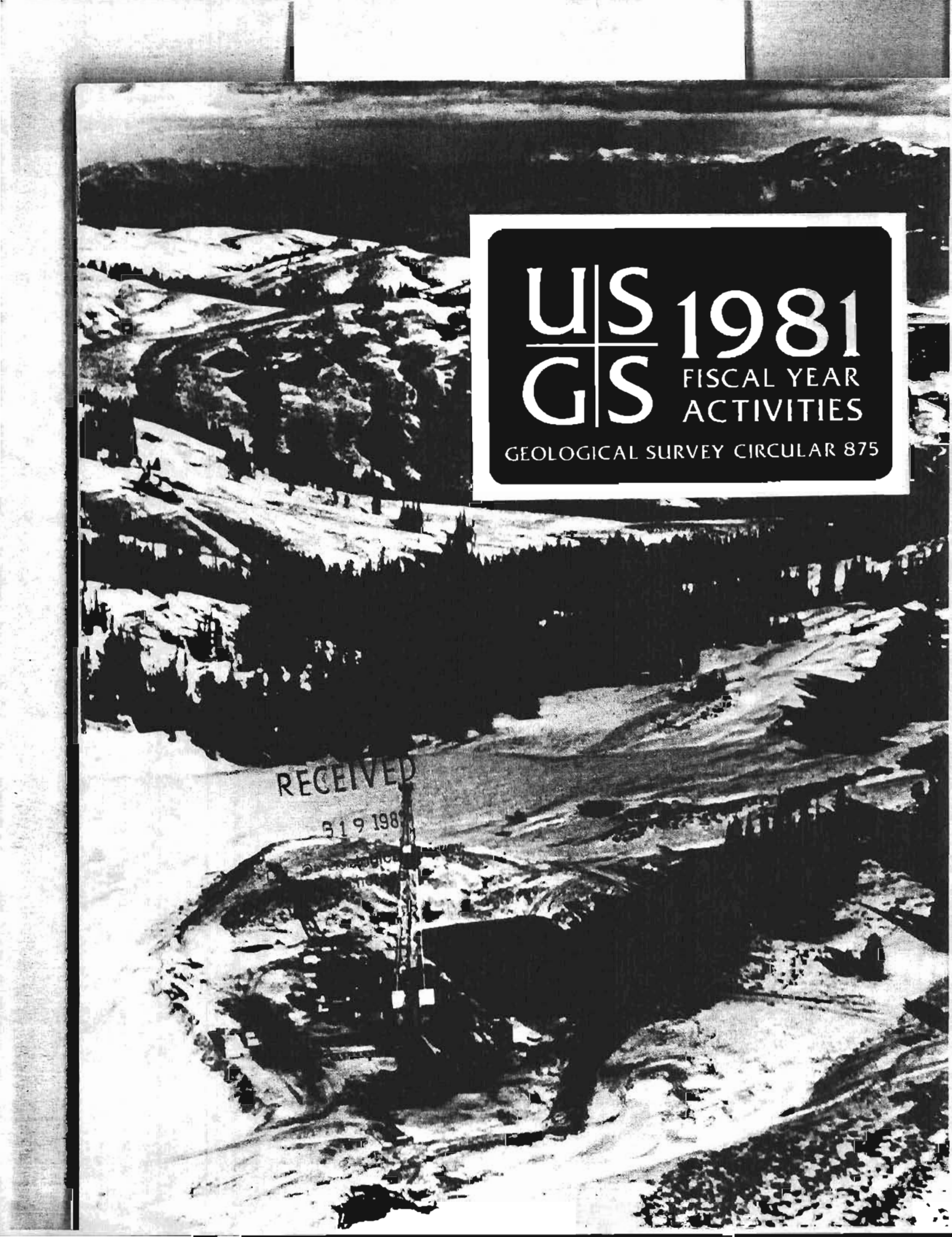
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Petroleum Exploration in the National Petroleum Reserve in Alaska

by George Gryc

INTRODUCTION

The completion of Awuna Test Well No. 1 on April 20, 1981, brought to a close the Federal Government's second exploration program (1974–81) in the National Petroleum Reserve in Alaska, formerly Naval Petroleum Reserve No. 4. Twenty-eight test wells—a total of 283,877 feet of borehole—were drilled on 26 "structures." [1] The tests were widely spaced over most of the Reserve and located in several different geologic settings to provide a basis for evaluating the resource of the entire Reserve. In addition, 13,455 line-miles of common-depth-point seismic surveys were completed and interpreted for most of the Reserve. New engineering, operational, and logistics techniques were devised to expedite the work and to minimize its impact on the environment. Each activity site was cleaned and rehabilitated after drilling was completed, and long-abandoned drilling and building sites in and adjacent to the Reserve were cleaned up and revegetated.

Nearly all of the test wells had at least traces, or shows, of oil, gas or both. A new small gasfield (12 billion cubic feet of producible reserve) was discovered 7 miles east of the South Barrow gasfield, and a new, potentially large gasfield was discovered at Walakpa, 14 miles southwest of Barrow. Determining the full extent of this gas accumulation and its potential for commercial development will require further drilling an analysis. Additional propects for gas accumulations in the Barrow area have been defined.

Except for the East Barrow gasfield, which is important to the local economy, no commercial deposits of oil or gas were discovered by this latest exploration program. What, then, has this program contributed to our national energy needs or to the advancement of the knowledge base on which future energy policy and planning decisions can be based?

HISTORICAL PERSPECTIVE

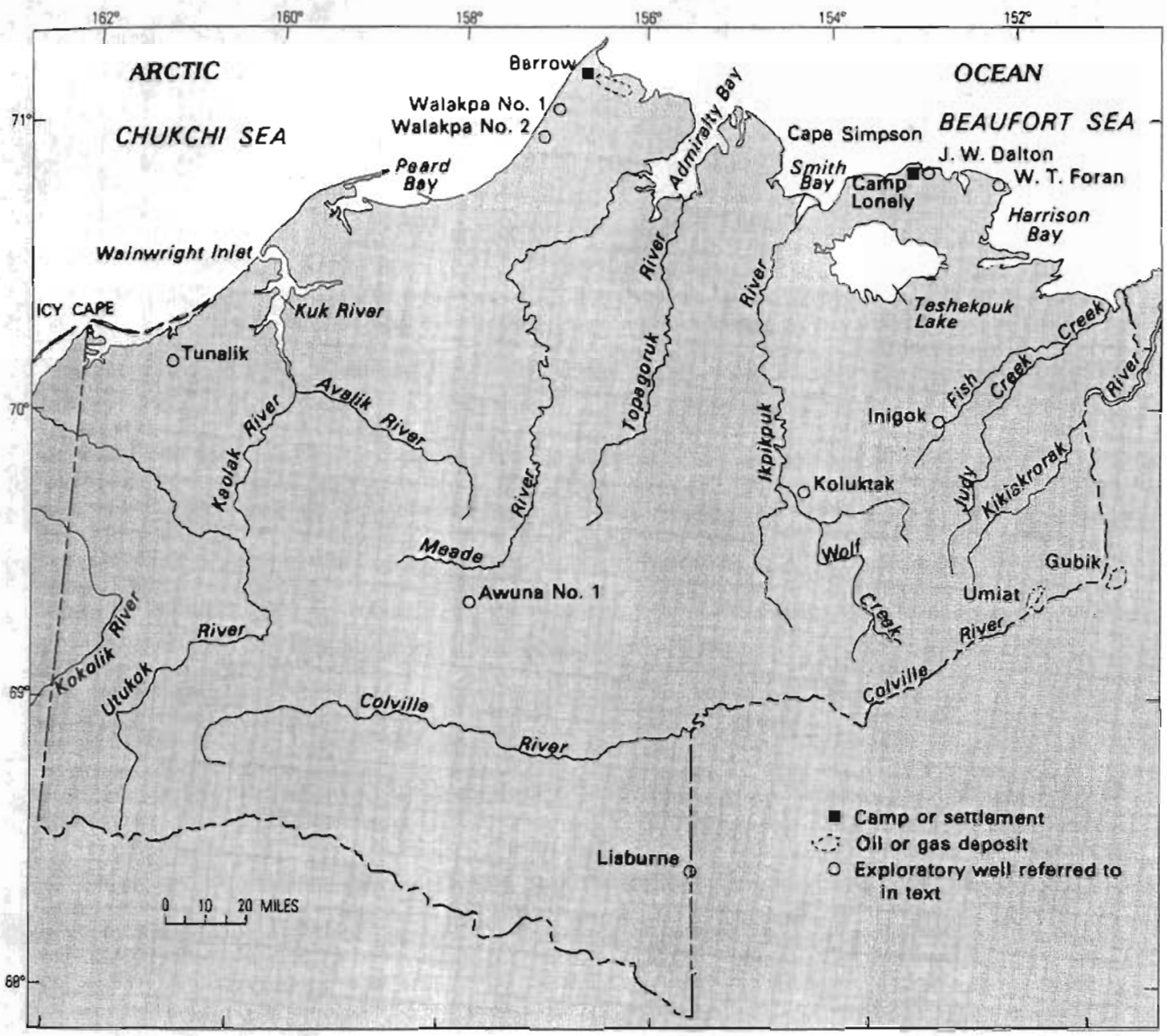
Any assessment of the Federal programs conducted in the National Petroleum Reserve in Alaska, including the one just completed, must be made in the context of the directives, the political setting, and the technology available when the program began. Nearly 60 years have passed since President Warren G. Harding signed an Executive Order on February 27, 1923, setting aside about 37,000 square miles of Northern Alaska as Naval Petroleum Reserve No. 4. The Order reads, in part, "Whereas there are large seepages of petroleum along the Arctic Coast of Alaska, and conditions favorable to the occurrence of valuable petroleum fields on the Arctic Coast and . . . Whereas the future supply of oil for the Navy is at all times a matter of national concern . . . [this order does] hereby set apart [the designated area] as a Naval Petroleum Reserve . . . " Thus, by 1923, the possibility that there were significant hydrocarbon deposits in northern Alaska was already recognized.

The first recorded description of oil seepages was sent to the U.S. Geological Survey by E. de K. Leffingwell in 1906 and published by A. H. Brooks (1909). Probably long before recorded history, the Eskimos harvested tar mats from the seepages and combustible oil shales found along major streams for fuel. What was undoubtedly oil shale was reported and described by W. L. Howard of the Stoney Expedition on his 1886 trip down the Etivluk River (within the area that was to become the National Petroleum Reserve in Alaska) (Stoney, 1900).

Several expedition traversed the Arctic Coast and the Brooks Range before 1900, but their objectives were primarily geographic and contributed little to the geologic knowledge of the region. The first recorded geologic traverse across the Brooks Range and the North Slope was made by W. J. Peters and F. C. Schrader in 1901, and the results were published in 1904 by the U.S Geological Survey (Schrader, 1904). Schrader named and described the Lisburne limestone formation of Mississippian age and described in considerable detail the Cretaceous rocks and the broad anticlinal structures in the foothills of the North Slope. Both of these rock units and this type of structure have proved to be commercially productive in the Prudhoe Bay district.

From 1906 to 1914, Leffingwell mapped the Arctic Coast east of Barrow and traversed inland in the Canning River region. His classic report (Leffingwell, 1919) is still an important and useful

[1] For specific data on well locations, depths, and discovery results, see chapter beginning on page 128



Location map showing the National Petroleum Reserve in Alaska.

reference, especially on the subject of permafrost. Leffingwell described and named the now-famous oil-bearing Sadlerochit sandstone in the Prudhoe Bay field. In 1917, "Sandy" Smith examined the oil seepages along the Arctic Coast and stimulated the interest of the oil industry. In 1921, several applications for prospecting permits were initiated under the old mining laws on claims near Cape Simpson and Peard Bay and along the Meade, Kukpowruk, and Kokolik Rivers. An excellent summary of these early expeditions and geologic studies was presented by Smith and Mertie (1930).

Thus, by 1923, the three main requirements for hydrocarbon accumulations—source rocks (oil shale and other organic sedimentary rocks), reservoir rocks (limestones and sandstones), and traps (anticlinal structures)—were known to be present in the area that was to become the National Petroleum Reserve in Alaska. After the establishment of Naval Petroleum Reserve No. 4, the U.S. Navy recognized that more complete geologic and geographic information was necessary for wise management and further assessment of the petroleum resources. From 1923 through 1926, the U.S. Geological Survey traversed most of the

larger rivers crossing the Reserve and mapped the geology and geography at reconnaissance scales.

The results of these surveys were published by Smith and Mertie (1930), who recorded and described (1) the oil seepages, especially those on the Simpson Penninsula; (2) the widespread occurrence of oil shales as a possible source rock; and (3) the many anticlinal structures in rocks of Cretaceous age, including sandstones that could provide traps and reservoirs for petroleum accumulations. Smith and Mertie studied the Lisburne limestone and discussed the possibility that these rocks were a source or a reservoir or both. They concluded, however, that the Lisburne was complexly broken and faulted in the area of exposure and too deeply buried along the coast to be important as a petroleum source or a reservoir, "unless there are great structural discordances."

We now know that, despite the reservations expressed by Smith and Mertie, there are, indeed, such discordances and that they are perhaps the most significant factors in the complex geologic history of the Prudhoe Bay deposit, the largest oilfield in North America. Smith and Mertie also cautioned would-be prospectors about the area's adverse geographic conditions and the resultant high costs of exploration. The geologic insight and long-range perspective documented by the Smith and Mertie (1930) paper is truly remarkable, considering the limited knowledge available at that time.

Nothing more was done to explore the petroleum potential of the Reserve until 1944, when the Pet-4 program was undertaken by the Navy as a wartime effort. The history of this program and much of the technical data collected were published in a series of U.S. Geological Survey Professional Papers (Robinson and Bergquist, 1956, 1958a, b, c; Patton, 1957; Bowsher and Dutro, 1957; Collins and others, 1958; Collins and Bergquist, 1958a, b, 1959; Reed, 1958; Patton and Matzko, 1959; Spetzman, 1959; Robinson and Collins, 1959; Robinson and Yuster, 1959; Chapman and Sable, 1960; Keller, Morris, and Detterman, 1961; Brewer, 1961; Woolson and others, 1962; Detterman, Bickel and Gryc, 1963; Black, 1964; Bergquist, 1966; Chapman, Detterman and Mangus, 1964; Patton and Tailleur, 1964; Robinson and Brewer, 1964; Brosge, Whittington, and Morris, 1966). A short summary of the exploration stategy of that program was published by Gyrc (1970). From 1945 through 1952, 45 shallow core tests and 36 relatively shallow test wells were drilled, for a total of 169,250 feet of borehole, and about 3,357 line-miles of reflection seismic surveys and 391 line-miles of refraction seismic surveys were completed within and immediately adjacent to the Reserve.

The results of the Pet-4 program include the discovery of one large oilfield at Umiat (70 million barrels of producible high-grade crude oil); one small gas deposit at Barrow (25 million cubic feet of producible gas); one potentially larger gas deposit at Gubik; three prospective gasfields at Meade, Square Lake, and Wolf Creek; and two minor oil accumulations near the seepages at Cape Simpson and Fish Creek. Perhaps the Pet-4 program's greatest contribution was to establish firmly, for the first time, the feasibility and practicality of operating a large-scale oil-exploration program, including geologic and geophysical surveys and studies and test drilling, in the Arctic.

In 1958, Public Land Order 82, which had withdrawn public lands in Alaska from entry in 1943, was cancelled, and these lands became available for lease. Private drilling begun in 1963 outside of the Reserve at first followed up on trends and leads provided by the Pet-4 program but eventually began looking at new prospects to the north and east. In 1968, the discovery of Prudhoe Bay was announced. This field, about 60 miles east of the Reserve initially was estimated to contain a producible reserve of 9.6 billion barrels of crude oil and 26 trillion cubic feet of gas. Additional reserves of oil are now being developed in the Kuparuk field just west of the Prudhoe Bay deposit, and new fields to the east and just offshore also have been discovered, although no reserve figures have been published.

EXPLORATION OF THE NATIONAL PETROLEUM RESERVE IN ALASKA, 1974–81

Stimulated by the discovery at Prudhoe Bay and seizing the opportunity by the Arab oil embargo of 1974, the Navy proposed and was authorized by Congress to begin another exploration program in Naval Petroleum Reserve No. 4. The plan, entitled "Engineering Plan for Assessment and Evaluation of NPR-4," called for exploring the Reserve systematically, from the northeastern corner to the southwestern corner, completing geophysical surveys, and establishing logistics bases in advance of drilling. Twenty-six test wells and 10,235 line-miles of geophysical surveys were to be completed over a 7-year period, later reduced to 5 years. At an earlier stage in planning, it was suggested also that the Umiat oilfield be produced and a small topping plant be installed to provide fuel for the rest of the program. This proposal was dropped from the final plan.

Between 1974 and 1977, the Navy used private oil-exploration contractors to drill seven wells in the northeastern corner of the Reserve, following the Prudhoe trend and hoping for similar results but with no success. The Navy also drilled four exploration wells in the Barrow area to increase gas reserves for local use and discovered, about 7 miles east of the South Barrow field, the East Barrow deposit, which had an estimated producible reserve of 12 billion cubic feet of gas.

In 1975, the Navy signed a 5-year contract with Husky NPR Operations, Inc., to manage and supervise all aspects of the exploration program. Four of the seven test wells in the northeastern corner of the Reserve were drilled for the Navy under the Husky contract.

The Naval Petroleum Reserves Production Act of April 5, 1976, authorized further development of and actual production and sale of crude oil from Naval Petroleum Reserves Nos. 1, 2, and 3 in California and Wyoming, and redesignated Naval Petroleum Reserve No. 4 as the National Petroleum Reserve in Alaska. Thus, the purpose of these Reserves was redirected from meeting naval requirements to augmenting domesting supplies of crude oil. The Act also mandated continuing the exploration program in the Reserve and required studies of other resources and alternative management systems, all to be completed and submitted to Congress by January 1980. Although the exploration program was not tied directly to the schedules of other studies in the Act, its results obviously would have had considerable influence on further land-use decisions. The Navy's 5-year plan, containing a schedule for the exploration program was stated for completion in 1980.

The Act transferred responsibility for the National Petroleum Reserve in Alaska to the Secretary of the Interior, who in turn assigned to the U.S. Geological Survey three responsibilities: (1) continuation of the exploration program, (2) continuation of operations, maintenance, and production at the Barrow gasfields, and (3) cleanup of debris left over from previous activities in and adjacent to the Reserve. The Navy's 5-year contract with Husky NPR Operations, Inc., as well as other minor contracts, also was transferred to the Geological Survey, in accordance with the Act. The Navy had moved the operational base for the exploration program from Barrow to Camp Lonely, 90 miles east on the Arctic coast. The Barrow gasfield had been operated and maintained for the preceding several years under an interservice agreement with the Office of Naval Research and its contractor for the operation of the Naval Arctic Research Laboratory at Barrow. This arrangement has been continued by the Survey. Until Congress directs otherwise, the Department of Interior will continue to be responsible for supplying gas to the Barrow community.

Thus, when the U.S. Geological Survey took over supervision of the exploration program on June 1, 1977, several constraints were already in place. The program was oriented toward future land-use decisions—national in scope rather than naval—and a timetable was imposed both by the reports that the Act required and by the 5-year contract transferred from the Navy. Further, a base of operations and an overall logistics capability already had been established. Three drill rigs capable of drilling to about 20,000 feet and one capable of reaching somewhat shallower depths were under subcontract. Another drilling rig was contracted for later drilling of shallow (2,500 feet) development wells at the Barrow gasfields. These subcontracts, along with others for services such as transportation, communication, and operation of the Camp Lonely base facility, constituted fixed costs. An additional, and perhaps the most significant, constraint on program planning in the Arctic was the absolute necessity to time activities to the seasons. To maintain a four- or five-well drilling program, each winter's activities had to be planned and coordinated on an extremely tight schedule. Logistics planning had to be completed at least 1 year in advance, and final locations had to be determined about 6 months in advance. Geophysical surveys were shot the winter before drilling was to begin, but interpretations of these surveys were not completed until a few weeks or days before the locations had to be staked. An environmental assessment, including archeologic clearance, had to be completed before work at the site began. An excellent review of this subject and other environmental considerations in the Reserve appeared in the "U.S. Geological Survey Yearbook, Fiscal Year 1978" (Britton, 1978).

Within these planning constraints and with the 1977–78 drilling season more or less already established by the Navy as of June 1, 1977, the Geological Survey reviewed the plan and various exploration strategies in an attempt to meet the objectives of the Naval Petroleum Reserves Production Act. The prime objective was defined as an assessment of oil and gas in the entire Reserve—an area of 37,000 square miles, or more than 23 million acres. An important but secondary objective was the discovery of commercially producible deposits. Thus, all tests were located "on structure" to the extent that it could be determined from the available data. To meet these objectives and to develop an exploration

strategy through 1980, the Survey made a "play" analysis. (A "play" is defined as a group or cluster of prospects having similar geological and geophysical characteristics.) Characteristics considered included the presence or absence of source rocks, reservoir beds, and traps; thermal history; the timing of oil generation and migration; and the history of trap formation. Originally, 10 plays were defined, 9 largely on the basis of specific stratigraphic units or of closely related units. The remaining play was a geologic and geographic "belt" that included several formations in a complex structural setting. Potential source rocks are present throughout the Reserve, and traps in the form of closed structures are abundant in the foothills and in the disturbed belt north of the Brooks Range. Closed structures, however, are scarce in the northern part of the Reserve, and trapping mechanisms, if they are present, are controlled by stratigraphy, unconformities, pinch-outs, and the like. These factors were all considered in the play analysis. It was proposed finally that the exploration strategy should call for at least two exploration test wells in each play to provide specific subsurface information and to discover any deposits that might exist within the area of the play; some followup test wells also were included in the strategy. It was concluded that about 20 to 40 test wells would have to be drilled to further refine the play approach, to assess which part of the Reserve had the greatest potential, and to make a more reliable assessment of resources in the entire Reserve. At no time, however, was it believed that 20 or even 40 wells would provide a definitive assessment of the hydrocarbon potential of the National Petroleum Reserve in Alaska.

HIGHLIGHTS OF DRILLING RESULTS

In all, 28 exploration wells were drilled during the 1974–81 program. All of the technical data gathered from these test wells have been released and can be obtained from the National Geophysical and Solar Terrestrial Data Center, National Oceanic and Atmospheric Administration, 325 Broadway, Boulder, Colorado 80303. All geophysical surveys and data are also available; all technical reports submitted by the prime contractor and by subcontractors either have been or will be released through that office, as well. Annual program summaries for 1977 through 1981 have been published by the U.S. Geological Survey in the Yearbooks.

A review of drilling results is most meaningful if the reviewer has an in-depth knowledge of the regional geology. Although such a discussion is beyond the scope of this essay, a few general comments will illustrate what the program has contributed to the knowledge base and to the understanding of the hydrocarbon potential of the National Petroleum Reserve in Alaska.

Basement rocks (that is, rocks with little or no hydrocarbon potential) rise from a depth of about 10,000 feet at Prudhoe Bay to their shallowest point at Barrow, where basement is at a depth of only 2,300 feet. These basement rocks dip south under the Reserve to a depth of a least 25,000 feet at about the latitude of the Colville River and then are exposed at the surface in the Brooks Range, where they form a trough of sedimentary rocks generally referred to as the Colville trough or geosyncline. All of the area underlain by this thick section of sedimentary rocks is considered a potential province for hydrocarbon accumulation. The Reserve covers about half of the province.

The seven wells drilled by the Navy between 1974 and 1977 explored the extension of the Prudhoe-Barrow trend into the Reserve. Perhaps the W. T. Foran Test Well came the closest to duplicating the geologic setting of Prudhoe Bay. A similar sequence of rocks was penetrated, and good porosity and permeability were present in the Sadlerochit formation, the main producing horizon at Prudhoe Bay. Although the test well produced only water, good oil and gas shows were present at several horizons. The Geological Survey's prime contractor, Husky, drilled nine more tests along the Prudhoe Bay trend, which includes several of what are believed to be the more favorable plays. Furthermore, because the sedimentary section above basement is no more than 10,000 feet thick and near the coast, development of a deposit there would be less expensive than it would be in the deeper and more remote parts of the Reserve. The J. W. Dalton Test Well, on the Arctic coast, also penetrated nearly 800 feet of sandstone and limestone having good porosity and permeability in the Sadlerochit and Lisburne formations, but only heavy residual oil was produced on test. There are good indications that the Dalton and Foran test wells represent older accumulations of oil that have moved basinward as the Arctic Ocean subsided. A Prudhoe Bay–type deposit may be present just offshore of the Reserve.

Several test wells were drilled on the southern flank of the Prudhoe-Barrow trend to test the onlap edges of potential reservoirs of Early Cretaceous and Jurassic age. The Survey test well at Walakpa No. 1, 14 miles southeast of Barrow, penetrated a 20-foot gas sand at a depth of about 2,075 feet. A followup well 5 miles to the south of Walakpa No 1 penetrated 40 feet of the same

gas sand. Tests show that each well could produce up to 3 million cubic feet of gas per day. At that rate, however, gas hydrates form and shut off the flow. If this problem can be solved, it may be possible to obtain higher flow rates. Ascertaining the full extent of this deposit will require additional drilling, but a reserve of several hundred billion cubic feet of gas may be present in the Barrow area.

Test wells farther south on the downslope of the Prudhoe-Barrow trend were drilled to test the wedge edge of the Lisburne group of Mississippian and Permian age. Although limestones of this age were penetrated, none had the porosity and permeability required to provide a good reservoir in which oil could have accumulated.

Two wells, Inigok and Tunalik, were drilled in the center of the sedimentary trough to test deep structures and older formations just above basement. The Inigok Test Well encountered hydrogen sulfide gas at 17,570 feet and bottomed at 20,102 feet in rocks of Mississippian age, but only minor shows of gas in Cretaceous rocks were noted. The Tunalik Test Well, in the extreme northwestern corner of the Reserve, encountered high-pressure gas at 12,550 and 14,725 feet in sandstone reservoirs of Early Cretaceous age. The test well bottomed in the Lisburne group at 20,335 feet, a new depth record for Alaska.

The shallow detached structures in rock of Cretaceous age in the central part of the Reserve were not tested in the early stages of this program because they had been drilled extensively in the 1945-53 program. Oil had been discovered at Umiat, and gas had been found at Gubik; thus, some assessment of this play was available. Other potential gas deposits also were encountered, but possible flow rates were not tested because gas in northern Alaska was of little or no economic interest at that time. However, in the latter stages of the 1974-81 program, it was deemed important to test and establish the potential gas reserves of these shallow structures and especially to test the entire Cretaceous sequence. Thus, the deeper horizons on the Umiat structure were tested, a high-pressure gas zone in the Cretaceous was penetrated at 5,340 feet. Tests indicated a depleting reservoir, however, and, after initial tests of up to 6 million cubic feet per day, production dropped sharply. At Awuna Test Well No. 1, highly fractured sandstone beds were drilled at about 8,400 feet in the Fortress Mountain formation of Early Cretaceous age. Tests produced strong blows of gas and a water flow of more than 2,000 barrels per day. From that point to the well's total depth of 11,200 feet, the rocks penetrated were predominantly fractured sandstones having several zones of high-water flow. The Koluktak test well was designed to test the potential of gas sandstone reservoirs equivalent to those at Gubik and Umiat. However, the test was a dry hole, and no further information was acquired on potential flow rates or reserves in this play.

The tenth play is defined as the Disturbed Belt, an area of complexly folded and broken thrust faults along the northern front of the Brooks Range. The structure of these rocks is very difficult to map and interpret. A test drilled at Lisburne on what appeared to be a closed structure encountered only minor hydrocarbon shows. The well penetrated at least five stacked plates and possibly seven plates of the Lisburne formation, further documenting the complex geologic history of this play.

During Congressional hearings for the fiscal year 1981 program, a number of members asked that discovery of commercial deposits be made the prime objective; accordingly, the focus of the program was returned to the shallower prospects along the Prudhoe-Barrow trend. This redirection resulted in the discovery at Walakpa Test Well No. 2 which may prove to be a large gas deposit of considerable interest as an energy source, at least locally. The exploration and development of local sources of energy fuels, here and elsewhere in the United States, are of considerable significance to national fuel requirements.

The Congressional mandate to continue supplying gas to the Barrow community also required drilling additional test and production wells in that area. Six wells were drilled, and four were completed for production.

A LOOK AHEAD

Although the exploration program just concluded did not find any commercial hydrocarbon deposits, it did provide a new and more sophisticated knowledge base for further assessment and exploration of the Reserve. All geological, geophysical, and geochemical data collected and analyzed systematically over the entire Reserve have been or are being made available to the general public. This set of data may be unique for so large an area in a single petroleum province because it was collected systematically in a relatively short time and was made readily available to the public.

As the exploration progressed, several appraisals of the potential hydrocarbon resources of the Reserve were made. The latest appraisal was made available by the Department of Interior in a press release dated July 17, 1980. The release reads, "The new estimates suggest a 95 percent

chance of 0.55 billion barrels of oil in place, a 5 percent chance of 15.8 billion barrels, and a 50 percent probability that 5.2 billions barrels of oil are contained in the Reserve. Revised figures for gas in place show a 95 percent chance of 2.5 trillion cubic feet (tcf), a 5 percent chance of 27.4 tcf, and a 50 percent chance of 9.4 tcf." All these figures were generated by a somewhat complicated, computer-based probability analysis that used as its geologic base the play concept. The 10 original plays were subdivided into 17 separate plays; several factors for each were evaluated quantitatively by a knowledgeable geologic team. Positive information on these factors is limited, however, and wide ranges of values had to be assigned on the basis of geologic judgements. The probability analyses sampled these values statistically. Obviously, as new data are collected, these values will change; thus, the range of values having assigned probability is the most significant and useful information to result from such assessments.

In the Department of Interior Appropriation Act for fiscal year 1982, Congress agreed to terminate Federal exploration and authorized a leasing program in the Reserve to begin in 1982. The leasing of up to 2 million acres without a new environmental impact statement was authorized. A call for lease nominations went out to all interested parties, and nearly all of the 23 million plus acres were nominated. The Geological Survey and the Bureau of Land Management selected 5.8 million of those acres for further study; 1.5 million acres have now been earmarked for lease in December 1981, and another 0.5 million acres will be available for lease in May 1982. Further lease sales will follow, but no schedule has been announced.

The 1974-81 exploration program has shown that vast quantities of oil and gas must have been generated in the Reserve portion of the Colville sedimentary trough. The existence of the Prudhoe Bay field has proved that at least one giant deposit and several other large deposits did accumulate in the eastern part of the trough. Substantial deposits of oil and probably of gas have been discovered by government exploration programs within the Reserve. The existence of deposits large enough to warrant economic development in the Reserve has not been proven or disproven. The government exploration program of 1944–53 led the way for modern oil exploration in the Arctic. The 1974–81 program has gathered a treasure trove of data from which new interpretations of Alaskan geology can be derived.

All of this information is readily available in public files and provides a sound base for making further land-use decisions and resource assessments and for the next stage of exploration by private industry.

As Chief of the Office of the National Petroleum Reserve in Alaska, George Gryc directed all U.S. Geological Survey programs and activities described in this essay from July 1977 until his departure in October 1981 to become Assistant Director for the Western Region. He has specialized in Alaskan geology and mineralogy since 1943 and is author or coauthor of more than 50 papers in his field.

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