REFERENCES AND NOTES

1. C. E. Birkeland and L. G. Eldredge, *Coral Reef Newsl. Pac. Sci. Assoc.* **16**, iii (1986).
2. E. H. Williams, Jr., *et al.*, *Summary Report of the IOCARIBE Steering Committee for Developing Regional Contingencies for Fish Kills* (CARI/-1/3, Unesco, Paris, 1982); paper presented at the Second Session of the Intergovernmental Oceanographic Commission's Subcommission for the Caribbean and Adjacent Regions (IOCARIBE), Havana, Cuba, 8 to 13 December 1986.
3. D. K. Atwood, Ed., *Unusual Mass Fish Mortalities in the Caribbean and Gulf of Mexico* (Atlantic Oceanographic and Meteorological Laboratories, National Oceanic and Atmospheric Administration, Miami, FL, 1984).
4. H. A. Lessios, D. R. Robertson, J. D. Cubit, *Science* **226**, 335 (1984).
5. H. A. Lessios, *Evolution* **35**, 618 (1981); P. W. Glynn, *Environ. Conserv.* **10**, 149 (1983); H. A. Lessios, P. W. Glynn, D. R. Robertson, *Science* **222**, 715 (1983).
6. T. F. Goreau, *Science* **145**, 383 (1964); C. Goenaga and M. Canals, in *Sexto Simposio Recurso Naturales* (Departamento Recurso Naturales, Puerto Rico, 1979), pp. 84–95; R. Acevedo and C. Goenaga, *Caribb. J. Sci.* **22**, 225 (1986).
7. V. Vicente and C. Goenaga, unpublished data.
8. R. D. Gates, Discovery Bay Marine Laboratory, Jamaica, personal communication.
9. B. D. Causey, Looe Key National Sanctuary, Florida, personal communication.
10. A. Szmant, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL, personal communication.
11. R. Wicklund, Caribbean Marine Research Center, Lee Stocking Island, Bahamas, personal communication.
12. E. Gladfelter, West Indies Laboratory, St. Croix, U.S. Virgin Islands, personal communication.
13. M. L. Hernández Avila, Sea Grant of Puerto Rico and the U.S. Virgin Islands, personal communication.
14. P. L. Jokiel and R. H. York, Jr., *Limnol. Oceanogr.* **29**, 192 (1984).
15. E. H. Williams, Jr., and L. Bunkley Williams, *Oceanus*, in press.
16. J. Morelock, Department of Marine Sciences, University of Puerto Rico, personal communication.
17. We thank J. Kubaryk and M. L. Hernandez Avila, Department of Marine Sciences, University of Puerto Rico, for emergency funding and L. Bunkley Williams, Association of Island Marine Laboratories of the Caribbean, for communication assistance.

Oil and Gas Discovery Rates

I would like to point out an omission in William L. Fisher's discussion of the future productive potential of the U.S. oil and gas resource base (Articles, 26 June, p. 1631). Fisher draws strong conclusions about past and future trends in oil and gas discovery rates that were presumably based on two different data sources. Fisher notes that Root's (*1*) projection of future natural gas discovery rates for the 1980s underestimated actual discovery rates. However, Root's analysis was based on discovery data reported by the annual reserve and discovery report of the American Petroleum Institute (API) and American Gas Association (AGA) (*3*), a series that ended in 1979. The data source for Fisher's "update" of Root's model [figure 2 in (*1*)] is not referenced, but presumably his post-1979 data is from the Department of Energy's (DOE's) annual report of reserves and discoveries, which began in 1977 (*3*).

Differences between the two data series may affect Fisher's conclusions about gas discovery rates for the period from 1978 to 1985 because the two series are not strictly comparable. For the 3 years that the data series overlap (1977 to 1979) the DOE series shows consistently higher levels of reserves and discoveries than the API series. It is highly likely that the observed differences were due to the different methodologies used in collecting the data rather than a change in actual reserves (*4*). Combining the two data series in a discovery rate analysis covering the post-1979 period will therefore tend to show an increase in that rate due simply to the shift in the data source alone, regardless of any real changes in the discovery rate. Two attempts have been made to produce linked time series that join the two time series (*4*).

Changes in petroleum discovery rates in response to price and drilling conditions of the early 1980s are important to an asessment of the potential to expand or at least maintain production. As Fisher describes, there undoubtedly was a real increase in discoveries due to unprecedented drilling rates from 1980 to 1984, but the magnitude of that change relative to the pre-1979 period is more difficult to assess precisely than Fisher's analysis suggests because of the lack of consistent data.

CUTLER J. CLEVELAND
Department of Geography,
Boston University, Boston, MA 02215

REFERENCES

1. D. H. Root, in *Oil and Gas Supply Modeling*, S. I. Gass, Ed. (National Bureau of Standards, Gaithersburg, MD, 1982), pp 350–368.
2. American Petroleum Institute, American Gas Association, and Canadian Petroleum Association, *Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada* (American Petroleum Institute, Washington, DC, annual report).
3. Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves* (Department of Energy, Washington, DC, annual report).
4. E. Murphy, in *Two Approaches to the Linkage of U.S. Oil and Gas Reserves* (Department of Energy, Washington, DC, 1984), section C, p. 28.

Fisher gives a clear account of the effect of reservoir heterogeneities on producibility of a significant portion of our domestic petroleum reserves and points out the consequent need for more infill drilling. But any recovery from the one-half of our reserve base that he classifies as "immobile" he relegates to high-cost, advanced-case, tertiary techniques that will alter either the character of the rock or the physical state of the fluid.

There is, however, growing evidence that enhanced versions of conventional secondary (flooding) processes may recover a large fraction of such oil at low cost. In this industry we tend to ignore the effects of chemical properties of the oil on producibility while concentrating on reservoir parameters. Almost all petroleum contains surface-active constituents that are strongly adsorbed at water, rock, and other high energy surfaces. This leads to oil wetting of rock and, possibly, to in situ formation of water-in-oil emulsions. These adsorbed constituents—generally lumped under generic names as "asphaltenes," "maltenes," and "petroleum resins"—form thick, viscous, or solid interfacial films that create high energy barriers to the displacement processes of water-wetting and demulsification (*1*).

The difficulties of obtaining realistic relative permeability data, a historical bias toward the assumption of water-wet conditions, and our inability to account accurately for the large increases in reservoir oil phase viscosity resulting from in situ emulsification lead to an explanation of the general finding of much lower actual secondary recovery production than that predicted from fractional flow theory.

Work on enhancement of secondary processes is advancing on a wide front. Recent progress has been made in enhancing wet-steam stimulation systems with a class of low-cost, nonionic, nonmicelle-forming surfactants (*2*). At low concentrations they appear to form thin, hydrophilic films at oil-rock and oil-water interfaces and to bring about large increases in production of oil that, it appears, would otherwise be immobile.

The first study of these reagents in a full-scale waterflood was recently completed (*3*). Their use resulted in a substantial increase in production and calculation of a threefold increase in the relative permeability ratio of oil to water.

Such findings strongly suggest that progress in the design of enhanced secondary processes will eventually allow the mobilization of a large fraction of the 240 billion barrels of reserves now labeled "immobile." Enhanced secondary processes conceivably could add 80 billion barrels or more of low-cost producible reserves to the 80 billion barrel addition that Fisher visualizes for infill drilling.

C. M. BLAIR, JR.
Baker Performance Chemicals, Inc.,
11808 South Bloomfield Avenue,
Santa Fe Springs, CA 90670

REFERENCES

1. D. K. Kimbler, R. R. Reed, I. H. Silberberg, *SPE Paper 1201 Preprint* (Society of Petroleum Engineers, Dallas, TX, 1965).
2. C. M. Blair, Jr., R. E. Scribner, C. A. Stout, *J. Petrol.*

Technol. **34**, 2757 (1982); ——, J. E. Frederiksen, *Oil Gas J.* **82**, 90 (8 October 1984); C. M. Blair, Jr., in *SPE/DOE Fifth Symposium on Enhanced Oil Recovery* (Society of Petroleum Engineers, Dallas, TX, 1986), pp. 345–352.
3. C. M. Blair, Jr., and C. A. Stout, *Oil Gas J.* **83**, 55 (20 May 1985).

Response: Cleveland is correct in pointing out the two different data series—that of the API and the AGA through 1979 and the DOE series from 1977 to the present. I used Nehring's linked data set, one of the two approaches indicated in Cleveland's reference 4 for the period 1970–1980, and the DOE data subsequently, applying standard appreciation values. The linkages, in my judgment reduce, if not eliminate, much of the inconsistencies inherent in different data sets.

Also, there are separate lines of evidence suggesting that discovery data I have used are consistent and that the conclusions drawn from the data are appropriate. It is worth noting that conclusions similar to my own can be drawn from Nehring's data (my reference 2) on the basis of his Significant Oil and Gas Fields of the U.S. Data Base and from Wood's paper (my reference 3) utilizing the Gas Research Institute's hydrocarbon model. Data from both sources indicate stability in the finding of oil and gas.

Blair cites the role of enhanced secondary recovery, which I gather he distinguishes on a cost basis from tertiary or enhanced oil recovery. I indicated that enhanced recovery, as generally defined, is more expensive than mobile, or standard, secondary oil recovery, which is not quite the same as relegating immobile oil recovery to high cost. The kinds of techniques Blair mentions will be critical, and may, in fact, eventually be low cost as he states. My expressed goal of keeping U.S. production stable over the next 45 years involves recovery of the mobile oil target (about 40 billion barrels) and one-fourth the immobile oil target (60 billion barrels). This implies, over the longer term, the importance of recovery strategies such as those mentioned by Blair.

W. L. Fisher
Bureau of Economic Geology, University of Texas, University Station, Box X, Austin, TX 78713-7508

Erratum: In the caption for the figures (p. 480) accompanying Richard A. Kerr's Research News article "Sunspot-weather correlation found" (23 Oct., p. 479), the key was inadvertently omitted. The solid lines in the figures represent solar flux and the broken lines represent stratospheric temperature.

Erratum: In Eliot Marshall's article "Reinventing the space truck" (News & Comment, 16 Oct., p. 266), the photo identification was reversed. The Martin Marietta rocket design was on the right, and the Hughes Aircraft design was on the left. Also, the Air Force's Space Division is in Los Angeles, not Denver.