by mining geology and engineering. It is divided into three parts, each of which has the dimensions of a normal Wiley book. It is therefore not possible within the space available, nor even wise, to attempt a detailed appraisal of the entire work. What I have to say is very selective and oriented towards presented the restaurant but not the dishes.

The first section is entitled **Geostatistical Data**. It is narrowly centred semantically on the *Geostatistique* of Matheron's thesis of 1962 with a heavy emphasis on the developments based on methods of predicting ore-grade from samples. Cressie takes up the logical *Sobresault*, implied by this restricted use of what in other hands receives a more general treatment, by defining his Geostatistics as now being freed from earthy shackles to take on a more universal role; that of statistical

There is a very extensive account of the methods, goals and solutions of francophone *Geostatistique*. For example, *kriging*, originally a simple



ad hoc procedure for estimating gold-content and introduced in the late forties by Daniel Krige for mining operations in the Witwatersrand, has blossomed into a subject of its own, with a whole hierarchy of techniques and theoretical developments. Most of the applications provided by Cressie are, however, not drawn from the Earth Sciences, but embrace a surprising variety of themes. Rather topical is the example dealing with the application of geostatistics to radioactive contamination of groundwater.

The second major section bears the title *Lattice Data*, by which is meant a countable collection of spatial sites at which observations are recorded, expanded by reference to the neighbourhood data. The example used as a paradigm throughout this part is the distribution of sudden infant deaths, county by county, in North Carolina. This is another very topical subject, of little geological interest, but serving to display the wide scope of spatial statistics as the subject has been developed over the last few years.

The third and last part is called **Point Patterns**. It is concerned with spatial point processes with applications to such diverse fields as archaeology, geography, seismology, and plant ecology via the classical Swedish quadrat method of Du Rietz. The theory of point processes as developed by Cox and Lewis, and which I know from applying it to volcanic eruptions and sequences of seismic shocks, is taken up here as a fundamental approach to the study of spatial point patterns. Geologically relevant applications, such as map-interpretation can be expected to develop from methods for analysing latitude–longitude pairs.

Personally, I found Chapter 9 treating the modelling of objects, the most interesting, given that I am currently working on visualization techniques in generalized Linnaean taxomony, evolutionary biology and quantitative genetics. After a concise introduction to relevant concepts, Benoit Mandelbrot's fractal geometry puts in an appearance in relation to the representation of outlines. There is a short review of what is becoming known as *geometric morphometrics*, but it is too brief and too incomplete to be of use to anybody really interested in the subject. I refer the interested reader to my recent review in *Terra Nova* of the book by F.L. Bookstein.

Cressie's book is not one that can be read over the Easter holidays. Some parts can be easily followed by non-specialists, but others require a good deal of preparation and application and more than just a general knowledge of statistical theory. He has obviously lived with his subject for some time and the text gives an impression of being authoritative, exhaustive and clearly written. I have little doubt that it will be a standard reference for many years to come and there is every hope that it will stimulate research and applications to geological problems.

Reviewed by Richard A. Reyment of the Paleontologiska Institutionen, Uppsala Universitet, Sweden

SATELLITES OF THE OUTER PLANETS

David A. Rothery

Oxford University Press, Oxford, UK.
1991, pp. 208, £40.00 (hbk)
ISBN 0-19-854290-9

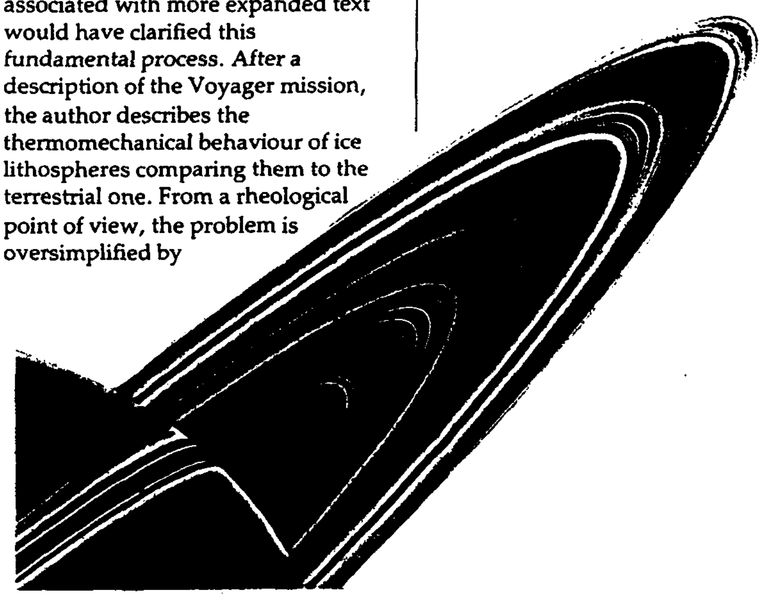
First launched in 1977, the two probes *Voyager 1* and *Voyager 2* visited over 12 years the planets and satellites of the outer solar system giving us our first opportunity to study the solid satellites of the gaseous planets from a geological point of view. This interesting book, very well illustrated and presented, describes the main results of these missions. For geologists and geophysicists involved only in terrestrial studies, it provides a good introduction to planetary problems.

The book comprises nine chapters of varying importance. The first chapter is an abstract of the book. The second one addresses the problems of the composition (ice, mixed ice and silica, silica), the origin (accretion around a planet or capture of an elsewhere-accreted body by a planet) and the evolution after accretion of the satellite with constant reference to the available sources of energy. Most of the energy sources mentioned are familiar to Earth scientists (accretional and radiogenic heating), but, for example, 'tidal heating' is more unusual and perhaps some equations associated with more expanded text would have clarified this fundamental process. After a description of the Voyager mission, the author describes the thermomechanical behaviour of ice lithospheres comparing them to the terrestrial one. From a rheological point of view, the problem is oversimplified by considering the lithosphere to be 'strong and rigid' and the asthenosphere to be 'weak and plastic' globally. Here again, some discussions about the possible strain rates and the profiles of shear strength would have clarified the main differences between a silica bi-layered lithosphere and an icy one. Then the description of the possible range of modification of thermodynamical properties of ice by contaminant such as NH_3, CH_4, CO is very interestingly presented.

The next three chapters are the principal aim of the book. The satellites and their internal models are described according to their geological activity. This activity is evidenced by the existence of tectonic structures independent of craterization or by the existence of resurfacing processes. The method of dating the surfaces by crater statistics is presented in chapter five along with the description of worlds which have never been active: Callisto, Rhea, Iapetus, Mimas Oberon and Umbriel. On worlds which have been active, at least two types of surfaces exist characterized by different types of albedo and different intensities of craterization. They often exhibit structures akin to grabens and more curious zones (grooved terrains) which have a debatable origin. In this book, the extensional origin is favoured but this is not convincingly supported by the available images. In this chapter Ganymede, Dione, Tethys, Ariel, Titania and Miranda are described. The next chapter considers active worlds. Io, Europe, Encelade and Triton are or have been active recently as shown by their very low cratered surfaces. On Io and Triton volcanism has been imaged. It is discussed how volcanism might be an efficient process for resurfacing. Chapter eight deals with unseen worlds: Titan, whose atmosphere is opaque, and the system Pluto-Charon, which remains the last to be imaged.

After reading this book, the Earth scientist will see that an efficient planetology needs a performant space technology and a multidisciplinary approach consisting of interpretative geology, remote sensing, rheological studies of material, numerical and analogical simulations. Competitive laboratories exist in all these fields in Europe but, curiously, planetology remains underdeveloped compared with the USA or the CIS. We hope that this book, that can be read by students and by professionals, will favour the growth of european planetology.

Reviewed by Pascal Allemand,
Reviewed by J.C. Varekamp, Department of Geology, University of South Carolina



SALT MARSHES: Morphodynamics, Conservation and Engineering Significance

J.R.L. Allen and K. Pye (eds)

Cambridge University Press,
Cambridge, UK.
1992, pp. viii+184, £24.95/$49.95 (hbk)
ISBN 0-521-41841-0

The book under review is a pleasant, small volume that summarizes current research on salt marshes. Parts of the contents were presented at a workshop on 'Morphodynamics, Conservation and Engineering Significance of Saltmarshes' at the Postgraduate Research Institute for Sedimentology (Reading, UK) in the spring of 1991. Salt marshes are among the most dynamic environments on earth, and form the heavily vegetated fringes between the marine and terrestrial realms. The physical environment of mudflat–marsh systems is conditioned to dissipate wave (including tidal) energy, and as such these systems serve an important natural function of coastal defence. Mudflats and marshes may also be looked upon as chemical filters; e.g. removal of marine sulphate through diagenetic sulphide formation and the deposition of heavy metals of continental (now largely anthropogenic) origin. The rapid response of salt marshes to shifts in environmental conditions make them preferred locales for studies of recent global change, because they carry proxies for changes in, e.g. climate, sea level, sediment supply, metal fluxes and ecology. Salt marshes have commonly been treated in society as expandable grounds for waste dumping, industrial development and grazing, and as suitable for reclamation. Their ecological importance as breeding grounds for many species, some commercially significant, has long been recognized. It is against this background that the 'science of salt marshes' is illustrated in eight chapters that cover geomorphological processes, the floral ecology of salt marshes, and the use of salt marsh sequences in sea level rise studies. A general introduction, two site-specific studies and chapters on conservation and engineering aspects complete the volume. The emphasis is on British coastal marshes, with some references to other regions.

Tooley reviews the modern instrumental record of sea-level change, provides examples of salt marsh sequences that record differences in the rate of relative sea-level rise, and draws attention to the fact that modern sea level rise is slow compared to that during several periods in the past. The chapter by Pethick presents some interesting views of the geomorphology of salt marshes, which he sees as 'the safety valves of the intertidal zone'. He argues that increasing rates of sea-level rise may increase marsh surface erosion, but that during quieter periods the marshes will respond with enhanced rates of accretion. He warns, however, that the disappearance of saltmarshes may simply be a geomorphic response to the adjustment of a low-energy coastal profile to rising sea levels. The chapter by Gray on marsh plant ecology takes the general reader somewhat deeper into a specialist field than the other chapters. The conservation chapter (by Doody) details the competing demands from society on the natural resources and scientific interests of the marshes. The chapter on the engineering significance (by Brampton) treats ways to prevent salt marshes from disappearing, more from the point of view of coastal defence than conservation. Allen provides an overview of the Severn estuary mudflat/marsh sequences, and treats a quantitative model for marsh accretion that takes many parameters into account, e.g. the rates of sediment supply and sea-level rise. Pye reviews the thoroughly studied marshes along the north Norfolk coast line.

This book is highly recommended for students of coastal salt marshes as well as conservationists and coastal engineers. It provides an up-to-date multidisciplinary review of current research approaches and gives some fresh insights into the nature of the processes that shape these coastal fringes.

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GRANITOID ROCKS

D.B. Clarke

Chapman & Hall, London, UK
1992, 283 pp., £25.00 (hbk)
ISBN 0-412-29170-3

For many years there has been something of a gap in the range of rock-types covered by modern petrological text-books. Basic and ultrabasic rocks have been the subject of several recent publications, unusual magmatic rocks like carbonatites and lamprophyres have received disproportionate attention, but granites, by and large, have remained the Cinderella of igneous rocks. One of their problems has been that although granitic rocks are undoubtedly abundant, the relationship between their formation and plate-tectonic processes is often obscure. As a result the attention that ophiolites and basalts have attracted over the past few decades has been denied them. When texts on granitic rocks have appeared, they have been more concerned with nomenclature and description than with magma-forming processes.

Granitoid Rocks covers, in roughly equal measures, their classification, petrography, geochemistry, geochronology, experimental petrology, and mineralisation, with a rather larger chapter devoted to field relations and emplacement mechanisms. The rest of the book focuses on case studies that illustrate how a diversity of analytical and field-based approaches are needed to unravel the petrogenesis of granitic rocks. In my view these case studies lift the book above the level of merely encyclopaedic petrological texts which imply that once the physical and chemical properties of a pluton are established it's time to move on to the next intrusion. Using examples from an ophiolitic plagiogranite, an island-arc suite from the Aleutians, alkalic granites from west Africa, Archaean granitoids from the Baltic Shield, the Peninsular Range batholith, and crustal melts from the Himalaya, the author demonstrates how field and analytical data can be combined in a petrogenetic and tectonic interpretation of the formation of granitic magmas.

Until recently, many research programmes into granite formation have all but ignored the integration of various Earth Science disciplines that the advent of plate tectonics forced on studies of melt-forming processes in the mantle several decades ago. In the absence of any real understanding of how and why melts form the emphasis has been on descriptive science in a way our Victorian forebears would have readily understood. In no other field of igneous petrology (except perhaps in the arcane labyrinth of alkaline rock classification) could the ramshackle 'alphabet classification' scheme for granites have survived so long, combining factual with interpretive criteria in an unholy alliance. From the first chapter this book argues persuasively for a non-genetic classification, with a critique of other schemes that should be read by all students of petrology.

If I have a criticism of this book it is that the author has underplayed the significance of a growing trend to study granites in tectonically active regions so that the reasons *why* granite melts form may be understood. In Professor Clarke's signposting to future investigations, little is said about the nature of the heat source or tectonic regime required for forming granitic melts. On the other hand, in keeping with recent trends in isotope geochemistry, much is made about *where* melts come from. I suspect that this endeavour will come to be seen in the same light as we now see the search for the sources of the world's great rivers by nineteenth century geographers. It may be of passing interest to know where the Nile starts, but it is not a worthy scientific end in itself. In the same way, establishing if a granite is a 30/70 or 70/30 mix between crustal and mantle endmembers is not in itself a justifiable goal. We know from the study of basalts that determining where a melt originates is not nearly as interesting as understanding why that source melted. To do this for granitic magmas, the petrologist must combine a knowledge of mineralogy and geochemistry with an understanding of both the appropriate mineral reactions in the source region, and the evolution of transient geotherms for the appropriate tectonic setting.

I could find little in *Granitoid Rocks* about the relationship between the study of basic rocks, and that of acidic rocks which is a pity because I think it is instructive even if in some respects basic petrologists have inadvertently led their granite cousins down blind alleys. For example, trace-element modelling of basaltic sources works because, amongst other reasons, most of the analysed trace elements reside in major phases in basalts, and because chemical equilibrium between melt and source is reached rapidly at temperatures above 1000°C. Unfortunately for the granite geochemist, most of the more widely used trace elements in granites sit in accessory phases that are readily entrained in the melt. This means that the bulk trace-element analysis of a granite is unlikely to represent the composition of the melt. Moreover, melting occurs at much lower temperatures for granites than for basalts so that intra-crystal diffusion is several orders of magnitude too slow for chemical equilibrium to be reached in the source region before the melt is extracted. It may take over 20 Myr for garnet in the source to reach chemical equilibrium with a low-temperature granitic melt, so that its presence will be unrecorded by the melt geochemistry. This means that modelling the geochemical behaviour of granitic magmas is much more complicated than for basalts, but its not impossible provided the significance of disequilibrium processes is recognized.

In other respects, the study of basalt petrogenesis has lit the way for comparable studies on granite magmas. Decompression melting of the mantle is well understood by petrology graduates, but do they also realize that vapour-absent melting in the crust can generate granite melts by an analogous process? The relationship between granite melts and tectonics can only be understood by integrated studies of young, tectonically active, regions. It is no coincidence that the northern slopes of Nanga Parbat, known from fission track studies to be one of the most rapidly uplifted regions on Earth, is also host to a rare example of Quaternary granites. It is also no coincidence that the alklaic granitoid intrusions which have peppered the basement of NE Africa during the past few hundred million years were emplaced only during periods of slow movement of the African plate. The implications of both these observations are, in their different ways, important, the first relating melt-formation to vertical tectonics and the second to lateral tectonics. Neither of them could be interpreted from observations restricted to the granite bodies themselves and both require a broader understanding of the tectonic environment in which the granite magmas form.

These points aside *Granitoid Rocks* is an excellent book. It is well written, comprehensive, systematic and succinct (less than 300 pages). It is a much-needed addition to the short list of petrological textbooks that are worth recommending not only to geological libraries but also to undergraduate and graduate students interested in the interpretation of granitic magmas.

Reviewed by Nigel Harris, Department of Earth Sciences, Open University, Milton Keynes, UK.