Book Reviews

Cosmology

Formation and Evolution of Galaxies and Large Structures in the Universe. JEAN AUDOUZE and JEAN TRAN THANH VAN, Eds. Reidel, Boston, 1984 (distributor, Kluwer Boston, Hingham, Mass.). xviii, 453 pp., illus. $58. NATO ASI Series C, vol. 117. From an institute, La Plagne, France, March 1983.

The last few years have seen some remarkable developments in cosmology. Many of these have derived from theoretical advances in particle physics; for example, the discoveries that baryon number may not be conserved, that neutrinos may have a small rest mass, and that the cosmological constant may not always be zero. Others have derived from observational developments; for example, the realization that most of the universe may be invisible, with galaxies and clusters of galaxies being enveloped in dark halos, and that it may contain giant voids, with most of the visible material being concentrated in filaments. Although these advances have not dethroned the big bang theory itself, they have radically transformed our understanding of how the universe came to evolve its currently observed structure.

They have also triggered an exciting interaction between previously disparate fields such as particle physics, astrophysics, stellar dynamics, and general relativity. The diverse and stimulating set of papers in this volume is the result of one of the many conferences spawned by this interaction. The book has a certain lack of editorial polish, perhaps as a result of the rapidity with which it was published. In several papers the English is bad, in one paper the references appear to be numbered randomly, and in another the equations are scrawled almost illegibly. Nevertheless, for those working in the field (at whom this book is primarily aimed) this is a modest price to pay for speedy publication.

Section 1 concerns the very early universe. It starts off with a review by Olive of how the grand unified theories of particle interactions may explain not only the preponderance of matter over antimatter in the universe but also how the universe developed its present uniformity and "flatness" as a result of an exponential expansion phase at 10^{-35}sec. Grand unified theories have generated much euphoria in recent years, so it is sobering to learn that the simplest "baryosynthesis" and "inflationary" scenarios no longer seem to work; one may need to invoke more complicated scenarios involving supersymmetry and supergravity theories. Another important process occurs at 10^{-5}sec when free quarks coagulate into hadrons. There are many uncertainties associated with this transition, as is discussed in a nice paper by Hakim and Collin. Nevertheless, it is clear that the transition may have interesting cosmological consequences, such as generating cosmological density fluctuations. This period has been somewhat neglected by cosmologists. Perhaps the fact that speculations about it are directly susceptible to experimental test is rather inhibiting.

Section 2 deals with the large-scale structure of the universe. An understanding of the origin of this structure is intimately connected with an understanding of the dark matter. A few years ago, the most popular approach to understanding both problems was to invoke massive neutrinos together with some form of primordial density fluctuations. In this case the first objects to form in the universe would be massive neutrino "pancakes" with masses comparable to those of clusters of galaxies. In principle, one would hope that these pancakes could cool and fragment as discussed by Bond *et al.* However, other papers indicate that there are potential problems with this solution. Szalay *et al.* show that the pancakes could produce noticeable distortions in the isotropy of the microwave background, excluding some models, and White *et al.* argue that it would have been difficult for the pancakes to form early enough to fit observation. These objections have gained force recently, suggesting that some particle other than the neutrino may have to be invoked. One may even have to adopt the more radical suggestion of Hogan that the present cosmological structure does not reflect primordial fluctuations at all but just the end point of astrophysical processes associated with the first stars.

Section 3 focuses on the dark matter itself. More than a dozen suggestions have been proposed concerning what the dark matter comprises, so it is a relief to find Hegyi eliminating at least some of the possibilities (snowballs, low-mass stars, and perhaps any candidate made of ordinary baryons). Most particle physicists presuppose, naturally enough, that some kind of elementary particle does the job. As Primack and Blumenthal explain in their excellent review of the subject, these are usefully classified as "hot," "warm," or "cold," corresponding to the scale below which primordial fluctuations are erased by the free-streaming of the particles. The best candidate would currently seem to be a cold particle (like the axion or photino), for which the damping scale is very small, even though there is no direct evidence that such a particle actually exists. Another enthusiast for the cold picture is Peebles, who explores its implication for the formation of cosmological structure in some detail. For Peebles the cold scenario clearly retains the attraction of having large-scale structure build up through the hierarchical clustering of smaller objects, a view of which he has always been the prime proponent. The neutrino picture may not be dead yet; despite the battering it receives in other papers, Schramm and Freese argue that a neutrino with a mass in the range 10 to 25 eV may be the best solution after all, so opinions clearly differ.

One explanation for the dark matter that has received rather scant attention since particle physicists entered the cosmological arena is the topic of section 4: pregalactic stars. The lack of attention to this explanation is surprising since, as Rees emphasizes, in most cosmological scenarios (including the favored cold particle model) one *expects* pregalactic stars to form, possibly in abundance. The mass of these stars, however, is very uncertain. While Rees himself favors a picture in which most of the stars are very small (around 0.01 $M_\odot$), Silk argues for a spectrum of masses that extends all the way up to 10^2 $M_\odot$. In the latter case pregalactic stars could have profound implications for cosmology. Not only could their black hole remnants provide the dark matter, but also, as is suggested in a paper by Audouze and Silk and in another by Rees, they could generate the light elements (like helium and deuterium) whose abundances are usually attributed to primordial nucleosynthesis. Such speculations indicate that in the path of progress not even the big bang itself can be regarded as hallowed ground.

Section 5 discusses the structure and evolution of galaxies and demonstrates

that some features of the universe are not easy to explain even when one can see them. For example, does one attribute the thickening of the disks in spiral galaxies (such as our own) to the effects of density waves, as Carlberg suggests, or to giant black holes in the halo, as Lacey suggests? In part, of course, it depends on whether there are any holes in the halo, so once more the dark matter problem raises its head. It raises it again when one tries to understand the origin of galactic and cluster rotation, as is discussed by Efstathiou and Barnes, and the formation mechanisms for different types of galaxies, as is discussed by Wyse and Jones.

The final section deals with the chemical evolution of galaxies. Considerable quantities of data have accumulated in the last few years concerning abundance anomalies in metal-poor stars, and, as is explained in Truran's fine review, one may thereby glean vital clues about the nature of the first stars. A particularly important anomaly concerns the apparent excess of oxygen in low-metallicity stars, which, according to Chiosi and Matteucci, suggests that the first stars may have been much more massive than the ones forming today.

It should be clear from the preceding discussion that this volume will not provide definitive answers to the questions that currently vex cosmologists. There are considerable differences of opinion on almost all the issues raised, and if the reader ends up disappointed by the lack of a clear-cut consensus and confused by the often contradictory conclusions of different papers that is no more than a reflection of the state of the art. For in the flurry of progress favored models come and go at an alarming rate. Only a year ago the simplest grand unified theory, SU(5), massive neutrinos, and inflation were the panacea of almost all cosmological ills. Now each of these remedies—at least in its most straightforward form—seems to have met its demise. Nevertheless, it would be inappropriate to end this review on a note of pessimism. For cosmology is a dynamic and rapidly developing field, and it is merely that the wealth of ideas sometimes appears confusing. Given the pace of development, it is inevitable that cosmologists will have to follow many false trails on the path to truth. We cannot yet see the end of the road, but we do have every reason to hope we are heading in the right direction.

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The Proterozoic Eon

Early Proterozoic Geology of the Great Lakes Region. L. G. MEDARIS, JR., Ed. Geological Society of America, Boulder, Colo., 1983. vi, 141 pp., illus. $28. Geological Society of America Memoir 160. From a symposium, Madison, Wis., May 1981.

Proterozoic Geology. L. G. MEDARIS, JR., C. W. BYERS, D. M. MICKELSON, and W. C. SHANKS, Eds. Geological Society of America, Boulder, Colo., 1983. viii, 315 pp., illus. $49. Geological Society of America Memoir 161. From a symposium, Madison, Wis., May 1981.

The Proterozoic eon is the unduly neglected middle half of geological time, separating the Archean (before 2.5 billion years ago) from the Phanerozoic (since about 0.6 billion years ago). A key controversy has concerned whether plate tectonics, the "dance of the continents," began near the end of the eon, near its beginning, or, in modified form, early in the Archean. This question is related to two other central issues in earth science today, the depth of mantle convection and long-term variation in the number and distribution of continents.

These two volumes stem from symposia held to discuss these and other issues in Proterozoic geology. Memoir 160 is specifically concerned with the Early Proterozoic (2.5 to 1.6 billion years ago) of the Great Lakes region, the Penokean orogen in particular. This belt evolved as the rifted southern margin of the late Archean Superior craton against which successive volcanic island arcs and microcontinents were apparently accreted, beginning about 1.85 billion years ago. The volume contains six papers on regional stratigraphic and tectonic synthesis, two on the geochemistry of igneous rock suites, and one on the sedimentology of siliciclastic rocks gradational with the "banded iron formations," for which the region is famous. Readers acquainted with Mesozoic-Cenozoic orogenic belts will find much that is familiar, although the state of knowledge is rather primitive, owing in part to poor bedrock exposure. Several important advances have been made since the symposium, notably in geochronology, structure, and geochemistry. As a result, none of the papers collected here should be considered definitive. Nevertheless, the volume may remain as the best overview on the subject until the Decade of North American Geology volumes on the Precambrian of North America are published in two or three years' time.

Memoir 161 is the more ambitious volume, consisting of 23 papers divided into sections on tectonics, magmatism and metamorphism, mineral deposits, life and oceans, and glaciation. The seven papers on tectonics present conflicting and, in some cases, eclectic views. Unfortunately, contributions concerning geophysics are limited to paleomagnetism. The section begins with a comprehensive and well-balanced paper by B. F. Windley asserting that plate tectonics operated throughout the Proterozoic, a view that all but one of the succeeding papers, more limited in scope, take issue with to varying degrees. J. D. A. Piper concludes from paleomagnetic data that all existing Precambrian shields were assembled into a single supercontinent throughout Proterozoic time, although his reconstruction requires such geologically unpalatable juxtapositions as the Arabian shield against southwestern United States. A. Kröner elaborates his idea that ensialic orogenic belts developed as the result of crust-mantle delamination. It has been proposed that the delamination and subsequent ensialic orogeny occurred in Cenozoic zones of lithospheric thickening due to plate convergence. Kröner attributes the delamination in the Proterozoic to the action of mantle plumes, though such a model is not consistent with the anastomosing geometry of Proterozoic orogenic belts. A. Y. Glikson updates his arguments for major Proterozoic global expansion, on the basis mainly of geochemical and isotopic evidence of an exclusively continental tectonic regime from 2.5 to 1.0 billion years ago. The analytical data presented are mainly from Australia and North America, where one suspects that the sample may be biased because the Archean crust is concentrated in the shields, which get sampled, and the juvenile Proterozoic crust is concentrated in the covered platforms, which do not. Proterozoic continentality is also stressed in another Australian contribution, by S. R. Taylor and S. M. McLennan, who report rare-earth element data for clastic sedimentary rocks. The global diachroneity Taylor and McLennan observe for the change from Archean to Proterozoic rare earth element signatures seems to refute their explicit assumption that such data represent world average compositions.

In the section on magmatism and metamorphism, J. L. Anderson compiles abundant new data on the enigmatic Middle Proterozoic "anorogenic" plutonism of the United States midcontinent, but the tectonic significance of the plutonism remains elusive. Perhaps the effects of thermal insulation of the man-