behavior, and the stretching and folding in state space that induces sensitive dependence on initial conditions.

Chapter 4 reviews some models of biological oscillations, including the Hodgkin-Huxley equations, pacemaker models that can generate irregular as well as regular dynamics, models of mutual inhibition and sequential disinhibition, and systems with feedback and time delays. Among the specific physiological systems discussed are ventilatory control function, the pupil-control system in the eye, white blood cell production, and recurrent inhibitory control in the hippocampus. Often it turns out that by varying a parameter in the model one observes a transition from regular to irregular behavior.

In chapter 5, the authors turn their attention to physiological rhythms and the ways in which such rhythms can be affected by external stimuli. Among the topics considered are "soft" *vs.* "hard" excitation and the annihilation of rhythmic behavior that may occur when a limit cycle coexists with an attracting point.

Chapters 6 and 7 continue the discussion of possible responses to perturbations. Both chapters begin with a review of experimental results. In chapter 6, the focus is single-pulse stimulation. Here the emphasis is on phase resetting. The authors distinguish between the two major types of this behavior, and there follows a discussion of the topological theories that have been advanced to account for the observations. Chapter 6 also includes a discussion of some of the difficulties entailed in using the topological theory to interpret data. In chapter 7, the focus shifts to periodic stimulation and the complex sequence of phase-locked and chaotic behaviors that can ensue when a nonlinear oscillator is subjected to varying degrees of periodic forcing. Among the experimental systems discussed is the periodically stimulated chick embryo heart cell preparation whose behavior has been analyzed in detail by Guevara, Glass, and their associates. This chapter also contains a review of apparent phase-locking in clinical situations: respiratory-locomotory coupling, ectopic cardiac pacemakers, and artificial ventilator-respiration coupling.

Chapter 8 takes up the matter of oscillations in space and includes some recent results on wave propagation in two and three dimensions. A major part of this chapter concerns cardiac fibrillation and its possible relation to rotating spiral waves. Finally, in chapter 9, the authors take up the idea of "dynamical diseases," by which they mean pathologies that result not from structural abnormalities *per se* but from abnormal temporal behavior. In cases such as chronic myelogenous leukemia, they suggest that understanding the dynamics in the absence of intervention may be crucial for efficacious treatment. The book concludes with a mathematical appendix, including problem sets, and an extensive bibliography.

As the foregoing summary should evidence, *From Clocks to Chaos* is an ambitious attempt to explore the application of an exciting branch of modern mathematics to real biological problems. Not all of the issues raised are resolved with anything approaching finality, and, indeed, a cynic might argue that none of them are. But it is clear that Glass and Mackey, together with their fellow theoretical biologists of the 1970s and '80s, have forever changed the ground rules for discussion of some measurable fraction of biological problems. In this reviewer's not unbiased opinion, that fraction is sure to grow in the coming decades as biologists concentrate more and more on comprehending how the machinery of life is set in motion and the circumstances that maintain it thus.

W. M. SCHAFFER
Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ 85721

Evolutionary Mechanisms

Mutation, Developmental Selection, and Plant Evolution. EDWARD J. KLEKOWSKI, JR. Columbia University Press, New York, 1988. xiv, 373 pp., illus. $55.

Plants (and some animals) lack a segregated germ line, yet often contain hundreds of thousands of meristems and live hundreds of years. Such conspicuous features of plant growth raise several questions: how often do somatic mutations arise? what effects do they have on somatic and reproductive tissues? does selection operate within or among meristems? what mechanisms might allow the usually deleterious effects of such mutations to be minimized? These questions are too important to have been overlooked, but this book is the first systematically to explore the causes, control, and implications of somatic mutation at all levels of biological organization. With this goal, the author leads the reader through a seemingly unlikely combination of topics, ranging from RNA retroviruses, supernumerary B chromosomes, and inverted repeats in chloroplast DNA to the fates of mutant cells within stratified meristems and mutant genes within populations. Such breadth is anomalous for one author in this age of specialization and represents a special strength of the book, as well as occasionally a weakness.

The book begins with reviews of the nature and organization of genetic information and the mechanisms and rates of mutation. Though some of this information is only tangentially relevant to the arguments presented later, these sections provide an accessible overview of modern molecular genetics as well as expose our ignorance of basic quantities like mutation rates per cell cycle in long-lived perennials. To discuss the fates of somatic mutations Klekowski next describes the structural organization and patterns of cell division in various types of plant meristems. Thorough reviews of the relevant morphological literature are combined with simple mathematical models to predict the probability that cells with or without a handicap will be retained and the likely spatial patterns of the resulting chimeras. These form the foundation for intriguing speculation regarding the likelihood that selection occurs among cells within a meristem or among meristems within a branched individual. The potential for such selection to occur depends, of course, on how somatic mutations are expressed (or hidden), the subject of the next chapter. The reader is again made aware of an absence of empirical data, this time on the extent of genetically based phenotypic variance among branches or ramets within a genet.

Do plants have an extraordinary ability to tolerate somatic mutations? By virtue of their relatively simple development and their fixed cell walls and consequent cell immobility, plants resist many of the conspicuous developmental effects of mutations that plague animals, such as teratomas and metastatic cancers. In addition, they seem to have evolved a number of contrivances (including diploidy itself) to minimize the somatic expression of deleterious mutations, described in a chapter entitled "Mutation buffering." For example, plants might reserve particular meristems (short shoots, for example) or parts of meristems ("méristème d'attente") with reduced mitotic activity for reproduction, resembling the segregated germ line in higher animals. Even this trick, however, cannot protect meristems against ultimately accumulating errors in protein synthesis, causing aging analogous to that of bacteria in a chemostat. Furthermore, the short-term solution of shielding mutations by diploidy or cross-feeding of meristem cells only postpones the day of reckoning, transforming the problem to one of accumulated individual and population mutational load. (That solving problems created by mutations on one level often causes problems at a higher level of biological organization is a recurring theme.) The extent of this load in ferns, gymnosperms, and several flowering plants and its evolutionary conse-

quences are the subjects for the final interesting chapters. Evidence is also reviewed that competition among gametophytes, embryos, and immature fruits (termed "soft selection sieves") might permit plants gracefully to dispose of many of their mistakes at minimal cost (but biasing our estimates of load).

The book judiciously reviews a wide and modern literature with over 700 references and many figures reproduced from original publications (not always well). Though such scope is impressive, it makes the book read at times like a succession of review articles. Specialists will probably be unsatisfied with the treatment of particular areas. This reviewer felt that too much detail was presented for certain topics (as in the case of the elementary mathematical models, one of which contains errors), whereas other relevant topics (like the potential for meiotic drive under gametophytic selection) remained unexplored. Nevertheless, the book as a whole achieves a noteworthy synthesis by posing the right questions and exposing the need for further experimental and theoretical work. It should fuel interest in somatic plant mutations and their phenotypic and genetic consequences, as well as contribute to the genetic literacy of botanists and the botanical literacy of geneticists.

DONALD M. WALLER
Department of Botany, University of Wisconsin, Madison, WI 53706

The Geology of Fluid Flow

Fluid Flow in Sedimentary Basins and Aquifers. J. C. GOFF and B. P. J. WILLIAMS, Eds. Published for the Geological Society by Blackwell Scientific, Palo Alto, CA, 1987. x, 230 pp., illus. $72. Geological Society Special Publication no. 34. From a meeting, London, U.K., June 1985.

The study of sedimentary basins is a venerable area of research in the earth sciences. Basins are large sediment-filled depressions in the shallow continental and oceanic crust, and as such they play an important role in preserving earth history as a stratigraphic record. Basins also contain nearly all of the oil and gas fields distributed in the earth's crust and host some of the largest metallic and nonmetallic ore deposits. Geologists have long been interested in the nature of fluid circulation within sedimentary basins because of the economic importance of groundwater flow systems, petroleum migration, geothermal reservoirs, and ore-forming hydrothermal fluids. It is clear also that groundwater-sediment interactions have a profound influence on the chemical transport of toxic wastes in the subsurface, on the alteration of sedimentary and crystalline rocks, on the geomorphic evolution of landforms, and on the mechanics of crust deformation.

In this publication Goff and Williams have put together a collection of 13 papers from a symposium the theme of which was the principles and geological controls of groundwater flow at scales from regional systems down to individual aquifers.

The book is conveniently divided into four sections. The first section contains two papers that describe large-scale geologic controls on fluid migration in compacting sedimentary basins. The material here is somewhat dated, drawing heavily on the authors' published books on petroleum geology. Both papers are too short to provide significant background on the mechanics of flows in compacting basins, nor do they take into account the recent literature on compaction-driven flow in intracratonic basins, passive margins, or accretionary wedges.

The second section contains four papers on the analysis of present-day and ancient groundwater flow in the Western Canada sedimentary basin. The most notable here is the paper by Tóth and Corbet, who document the effects of erosional unloading on the hydrologic history of groundwater systems in southern Alberta. The authors argue that transient adjustment of the flow patterns over the last 20 million years has had a profound influence on the accumulation of petroleum. A second novel paper in this section is presented by Bradbury and Woodwell. They utilize stable isotope data for rock oxygen and carbon to theorize on the hydrology of mountain-building thrust sheets. Two field data sets are discussed briefly, one from the front range of the Canadian Rockies and one from the southern Pyrenees. Bradbury and Woodwell interpret two scenarios of fluid migration in thrust belts based on their geochemical data. Groundwater flow in the Rockies was restricted to a basal aquifer, where flow was most active during thrusting. Basement shear zones in the Pyrenees channelized flow up into the cover sediments, where flow was pervasive. These geochemical models for fluid migration are intriguing but have yet to be verified with hydrodynamic theory.

Section 3 of the book contains four papers describing aquifers in the United Kingdom. The paper by Michael Price on the Chalk Aquifer should be of great interest to groundwater geologists. Price summarizes the hydraulic properties and demonstrates the close association between fracture permeability and dissolution near groundwater discharge zones. Readers needing a more quantitative treatment of dual-porosity flow in the Chalk ought to refer to R. Bibby's 1981 benchmark paper in *Water Resources Research*.

The last section of the volume contains three papers on fluid migration in low-permeability rock. J. H. Black's paper on the hydrogeology of crystalline rock summarizes useful permeability data from laboratory and borehole packer tests on some of the European and Canadian sites being explored as repositories for high-level nuclear wastes.

On the whole, this volume will be of most use to practicing geologists and hydrologists who have limited access to major journals and want an overview of basin hydrology in the United Kingdom and Alberta. Several of the papers in the book have since been published as full-fledged journal articles. For conveying the general principles of groundwater flow and oil migration in sedimentary basins, a more valuable work would be *Groundwater* by R. A. Freeze and J. A. Cherry.

GRANT GARVEN
Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218

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