Maintaining Oil Production from Marginal Fields

A Review of the Department of Energy's Reservoir Class Program

Panel on the Review of the Oil Recovery Demonstration Program of the Department of Energy
Committee on Earth Resources
Board on Earth Sciences and Resources
Commission on Geosciences, Environment, and Resources
National Research Council

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PANEL ON THE REVIEW OF THE OIL RECOVERY DEMONSTRATION PROGRAM OF THE DEPARTMENT OF ENERGY

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Preface

Premature abandonment of marginal oil wells and fields is a growing energy problem in the United States. Once a field is abandoned, the remaining resources are essentially removed from future access by the high cost of reestablishing production. The growing rate of abandonment of wells and fields that contain substantial amounts of potentially recoverable oil will increase the nation's dependence on imported petroleum products, which currently account for about half of total U.S. oil consumption and nearly one-third of the merchandise trade deficit. Maintaining a viable domestic supply of oil and natural gas is important to the United States for both economic and strategic reasons.

Prolonging the life of marginal oil wells and fields is a major component of the Department of Energy's Oil Program. Based on its conclusion that the application of new and existing recovery technologies to marginal fields would have a major positive effect on future domestic oil production, DOE developed its Reservoir Class Field Demonstration Program to encourage industry, in a 50-50 cost-sharing effort, to demonstrate technologies that would prolong oil production in marginal fields at current and projected oil prices.

There are two main challenges to be met in achieving the desired outcome. The first, and perhaps the easiest, is demonstrating the variety of extraction technologies that can be applied to the various geologic classes of reservoirs that contain the greatest amount of remaining oil. Guided by careful geologic characterization of the reservoirs, successful field testing of technologies can be applied to other reservoirs in the same class and some technologies can be utilized in several classes. The second challenge is to communicate the successes and the procedures that produced them to other operators across the basin and the country. This is a daunting task in the current setting dominated by numerous small producers that are not linked by large corporation ties or well established networks. The cost effectiveness of the DOE Reservoir Class Program will ultimately be measured by the prolonged production that results from the application of appropriate extraction technologies, and this, in turn, depends on effective transfer of technology to large numbers of producers.

At the request of the U.S. Department of Energy, in a letter dated September 14, 1994, from Mr. Reginal W. Spiller, Deputy Assistant Secretary for Gas and Petroleum Technologies, the National Research Council (NRC) established a panel to assess the effectiveness of the Reservoir Class Program and to recommend improvements. The panel operated under the auspices of the Committee on Earth Resources of the Board on Earth Sciences and Resources. It carried out its work through five meetings, all but the last of which included presentations by program participants. A list of participants who discussed their projects with the panel is presented in Appendix A. The panel delivered an interim letter report (Appendix B) that addresses the effectiveness of the program on February 28, 1995. The final report, *Maintaining Oil Production from Marginal Fields: A Review of the Department of Energy's Reservoir Class Program,* fully addresses the charge to the panel. In August, 1995, the DOE canceled Class 4 of the program in response to preliminary actions taken by Congress. The cancellation does not diminish the relevance or importance of this study, and the DOE asked the panel to complete its report.

In responding to the DOE's request to review the Reservoir Class Program, the panel paid particular attention to the technology transfer component of the program. The panel was also very interested in the processes used to solicit, select, monitor, and review projects and in the expertise of the people carrying out these functions. Because the impact of the program cannot be directly measured for several years, the panel emphasized measures that would help ensure long-term program success.

It is beyond the scope of this report to provide peer reviews of individual projects sponsored by the Reservoir Class Program. The panel has focused on evaluating the overall program, and it has refrained from offering advice on the quality of specific projects. However, the need for peer reviews conducted by qualified experts from outside the contracting companies is the subject of several recommendations in the report. The panel envisions a system of external peer review for proposal selection, monitoring, and post-mortem evaluation of each project.

The panel's term coincided with a period of technical staff change in the NRC's Board on Earth Sciences and Resources. Three study directors supported and contributed substantially to the work of the panel. Jonathan Price, Kevin Crowley, and Craig Schiffries were essential elements in the work of the panel. Lally Anne Anderson was with us from start to finish and provided essential logistical, technical, and word-processing support. The members and staff of the panel and the Board on Earth Sciences and Resources extend special thanks to Edith Allison of DOE who responded quickly and effectively to every request for information and assistance.

The role of government in cooperating with industry to advance common interests was a continuing subject of discussion and debate in the Congress and other political circles during the term of this review. In reaching its conclusions that the Reservoir Class Program is demonstrating appropriate technologies for prolonging production, and that the program can, with the implementation of the recommendations offered by the panel, make an important contribution to reducing the rate of abandonment of marginal wells and fields, the panel also provides unspoken support for cooperation between government and industry. At a time when the financial resources of both parties are limited, it is a clear sign of commitment when both partners back interest and rhetoric with dollars.

Charles G. Groat
Chairman

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Executive Summary

The Reservoir Class Field Demonstration Program [1] of the U.S. Department of Energy's (DOE) Office of Fossil Energy is designed to contribute to the sustainability of domestic production by decreasing the rate of abandonment of marginal oil wells and fields. The specific objective of the program is to encourage the application of a broad range of conventional and advanced recovery technologies to the geologic classes of reservoirs that contain most of the known unrecovered oil. It is an industry-driven program that depends on no more than 50-percent funding from DOE. The Reservoir Class Program involves a diverse group of participants that includes independent oil and gas producers, small and major petroleum companies, state geological surveys, and universities.

The National Research Council formed the Panel on the Review of the Oil Recovery Demonstration Program of the Department of Energy in response to a request by DOE to assess the effectiveness of the Reservoir Class Program and to recommend improvements. The panel was charged with addressing the following two questions:

(1) Has the Reservoir Class Program proven effective in demonstrating the application of new and existing technologies to prolong production in marginal fields?
(2) How should this program be modified to improve its effectiveness in meeting this goal?

Because the field demonstration phases of most projects have not been in place long enough to be expected to produce significant increases in production, the panel's conclusions and recommendations are based on a review of program procedures and individual project purpose, design, and progress. The panel concluded that the Reservoir Class Program is demonstrating advanced and conventional technologies that have the potential to prolong the lives of marginal oil fields.

Most projects in the Reservoir Class Program have an up-front reservoir characterization element that is intended to provide geologic and engineering parameters that will increase the effectiveness of the recovery technology being applied and help to define reservoir characteristics that will guide future applications. The emphasis on this program element varies considerably among the projects. The panel concluded that appropriate reservoir characterization is essential to the success of the program and that reservoir class is justified as the basis for organizing the program and for guiding the application of successful technologies. The panel concluded that in future phases of the program, DOE should encourage a larger number of proposals by opening up future proposal solicitations to meritorious projects from previously funded reservoir classes. This would also provide increased opportunities for application of cross-cutting technologies.

The process of selection and review of projects for the Reservoir Class Program originally was conducted by in-house DOE professionals supplemented by people with suitable expertise from other federal agencies. Concerns about the length and complexity of the proposal review, project selection, and contract negotiation process, however, led DOE to take actions to streamline the selection and contract negotiation process. The panel agreed that these changes would have the intended effect on procedures, but the panel was concerned that it would further limit the breadth of proposal and project review by qualified geoscientists and engineers. The panel also concluded that monitoring of progress and review of project results by recognized external peers is essential, and would improve the quality and acceptance of project outcomes.

Effective technology transfer is essential to the success of the program. Review of the technology transfer elements of several projects led to the conclusion that there is an over-reliance on loosely defined programs composed of standard communication techniques such as papers at technical meetings and workshops. Organizations geared toward technology transfer, such as state geological surveys and the Petroleum Technology Transfer Council, generally have more clearly defined technology transfer programs than companies that are not traditionally in the business of sharing their successes with competitors. The panel concluded that DOE should take overall responsibility for technology transfer and that it should develop a comprehensive technology transfer plan that integrates plans and activities of individual projects, participating organizations, contractors, and interested field operators. Technology transfer program design also should include input from professionals in the area of public relations and communications.

The panel concluded that the Reservoir Class Program was applying appropriate conventional and advanced technologies to classes of reservoirs that could contribute significant continued production if these technologies prove to be successful in economically recovering oil and if they prove to be broadly applicable. The program contains the necessary elements for success and the target audience is the appropriate one. The program could be improved by implementing these recommendations:

- continue to use reservoir class as a basis for organizing the program; however, future proposal solicitations should be open to meritorious projects from previously funded reservoir classes as well as the targeted class;
- create a system of external peer review for proposal selection, monitoring, and post-mortem evaluation of the projects;
- shift responsibility for technology transfer to DOE and create a master plan to ensure that the intended audience is reached and that no results are disseminated without proper external peer review.

1

Background on Reservoir Class Program

PURPOSE

Premature abandonment of marginal oil wells and fields is a growing energy problem in the United States. Once a field is abandoned, the remaining resources are essentially removed from future access by the high cost of reestablishing production. Prolonging production from marginal oil fields and halting the potentially irreversible loss of access to an increasingly scarce domestic resource are important goals of U.S. energy policy.

Maintaining a viable domestic supply of oil and natural gas is important to the United States for both economic and strategic reasons. Income generated by the domestic oil and gas industry fuels the economy, creates jobs, and generates federal revenues from bonuses, leases, and royalties from exploration and production on offshore and onshore federal lands.[1] Domestic production also decreases U.S. dependence on imported petroleum products, which currently account for slightly more than 50 percent of total U.S. oil demand[2] and about 31 percent of the

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[1] In 1993, revenues to the U.S. Treasury from oil and gas bonuses, leases, and royalties totaled about $3.5 billion (Minerals Management Service, *Mineral Revenues 1993*).

[2] In 1994, domestic field production of crude oil averaged 6.63 million barrels per day (bpd); net imports (i.e., imports minus exports) of crude oil averaged 6.92 million bpd (Energy Information Administration, *Monthly Energy Review*, January 1995).

merchandise trade deficit.[3] Further decreases in domestic production will exacerbate the trade deficit problem and increase foreign dependence for a resource that provides about 40 percent[4] of the total U.S. energy supply.

The Reservoir Class Field Demonstration Program, hereafter referred to as the *Reservoir Class Program*, was initiated in 1992 as part of a broad DOE effort to counter the continuing drop in domestic oil production[5] and to slow the abandonment, because of unfavorable economics, of wells in "mature" fields that typically still contain 60 to 70 percent of the original oil in place (OOIP).[6] Of this remaining oil, approximately 32 percent (113 Bbbl; 21 percent of OOIP) is mobile[7] but bypassed during primary recovery and waterflooding and about 68 percent (238 Bbbl; 45 percent OOIP) is immobile, requiring advanced recovery methods to produce.[8] The specific goal of the program is to encourage oil companies to employ techniques that will increase oil recovery from wells in these "mature" fields.

As major companies reduced their efforts in domestic onshore operations and shifted their emphasis to frontier areas (Alaska and offshore) and international operations, DOE recognized that production of oil from mature fields in the lower 48 states and the continental shelf of the United States would shift to smaller companies and independent producers. Such companies generally lack the internal technical expertise and capital resources to undertake technically or economically risky projects, leading to

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[3] For 1994, the U.S. merchandise trade deficit totaled $168.4 billion. Imports of petroleum and petroleum products accounted for $51.5 billion of this total (U.S. Department of Commerce, *Survey of Current Business*, January 1995).

[4] In 1993, the latest year for which complete data are available, U.S. energy consumption totaled 83.89 Quadrillion BTU (Quads), of which 33.84 Quads were supplied by petroleum—crude oil, lease condensate, and natural gas plant liquids (Energy Information Administration, *Monthly Energy Review*, January 1995).

[5] U.S. domestic field production of crude oil declined from 8.60 million barrels per day (bpd) in 1980 to 6.63 million bpd in 1994 (Energy Information Administration, *Monthly Energy Review*, January 1995).

[6] In 1994, for example, there were approximately 442,500 stripper wells (wells that produce less than 10 barrels of oil per day) in the United States, which accounted for about 14 percent of domestic production of crude oil. In the same year, about 18,000 (4.0 percent) stripper wells were abandoned (Interstate Oil and Gas Compact Commission, *Marginal Oil: Fuel for Economic Growth*, 1995), presumably due to unfavorable economics.

[7] Mobile oil is that oil which can be moved to the well under the force of gravity, the natural pressure of the reservoir, or with the aid of conventional pressure maintenance or displacement technologies (e.g., water or natural gas flooding). Immobile oil is that oil held in the rock pores by capillary or viscous forces and is usually produced using gas, chemical, or thermal methods.

[8] *An Assessment of the Oil Resource Base of the United States*, Oil Resources Panel: A Commentary by William L. Fisher, Noel Tyler, Carol L. Ruthven, Thomas E. Burchfield, and James F. Pautz. U.S. Department of Energy Report DOE/BC-93/1/SP, 1992.

the abandonment of many oil fields that still contain significant amounts of potentially recoverable oil.

The ultimate objective of the Reservoir Class Program is to promote the application of advanced technologies and more effective use of conventional technologies in order to maintain or increase oil production in marginal fields in the United States. The program utilizes a cost-sharing plan to encourage industry to apply new techniques with high potential to improve oil recovery. By encouraging the application of a wide variety of new technologies, the Reservoir Class Program will permit DOE and industry to determine which (if any) of these techniques are most effective in increasing oil recovery from a specific reservoir class. Transfer of those technologies found to be most cost-effective to small companies, independent producers, and major companies will encourage the widespread adoption of these techniques throughout the domestic oil industry. DOE projects that this program will allow industry to add about 1.5 billion barrels to domestic production by the year 2020.

The success of the Reservoir Class Program will ultimately be measured by increased production from marginal fields and by the economic return on the DOE's investments in the program. Although its impact cannot be directly measured for several years, early results suggest that the program has already begun to pay significant dividends. For example, the Lomax Exploration Company estimates that a minimum of 31 million barrels of oil will be recovered as a result of its demonstration project. According to a study by Grabhorn (1995), "The return to the government in form of taxes generated from this project alone is probably more than enough to pay for the entire Class 1 field demonstration program".[9] As required by the technology transfer component of the Reservoir Class Program, the Lomax Exploration Company has published papers and held workshops about its project. As a result, other operators in the immediate area are adopting the technology that was successfully demonstrated by the Lomax project. If this pattern is repeated, then a small number of successful projects have the potential to repay the DOE's investment many times over and generate significant increases in oil production from marginal fields. Reports of success from another demonstration project emerged as this report was being finalized. Production from the Dundee Formation project (Chapter 2 and Appendix B, Project 19) has increased by a factor of ten, and this success has rejuvenated interest in old Dundee fields that had produced over 352 millions barrels of oil before they were largely abandoned by 1945.

[9] Grabhorn, Merle, 1995, DOE field demonstration program logs successes, *Oil and Gas Journal*, Oct. 23, 1995, p. 77.

ORGANIZATION AND RESERVOIR CLASS BASIS

The Reservoir Class Program is organized on the basis of geologically defined reservoir classes. DOE uses the term class to denote a group of reservoirs with a similar depositional history. Depositional history strongly influences the internal variability of porosity and permeability—and thus the flow of hydrocarbons—in the reservoir. Twenty-two reservoir classes are recognized by DOE, 16 clastic (sandstone) and six carbonate (limestone and dolomite) classes. Classes 1, 2, and 3 (Fluvial Dominated Delta, Shallow Shelf Carbonate, and Slope and Basin Clastic Reservoirs, respectively) are thought to include the reservoir types with substantial resources from which oil recovery has historically been least efficient. These classes were selected for demonstration projects during the first four years of the program.[10] Depositional models for Class 1, 2, and 3 reservoirs are illustrated in Figures 1.1, 1.2, and 1.3, respectively.

PROGRAM COMPONENTS

Reservoir Characterization

A key technical component in most of the projects examined by the committee is reservoir characterization. Reservoir characterization involves the integration of geological (especially well data), geophysical, and engineering data to determine the shape, size, internal structure, and other physical and chemical properties of the reservoir. Reservoir characterization is used to develop models to better understand fluid flow within reservoirs to enhance recovery of mobile oil and guide the application of advanced recovery techniques to maximize the recovery of residual (immobile) oil. Reservoir characterization is performed in the early stages of a project so that infill drilling, waterflooding, and advanced recovery techniques can use these data most effectively. In many cases, reservoir characterization is continually reassessed during the life of a field.

Demonstration of Advanced and Conventional Technologies

The decline in oil prices and the reduction of domestic operations by the major oil companies have combined to decrease the application of both advanced and conventional recovery technologies. By demonstrating that a wide variety of advanced and conventional technologies can be economically feasible, the Reservoir Class Program seeks to develop the technical

[10] See, for example, U.S. Department of Energy, *Program Opportunity Notice (PON), Number DE-PS22-94BC14972, Class III Oil Program—Near Term Activities*, p. 1-1.

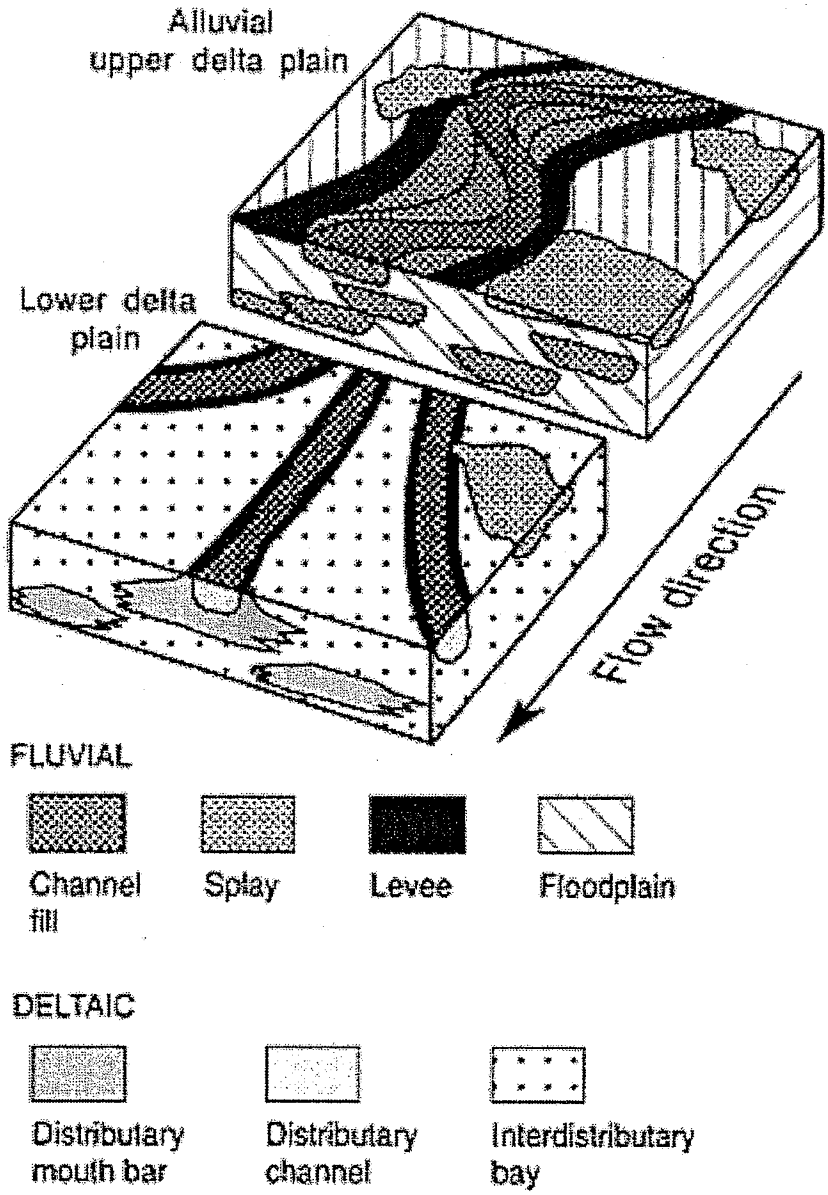


FIGURE 1.1 Schematic block diagram illustrating depositional model for fluvial (river) dominated deltaic reservoirs, which correspond to Class 1 of the Reservoir Class Program. After Holtz, M.H., and L.E. McRae, 1995, Identification and assessment of remaining oil resources in the Frio fluvial-deltaic sandstone play, South Texas. *The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 227,* Fig. 13, p. 12. Reprinted by permission of the Bureau of Economic Geology.

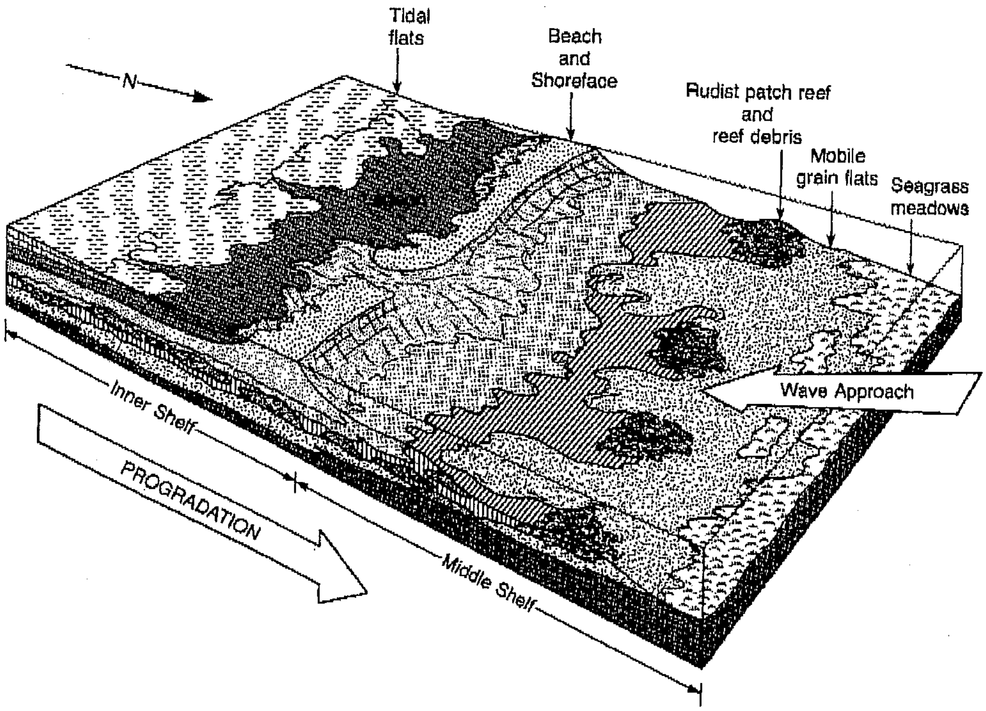


FIGURE 1.2 Schematic block diagram illustrating depositional model for shallow shelf carbonate reservoirs, which correspond to Class 2 of the Reservoir Class Program. After R. S. Kerr, 1977, *The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 89*, Fig. 9, p. 223. Reprinted by permission of the Bureau of Economic Geology.

and economic experience necessary to encourage adoption of these technologies by independent operators, small companies and major companies. In addition, some conventional technologies are being applied in new areas where the technology has not been demonstrated as economically viable. An implicit tenet of the Reservoir Class Program is that the demonstration of these technologies is unlikely to occur under current and projected oil prices and in a time frame that can substantially reduce field abandonments without the economic boost and risk sharing provided by program funding.

Technology Transfer

In order for the Reservoir Class Program to achieve its overall objectives, the economically sound and effective technologies demonstrated in the projects must be effectively transferred throughout the oil industry. The purpose of technology transfer is to encourage the broader application of cost-effective technologies by disseminating the knowledge, data, and techniques most useful for solving reservoir characterization and oil production

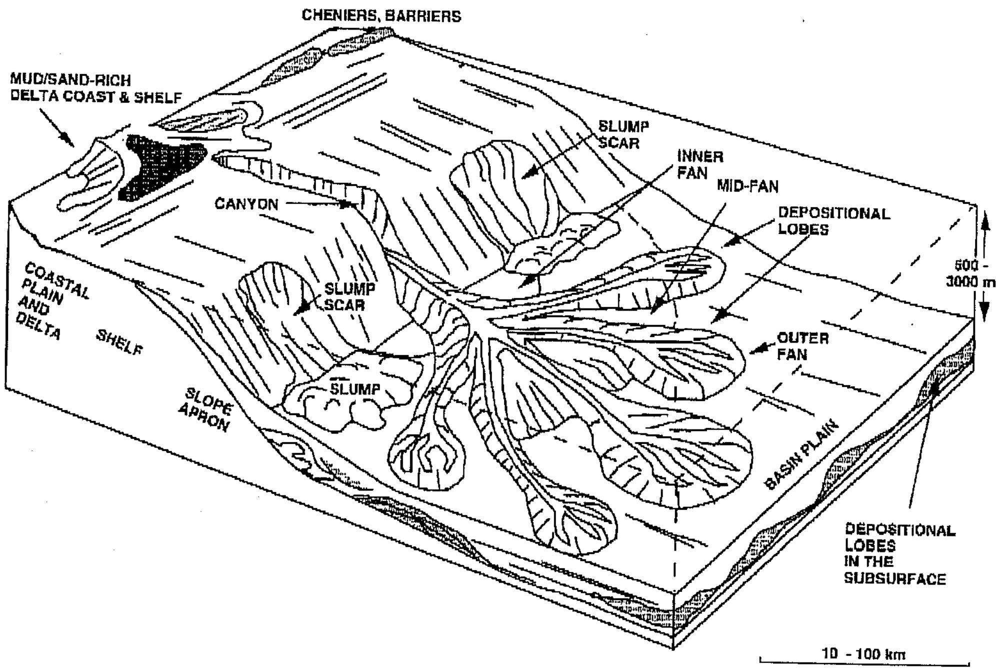


FIGURE 1.3 Schematic block diagram illustrating depositional model for slope and basin clastic reservoirs, which correspond to Class 3 of the Reservoir Class Program. After H.G. Reading, and M. Richards, 1994, Turbidite systems in deep-water basin margins classified by grain size and feeder system. *AAPG Bulletin*, vol. 78, Fig. 5, p. 803. Reprinted by permission of the American Association for Petroleum Geologists.

problems. DOE has made technology transfer a key component of each of the Reservoir Class Program projects.

IMPLEMENTATION

Implementation of the Reservoir Class Program began in fiscal year 1992 (FY92) with the selection of 14 Class 1 projects (Fluvial Dominated Deltaic Reservoirs; see Appendix B for a list of Class 1 and Class 2 projects). In FY93, 10 Class 2 projects (Shallow Shelf Carbonate Reservoirs) were selected for support. Nine Class 3 projects (Slope and Basin Clastic Reservoirs) were selected in FY95. Location maps for the Class 1, 2, and 3 projects are shown in Figures 1.4, 1.5, and 1.6, respectively. The budget for the Reservoir Class Program is presented in Table 1.1, which shows that DOE's share of the total cost of the program is 43 percent.

Projects are organized into two groups: near-term, which focus on applying conventional but underutilized technologies, and mid-term, which focus on advanced technologies. Both groups of projects include a reservoir characterization element and an emphasis on technology transfer.

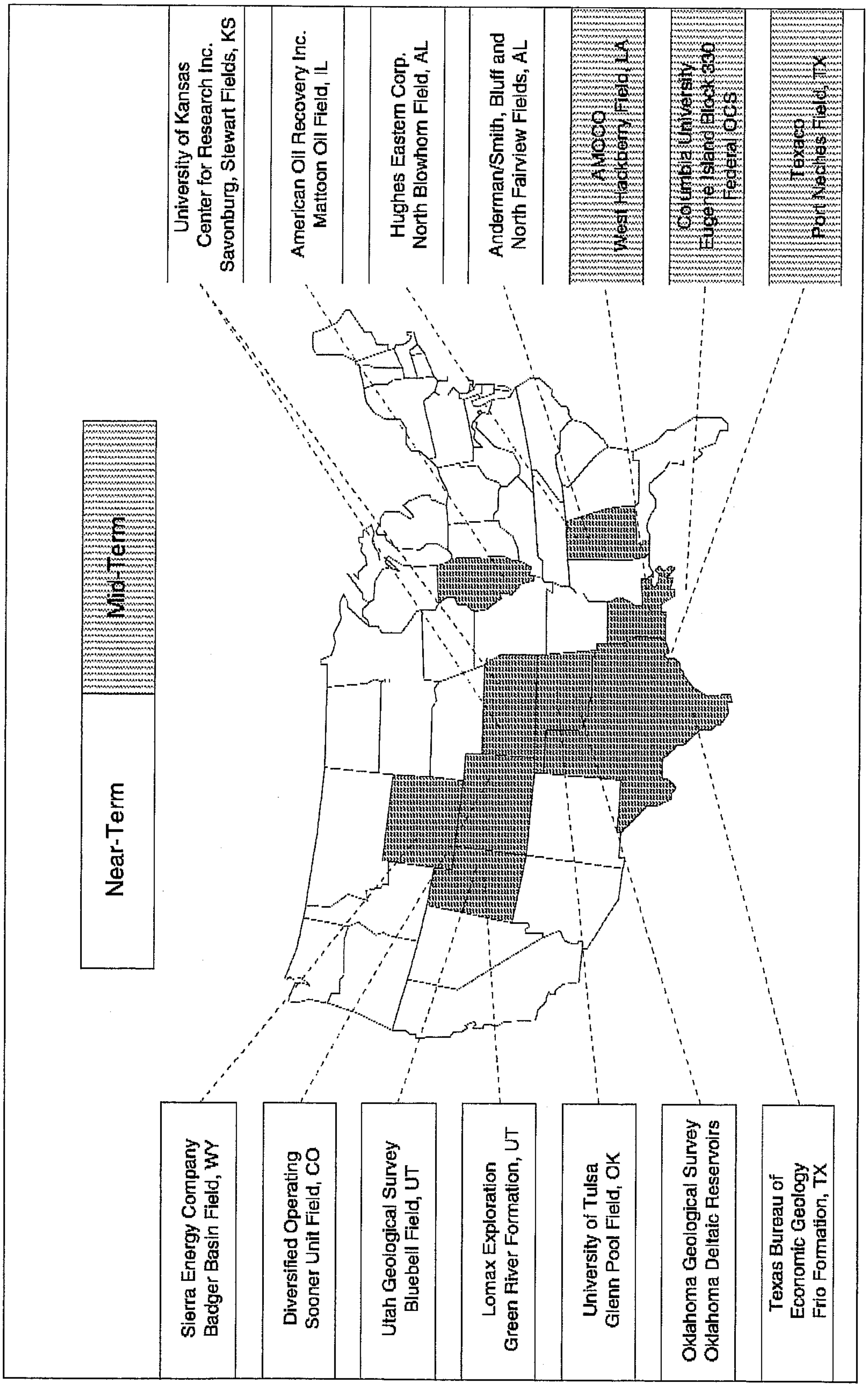


FIGURE 1.4 Location map for Class 1 projects (fluvial dominated deltaic reservoirs).

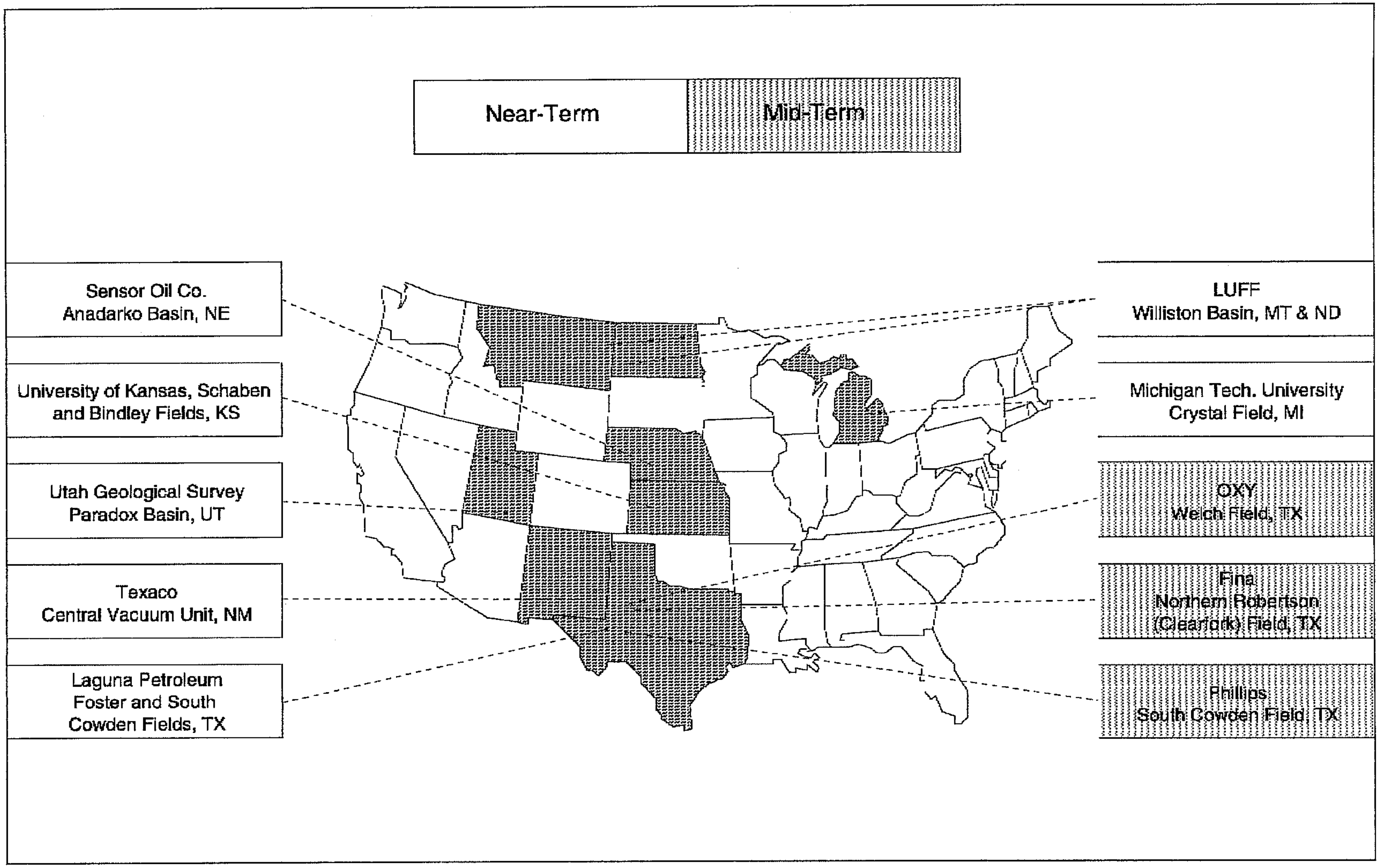


FIGURE 1.5 Location map for Class 2 projects (shallow shelf carbonate reservoirs).

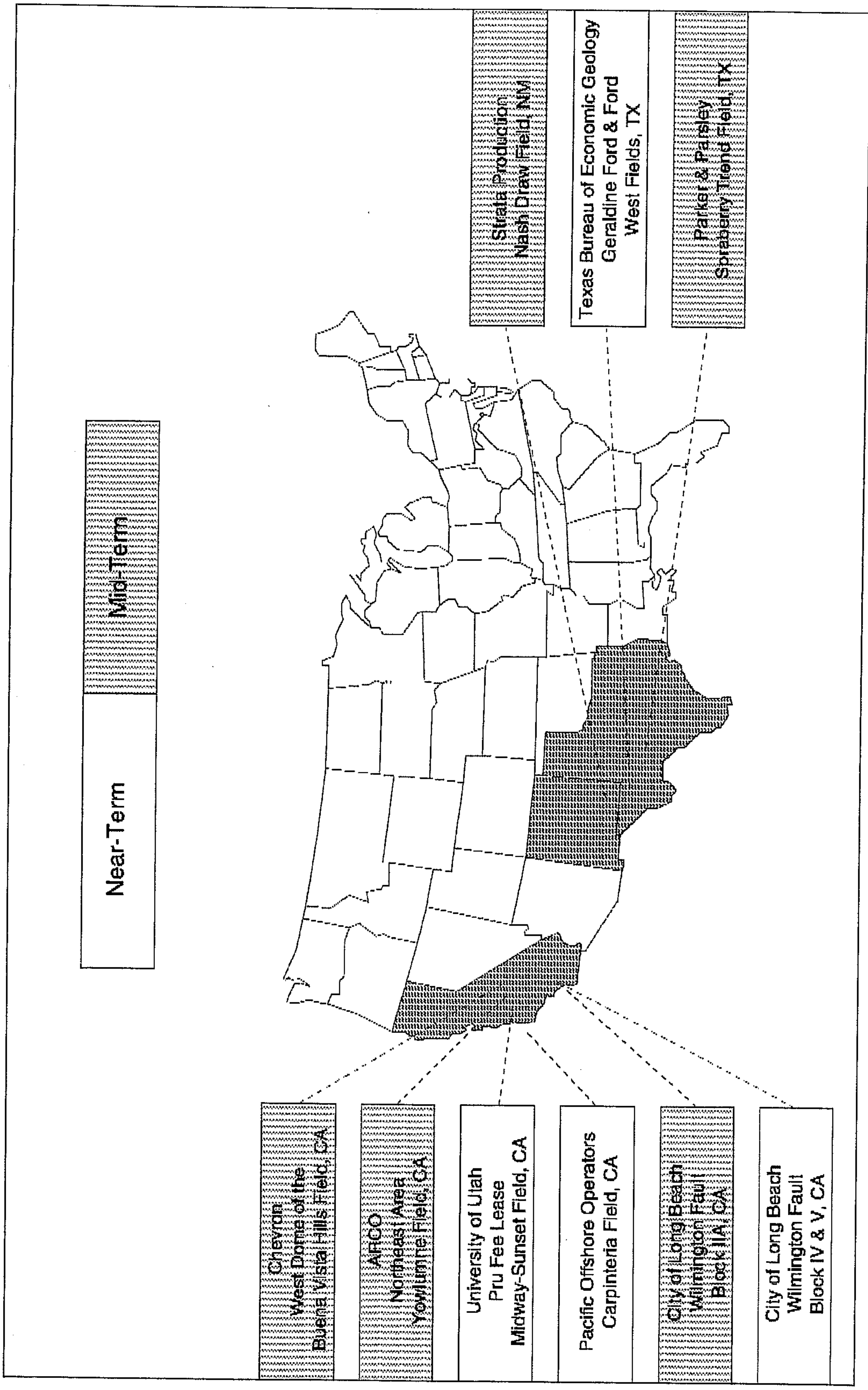


FIGURE 1.6 Location map for Class 3 projects (slope and basin clastic reservoirs).

TABLE 1.1 Reservoir Class Program Budget (thousands of dollars)

Class	Cost to DOE	Cost to Participants	Total Cost	Percent DOE Funding
1	43,258	54,667	97,925	44%
2	36,681	49,021	85,702	43%
3	36,757	49,003	85,760	43%
Total	116,696	152,691	269,387	43%

Source: Department of Energy

2

Review of Program Basis and Components

RESERVOIR CLASS AS BASIS FOR ORGANIZATION

Conceptual Basis

Organization of the Reservoir Class Program on the basis of reservoir class is based on observations that oil recovery responses of reservoirs are closely related to the geologic origins of the reservoir rocks. This is a concept widely recognized by industry, academia, and government scientists and engineers.[1] The geological origin of a reservoir controls or strongly influences its geometry, internal structure, and other physical and chemical characteristics, which in turn control oil production performance. The extrapolation of primary heterogeneities among a reservoir class is based on the results of numerous studies of modern and ancient environments that show the range of processes present within a particular reservoir class. These studies have shown that each reservoir class is characterized by a unique set of rock properties, which vary within definable limits. These

[1] Geoscience Institute for Oil and Gas Recovery Research, 1990, *Reservoir Heterogeneity Classification System for Characterization and Analysis of Oil Resource Base in Known Reservoirs*, prepared for U.S. Department of Energy, Office of Fossil Energy, Bartlesville Project Office. See also M.R. Ray, J.P. Brashear, and J. Biglarbigi, 1991. Classification system targets unrecovered U.S. oil reserves, *Oil and Gas Journal*, v. 89, no. 39, p. 89.

observations are the geologic foundation for the Reservoir Class Program. Because the physical properties of a reservoir are coupled to the nature and scale of heterogeneities affecting fluid flow, DOE believes that successful demonstrations of advanced or conventional technologies in a given reservoir in a class should be applicable to other reservoir systems in the same class. This is particularly important because of the small number of demonstration projects compared to the large number of fields.

The broad acceptance of reservoir classes has allowed DOE to organize and access its Tertiary Oil Recovery Information System (TORIS) data base to support the Reservoir Class Program. The TORIS database recognizes that reservoirs range from simple to complex based on depositional processes. DOE has used the TORIS database to quantify remaining oil in place in different classes and has given priority in funding to classes with the greatest potential to improve oil recovery (Figure 2.1).

While the DOE Reservoir Class Program has a clear mission to apply the results of a project to other reservoirs in the same class, the projects generally do not define how that will be accomplished. The project results will be made available to industry through the requirements of technology transfer, but other operators or consultants must determine if the results can be applied to other fields.

Findings and Recommendations

Finding

The reservoir class concept provides an acceptable scientific basis for classifying reservoirs and organizing the Reservoir Class Program. The concept provides a useful framework for DOE to target specific classes that have the greatest potential for improved oil recovery. It also emphasizes the importance of reservoir genesis and characterization so that effective technologies may be transferred to other reservoirs in the same class. Despite its usefulness as an organizational tool, however, the reservoir class concept does not consider all reservoir properties that affect oil recovery. The importance of fractures, in particular, is not recognized in the reservoir class concept. Strict adherence to the reservoir class concept during project selection may also result in the exclusion of particularly meritorious projects because they do not belong to the class being solicited or they belong to a class that is not likely to be solicited in the future.

Recommendations

The DOE should continue using the reservoir class concept as a basis for organizing the Reservoir Class Program.

The DOE should also consider the possible effects of other reservoir properties in improved oil recovery techniques. In particular, the DOE should consider adding a class of fractured reservoirs to future Reservoir Class Programs.

Future proposal solicitations should be open to meritorious projects from previously funded reservoir classes as well as the targeted class.

RESERVOIR CHARACTERIZATION

Role and Importance

High-quality reservoir characterization is vital to the efficient production of both mobile and immobile oil in most mature reservoirs in the United States. For example, reservoir characterization has significantly increased oil recovery in many mature fields by helping to locate infill wells.[2] High quality characterization is even more important for advanced recovery techniques because such techniques must contact the residual oil to be effective. The relative importance of reservoir characterization was recognized in a previous National Research Council report, which consistently gave reservoir characterization a high priority in funding even in a decreased budget scenario.[3] According to a recent report by the National Petroleum Council,[4] the highest priority need for the development area in the short term is in better reservoir characterization.

The Reservoir Class Program has emphasized reservoir characterization from its inception. A major reason that reservoir classes 1-3 (Fluvial Dominated Deltas, Shallow Shelf Carbonates, Slope and Basin Clastics) contain large amounts of unrecovered oil is that they are geologically complex with relatively discontinuous or heterogeneous reservoir rocks. Fields with discontinuous reservoir intervals and/or heterogeneous permeability require sophisticated reservoir characterization to accurately locate, assess, and recover hydrocarbons (see Appendix C). Good reservoir characterization is needed in every project to (1) help understand why certain recovery tech-

[2] N. Tyler and R.J. Finley, 1991, Architectural controls on the recovery of hydrocarbons from sandstone reservoirs, in A.D. Miall and N. Tyler, eds., *The Three-Dimensional Facies Architecture of Terrigenous Clastic Sediments and its Implication for Hydrocarbon Discovery and Recovery*, SEPM Society for Sedimentary Geology, Tulsa, Okla., Concepts in Sedimentology and Paleontology, vol. 3, pp. 1-5.

[3] National Council, 1993, *Advanced Exploratory Research Directions for Extracting and Processing of Oil and Gas*, Committee on Applied Research Needs Related to Extraction and Processing of Oil and Gas, Table 4.1, p. 44. Washington, D.C.: National Academy Press.

[4] National Petroleum Council, 1995, *Research, Development and Demonstration Needs of the Oil and Gas Industry*, vol. 1, p. 29.

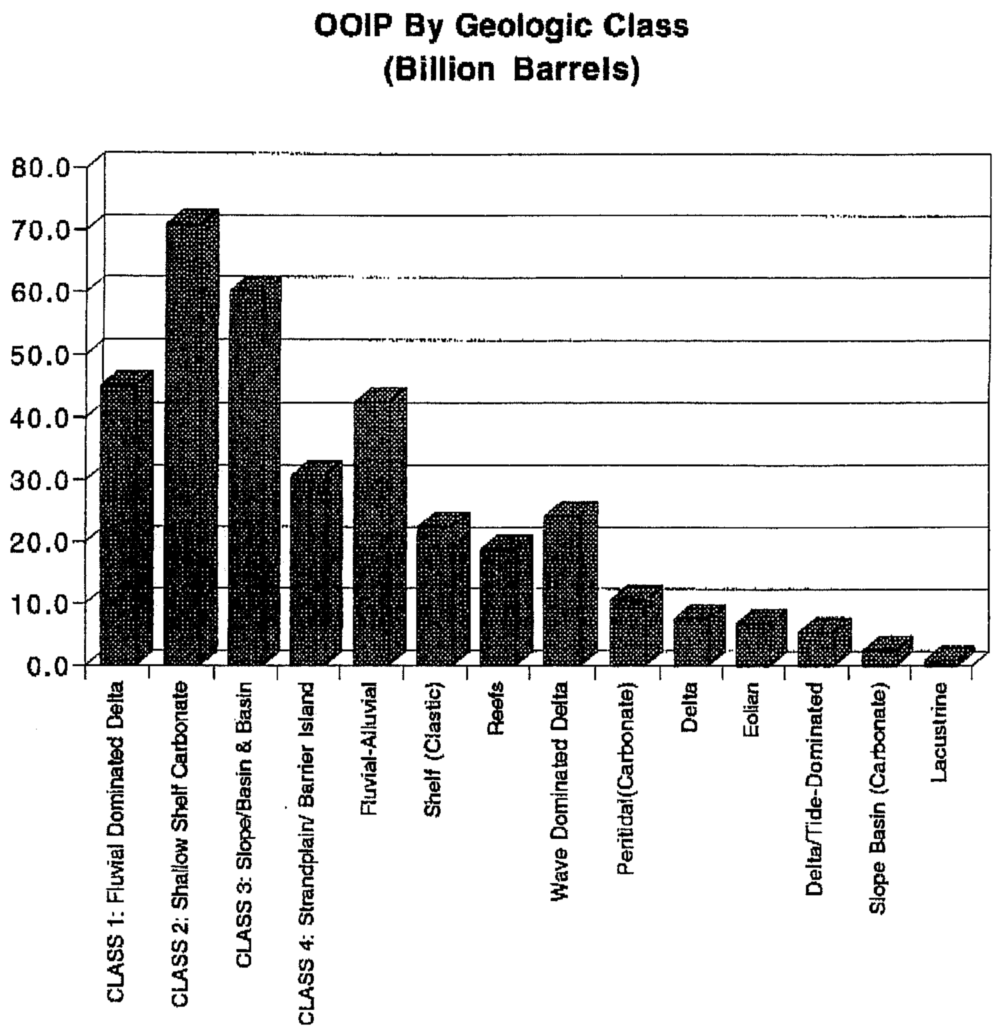
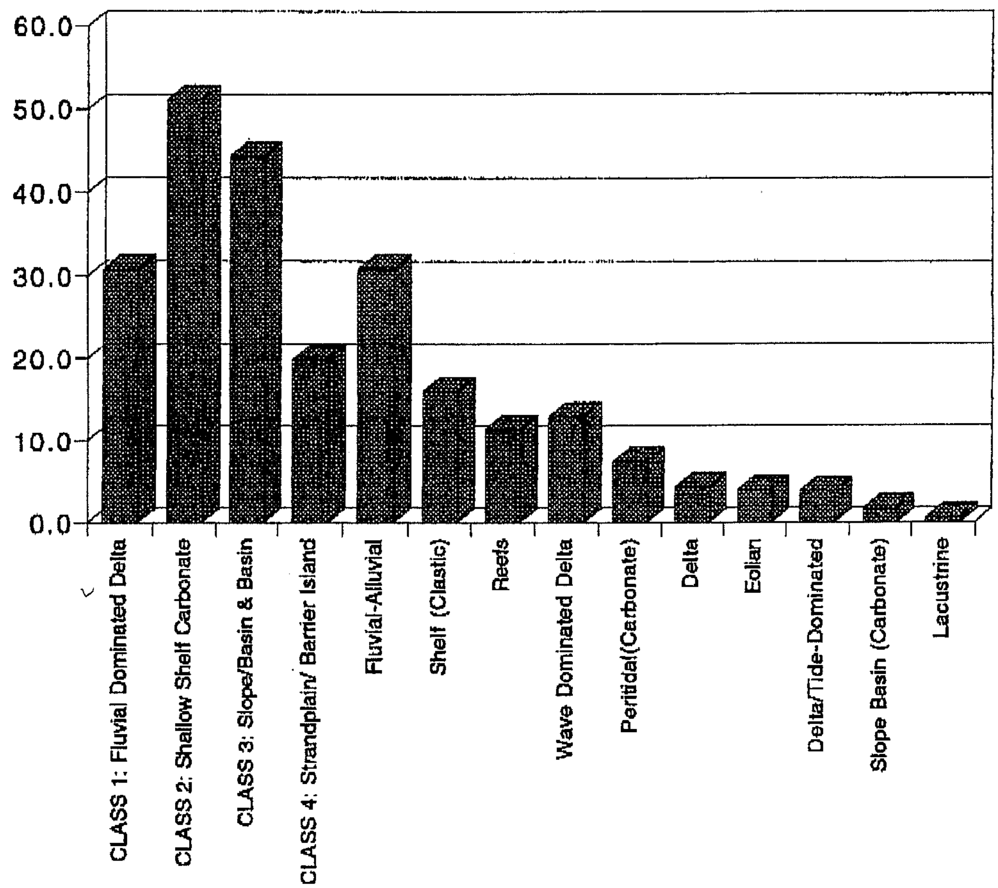


FIGURE 2.1 Original Oil in Place (OOIP; lefthand figure), and Remaining Oil in Place (ROIP; righthand figure) in Classes 1-4, and other reservoir classes. Source: Unpublished data from DOE's TORIS database. See also Department of Energy, Office of Fossil Energy, Bartlesville Project Office, 1993, *A Review of Slope-Basin and Basin Clastic Reservoirs in the United States*, p. 1-6.

nologies are successful in some fields but not in others, (2) determine which technologies are likely to be transferable within a class, and (3) determine which technologies are transferable across reservoir classes.

The Reservoir Class Program has effectively emphasized reservoir characterization. The primary roles of reservoir characterization for most Class 1 and Class 2 projects are listed in Appendix C (Table C.1). Listed first are 12 projects in which reservoir characterization is intended to locate bypassed oil and hence identify locations for infill wells and/or recompletions

ROIP by Geologic Class
(Billion Barrels)



in existing wells. Listed next are 11 projects which use reservoir characterization to better understand subsurface flow units and hence improve the efficiency of waterflooding and advanced flooding methods. The final three projects listed in Table C.1 emphasize recovery methods and do not include reservoir characterization as a significant component of the project. In addition, several projects were not listed because they were canceled or are otherwise anomalous.

Quality of Reservoir Characterization

Among the Class 1 and 2 projects examined through presentations by project staff members, the panel observed significant variations in quality and thoroughness of reservoir characterization, integration of various disciplines, and use of relevant information to design and implement conventional and advanced recovery techniques. Confirmation that there are substantial variations in the quality of reservoir characterization will not be possible until the projects are completed. The economic viability of most projects depends on the appropriate amount of reservoir characterization being performed. Data that will not significantly affect technical decisions will only add expense and hence will decrease the economic viability of a specific project. In the panel's opinion, experimental techniques that might provide technically feasible and useful information and have the potential to be economic in the future should be encouraged. Economic considerations should include the DOE cost sharing.

Findings and Recommendations

Finding

The DOE has correctly placed a substantial emphasis on reservoir characterization in the Reservoir Class Program. The quality of reservoir characterization in funded projects, however, has been difficult to evaluate, partly because of the lack of formal peer review of reservoir characterization throughout the project. In some cases, it appears to be good, and in others it may be weak. In most projects, reservoir characterization appears to be having a significant impact on recovery strategies. In two projects where reservoir characterization was not a priority—North Blowhorn Creek Field (Appendix B, Project 7) and Port Neches Field (Appendix B, Project 10)—flood performance was not as expected.

Recommendation

To ensure high-quality reservoir characterization and its utilization in all projects, we recommend that DOE initiate a system of periodic peer review by regional experts from outside the contracting companies, especially in the early stages of a project. The reviews should emphasize constructive suggestions that are possible to implement given the economic and technical constraints of the project. The objective of such interim peer reviews by local geological, geophysical, and engineering experts would be to improve the quality of reservoir characterization in most projects, and that will hopefully improve the chances for economic success. Internal company reviews should not be the sole basis for ensuring high-quality reservoir characterization. In addition, the quality and effectiveness of reservoir characterization and its impact on oil recovery should be thoroughly evaluated at the end of each project.

DEMONSTRATING ADVANCED AND CONVENTIONAL TECHNOLOGIES

A wide range of conventional and advanced technologies for reservoir characterization and oil recovery are being utilized in projects examined by the panel. Conventional techniques can recover mobile oil from untapped or uncontacted compartments in known fields. Immobile oil can be recovered using advanced techniques that alter the properties of the reservoir fluids or the interactions between these fluids and the host rock.

Range of Technologies Reviewed

Conventional Technologies

Although many of the projects examined by the panel employed conventional technologies, these technologies were new to the geographic areas in which they were being applied. Conventional techniques for reservoir characterization include core and cuttings analysis, facies mapping, comparative outcrop studies, and conventional well-log analysis. Conventional techniques for recovery include infill drilling and waterflooding.

Two projects that have entered production demonstrate the significant potential of the Reservoir Class Program to increase oil recovery in marginal fields:

- Uinta Basin, Utah (Appendix B, Project 8). Lomax Exploration Company has demonstrated that water injection can be used to increase production and prolong the life of marginal fields in the Uinta Basin. As of June 30, 1994, the project has produced 216,000 barrels of additional oil and 200 MMCF of natural gas. The Lomax program is projected to recover 20 percent of the original oil in place, versus about 4 percent for primary recovery without waterflooding. Before this project was initiated, most operators in the area did not believe that waterflooding would be economically successful. However, this project has served as a model for 11 other waterfloods in the area.
- Dundee Formation, Michigan (Appendix B, Project 19). The Michigan Technological University's Dundee project has demonstrated the viability

of horizontal wells in old, largely abandoned oil fields in the Dundee Formation. Crystal Field, discovered in the mid-1930s, had produced 8 million barrels of oil from 193 wells by 1940. In the late 1960s, Crystal Field had only seven active producers, the best of which produced five barrels of oil and 170 barrels of water per day. The DOE Dundee project drilled a horizontal well in Crystal Field in October, 1995, which encountered oil at original reservoir pressure. The well has produced oil with no water at the maximum rate surface facilities could handle (50-100 barrels per day) from November to the present (mid-February, 1996). This and additional horizontal wells in Crystal Field could increase ultimate oil recovery by over 2 million barrels. Horizontal-well technology promoted by this project may help rejuvenate many other old Dundee fields in Michigan.

Although most projects have not been in place long enough to be expected to generate significant increases in production, the following studies illustrate the variety of conventional technologies that are being applied in the Reservoir Class Program:

- N.E. Savonburg Field, Kansas (Appendix B, Project 11). The University of Kansas and James Russell Petroleum Company introduced reservoir simulation technology and water treatment processes for waterflooding to improve production from a Pennsylvanian reservoir in eastern Kansas. The technology is expected to find application to other reservoirs in this region.
- Northern Robertson, Clearfork, Texas (Appendix B, Project 16). This Fina Oil and Chemical Company project involves selective infill drill-

Uinta Basin, Lomax Exploration

Lomax Exploration has demonstrated the viability of waterflooding the Green River Formation in the Uinta Basin (Utah). Waterflooding was previously considered ineffective in this area. The Lomax project alone is expected to produce 2.4 million barrels of incremental oil, which would return $12.7 million to the public sector through additional taxes and royalties. The Lomax project is apparently serving as a model for 11 additional waterflood projects in the area. These waterflood projects are projected to produce a minimum of 31 million barrels of additional oil. (Source: Department of Energy, 1995, *First Annual Progress Report, The Domestic Natural Gas and Oil Initiative*)

Dundee Formation, Michigan Technological University

The Michigan Technological University's project has rejuvenated interest in the Dundee Formation in the Michigan Basin. The Devonian Dundee Formation in Michigan has produced over 352 million barrels of oil, mainly between 1935 and 1945. Most Dundee wells were abandoned by 1945. Crystal Field had produced 8 million barrels of oil from 193 wells by 1940. By 1970, only seven producers were active, the best of which produced five barrels of oil and 170 barrels of water per day. The DOE Dundee project drilled a horizontal well in October, 1995, which has produced water-free oil at the maximum rate surface facilities could handle (50-100 barrels per day) from November to the present (mid-February, 1996). This and additional horizontal wells in Crystal Field could increase ultimate oil recovery by over 2 million barrels. Horizontal-well technology promoted by this project may help revive many other oil fields in Michigan.

ing based on reservoir characterization. Additional production is expected from these infill wells, and that production should encourage more infill drilling in the Clear Fork Formation in the Permian Basin.

- Fluvial Dominated Deltas, Oklahoma (Appendix B, Project 12). This Oklahoma Geological Survey project involved a compilation of geological and engineering data on fluvial dominated deltas in Oklahoma. Most of these fields are operated by small companies, and this project provided information on the success and failure of waterflooding in these reservoir sands. The project is a good example of effective technology transfer, mainly through local workshops.
- Frio Formation, Texas (Appendix B, Project 4). The Texas Bureau of Economic Geology used core description, petrophysical analysis, and log correlations to map areas of potential well deepenings in a complex mixed fluvial-deltaic system. Even though no field demonstration is involved in this project, operators in the area are shooting 3D seismic surveys and planning well deepenings which should result in increased production.

Advanced Technologies

Examples of advanced technologies for reservoir characterization in-

Williston Basin, Luff Exploration

Luff Exploration's multifaceted approach to exploration and production shows promise for recovering additional oil from Paleozoic carbonates in the Williston Basin (North Dakota, South Dakota, and Montana). Their 3D seismic program is designed to locate untapped structural and stratigraphic compartments of oil reservoirs. If successful, this seismic technique could serve as a model for many other independent producers and increase oil production in the Williston basin. Experimental but rapidly evolving hydraulic "lance" jet technology will be used by Luff to stimulate wells that currently have low oil production. Lance jets will hydraulically drill lateral holes extending 10 to 80 feet away from the original vertical well. If successful, this relatively low-cost technology could substantially increase production from many old wells.

clude 3D and 4D[5] seismic analysis, tomography, advanced logging techniques (e.g., nuclear magnetic resonance logging and borehole imaging), sequence-stratigraphic modeling of flow units, and 3D geologic modeling. Examples of advanced technologies for recovery include the use of horizontal wells for injection and production, CO_2 flooding, and combustion/gravity draining. The following projects illustrate the range of advanced technologies used in the Reservoir Class Program:

- West Hackberry Field, Louisiana (Appendix B, Project 2). Amoco is utilizing double displacement technology for tertiary production from the West Hackberry Field. This process starts with air injection near the top of a water-invaded oil column. The injected air causes combustion of a small amount of the oil in the reservoir, thereby producing flue gases and steam to mobilize the waterflood residual oil, which is recovered by gravity drainage.
- Eugene Island Block 330 Field, Gulf of Mexico (Appendix B, Project 5). This Columbia University project has developed an improved time-dependent seismic imaging methodology (4D seismic imaging; see footnote 5) that can be used to monitor changes to the reservoirs during production.
- North Blowhorn Creek Field, Black Warrior Basin, Alabama (Appendix B, Project 7). Hughes Eastern Corporation is pumping nutrients into the formation from injectors to promote bacterial plugging of high-perme-

[5] Three spatial dimensions and the fourth dimension of time.

West Hackberry Field, Amoco Production

Amoco Production Company's project in the West Hackberry Field (south Louisiana) is using air injection and subsurface combustion in an innovative double displacement process to recover oil remaining in this depleted reservoir. Oil should drain down under the force of gravity and, it is hoped, be recovered by downdip wells. This experimental technique may represent a new, low-cost, advanced method to recover additional oil from many steeply dipping oil reservoirs in the Gulf of Mexico and adjacent areas. Initial results appear promising as production from one well in the field has increased from 10 BOPD to 190 BOPD.

ability conduits to allow better sweep efficiency in the waterflood. Although the results of the bacterial project are uncertain, more oil has been recovered in an infill well drilled as a part of this program, illustrating the serendipity that can be involved in oil and gas production.

- Welch Field, San Andres Formation, Texas (Appendix B, Project 20). OXY USA, Inc. is doing extensive reservoir characterization in preparation for a cyclic CO_2 flood which may produce incremental oil in a relatively short time frame. If this project succeeds, it may enable many other local operators to recover oil economically from the San Andres Formation in the area.
- Williston Basin Carbonates, North Dakota and Montana (Appendix B, Project 18). Luff Exploration Company is using 3D seismic surveys to identify fracture trends in deep subsurface reservoirs. This project will employ jet lance perforations that extend more than 10 feet away from the borehole to increase productivity. The technology is being used because vertical wells are characterized by low oil production and horizontal wells are too expensive for most operators in this basin.

Findings and Recommendations

Findings

The projects examined employ an appropriate range of both conventional and advanced technologies in the areas of reservoir characterization, drilling, well completion, and production. Ultimate economic success of many projects will depend on the sophisticated use and integration of technologies. An important feature of the program is that these projects provide direct tests of the economic viability of applying technology in particular plays or basins.

In the panel's opinion, most technologies used in the Reservoir Class Program to increase recovery from oil reservoirs are crosscutting and can be applied to more than one reservoir class. A weakness of the existing program is that projects in classes already funded cannot be considered, thereby excluding some crosscutting technologies.

Recommendations

Projects involving advanced technologies need a thorough review of the technology by qualified experts to ensure that the technologies are utilized correctly.

Although some of the funded projects (e.g., Oklahoma Geological Survey, Texas Bureau of Economic Geology) have no field demonstration component, these projects have provided important information to small operators in particular basins, and projects of this type should be included in future solicitations.

TECHNOLOGY TRANSFER

Role and Importance

The primary goal of technology transfer in the Reservoir Class Program is to encourage the widespread use of technologies and approaches that are demonstrated to be most cost-effective in (1) nearby fields within the same reservoir class type, (2) fields within the same reservoir class in other parts of the country, and (3) other fields in other classes where applicable.

An effective technology transfer program is absolutely critical in assuring the broad application of the new and existing technologies demonstrated in this program. Both positive and negative results of sound scientific and operational merit discovered in the Reservoir Class Program must be efficiently and effectively communicated to producers in the marginal fields. If this part of the program fails, the DOE will be in a position of having partially funded oil companies to carry out applied research programs that did not benefit a large number of marginal domestic fields.

Present Responsibilities

DOE and Individual Projects

Technology transfer is an explicit component of the DOE Reservoir

Class Program and each project is required to have a technology transfer plan. Currently, DOE holds each project individually responsible for technology transfer during and at the end of the research period. To date, DOE staff have not assumed any overall technology transfer role that is an integral part of the Reservoir Class Program.

Various methods of carrying out the technology transfer component are employed in the projects. Collectively, the funded projects are using primarily traditional procedures in transferring project information to the other potential users. These include the following:

- publications, including refereed papers, proceedings of professional meetings, trade journals, newsletters, and the popular press;
- databases (printed and electronic formats), technical progress reports, electronic bulletin boards, open-file reports, and videos;
- technical meeting presentations, including displays, oral presentations, and poster presentations;
- workshops, project site visits, short courses, and special topical meetings (e.g., geologic reservoir characterization, core workshops, reservoir engineering, seismic interpretation); and
- informal meetings by investigators with colleagues and other users that communicate results.

Each of the projects reviewed by the panel contains a technology transfer plan, and the contractors appear to recognize the importance of the plan. There is considerable variation in the technology transfer methods being employed in the various projects and the degree to which technology transfer is occurring. To date, few innovative technology transfer strategies are being used by Reservoir Class Program. The chief motivations for technology transfer seem to be the requirement itself and the desire to publish.

The most successful technology transfer programs occur where either (1) the participants previously carried out technology transfer as part of their normal responsibilities (e.g., state geological surveys) or (2) projects where a close relationship exists between the main contractor (e.g, Lomax) and other operators in a producing area. In these cases, technology transfer is occurring as a natural part of doing business, and end-users are being kept up to date on project developments through both formal and informal technology transfer activities.

For the vast majority of contractors, however, emphasis on technology transfer is lacking and it is not an integrated part of the project. Although papers presented orally or published in technical journals accomplish some measure of technology transfer, these methods often do not reach smaller independent producers who constitute part of the intended audience. As a result, the expected effectiveness of the technology transfer program is limited, and only a major effort by DOE at the end of projects will ensure a significant transfer of technology. Currently, there is little evidence that this will occur without a major change in policy.

Another criticism of the current efforts in technology transfer is that the quality of the technology being transferred from the Reservoir Class Program projects may not meet scientific standards. The panel questions the technical soundness of some of the technology and approaches being employed and, therefore, questions their value as a subject of technology transfer.

Role of Other Organizations

While technology transfer is presently the responsibility of the DOE and the individual contractors, other agencies and groups could play an important role in helping in this undertaking. Most notable of these is the Petroleum Technology Transfer Council (PTTC), a new, industry-driven (but primarily DOE-funded in the early stages) national group formed to identify and transfer upstream technology. The PTTC was initiated by Independent Petroleum Association of America (IPAA) and is being jointly funded by DOE and industry over a five-year period. This group is well positioned to carry out technology transfer for the Reservoir Class Program over the next several years.

The PTTC is organized into ten regions in the United States, each of which consists of a Producers Advisory Group (PAG) and a Regional Lead Office (RLO). The PAG is composed of oil and gas producers from the area and is charged with providing the direction for the regional activities, developing the budget, and coordinating industry cost sharing. The RLOs are responsible for managing the regional program; they are generally associated with a university or state geological survey, most of which have a history of contact with at least part of the industry in the region they represent. Such groups also, in most cases, have the technological background and resources to run a credible technology transfer program. The technological advisory group responsible for technological integrity within the PTTC structure at the regional level has not yet been formed.

Although the PTTC is ideally suited to carry out technology transfer for the Reservoir Class Program, continued support for the PTTC is threatened by possible cuts in DOE funding and an apparent lack of financial commitment from industry. Funding proportions for the PTTC program are on a sliding scale with DOE providing the larger share of the funding early in the program and industry taking up the larger share later in the program, with a goal of 50:50 fund sharing at the end of five years. Unfortunately, industry is already asking state governments and universities for help with its share of the funding. To date, the states of Louisiana and New York have obtained state appropriations for participation, and several other states have pending legislation, but it is not clear whether support from all sectors for the PTTC program will continue through 2000.

During the presentations, the panel learned that BDM-Oklahoma (an Oklahoma-based contractor) was granted $500,000 by DOE to help fill the gaps in the technology transfer efforts being made by the individual Reservoir Class Program contractors. Specifically, the BDM-Oklahoma project includes:

- Development of one-day workshops focusing on Class 1 results slated for FY96.
- Development of information services on the Internet for the DOE programs.
- Development of databases for the Class 1, 2, and 3 projects that are accessible over the Internet.

During the course of this study, however, the entire DOE-BDM subcontract was canceled due to funding changes at DOE. After the conclusion of the BDM technology transfer project at or near the end of FY 1996, DOE staff anticipate that similar technology-transfer implementation programs will be performed by other groups. In addition, the management role of BDM as subcontractor to DOE for the PTTC program will terminate and DOE will reassume this responsibility. As a result of these changes it is critical that DOE pay particularly close attention to the reservoir class technology transfer program and assume ultimate responsibility for it.

The role of state geological surveys and other similar state agencies in helping DOE with technology transfer could be considerable. Generally such agencies are mandated by state statute to collect and maintain oil and gas data and to engage in technology transfer activities that will develop the state's resources. Because this is a part of the function of such agencies, they are often very familiar with the oil and gas producing community, the geology of the various plays, the engineering practices and the problems associated with the production in various reservoirs, and the exploration trends active in their respective states. DOE should consider setting up cooperative agreements with such state agencies for future technology transfer activities.

Findings and Recommendations

In evaluating the technology transfer program of the Reservoir Class Program, the panel makes the following findings and recommendations:

Finding

One of the major strengths of the program is the *requirement* for technology transfer, which has already led to the dissemination of important recovery results that would generally not have been made public. A limitation of the current technology transfer plan, however, is that the primary means of transfer is the individual contractor rather than DOE itself. A more centralized technology transfer program would allow DOE to more effectively evaluate the results of all Reservoir Class Program projects and transfer those results throughout the oil industry.

Recommendation

The DOE should accept the primary responsibility for technology transfer in the Reservoir Class Program. As such, the DOE should develop an innovative and comprehensive technology transfer plan that should include the following elements:

- Ensure that no results are disseminated without proper peer review.
- Increase DOE-industry contacts to improve DOE's credibility with independent producers.
- Design workshops by reservoir class for independent producers in various producing basins in order to encourage the application of technologies to similar fields within the basins and elsewhere.
- Apply electronic media technologies to disseminate information, including a newsletter and publication series.
- Improve exhibits and activities at national, regional, and local scientific and professional meetings to attract independent oil producers.
- Work with the PTTC and/or other contractors to disseminate project results within an overall plan.
- Consider the development of cooperative agreements with state geological surveys or similar organizations to assist with technology transfer activities.
- Consider funding post-mortem studies of all class projects with dissemination of results.
- Technology transfer program design should include input from professionals in the area of public relations and communications.

Finding

Implementation of the Class 1, 2, and 3 projects has occurred without an organized system of peer review to evaluate the results of individual projects.

Recommendation

The results of all projects should be subject to review by qualified experts before being transferred. The panel believes that peer review must take place before dissemination in order to prevent possible damage to the credibility of the Reservoir Class Program and DOE. The peer review process must be conducted in a timely manner because of the threat of premature abandonment and the rapid pace of technological change. DOE should evaluate various mechanisms for obtaining timely peer reviews from qualified experts from outside the federal government and the contracting companies; one possible mechanism would be to establish an external peer review and technology transfer review panel for each project.

3

Project Selection, Implementation, Monitoring, and Review

PROJECT SOLICITATION

Process

Projects for the Reservoir Class Program have been solicited using two different procedures: (1) a Program Opportunity Notice (PON/DOE) and (2) a Request for Proposal (RFP/BDM-Oklahoma). DOE handled the solicitations and project management for Classes 1, 2, and 3 using the PON process. Class 4 responsibilities were contracted to BDM-Oklahoma which utilized an RFP process. Termination of the Class 4 procurement process due to pending budget cuts for FY96 prevented an evaluation of its effectiveness. The issuance of solicitations was followed by pre-proposal conferences designed to provide information about the program and to answer questions. PONs and RFPs have undergone an evolution in terms of length, deadlines, requirements, and objectives. In all cases, proposals have been solicited for near-term and mid-term projects. Near-term projects take place within a five-year period and have the goal of preserving access to similar reservoirs that have a high potential for increased productivity but are rapidly approaching their economic limit. Preserving access to these reservoirs is to be accomplished by conducting technology transfer that motivates operators to identify bypassed oil and apply underutilized technologies to produce that oil. Mid-term projects occur within a ten-year period and have the goals of developing and testing advanced technologies through an integrated multidisciplinary approach.

Audience Reached

The primary mechanism for distributing both PONs and RFPs was a mailing list developed by DOE and targeted primarily to the technical community. In addition, notices of upcoming projects and deadlines were published in trade journals for independent oil companies. Small oil producers were also reached through trade organizations. In the panel's judgment, the distribution of PONs and RFPs has been effective in all class projects. This is important because the deadline for submitting a proposal is generally three months after the PON or RFP is released (Table 3.1).

Project Eligibility

The criteria used to determine project eligibility changed from Classes 1-3 to Class 4. Eligibility requirements for the Class 4 program are broader than those for Classes 1, 2 and 3. Class 4 proposals, which still call upon reservoir characterization as a major component, opened up funding to enhanced oil recovery projects. Although this type of project was not expressly excluded from Classes 1, 2, and 3, it was not openly solicited.

No maximum length was imposed on proposals for Classes 1, 2, and 3, but for Class 4, an 80-page maximum (Executive Summary—5 pages; Technical Proposal—75 pages) was applied. This is a definite improvement; in fact, the panel feels that a 25-page proposal length is more appropriate.

The level of financial detail required in proposals has been a frequently cited criticism of the selection process. Proposals for Classes 1, 2, and 3

TABLE 3.1 Proposal solicitation and selection data

Project	Date of PON/RFP	No. Mailed	Deadline for Proposals	Near-term Proposals Received/ Awarded	Mid-term Proposals Received/ Awarded
Class 1	15 Oct 1991	1,850	15 Jan 1992	23/10	12/4
Class 2	8 Oct 1992	2,500	15 Jan 1993	27/8	17/3
Class 3	28 Feb 1994	900	8 Jun 1994	10/4	21/5
Class 4	28 Apr 1995	578	NA	NA	NA

NOTE: Class 1 and Class 2 solicitations were open 90 days for proposal preparation and Class 3 was open 98 days. One Class 2 proposal was withdrawn after it was submitted. Class 4 was canceled by DOE in August 1995, in response to preliminary actions taken by Congress. NA = not applicable. Source: Department of Energy.

required detailed financial summaries during the negotiation phase, whereas Class 4 proposals were to require fixed cost contracts and costs determined using price-analysis techniques.

All proposals require one or more teaming agreements in which subcontractors outline the terms of their partnership with the main contractor.

Project Selection

The project selection method for Classes 1, 2, and 3 was similar to the Source Evaluation Board model developed for clean coal projects with funding in excess of $25,000. Principal concerns in that program are in the areas of technical evaluation, confidentiality, and conflict of interest. Fairness has to be assured and demonstrable because authors of unsuccessful proposals typically challenge the evaluations.

Reservoir Class Program evaluation teams have been variously composed of geologists, petroleum engineers, environmental specialists, chemists, geophysicists, and policy analysts. Evaluation teams for Class 1 and 2 proposals were made up of DOE, U.S. Geological Survey, and Minerals Management Service personnel. Class 3 evaluation teams were composed of DOE and BDM-Oklahoma personnel. Each team reported to a Source Evaluation Board chairperson who was the contact person for nongovernmental employees.

Each proposal was reviewed in a four-step process. Step one ascertained whether the proposal met basic qualification requirements. Step two, the preliminary review, determined whether the proposal was consistent with program objectives and contained enough information to undergo comprehensive review. In step three, the comprehensive review, each proposal was scored (Excellent, Good, Fair, or Poor) in six categories: (1) technical and project management approach; (2) evidence of technical readiness; (3) technology transfer; (4) relevance of project; (5) environmental, health, and safety aspects; and, (6) funding plan, financial capability, and commitment. Scores were weighted differently in various classes and in near-term versus mid-term projects. In all cases, technical criteria received the highest weighting. Cost was considered, but not point scored. The selection process occurred at a single site over a three- to four-week period. During this time, review teams spend 100 percent of their time performing this task. Although the process is tedious, DOE feels it is effective.

The fourth step in proposal selection involved a Source Selection Official who made the final selection of projects from among all proposals that were highly ranked and met program objectives. In making the final decision, the Source Selection Official also considered factors such as technical and geographic diversity, and type and size of the proposing organization. Applicants were informed in advance that these factors would be considered.

In response to concerns about the solicitation, review, selection, and contracting processes that arose during the Class 1 and 2 selection process, DOE selected BDM Oklahoma to assist in the Class 3 selection process. DOE planned to have BDM-Oklahoma handle the entire process for Class 4. Although the Class 4 program was discontinued before proposals were received, it is instructive to review some of BDM's plans to streamline and simplify the selection process for the Class 4 proposals. BDM first organized a pre-proposal conference to clarify the RFP and answer questions from potential contractors. BDM planned to assemble an evaluation team of 10 to 12 individuals from among BDM employees. This team would have been given two months to evaluate technical, business, past performance, and cost criteria. Technical criteria would have been given the greatest weight, and proposals would have been rated as exceptional, acceptable, marginal, or unacceptable. BDM planned to use price-analysis techniques to determine standard prices for proposed expenditures in order to reduce the burden of detailed financial statements from the contractors. They anticipated firm fixed-price contracts rather than reimbursements now used by DOE.

Contracting Process

The length of contract negotiation has been a contentious issue for some of the Class 1, 2, and 3 projects. Figure 3.1 shows the length of time between the announcement of an award and the signing of a contract. Lengthy contract negotiations were in some cases caused by DOE and in others caused by individual contractors, but both parties were responsible for extended delays in many specific projects.

The post-selection/pre-award process involves fact-finding and negotiation. During the fact-finding stage, DOE performs a comprehensive review of the proposal by functional area. Following this review, a fact-finding letter is issued to the potential contractor with a response expected in 30 days. The participant must then prepare a detailed cost estimate for the project for DOE to audit. The entire fact-finding stage generally takes several months. After the audit has been completed, DOE is able to authorize pre-award costs, allowing the project to begin.

The negotiation stage involves subcontracts to third parties, joint ventures, and/or partner agreements. Depending on the complexity of the proposal, this stage can also take several months. A pre-negotiation plan, negotiation, and a post-negotiation summary are required. The form of award that follows is a Cooperative Agreement. DOE payment begins at this point, although payments can be retroactive to the date of the pre-grant authorization.

For Class 4, BDM-Oklahoma planned to implement a simplified contract-

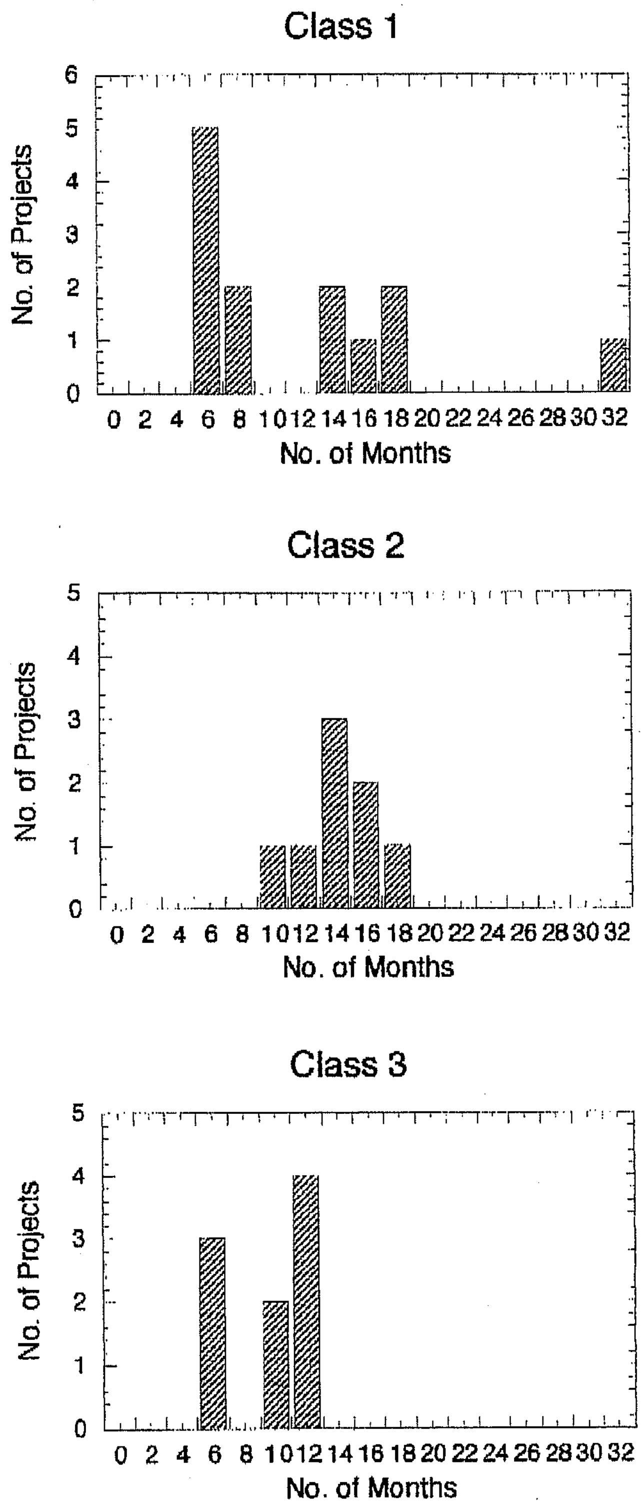


FIGURE 3.1 Contracting process: length of time from award announcement to contract signing. Source: Unpublished data provided by DOE.

ing process. Contracts were to be firm, fixed-price agreements with a minimum 50 percent cost share. Costs were to be determined using price-analysis techniques, which would have reduced the detailed cost estimates required from contractors in the past. Some of the negotiation steps were to be eliminated by having certain issues addressed at the pre-proposal conference. Award would be made without discussions whenever possible. The objective of these intended changes was to reduce the length of the contracting period to two to five months. Due to the cancellation of the Class 4 solicitation, however, the overall effect of these proposed changes is uncertain.

MONITORING AND REVIEW OF PROJECTS, PROGRESS, AND RESULTS

Objectives

Because the projects are cost shared, it is DOE's view that review and monitoring of the project are a joint industry-DOE responsibility. The DOE's approach is to allow the industry, university, or state survey participant to manage the day-to-day operation of projects, whereas DOE's main function is to monitor the project to assure that program goals are met and government funds are used properly.

Process

The DOE review process consists of review and approval of the quarterly progress reports, milestone reports, cost reports and invoices, and annual and final reports. Site visits are occasionally conducted, and DOE participates in project team and industrial consortia meetings. This review is conducted by the contracting officer or his/her technical representative. In addition, DOE requires the review and approval of any change in the statement of work. Three criteria must be met for the approval of a change in the contract: (1) the revision complies with the scope of work; (2) the revision contributes to the program objectives; and (3) the cost is no more than the original proposal.

For each project, there is also a distinct phase-1/phase-2 decision point when DOE and the contractor meet to evaluate the status of the project before entering the field demonstration phase. To date, several projects, including American Oil Recovery/Mattoon Oil Field and Anderman/Smith Operating Company/Black Warrior Basin, have been canceled for a variety of reasons.

Examples of significant changes the DOE has approved include:

Lomax Exploration Co., Uinta Basin Waterflood: DOE approved the use of an alternate source for the injection water, and the delay in drilling a well until unexpected nearby well performance had been evaluated.

Fina Oil and Chemical Co., Integrated reservoir management for optimizing infill drilling: Crosswell seismic tomography has been deleted because of expense and mechanical problems, and no alternative has been found. The rest of the project is proceeding without the data from tomography. The DOE funding has been adjusted to reflect this.

University of Tulsa, Application of horizontal wells to improve a waterflood performance: The drilling of a horizontal injection well has been deleted due to unacceptable economic projections and targeted recompletions are being used instead. DOE feels that the project still complies with the primary objective of comparing waterflood optimization using state-of-the-art technology and conventional technology.

BDM has not formalized their progress monitoring and review process, but at this time it is anticipated to be similar to that of DOE.

EVALUATION OF RESULTS OF PROJECTS BY DOE

The evaluation of the technical results by DOE is performed by the contracting officer and/or the contracting officer technical representatives (COTR). There is no additional review, even within the DOE. Although this is common practice for many federal and private funding agencies, the Reservoir Class Program is significantly different from most federal programs due to the length of the project involved. For example, in some projects the length of time from proposal submission and project selection to the end of the project will exceed eight years. Due to the significant changes in technology and economic conditions that are possible over such a length of time, it is important that Reservoir Class Program projects be evaluated on a technical basis throughout their duration.

QUALIFICATIONS AND CREDIBILITY OF DECISION MAKERS

Most of the internal DOE/BDM reviewers appear to have the required education to effectively evaluate proposals. It is not known, however, whether they have the necessary industrial experience or are up-to-date with the current technology because a number of reviewers have not been active participants in professional society meetings and workshops that play an important role in the petroleum industry. As a result, the research and industry communities are unfamiliar with the DOE staff who reviewed the proposals and have little faith in the project selection process. Any mistakes in project selection, whether real or perceived, only work to enhance this impression. To put it simply, a number of DOE decision makers have not been an active part of the petroleum industry through participation in the normal professional society meetings and workshops. Thus, an image of directing the program from a distance is projected, despite the fact that monitoring of the projects is left to the industry. It certainly does not help that in the Reservoir Class Program, factors other than technical merits are acknowledged to be considered as heavily as the technical merits of the projects. In fact, it appears that some of the projects may have been awarded primarily on the basis of geographic location and political considerations. While this is certainly a reality of the funding process, some of these projects do not appear to meet a minimal technical standard.

FINDINGS AND RECOMMENDATIONS

Finding

The likelihood of having the best possible set of projects is enhanced if there is a large number of proposals from a broad range of organizations. The panel feels the quantity of proposals submitted is not adequate to ensure the number of high quality projects necessary to satisfy the various goals of the Reservoir Class Program.

Recommendation

DOE should take measures to increase the number of proposals submitted. Two possible mechanisms are suggested: (1) open future proposal solicitations to meritorious projects from all previously funded classes, as well as the class currently being solicited; and (2) simplify the procedure used in proposal preparation. Changes in the proposal preparation procedure planned for Class 4, such as a maximum proposal length and fixed cost contracts to reduce negotiation time, should be implemented for future DOE programs. In addition, DOE should ensure that the technical documentation that accompanies any future program solicitation includes current information about depositional models of the targeted reservoir class.

Finding

An important feature of the Reservoir Class program is that the contract period is divided into two phases: an initial phase dominated by reservoir characterization, followed by a second phase of field demonstration if the project is deemed feasible. This provides both the contractor and DOE the option to terminate a project that is proceeding unsatisfactorily.

Recommendation

The panel recommends that DOE not be reticent in exercising the option to terminate a project after Phase 1, where appropriate. In particular, the DOE should consider this option for projects in which there was a major change in the technology employed.

Finding

The cost-sharing arrangement adopted for the reservoir class program has resulted in the successful application of new technologies to marginal oil fields in the United States. The 50 percent contribution from DOE has resulted in innovative projects that might not have been attempted otherwise and the financial commitment from industry insures financial accountability from industry.

Recommendation

We recommend that DOE continue the cost-sharing aspect of the Reservoir Class Program in future programs.

Finding

The current anonymous internal DOE/BDM review has led to uncertainty and mistrust among applicants about the project selection process.

Recommendation

DOE should implement a system of external technical reviews in the proposal evaluation phase of the Reservoir Class Program. The review process should include experts from outside the federal government and the contracting companies.

Finding

The panel saw little evidence that the present DOE review process, both during the projects and after completion, is producing mid-course modifications that are normally called for in projects of this type. The lack of an external project review process contributes to this shortcoming

Recommendation

DOE should implement a system of external technical reviews for monitoring the technical status of all Reservoir Class Program projects on an annual basis. In addition, upon completion of a project, thorough technical review by external experts should be carried out prior to the distribution of project results.

4

Program Effectiveness and Recommendations for Improvement

This section contains, in summary form, the panel's response to the two questions posed to it by the Department of Energy. The first question, "Has the Reservoir Class Program proven effective in demonstrating the application of new and existing technologies to prolong production in marginal fields?" is addressed in the following two sections of this chapter. The second question, "How should the program be modified to improve its effectiveness in meeting this goal?" is dealt with in the final section.

ELEMENTS NECESSARY FOR SUCCESS

By expanding reserves, effective recovery techniques can greatly prolong the productive life of marginal reservoirs. Applying technologies that are compatible with the reservoir architecture, trap conditions, oil properties, and drive mechanisms will result in the desired increased production and prolonged reservoir life. Whether or not such technologies are applied in a given field depends on the economics of their application and acceptance of these technologies as effective by the producer community. Success of the Reservoir Class Program therefore depends on two factors: (1) demonstrating economically successful technologies that have broad application for improving oil recovery within and among reservoir classes, and (2) conducting successful technology transfer that reaches a wide range of operators who produce from marginal fields. Success also depends on favorable economic conditions and a confidence that such conditions will persist through the intended period of technology utilization. The program intends to demonstrate technologies that can be applied under present oil prices. It is worthy to note that some project operators who briefed the committee stated that their project would not have been accomplished without the 50 percent cost-sharing from the DOE. All of the operators stated their projects certainly would have been smaller in scope without DOE funding, and they would not have had an element of technology transfer.

EFFECTIVENESS OF THE PROGRAM

The Reservoir Class Program has been successful in encouraging the application of a broad spectrum of conventional and advanced technologies for increasing oil recovery from existing fields. Some of the projects, as cited in the report, are already showing promising results. In most projects, however, it is too early to determine whether the application of these technologies will result in increased oil production. The most effective features of the program are the large number and variety of participants, the geographic diversity of the projects, and the requirements for a 50 percent cost-sharing arrangement. The cost-sharing arrangement ensures a commitment to obtaining results that lead to the practical outcomes that benefit both industry and the nation, namely increased domestic oil production. The main weaknesses of the program are in the areas of project review and technology transfer, and these issues are addressed in the recommendations of the report and summarized in the following section.

The greatest uncertainties regarding the effectiveness of the program in prolonging the production from marginal fields are the success of individual projects, technology transfer, and the price of oil. If the technologies demonstrated are successful, if the technology transfer process is effective, and if oil prices remain at or above their present levels, then the program will likely contribute significantly to enhancing domestic production by reducing the rate of well and field abandonment thus extending the life of marginal fields.

KEY RECOMMENDATIONS

Reservoir Class as Basis for Organization

Continue using the reservoir class concept as a basis for organizing the Reservoir Class Program. Future proposal solicitations, however, should be open to meritorious projects from previously funded reservoir classes as well as the class currently being solicited.

Peer Review and Quality Control

Establish a more complete review process that features the use of external technical experts (peer reviewers) to conduct:

(1) Proposal evaluation
(2) Project monitoring, including
  (a) evaluating the completeness and appropriateness of reservoir characterization
  (b) assuring correct application of technology
(3) Review of project results prior to technology transfer
(4) Evaluation of results after project completion

Technology Transfer

The ultimate responsibility for transferring the results of all field demonstration projects should be accepted by DOE. Furthermore, DOE should design and implement a new and innovative comprehensive plan for transferring technology for the Class Reservoir Program.

A

List of Presentations to the Panel

MEETINGS OF THE PANEL ON THE REVIEW OF THE OIL RECOVERY DEMONSTRATION PROGRAM OF THE DEPARTMENT OF ENERGY

Edith Allison, Department of Energy, Bartlesville Project Office, Oklahoma
Overview of the reservoir class oil recovery program: who is doing what where?
DOE review of proposals

M. Lee Allison, Utah Geological Survey
Developing improved completion techniques in the Bluebell Field plus aspects of Class II and III projects

Roger N. Anderson, Lamont-Doherty Earth Observatory, New York; Lana Billeaud, Lamont-Doherty Earth Observatory, New York; Larry Cathles, Cornell University, New York; and Peter Flemings, Pennsylvania State University
Dynamic enhanced recovery technologies

Sami Bou-Mikael, Texaco E&P, Inc., New Orleans
Post waterflood CO_2 miscible flood in light oil fluvial dominated deltaic reservoirs

Thomas D. Coffman, Cielo Energy Corporation, Texas
Perceptions and experience of an independent operator

William L. Fisher, University of Texas at Austin
Use of the "reservoir class" as an organizing concept

Travis Gillham and Reza Fassihi, Amoco Production Company, Houston; and Edward Turek, Amoco Exploration and Production Technology Group, Tulsa
West Hackberry tertiary project

Don W. Green, University of Kansas
Improvement of oil recovery in fluvial dominated deltaic reservoirs in Kansas - Class I project, and improved oil recovery in Lower Meramecian (Mississippian) carbonate reservoirs of Kansas - near term - Class II project

J. C. (Chris) Hall, Chairman, Petroleum Technology Transfer Council, Washington, D.C.
Technology transfer activities and plans

George Hirasaki, Dept. of Chemical Engineering, Rice University, Texas
The oil recovery program in Norway

Mohan G. Kelkar, University of Tulsa
Integrated approach towards the application of horizontal wells to improve waterflooding performance

John Lomax, Lomax Exploration Company, Laguna Beach, California; and Miland Deo, University of Utah
Green River Formation water flood demonstration project

Kenneth Luff, Luff Exploration Company, Colorado
Improved recovery demonstration for Williston Basin carbonates

Charles Mankin, Oklahoma Geological Survey
Identification and evaluation of fluvial-dominated deltaic reservoirs

Todd Martinez, Michael Collins, and Lance Cole, BDM-Oklahoma
BDM management of Class 4 programs and management of technology transfer

Lee McRae and Mark Holtz, Bureau of Economic Geology, University of Texas at Austin
Revitalizing mature oil plays in Frio reservoirs of South Texas

Keith Miles, Pittsburgh Energy Technology Center, DOE
Contract awards/negotiations

P. K. Pande, Fina Oil and Chemical Company, Texas
Application of integrated reservoir management and reservoir characterization to optimize infill drilling

Reginal W. Spiller, Deputy Assistant Secretary for Gas and Petroleum Technologies, Department of Energy, Washington, D.C.
Overview of the program, DOE Office of Fossil Energy

James O. Stephens, Hughes Eastern Corporation, Mississippi
The utilization of the microflora indigenous to and present in oil-bearing formations to selectively plug the more porous zones thereby increasing oil recovery during waterflooding

Archie Taylor, OXY USA, Midland, Texas; Jim Justice, Advanced Research Technology; and Scott Hickman, Hickman & Associates, Houston, Texas
Application of reservoir characterization and advanced technology to improve recovery and economics in lower quality shallow shelf San Andres reservoirs - Class II

Noel Tyler, Director, Bureau of Economic Geology, University of Texas at Austin
Background on definition of reservoir classes

Don R. Wier and Larry Hallenbeck, Phillips Petroleum Co., Odessa, Texas
Design and implementation of a CO_2 flood utilizing advanced reservoir characterization and horizontal injection wells in a shallow shelf carbonate approaching waterflood depletion - Class II

James R. Wood, University of South Florida and Michigan Technical University
Recovery of bypassed oil in the Dundee formation using horizontal drains

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February 28, 1995

Mr. Reginal W. Spiller
Deputy Assistant Secretary for Gas and Petroleum Technologies
U.S. Department of Energy
1000 Independence Ave., S.W.
Washington, DC 20585

Dear Mr. Spiller:

The National Research Council formed the *Panel on the Review of the Oil Recovery Demonstration Program of the Department of Energy* to respond to your request to assess the effectiveness of the Reservoir Class Field Demonstration Program[1] and to recommend improvements. The panel has been charged with addressing the following two questions:

1. Has the Field Demonstration Program proven effective in demonstrating the application of new and existing technologies to prolong production in marginal fields?

2. How should this program be modified to improve its effectiveness in meeting this goal?

This letter report presents the panel's findings on the first question concerning the effectiveness of the program. This report reflects a consensus of the panel and is a formal, fully reviewed report of the National Research Council. The second question will be addressed in the panel's final report, which we hope to complete in November 1995.

Members of the panel were selected to provide perspective and expertise in the areas of petroleum geology, geophysics, petroleum and reservoir engineering, and energy policy. A list of panel members is given at the end of this letter report.

The panel met for two days in December 1994 and for three days in January 1995 (Appendix A) in the course of developing this report. During these meetings, the panel received progress reports from contractors on 12 DOE-supported demonstration projects (see Appendix B). The contractors also provided the panel with copies of publications and reports and answered questions. In addition, DOE representatives provided briefings on the program, copies of recent quarterly project reports, and other program documents. The panel also read

[1] Hereafter referred to as the *Field Demonstration Program*.

and discussed two recent National Research Council reports regarding oil production technologies.[2] The panel's findings are drawn from these presentations, materials, and discussions.

BACKGROUND ON THE FIELD DEMONSTRATION PROGRAM

Maintaining a viable domestic supply of oil and natural gas is important to the United States for both economic and strategic reasons. Income generated by the domestic oil and gas industry fuels the economy, creates jobs, and generates federal revenues from bonuses, leases, and royalties from exploration and production on offshore and onshore federal lands.[3] Domestic production also decreases U.S. dependence on imported petroleum products, which currently account for slightly more than 50% of total U.S. oil demand[4] and about 31% of the merchandise trade deficit.[5] Further decreases in domestic production will exacerbate the trade deficit problem and increase foreign dependence for a resource that provides about 40%[6] of the total U.S. energy supply.

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[2] The reports are *Advanced Exploratory Research Directions for Extraction and Processing of Oil and Gas*, Committee on Applied Research Needs Related to Extraction and Processing of Oil and Gas, Board on Chemical Sciences and Technology, Commission on Physical Sciences, Mathematics, and Applications, National Research Council, 1993, and *Letter Report to Thomas C. Wesson, Director, Bartlesville Project Office, U.S. Department of Energy, on the Accelerated Oil Program Plan (Reservoir Characterization and Production Area), A Report to Congress*, Committee on Earth Resources, Board on Earth Sciences and Resources, Commission on Geosciences, Environment, and Resources, National Research Council, 15 December 1993.

[3] In 1993, revenues to the U.S. Treasury from oil and gas bonuses, leases, and royalties totaled about $3.5 billion (Minerals Management Service, *Mineral Revenues 1993*).

[4] In 1994, domestic field production of crude oil averaged 6.63 million barrels per day (bpd); net imports (i.e., imports minus exports) of crude oil averaged 6.92 million bpd (Energy Information Administration, *Monthly Energy Review, January 1995*).

[5] For 1994, the U.S. merchandise trade deficit totaled $168.4 billion. Imports of petroleum and petroleum products accounted for $51.5 billion of this total (U.S. Department of Commerce, *Survey of Current Business*, January 1995).

[6] In 1993, the latest year for which complete data are available, U.S. energy consumption totaled 83.89 Quadrillion BTU (Quads), of which 33.84 Quads were supplied by petroleum—crude oil, lease

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The Field Demonstration Program was initiated in 1992 as part of a broad DOE effort to counter the continuing drop in domestic oil production[7] and to slow the abandonment, because of unfavorable economics, of wells in "mature" fields that typically still contain 60% to 70% of the original oil in place.[8] DOE recognized that as major companies reduced their efforts in domestic onshore operations and shifted their emphasis to frontier areas (Alaska and offshore) and international operations, the production of oil from mature fields in the lower 48 states and the continental shelf of the United States would shift to smaller companies and independent producers, which generally lack the internal technical expertise and capital resources to undertake technically or economically risky projects. The objective of the Field Demonstration Program is to encourage the application of new technologies and more effective use of existing technologies to prolong production in marginal fields and to encourage the adoption of these technologies by the small companies, independent producers, and major companies that will comprise the domestic energy industry of the future. DOE anticipates that this program will allow industry to add about 1.5 billion barrels to domestic production by the year 2020.[9]

The Field Demonstration Program is organized on the basis of reservoir classes. DOE uses the term *class* to denote a group of reservoirs with a similar depositional history.[10] Depositional history controls the internal variability of porosity and permeability—and thus the flow of hydrocarbons—in the reservoir. DOE believes that by grouping reservoirs into

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condensate, and natural gas plant liquids (Energy Information Administration, *Monthly Energy Review, January 1995*).

[7] U.S. domestic field production of crude oil declined from 8.60 million barrels per day (bpd) in 1980 to 6.63 million bpd in 1994 (Energy Information Administration, *Monthly Energy Review, January 1995*).

[8] In 1993, for example, there were approximately 452,000 stripper wells (wells that produce less than 10 barrels of oil per day) in the United States which accounted for about 14% of domestic production of crude oil. In the same year, about 17,000 (3.7%) stripper wells were abandoned (Interstate Oil and Gas Compact Commission, *Marginal Oil: Fuel for Economic Growth*, 1994), presumably due to unfavorable economics.

[9] U.S. Department of Energy (Bartlesville Project Office), 1994, *Oil Program Implementation Plan FY 1996-2000*, p. 107.

[10] See, for example, U.S. Department of Energy, *Program Opportunity Notice (PON), Number DE-PS22-94BC14972, Class III Oil Program—Near Term Activities*, p. 1-1.

classes this internal variability can be identified and exploited using improved production strategies to increase the ultimate recovery of hydrocarbons. Twenty-two reservoir classes are recognized by DOE, 16 clastic (sandstone) and six carbonate (limestone and dolomite) classes. Classes 1, 2, and 3 (Fluvial Dominated Delta, Shallow Shelf Carbonate, and Slope and Basin Clastic Reservoirs, respectively) are thought to include the reservoir types with substantial resources from which oil recovery has been least efficient. These classes were selected for demonstration projects during the first four years of the program.

Implementation of the program began in fiscal year 1992 (FY92) with the selection of 14 Class 1 (Fluvial Dominated Deltaic Reservoirs) projects (see Appendix B for a list of Class 1 and Class 2 projects). In FY93, 10 Class 2 (Shallow Shelf Carbonate Reservoirs) projects were selected for support. Nine Class 3 (Slope and Basin Clastic Reservoirs) projects were selected in FY95; awards for these projects are currently under negotiation.

Projects require a minimum 50% cost share by industry and its partners and are organized into two groups: *near-term*, which focus on applying currently available but underutilized technologies, and *mid-term*, which focus on advanced technologies. Both groups of projects include a reservoir characterization element and an emphasis on technology transfer.

PROGRAM COMPONENTS

Reservoir Class

Organization of the Field Demonstration Program on the basis of reservoir class is based on observations that oil recovery responses of reservoirs are closely related to their geologic origins.[11] The geologic origin of a reservoir controls or strongly influences its structure, geometry, and other physical and chemical characteristics, which in turn control oil production performance. Therefore, DOE believes that successful demonstrations of new or existing technologies on a given reservoir in a class should be applicable to other reservoir systems in the same class.

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[11] See, for example, N. Tyler and R.J. Finley, 1991, Architectural controls on the recovery of hydrocarbons from sandstone reservoirs, in A.D. Miall and N. Tyler, eds., *The Three-Dimensional Facies Architecture of Terrigenous Clastic Sediments and its Implication for Hydrocarbon Discovery and Recovery*, SEPM Society for Sedimentary Geology, Tulsa, Okla., Concepts in Sedimentology and Paleontology, vol. 3, pp. 1-5.

The panel plans to examine and comment on the usefulness of reservoir class as the organizing precept for this DOE program in its final report.

Demonstration of New or Existing Technologies

The decline in oil prices and the reduction of domestic operations by the major oil companies have combined to decrease the application of both new and existing recovery technologies. The abandonment of oil fields, many of which still contain significant amounts of potentially recoverable oil, will preclude later access to these resources owing to the high costs of leasing, drilling, and production. By demonstrating a wide variety of new and existing technologies, the Field Demonstration Program seeks to develop the technical and economic experience necessary to encourage adoption of these technologies by independent operators, small companies, and major companies. Without the economic boost and risk sharing provided by program funding, DOE believes that, under current and projected oil prices, demonstration of these technologies is unlikely to occur in a time frame that can substantially reduce the rate of abandonment of fields containing significant amounts of recoverable oil.

Technology Transfer

For the Field Demonstration Program to achieve its stated objectives, the technologies developed in these demonstration projects must be transferred to the entire industry. The purpose of technology transfer is to motivate the broader application of cost-effective technologies by disseminating the knowledge, data, and techniques for solving production problems. DOE has made technology transfer a key component of each of the Field Demonstration Program projects.

The primary goals of technology transfer are (1) to involve a broad base of participants in projects, including scientists and engineers from different agencies or organizations (industrial companies of all sizes, consultants, universities, state surveys, and other federal government programs), and (2) to have periodic, user-friendly reviews, demonstrations, and updates to all interested industry entities, regulators, and legislators.

PROGRAM EFFECTIVENESS: PRESENT AND POTENTIAL

Demonstrating New and Existing Technologies

There is a wide range of technologies being utilized in the projects examined by the panel, including both conventional (existing) and advanced (new) technologies. Program projects targeted mobile oil and (or) immobile oil.[12] Additional mobile oil can be recovered from known fields using properly applied conventional techniques to identify and produce from untapped or uncontacted portions of compartments in the reservoir. Immobile oil can be recovered using techniques that alter the chemistry of the reservoir fluids or the interactions between these fluids and the host rock.

A key technical component in most of the projects examined by the committee is reservoir characterization, that is, determination of the shape, size, internal structure, and other physical and chemical properties of the reservoir using invasive and noninvasive techniques. The projects examined by the panel employed a wide range of conventional and advanced technologies to characterize reservoirs. Conventional techniques include core and cuttings analysis, facies mapping, comparative outcrop studies, and conventional well-log analysis. Examples of advanced technologies include 3D and 4D[13] seismic analysis, tomography, advanced logging techniques (e.g., nuclear magnetic resonance logging and borehole imaging), sequence-stratigraphic modeling of flow units, and 3D geologic modeling.

The projects examined by the panel also employed a wide range of conventional and advanced technologies for drilling, completion, and production. Examples of advanced technologies employed by the projects include the use of horizontal wells for injection and production, CO_2 flooding, and air combustion/gravity drainage.

Although many of the projects examined by the panel employed conventional technologies, these technologies were new to the geographic areas in which they were being applied, as illustrated by the following examples:

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[12] Mobile oil is that oil which can be moved to the well under the force of gravity, the natural pressure of the reservoir, or with the aid of conventional pressure maintenance or displacement technologies (e.g., water flooding). Immobile oil is that oil held in the rock pores by surface tension and capillary forces and is usually produced using chemical or thermal methods.

[13] Three spatial dimensions and the fourth dimension of time.

• Uinta Basin (Appendix B, Project #8). Lomax Exploration Company has demonstrated that water injection can be used to increase production and prolong the life of marginal fields in the Uinta Basin. The Lomax program is projected to recover 20% of the original oil in place, versus about 4% for primary recovery without water flooding. Before this project was initiated, most operators in the area did not believe that water flooding would be economically successful. However, this project has served as a model for five other water floods in the area.

• N.E. Savonburg Field, Kansas (Appendix B, Project #11). The University of Kansas and James Russell Petroleum Company introduced reservoir simulation technology and water treatment processes for water flooding to improve production from a Pennsylvanian reservoir in eastern Kansas. The technology is expected to find application to other reservoirs in this region.

Several of the projects reviewed by the panel also utilized advanced technologies, for example:

• West Hackberry Field (Appendix B, Project #2). Amoco is utilizing *double displacement technology* for tertiary production from the West Hackberry Field. This process utilizes air injection near the top of a water-invaded oil column. This injection causes combustion of a small amount of the oil in the reservoir, thereby producing flue gases and steam to mobilize the residual oil, which is recovered by gravity drainage.

• Eugene Island Block 330 Field (Appendix B, Project #5). This Columbia University project has developed an improved time-dependent seismic imaging (4D seismic imaging; see footnote 13) methodology that can be used to monitor changes to the reservoirs during production.

In the panel's judgment, the projects examined employ an appropriate range of both conventional and advanced technologies in the areas of reservoir characterization, drilling, well completion, and production. Although different projects use different subsets of the available technologies, the panel believes that the technologies are used appropriately and are representative of the range of conventional and advanced technologies employed by industry.

Prolonging the Lives of Marginal Fields

A number of the technologies utilized by projects in this DOE program have the potential to prolong the lives of marginal oil fields by increasing the rate of production and (or) the total amount of recovered oil. Examples of such technologies are indicated in Appendix C. Based on reviews of 12 of the 24 Class 1 and Class 2 projects in this program (Appendix B), the panel judges that many of the projects will eventually be successful in demonstrating improved oil production. However, most projects are at an early stage of development and have not had sufficient time to demonstrate commercial success, except for the Uinta Basin project (Appendix B, Project #8), which was briefly described in the previous section. Other projects that are likely to be successful in demonstrating prolonged production include the following:

• Bluebell Field (Appendix B, Project #14). Reservoir modeling by the Utah Geological Survey (UGS) has demonstrated that much of the production at Bluebell Field is from fractures, and the UGS showed that fractures can be identified using advanced logging tools (i.e., formation microscanning imaging logs). This project will likely lead to changes in completion practices to reduce completions in unproductive zones and thereby to increase production and prolong the life of this field.

• Welch and South Cowden Fields (Appendix B, Projects 20 and 21). CO_2 floods are important for prolonging production in many carbonate reservoirs. However, the economics of CO_2 flooding are poor for many fields. DOE-supported projects in the Welch and South Cowden Fields show promise for prolonging production using more effective CO_2 flooding technologies. In the Welch Field, the OXY consortium is utilizing cyclic CO_2 flooding to increase production and lower cost. In the South Cowden Field, the Phillips consortium is attempting to demonstrate CO_2 injection via horizontal wells to significantly decrease the cost of CO_2 flooding.

• West Hackberry Field (Appendix B, Project #2). The Amoco air injection program at West Hackberry Field has promise of recovering residual oil in steeply dipping formations commonly associated with salt domes. If successful, this technique could find widespread application in the Gulf Coast region.

The panel judges the likelihood of future success of these technologies in prolonging the life of marginal fields to be high. This judgment is based both on examination of the 12 projects indicated in Appendix B and on previous studies which show that the types of approaches and technologies being applied here have been used elsewhere to increase oil production in marginal fields.[14]

Technology Transfer

The primary goal of technology transfer is to spread the use of technologies and approaches that are developed and applied during the demonstration projects to other fields within the same plays,[15] more broadly to fields within the same classes of reservoirs, and to fields in other classes where applicable. Various methods of accomplishing this goal are employed by the projects.

Collectively, the funded projects are using conventional procedures in transferring project information to the other potential users. These include the following:

• publications, including refereed papers, proceedings of professional meetings, trade journals, newsletters, and the popular press;

• databases (printed and electronic formats), technical progress reports, electronic bulletin boards, open-file reports, and videos;

• technical meeting presentations, including displays, oral presentations, and poster papers;

• workshops, project site visits, short courses, and special topical meetings (e.g., geologic reservoir characterization, reservoir engineering, seismic interpretation); and

[14] For example, the Bureau of Economic Geology (BEG), University of Texas at Austin has demonstrated that integrated geological and engineering characterization can lead to significant increases in oil production from marginal fields. See *Integrated Characterization of Permian Basin Reservoirs, University Lands, West Texas*, BEG Report of Investigations No. 203, 136 pp., 1991, and *Analysis of Production Response to Advanced Characterization of University Lands Reservoirs*, BEG, 1992, 16 pp.

[15] A play is a set of oil and gas accumulations that share similar geologic, geographic, and temporal properties, including source rocks, migration pathways, trapping mechanisms, and hydrocarbon types.

Mr. Reginal W. Spiller
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• personal commitments by investigators to informally communicate results to colleagues.

Each of the projects reviewed by the panel contains a technology transfer plan, and the contractors appear to recognize the importance of the plan to the overall success of their projects. However, there is considerable variation in the procedures being used in each project. Because the projects are at an early stage of development, the overall effectiveness of technology transfer is difficult to evaluate. At present, however, these efforts appear to be satisfactory.

In the panel's judgment, the effectiveness of technology transfer could be improved by the organization of regional workshops implemented by DOE. At such workshops, the results of individual demonstration projects would be presented to industry active in the same producing basin or in other similar basins nationwide. The panel plans to investigate and report on possible mechanisms for such exchange in its final report.

FINDINGS AND FUTURE WORK

Based on information reviewed to date, it is the judgment of the panel that the DOE Field Demonstration Program is proving effective in demonstrating the application of new and existing technologies to prolong the lives of marginal fields. However, it is too early to determine whether this program will be ultimately successful in reducing the rate of abandonment of marginal wells or slowing the decline of domestic oil production. The panel will attempt to address the likelihood of success in its final report.

In the panel's view, the emphasis on reservoir characterization and technology transfer is appropriate and needs continuing attention by DOE to ensure that effective levels of both are maintained throughout the program.

The effectiveness of the program is enhanced by the large number and variety of participants, the geographic diversity of the projects, and the requirements for a 50% match, which ensures a commitment to obtaining results that lead to the practical outcomes that benefit both industry and the nation, namely increased domestic oil production. The panel has determined that review of additional projects is necessary to obtain a more representative sample of the program and will accomplish this in its future meetings.

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On the basis of discussions with DOE managers and contractors during the first two meetings, the panel has determined that four topics need focused attention as it continues its work to address the second charge of the study: (1) proposal review and project selection process, (2) length of the contracting process, (3) reservoir class as the organizing precept for the program, and (4) effectiveness of the technology transfer process. Discussions and recommendations regarding these topics will be included among those presented in the final report.

Sincerely,

Charles G. Groat, Chair
Panel on the Review of the Oil Recovery Demonstration Program of the Department of Energy

Other Members of the Panel:

Arthur Cheng, Massachusetts Institute of Technology
James A. Drahovzal, Kentucky Geological Survey
George J. Hirasaki, Rice University
Neil F. Hurley, Marathon Oil Company
Randi S. Martinsen, University of Wyoming
Charles S. Matthews, retired
Arthur Saller, Unocal Corporation
Robert J. Weimer, Colorado School of Mines
W. Frank West, PACO Minerals, Dallas

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APPENDIX A

List of Presenters

Panel on the Review of the Oil Recovery Demonstration Program of the Department of Energy

Meeting #1: December 13-14, 1994 (Houston, Texas)

Edith Allison, U.S. Department of Energy: *Overview of the Reservoir Class Oil Recovery Program*

Noel Tyler, Bureau of Economic Geology, The University of Texas at Austin: *History of the Reservoir Class Program and the Definition of Classes*

Mark Holtz and Lee McRae, Bureau of Economic Geology, The University of Texas at Austin: *Revitalizing Mature Oil Plays in Frio Reservoirs of South Texas*

Scott Hickman, Hickman and Associates; Archie Taylor, OXY USA; and Jim Justice, Advanced Research Technology: *Application of Reservoir Characterization and Advanced Technology to Improve Recovery and Economics in Lower-Quality Shallow-Shelf San Andres Reservoirs*

Charles Mankin, Oklahoma Geological Survey: *Identification and Evaluation of Fluvial-Dominated Deltaic Reservoirs*

Larry Hallenbeck and Don Wier, Phillips Petroleum Company: *Design and Implementation of a CO_2 Flood Utilizing Advanced Reservoir Characterization and Horizontal Injection Wells in a Shallow-Shelf Carbonate Approaching Waterflood Depletion—Class II*

Sami Bou-Mikael, Texaco E&P: *Post Waterflood CO_2 Miscible Flood in Light Oil Fluvial-Dominated Deltaic Reservoirs*

Travis Gillham, Ed Turek, and Reza Fassihi, Amoco Production Company: *West Hackberry Tertiary Project*

APPENDIX A (continued)

Meeting #2: January 17-19, 1995 (Washington, DC)

Reginal W. Spiller, U.S. Department of Energy: *DOE Perspectives on the Fossil Energy Programs*

Roger Anderson and Lana Billsaud, Lamont Doherty Earth Observatory, Columbia University; Larry Cathles, Cornell University; and Peter B. Flemings, Pennsylvania State University: *Dynamic Enhanced Recovery Technologies*

M. Lee Allison, Utah Geological Survey: *Developing Improved Completion Techniques in the Bluebell Field, Plus Aspects of Class II and III Projects*

John Lomax, Lomax Exploration Company; and Miland D. Deo, University of Utah: *Green River Formation Water Flood Demonstration Project*

Don W. Green, Tony Walton, and Paul Willhite, University of Kansas: *Improvement of Oil Recovery in Fluvial-Dominated Deltaic Reservoirs in Kansas (Class I), and Improved Oil Recovery in Lower Meramecian (Mississippian) Carbonate Reservoirs of Kansas (Near-Term, Class II)*

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APPENDIX B

List of Class 1 and Class 2 Projects

Project Number	Reservoir and (or) Basin Name	Contractor	Reservoir Class
1*	Mattoon Oil Field (Illinois)	American Oil Recovery, Inc.	1
2†	West Hackberry Field (Louisiana)	Amoco Production Company	1
3*	Black Warrior Basin (Alabama)	Anderman/Smith Operating Company	1
4†	Frio Formation (Texas)	Texas Bureau of Economic Geology	1
5‡	Eugene Island Block 330 Field (Gulf of Mexico)	Columbia University	1
6	Sooner-Unit Field (Colorado)	Diversified Operating Corporation	1
7	North Blowhorn Creek Field, Black Warrior Basin (Alabama)	Hughes Eastern Corporation	1
8‡	Green River Formation, Uinta Basin (Utah)	Lomax Exploration Company	1
9	Badger Basin Field (Wyoming)	Sierra Energy Company	1
10†	Port Neches Field (Texas)	Texaco Exploration and Production, Inc.	1
11‡	N.E. Savonburg & Stewart Fields (Kansas)	University of Kansas Center for Research	1
12†	Fluvial-Dominated Deltaic Reservoirs in Oklahoma	Oklahoma Geological Survey	1

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APPENDIX B (continued)

Project Number	Reservoir and (or) Basin Name	Contractor	Reservoir Class
13	Glenn Pool Field (Oklahoma)	University of Tulsa	1
14‡	Bluebell Field, Uinta Basin (Utah)	Utah Geological Survey	1
15	Anadarko Basin (Nebraska)	Sensor (formerly Beard)	2
16	Clearfork Reservoir (Texas)	Fina Oil and Chemical Company	2
17	Foster and South Cowden Fields, Grayburg/San Andres Formations (Texas)	Laguna Petroleum Company	2
18	Williston Basin Carbonates	Luff Exploration Company	2
19	Crystal Field, Dundee Reservoir (Michigan)	Michigan Technological University	2
20†	Welch Field, San Andres Formation (Texas)	Oxy USA, Inc.	2
21†	South Cowden Field, Grayburg/San Andres Formations (Texas)	Phillips Petroleum Company	2
22	Central Vacuum Unit (New Mexico)	Texaco Exploration & Production, Inc.	2
23‡	Schaben and Bindley Fields (Kansas)	University of Kansas Center for Research	2
24‡	Paradox Basin (Utah)	Utah Geological Survey	2

* Project has been terminated.
† Presentations were made to the committee by the contractor at the December 1994 meeting.
‡ Presentations were made to the committee by the contractor at the January 1995 meeting.

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APPENDIX C

Examples of Technologies that Could Prolong the Lives of Marginal Fields

Waterflooding
- Green River Formation, Uinta Basin (Lomax Exploration Company)
- N.E. Savonburg and Stewart Fields (University of Kansas Center for Research)
- Glenn Pool Field (University of Tulsa)

Infill Drilling/Waterflooding
- Sooner-Unit Field (Diversified Operating Corporation)
- Williston Basin Carbonates (Luff Exploration Company)
- Foster and South Cowden Fields (Laguna Petroleum Company)
- Clearfork Reservoir (Fina Oil and Chemical Company)

Well Completion Practices
- Bluebell Field, Uinta Basin (Utah Geological Survey)

Horizontal Wells
- Crystal Field, Dundee Reservoir (Michigan Technological University)
- South Cowden Field (Phillips Petroleum Company)

Biological Treatments
- Black Warrior Basin (Hughes Eastern)
- Green River Formation, Uinta Basin (Lomax Exploration Company)

CO_2 Injection
- Port Neches Field (Texaco Exploration and Production Company)
- West Welch Field (OXY USA, Inc.)
- South Cowden Field (Phillips Petroleum Company)
- Paradox Basin (Utah Geological Survey)
- Central Vacuum Unit (Texaco Exploration and Production Company)

Air Injection
- West Hackberry Field (Amoco Production Company)

C

Reservoir Characterization

Reservoirs range from simple to complex based on their geologic origins. All reservoirs are characterized by some degree of heterogeneity (variability) of properties (porosity, permeability, fluid saturations, etc.) on a variety of scales (Figure C.1). The more complex a reservoir is, the higher its degree of heterogeneity and the more difficult it is to predict the occurrence and producibility of hydrocarbons. Reservoir characterization therefore is necessary in order to understand and predict the occurrence and producibility of hydrocarbons from a reservoir.

Reservoir characterization involves a large component of interpretation. Most producing wells are four to twelve inches in diameter, and most well logs provide constraints on data about rocks six to twelve inches away from the well bore. Therefore, wells provide information about a very small fraction of a reservoir, and hence good interpretation is needed to estimate characteristics of the vast majority of the reservoir located between wells. High-quality reservoir characterization is needed to accurately interpret data from wells and infer the distribution of flow units between wells. Techniques for reservoir characterization include core analysis, wireline log analysis, 3D reflection seismic data, crosswell tomography, vertical seismic profiles (VSPs), transient pressure analysis, tracers, 3D geological modeling, geostatistical modeling of reservoirs, production history matching, fracture analysis, and reservoir fluid analysis (PVT analyses).

Because wells provide information on such a small fraction of the res-

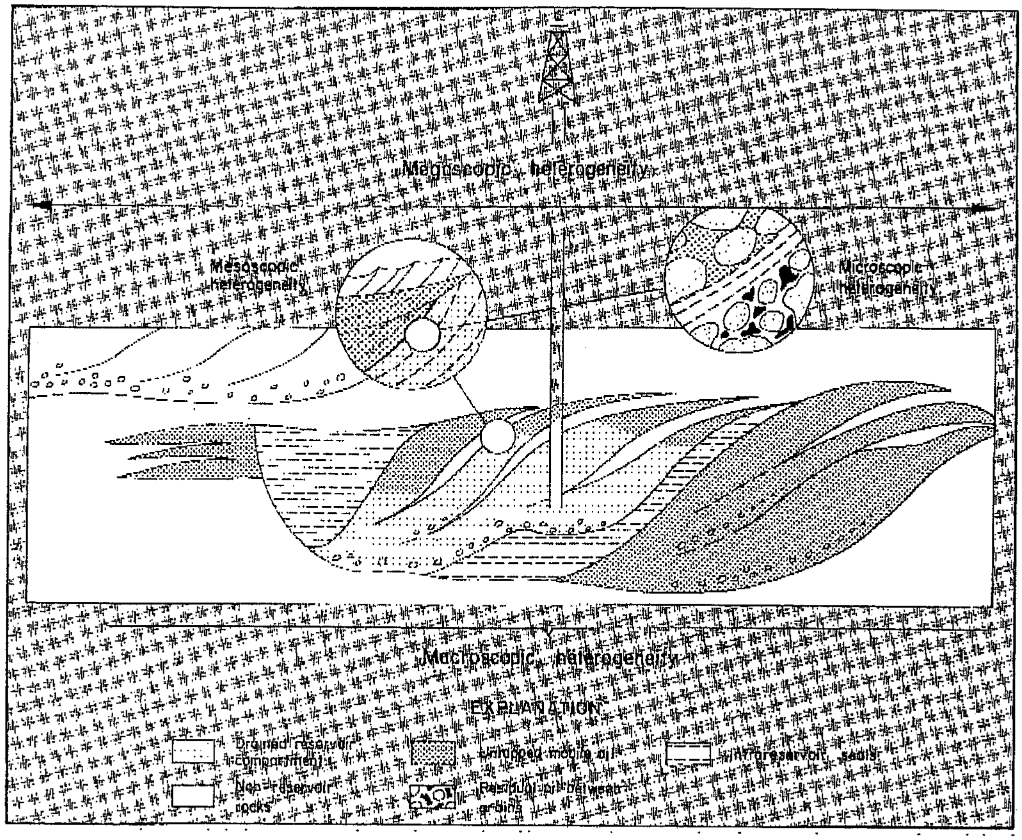

FIGURE C.1 Levels of reservoir heterogeneity. From: Tyler, N., 1988, New Oil from Old Fields. *Geotimes* vol. 33, no. 7, p. 9. Reprinted by permission of the American Geological Institute.

ervoir, integration of geophysical and engineering data with geological well information is required to give the best interpretation possible. Geophysical techniques can provide information about a large fraction of the reservoir. Conventional 3D seismic data can provide structural data for an entire reservoir, but conventional surface seismic data can only image bodies of rock approximately 100 by 100 by 100 feet. Seismic data cannot, therefore, directly provide data on many of the most important reservoir properties like porosity, permeability, and fluid saturations. And while other geophysical techniques like crosswell tomography can give much finer resolution, they also do not directly provide information on porosity, permeability, and fluid saturations. Fluid flow and pressure data from wells can provide much data on bulk properties of fluid flow within a reservoir. In general, the most accurate and comprehensive estimate of reservoir characteristics results from the integration of geologic, engineering, and geophysical data.

TABLE C.1 GOALS OF RESERVOIR CHARACTERIZATION

MAJOR PURPOSE OF RESERVOIR CHARACTERIZATION: LOCATION OF INFILL WELLS

Project No.	Contractor	Area	Purpose
Class 1			
4	Texas Bureau of Economic Geology	Frio Formation	No field demonstration
6	Diversified Operating Corporation	Sooner Field	Infill and recompletion locations
9	Sierra Energy Company	Frontier Formation	Locations of horizontal well to intersect fractures
11	University of Kansas	Savonburg and Stewart Fields	Locate infill wells and design waterflood
12	Oklahoma Geological Survey	Fluvial-dominated deltaic reservoirs in Oklahoma	Classification of reservoirs and recovery technologies being used
14	Utah Geological Survey	Bluebell Field	Locate infill wells and zones to recomplete in existing wells
Class 2			
16	Fina Oil and Chemical Co.	Clearfork Reservoir	Locate infill wells and redefine waterflood**
17	Laguna Petroleum Co.	Foster and S. Cowden Fields	Locate infill wells and redefine waterflood
18	Luff Exploration Co.	Williston Basin	Locate drilling locations to utilize horizontal drains
19	Michigan Tech. University	Dundee Formation	Locate horizontal wells
23	University of Kansas	Schaben and Bindley Fields	Locate infill wells
24	Utah Geological Survey	Paradox Basin	Locate infill wells and assess viability of waterflood and CO_2 flood

**Mid-term project

TABLE C.1 Continued

MAJOR PURPOSE OF RESERVOIR CHARACTERIZATION: IMPROVED DESIGN OF A WATERFLOOD OR ADVANCED FLOODING TECHNIQUE

Project No.	Operator	Area	Purpose
Class 1			
8	Lomax Exploration Co.	Green River Formation	Waterflood design
11	University of Kansas	Savonburg and Stewart Fields	Waterflood plus infill
12	Oklahoma Geological Survey	Fluvial-dominated deltaic reservoirs in Oklahoma	Classification of reservoir and recovery technologies used
13	University of Tulsa	Glen Pool Field	Waterflood
Class 2			
15	Sensor	Anadarko Basin	Gel treatment
16	Fina Oil and Chemical Co.	Clear Fork Reservoir	Locate infill wells and redefine waterflood**
17	Laguna Petroleum Co.	Foster and S. Cowden Fields	Locate infill wells and redefine waterflood
20	Oxy USA, Inc.	Welch Field	Cyclic CO_2 flood**
21	Phillips Petroleum Co.	South Cowden Field	Horizontal well for CO_2 injection**
22	Texaco E&P, Inc.	Texaco Central Vacuum Unit	CO_2 Huff-n-Puff
24	Utah Geological Survey	Paradox Basin	Locate infill wells and assess viability of waterflood and CO_2 flood

**Mid-term project

TABLE C.1 Continued

LIMITED EMPHASIS ON RESERVOIR CHARACTERIZATION

Project No.	Contractor	Area	Purpose
Class 1			
2	Amoco Production Co.	West Hackberry Field	Air injection**
7	Hughes Eastern Corp.	North Blowhorn Creek Field	Microflora and waterflood**
10	Texaco E&P, Inc.	Port Neches Field	CO_2 flood with horizontal and vertical wells**

**Mid-term project

D

Biographical Information on Panel Members

CHARLES (CHIP) G. GROAT (Chairman) is Professor of Geological Sciences and Director of the Center for Environmental Resources Management at the University of Texas at El Paso. He received his M.S. from the University of Massachusetts and his Ph.D. in geology from the University of Texas at Austin. Dr. Groat has also held the positions of Director of the Louisiana Geological Survey; Executive Director, American Geological Institute; and Executive Director, Center for Coastal, Energy, and Environmental Resources, Louisiana State University. He is a member of the Geological Society of America, American Association of Petroleum Geologists, American Geophysical Union, and the American Association for the Advancement of Science.

ARTHUR C. H. CHENG received his B.Sc. in Engineering Physics from Cornell University and Sc.D. in Geophysics from the Massachusetts Institute of Technology. He is a Principal Research Scientist at the Earth Resources Laboratory, Department of Earth, Atmospheric, and Planetary Science, Massachusetts Institute of Technology and the project leader of the Borehole Acoustics and Logging Consortium at MIT. Dr. Cheng's research interests include seismic wave propagation in boreholes and in anisotropic media, seismic imaging using downhole and surface techniques, effects of pore shapes on the physical properties of rocks, relationship between elastic and flow properties of rocks, and application of parallel computing and visualization to geophysical problems. He is a member of the Society of Exploration Geophysicists, American Geophysical Union, the Acoustical Society of America, and the Society of Professional Well Log Analysts.

JAMES A. DRAHOVZAL is Geologist and Head of the Petroleum and Stratigraphy Section of the Kentucky Geological Survey and adjunct professor of geology at the University of Kentucky. Previously, he was a research associate in tectonics and basin analysis for ARCO Research and Technical Services. His research areas are regional geology, oil and gas reservoirs and plays of the Appalachian and Illinois Basins, and Cincinnati Arch fractured carbonate reservoirs. He received his B.A., M.S., and Ph.D. (geology) degrees from the University of Iowa. He is a member of the Geological Society of America and the American Association of Petroleum Geologists.

GEORGE J. HIRASAKI received his Ph.D. degree in chemical engineering from Rice University. He is a member of the National Academy of Engineering, American Chemical Society, Society of Core Analysis, Society of Professional Well Log Analysts, SIAM, the Society of Petroleum Engineers, and the American Institute of Chemical Engineers. He is a Professor in the Department of Chemical Engineering at Rice University in Houston, Texas. He has been a staff reservoir engineer with Shell Oil Company and research advisor at the Bellaire Research Center of the Shell Development Company. Prof. Hirasaki is the author of various publications and has been granted three patents. His research interests are interfacial phenomena, numerical simulation, multiphase flow in porous media, wettability, foam in porous media, and surfactant flooding.

NEIL F. HURLEY is an advanced research geologist with Marathon Oil Company. Previously, he was a geologist with Conoco Incorporated. He received a B.S. in geological sciences and a B.S. in petroleum engineering from the University of Southern California, an M.S. in geology from the University of Wisconsin at Madison, and a Ph.D. from the University of Michigan. He currently works for Marathon Oil Company. His research interests are reservoir characterization, carbonate reservoirs, fractured reservoirs, and horizontal wells. He is a member of the Society of Petroleum Engineers, Society for Sedimentary Geology, Society of Petroleum Well Log Analysts, and the American Association of Petroleum Geologists.

RANDI S. MARTINSEN received her B.S. in geology from the State University of New York, Stony Brook, and her M.S. in geology from Northern Arizona University. She is a Senior Lecturer in the Department of Geology and Geophysics at the University of Wyoming and a consulting petroleum geologist. Prior to this, she was a geologist with Cities Service Company. Her research interests include processes and models of clastic depositional systems, hydrocarbon exploration and development. She is a member of American Association of Petroleum Geologists, Society of Sedimentary Geology, the Wyoming Geological Association, and the Rocky Mountain Association of Geologists.

CHARLES S. MATTHEWS received his B.S. in chemical engineering and his M.S. and Ph.D. in physical chemistry from Rice University. Dr. Matthews spent many years with the Shell Development Company and Shell Oil Company as Director of Research and Manager of Engineering. He retired from Shell Oil Company as senior petroleum engineering consultant. He is a member of the National Academy of Engineering, Society of Petroleum Engineers, and the American Petroleum Institute. His research interests include new methods for recovery of petroleum, behavior of petroleum reservoirs, geothermal energy, and recovery from tar sands and oil shale.

ARTHUR H. SALLER received his B.S. from the University of Kansas, M.S. from Stanford University, and Ph.D. (geology) from Louisiana State University. He is a carbonate sedimentologist specializing in reservoir characterization for Unocal Oil and Gas Corporation. He was a research assistant in sedimentary geology at Stanford University and Louisiana State University, and he then worked as a research geologist for Cities Services Oil and Gas. He has helped in a successful exploration program in the Devonian of Canada, successful development projects in west Texas, and more cost-effective evaluation of gas discoveries in Indonesia. He is a member of the American Association of Petroleum Geologists, the Geological Society of America, and the Society for Sedimentary Geology.

ROBERT J. WEIMER received a B.A. and M.A. from the University of Wyoming and a Ph.D. from Stanford University. He is Emeritus Professor of Geological Engineering at the Colorado School of Mines, as well as a consultant in the petroleum industry. Before teaching, he worked for the Union Oil Company of California. Dr. Weimer is a member of the National Academy of Engineering, the American Association for the Advancement of Science, the Geological Society of America, and the American Association of Petroleum Geologists. His research interests are sedimentary basin analysis; stratigraphic research in the application of modern sedimentation studies to the geologic record; fossil fuel exploration and production; geologic history of the Rocky Mountain region; and stratigraphic record of global sea level changes.

W. FRANK WEST received his A.B. and M.S. degrees from Stanford University. He is owner and president of PACO Minerals, Inc. He was a petroleum engineer with Continental Oil; assistant manager at Stoddard Oil; co-owner of Oliver and West, Inc. (petroleum consultants); President, Chief Operating Officer, and Director of Hanover Petroleum Corporation; and President and Chairman of Santa Fe Minerals, Inc., a wholly owned subsidiary of Santa Fe International Corporation, which itself is a wholly owned subsidiary of Kuwait Petroleum Corporation (the government of Kuwait). Mr. West was Senior Vice President of Santa Fe International Corporation.