written essay show how to express the foundations of the canonical formalism of Yang-Mills theory and general relativity in a manifestly covariant way.

This volume is unusual because of the clarity with which many of the essays are written. The less technical contributions may be read with enjoyment by nonspecialists and students interested in learning about the state of gravitation 300 years after the *Principia*. They will see that gravitation is a healthy and vital area of research, which may yet hold the answers to many of the unsolved fundamental problems of physics. Many of the more technical contributions will be of value to advanced students and researchers in the field. I heartily recommend this volume.

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A Natural Resource

Georges Bank. RICHARD H. BACKUS, Ed. MIT Press, Cambridge, MA, 1987. x, 593 pp., illus., + chart in pocket. $225.

Georges Bank is situated to the east of Cape Cod and Nantucket, between the Gulf of Maine and the edge of the continental shelf. The bank, as defined by its 60-meter depth contour, measures approximately 200 by 100 kilometers with a minimum water depth of less than 3 meters on modern charts. European explorers marked Georges Bank on maps as early as the 1520s. However, the region first became famous as a fishing ground, initially for cod in the 18th century and then for mackerel, halibut, and haddock as new fishing techniques and markets were developed in New England in the 19th century.

The fishing continued into the present century, surviving various crises as stocks of particular species were reduced. As a result, marine biologists began to consider why fish production should be so high on Georges Bank. Through the pioneering works of Henry Bigelow (1879–1967), who was the first director of the Woods Hole Oceanographic Institution, Gordon Riley (1911–1985), to whom this book is dedicated, George Clarke, and others, new ideas about the marine food chain were developed, including early models of the effects of light, nutrients, and grazing on phytoplankton growth. However, it was the severe depletion of fish stocks by East Bloc trawlers in the 1960s and 1970s and events leading up to the exploratory drilling of the first deep holes for hydrocarbons in 1981–82 that really drew political and public attention to Georges Bank.

With the announcement of leasing plans for drilling sites in 1974, the establishment of a 200-mile Exclusive Economic Zone, and the dispute over the international boundary between the United States and Canada (settled in 1984), there grew an urgent need for information on all aspects of

"Henry Bigelow aboard the U.S. Fish Commission schooner *Grampus* during the pioneering cruises of 1912–1916." [From *Georges Bank*; Museum of Comparative Zoology, Harvard University]

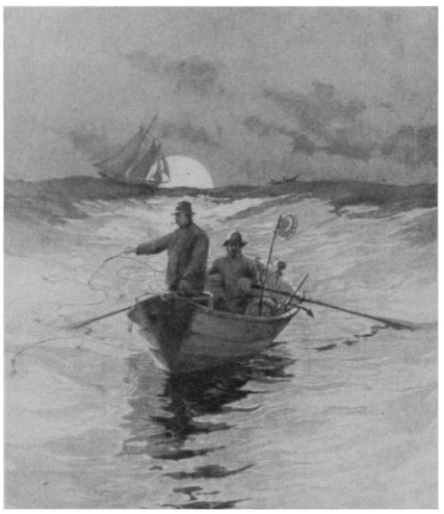
Georges Bank that could only be met through new research. One result is this admirable book, edited by Richard Backus of the Woods Hole Oceanographic Institution, covering the physical science, biology, fisheries, and uses of Georges Bank. Although intended for a general audience, the 57 chapters have been written and carefully reviewed by well-known scientists; together they form an outstanding reference book on exploration, exploitation, and scientific knowledge up to 1984.

The account of subsurface geology (chapter 5) traces the various phases of sedimentation in the Georges Bank basin since the Triassic period at the early stages of the formation of the Atlantic Ocean. The Jurassic sequence, consisting of up to 5 kilometers of calcareous rocks, sandstones, and mudstones, became overlain by thinner Cretaceous and Tertiary deposits as the rate of basin subsidence declined. Despite ample evidence for potential hydrocarbon traps (chapter 50), the two deep exploratory drill holes were dry and showed only low levels of organic material. But on the basis of past exploration on the Mid-Atlantic and Scotian shelves, it is estimated that a further 10 to 15 years' work would be needed to establish whether commercial quantities of hydrocarbons (with gas most likely) exist in the sedimentary basin. A discussion of the politics of oil drilling (chapter 55) considers the problems of communication among federal and state agencies, industry, and scientists and concludes that it is unlikely that "fish and oil" can coexist on Georges Bank.

The possible effects of petroleum on benthic and pelagic ecosystems are discussed with particular reference to larval recruitment in summer months (chapter 53). The speculative approach may not meet with everyone's approval, but low-level contamination by fossil fuels, as well as by PCBs, has already occurred on Georges Bank (chapter 19). Good observational data on fluxes of such materials from land, via rivers and the atmosphere, and on their fate within shelf waters are still lacking despite adequate technology for appropriate chemical measurements.

The reasons for the abundance of fish on Georges Bank is one theme in a fascinating account of scientific exploration (chapter 1). That problem remains essentially unsolved. However, physicists have recently provided a much more rigorous picture of the hydrodynamic environment, thus opening the way to new interdisciplinary studies. Observations and models have defined four main physical regions (chapter 11) and shown the importance of tidal and shelf-edge fronts in determining seasonal circulation patterns. Various factors contribute to reducing the exchange of water between the bank and surrounding areas, but residence times for bank waters are extremely difficult to define, let alone estimate, for open boundary conditions (chapter 14).

The account of phytoplankton production (chapter 21) compares mixed and stratified waters and considers the various mechanisms by which nutrients are supplied to the phytoplankton. An explicit treatment of respiration yields an annual upper limit of 272 grams of carbon per square meter for net primary production. An important criticism, however, is that there is a lack of consistency in the interpretation of these data in relation to those in chapter 22 for nitrogen budgets (for example, table 22.2 implies twice as



"Setting trawl on a fine evening, using a 'heaving stick.' " This picture, by M. J. Burns, "originally illustrated an account of a winter trip to Georges published in *Scribner's Magazine* in 1902." [From *Georges Bank*; photograph by Claire White Peterson; Mystic Seaport, Mystic, CT]

much net primary production on the basis of nitrogen fluxes) and to estimates of secondary production.

Possibly the greatest obstacle to explaining the high level of fish production on Georges Bank lies in the paradoxically low estimates of secondary production by zooplankton and benthos (chapters 25 and 37). To construct realistic trophic models requires the assumption of inordinately high transfer efficiencies of energy from intermediate to higher trophic levels. The problem is assumed to be due to losses of zooplankton from the system, a function of short residence times of zooplankton on the bank relative to their generation times, and perhaps to the as-yet-undefined role of microbes. It is clear that direct measurements of secondary production and microbial processes will be needed if the question is ever to be resolved; significant advances have been made in the second area since 1984.

The increase in fishing pressure brought about by the distant-water fleets in the 1960s and 1970s and the resulting decrease in biomass and production of the exploitable fish stocks have led to a much closer examination of recruitment processes and management strategies and underscored the role of humans in marine ecosystems (chapter 48). With the United States and Canada now jointly controlling the bank, an effective international management plan is still needed.

All those concerned about the future of Georges Bank are well advised to read this fascinating book, even though (with a page size of approximately 13½ by 15 inches) it may be too unwieldy to carry around in a briefcase. Backus recommends cautious development and suitable monitoring of Georges Bank, for which there should be time since further drilling depends on increases in the price of oil and gas. Whether the continuing uncertainty, frustration, and sense of crisis about future exploitation of the fisheries will "force a consensus on management purposes" (chapter 49) is far from clear, but new hypotheses about physical-biological interactions are already being tested.

Final thoughts must go to the fishermen who have perished on Georges Bank. During one storm in February 1879, 143 Gloucester fishermen drowned: "The hopless, terror striken faces of the crew we saw but a moment . . . . The doomed craft . . . struck one of the fleet, a short distance astern, and we saw the waters close over both vessels" (p. 99).

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Subterranean Systems

Paleokarst. N. P. JAMES and P. W. CHOQUETTE, Eds. Springer-Verlag, New York, 1987. xii, 416 pp., illus. $64. Based on a symposium, Golden, CO, 1985.

Caves have attracted humankind since time immemorial. In the Cretaceous reefs of Mount Carmel, Israel, caves were the refuge of humans when ice covered much of Europe. In biblical times the prophet Elijah hid in the same caves from the king of Israel. Paleolithic and later art is still preserved in the caves of France, where humans survived during the Ice Age. This book delves further into history: its chapters span the time between the Precambrian and Cretaceous. A good reason exists why paleokarst is of current interest. Caves form significant reservoirs of oil and gas. In a recent oil-exploration venture in the Park City Basin of Kansas, fluids and rods vanished in the Ordovician Arbuckle Formation. Several years earlier a similar event occurred in the correlative Ordovician Knox Group of Ohio and in a cave in Cretaceous strata 6 kilometers below Lake Maracaibo in Venezuela. Where caves are vast, exploration may be unsuccessful and fluid and drillrods vanish.

Caves are part of a karst system. The term "karst" derives from the Serbian province of what is now Yugoslavia, where limestone floors the type locality, known as Krš, a plateau in the Dinaric Alps. By extension karst is now a common term describing a topography formed on limestone or evaporite deposits, where extensive dissolution has created caves, solution-collapse, underground rivers, and sinkholes. Dissolution creates porosity, the basic condition for oil, gas, and water. But karst reflects megaporosity. As an example, commercial oil usually occurs in tiny pores in bedrock. By contrast the Golden Lane oil field in Mexico, where the karst is expressed as caves, comes closest to what a nonscientist thinks an "oil pool" should be, almost a cave of oil. Yet there is more to karst than oil, gas, and water. Karst hosts important mineral deposits, like lead and zinc.

This book presents a sequence of studies on buried karst, termed paleokarst. Its initial chapters relate to modern cave systems and their various precipitates, known as speleothems. Geochemical characteristics of carbonate cements derived through dissolution are described, and the application of geochemical patterns to studies of paleokarst is discussed. Most of the volume is devoted to case histories of ancient karst at scales ranging from local to regional and interregional. Economic examples include lead-zinc deposits in carbonate rocks and a subsurface case history from the San Andres Formation of the Permian Basin of West Texas. To appreciate the importance of the karst, note that the San Andres Formation holds 40% of the Permian Basin's oil reserves and the Permian Basin holds 20% of the total reserves of the conterminous United States. Among the examples of paleokarst terranes that are treated in separate papers are the Dismal Lakes Group in the Northwest Territories, Canada; the Leadville Formation in central Colorado; and the Subbetic Zone of southern Spain. Most of the papers are concerned with field exposures. Some of this material has been published before.

However, the significance of karst goes further than the authors and editors have shown. During much of geologic history, shallow seas, known as epeiric seas, covered the continents. Intervals of subaerial emergence during which karst developed are signals for globewide sea-level retreat. Why were the continents emergent? Did emergence reflect the freezing of polar ice or, during the Cretaceous when no ice occurred at the poles, was collapse of midocean spreading centers with consequent sea-level fall responsible? A key may be epeirogeny, the process by which broad vertical movements of the earth's crust take place unaccompanied by crumpling of strata. Large-scale vertical movements of the crust and lithosphere must be recognized in paleogeographic reconstruction. Such drastic changes represent isostatic unroofing, much of which results in the kinds of changes that generate karst.