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AMBROSIA LAKE, NEW MEXICO—A GIANT URANIUM DISTRICT

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Abstract—Wildcat drilling on the northern flank of the Ambrosia Lake dome, McKinley County, New Mexico, made the initial uranium discovery in the Ambrosia Lake district in March 1955. This orebody occurred in the Westwater Canyon Member of the Jurassic Morrison Formation. This discovery, made by a single individual, triggered a huge exploration drilling effort, and, within two years, the ore trends in the western part of the district had been well established.

The small companies that made the early discoveries entered into partnerships with major petroleum and mining companies to develop, mine and process the ore. The checkerboard pattern of the mineral ownerships resulted in a large number of shafts being sunk to develop the deposits. Many unanticipated problems resulting from the attempts to develop and mine in poorly consolidated, friable sandstone lying below the water table caused delays in bringing the mines into production. Four mills were built to process the ore under contracts with the U.S. Atomic Energy Commission (AEC), the sole market for uranium in the United States. Exploration extended the Ambrosia Lake ore trends to the east in the late 1960's and early 1970's with the discovery of a deep, large, high grade, cluster of orebodies.

Production reached an all-time annual high in 1962, when 10,903,811 pounds of uranium oxide (U_3O_8) in ore were produced. The large discoveries at Ambrosia Lake were partly responsible for the AEC establishing limits for its procurement program during the period 1962 through 1970. Beginning in 1967, some uranium was produced for commercial sale to electric utilities. After 1970, the utilities were the only market for uranium. As the demand for uranium increased, the price of uranium rose in the mid-to-late 1970's, new mines were opened and production increased.

Falling prices and an oversupply of uranium in the early 1980's forced most of the mines to close. Currently (February 1989) there are only two underground mines in operation; however, uranium is also recovered from water that has been recirculated through many of the closed mines.

During the period 1956 through 1988, mines in 33 sections of the Ambrosia Lake district produced 189,769,000 pounds U_3O_8 in ore and mine water. This amounts to about 19% of the entire domestic uranium-ore production. Ambrosia Lake is truly a giant uranium district.

INTRODUCTION

The Ambrosia Lake district of the Grants uranium region is located about 20 mi (32 km), by road, northwest of the town of Grants in southeastern McKinley County, New Mexico. The southeastern end of the district extends into northern Cibola County (Fig. 1). As used in this report, the Ambrosia Lake district includes only the deeper uranium-ore deposits that have been found in the trends from the Ambrosia Lake dome to San Mateo (Fig. 1). The ore deposits of the so-called "Poison Canyon trend" (Kelley, 1955, p. 122–135), which occur to the south near the outcrops of the Morrison Formation, are excluded.

Ambrosia Lake was a small, ephemeral lake situated in the SW¼ sec. 12, T14N, R10W. It is now dry and is the site of Cobb Nuclear's Section 12 shaft. Originally the name was La Laguna del Defunto Ambrosio. The story is that an individual named Ambrosio was found floating in the lake, his body pierced by Indian arrows (Pearce, 1965). The form "Ambrosia" is modern. During the 1960's, Jim Barber, editor of the Grants Beacon newspaper, lead an unsuccessful campaign to change the name of the mining district to Ambrosio Lake, but the modern version was too entrenched in the mining parlance to be changed.

The Ambrosia Lake district contains world-class uraniferous humate-uranium deposits. These tabular, peneconcordant orebodies occur at several stratigraphic levels within the Westwater Canyon Member of the Jurassic Morrison Formation. These orebodies occur in narrow trends that are several mi in length; the ore trends appear to be controlled by sedimentary trends within the host sandstone. The east-southeast ore trends shown on Figure 1 also are the direction of fluvial sedimentation. Other important deposits are the so-called "stack" deposits, which are controlled by steeply dipping faults of Tertiary age that strike across the main ore trends. These secondary deposits are rectangular or equidimensional in cross section. The area underlain by deposits is approximately 20 mi (31 km) long, with a maximum width of 4 mi (6.5 km) (Fig. 1).

As this paper deals only with the exploration and mining history of the district, the reader is referred to volumes by Kelley (1963), Rautman (1980) and Turner-Peterson et al. (1986), and a summary report by Adams and Saucier (1981), for geologic descriptions of the deposits. Information on the development of the individual mines is given in reports by the U.S. Atomic Energy Commission (1959) and Holmquist (1970). Perkins (1979) gives an excellent review of the industry in New Mexico.

Most of the information used in this report was obtained while the author was employed by the U.S. Atomic Energy Commission (AEC) and succeeding agencies, the U.S. Energy Research and Development Administration and the U.S. Department of Energy. Production statistics for the period 1956–1982 were compiled from unpublished information in the files of the Department of Energy. Those for 1983–1988 were estimated from reports of the New Mexico Energy, Minerals and Natural Resources Department, Mining and Minerals Division.

EXPLORATION AND PRODUCTION HISTORY

Early activities

The initial uranium boom in the Grants area started soon after Paddy Martinez, a Navajo sheepherder, found uranium-bearing outcrops in the Todilto Limestone Member of the Wanakah Formation at the foot of Haystack Butte in the spring of 1950. This discovery was successfully promoted by Grants businessmen to create interest for uranium prospecting in the Grants area.

Since Martinez's discovery was on land owned by the Santa Fe Pacific Railroad, the railroad sent geologist Tom O. Evans to investigate the area. Evans discovered uranium in sandstone beds of the Morrison Formation in the area of Poison Canyon on 4 January 1951 (Hilpert, 1959). Poison Canyon, also on railroad land, was so named because of the poisonous selenium-bearing "loco weed" (*Astragalus*) that grew there. This discovery at Poison Canyon touched off prospecting efforts which located other mineralized outcrops of Morrison sandstone in the immediate area. These occurrences were in units that became known as the Poison Canyon Sandstone (Gabelman et al., 1956), which is a tongue of the Westwater Canyon Member within the lower part of the overlying Brushy Basin Member of the Morrison Formation. Exposures

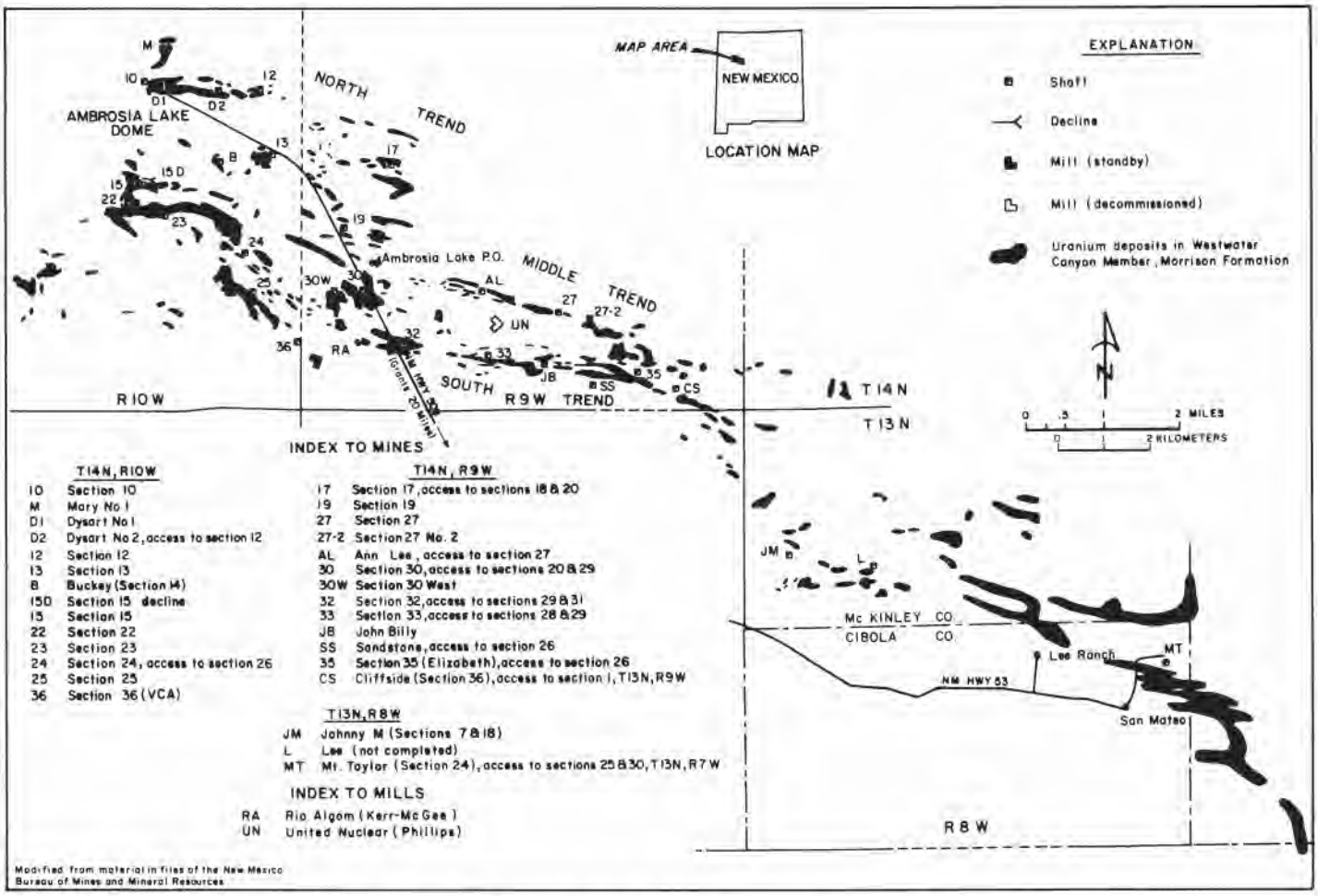

FIGURE 1. Map showing uranium deposits and mines, Ambrosia Lake district, New Mexico.

of the main Westwater Canyon Member were found to be barren of uranium and were generally considered to be unfavorable.

Mining in the Poison Canyon area began in 1951, and by 1954, five properties in the area had produced some 65,191 tons of ore averaging 0.25% U_3O_8 in grade and containing 327,762 pounds U_3O_8. By 1954, there had been some drilling downdip from the mineralized outcrops. Some drilling had occurred in sec. 8, T13N, R9W, which was 2 mi (3 km) north of the Poison Canyon outcrop, but only the Poison Canyon Sandstone was investigated (Holmquist, 1970).

Surface exposures of the Dakota Sandstone are found above the apex of the eroded Ambrosia Lake dome in secs. 10, 11, 14 and 15, T14N, R10W. This dome is the only place within the large valley, which is eroded into the Mancos Shale, where the Morrison Formation is at a shallow depth. It was this area that attracted the interest of Louis Lothman in 1955. The dome had been drilled for oil and gas in 1952, and upon examination of a driller log and the cuttings, Lothman determined that sandstones in the Morrison Formation occurred at a reasonable drilling depth. Information on this well was on file at the New Mexico Bureau of Mines and Mineral Resources at Socorro, New Mexico. However, the cuttings were not radioactive as has been reported in some earlier reports (Kelley, 1963, p. 4; Hilpert, 1969, p. 5).

The discovery of Ambrosia Lake is described by Lothman in a 1959 letter to the AEC, as follows:

> I had convinced myself that the most ideal conditions were present for the drilling for uranium. I also had conferences with Mrs. Dysart and on February 15, 1955, secured from her a lease on the south-half of Section 11, T.14N., R.10W., NMPM New Mexico.
>
> I then returned to Houston, Texas and secured financing for a Mayhew 200 rotary drilling rig and some drill stem, bits, etc. I returned to Ambrosia Lake about the first of March, 1955, and commenced to put down an exploratory hole located close to the top of the dome. The first hole was bottomed at 290 feet and at the time, I had no more drill stem with which to drill and no apparent radio-activity, but with the Morrison formation apparent. I then pulled off the hole, borrowed additional drill stem—60 feet, to be exact—and decided to move the rig to the flank of the anticline and commenced drilling on the second hole, reaching uranium which averaged .45 grade at 292 feet on March 17, 1955.

Soon after his discovery, Lothman hired Robert A. Strothard, a self-styled doodlebugger, to survey sec. 11 with an ionization chamber. This device was constructed to detect radon gas that seeped to the surface through joints and faults. Mr. Strothard outlined an L-shaped area. Remarkably, of the first 50 holes drilled in the area, 48 penetrated uranium ore (Gabelman et al., 1956).

The boom years, 1956–1962

The news of Lothman's discovery spread rapidly, and soon numerous small companies and individuals were acquiring leases and staking claims in the immediate area. The land ownership was very fragmented. About half of the odd-numbered sections belonged to the Santa Fe Pacific Railroad, and the other half were patented homesteads. Except for secs. 2, 16, 32 and 36, which were state owned, the even-numbered sections were about equally divided between public domain and patented homesteads. Section corners in the Ambrosia Lake area are marked with stone monuments from the original land survey in the 1890's. However, during the rush to acquire leases and claims in the area, many of the markers disappeared or appeared to have been moved from original positions. The situation was so bad that on the 1957 issue of the U.S. Geological Survey's 7.5 minute Ambrosia Lake topographic

quadrangle sheet, no section corners are shown. Moreover, the following footnote is on the sheet: "Land lines are omitted in T.13 and 14N., R.9W. and in parts of T.14N., Rs. 9 and 10W. because of alleged fraud or defects in the surveys." In order to remedy the situation, the mine operators had a private survey reestablish the correct locations of the section corners.

In May 1955, Dunn Brothers began sinking a 396 ft (121 m) deep shaft near the center of the orebody that Lothman had discovered. This would be the Dysart No. 1 mine and would be operated by Rio de Oro Uranium Mines, Inc. By July 1955 ore had been discovered by drilling in secs. 10, 15, 22, 23, 24 and 36, T14N, R10W. At the end of 1955, drilling had extended into T14N, R9W, where depths to the Westwater Canyon exceeded 1200 ft (366 m). At that time, some 35–40 drill rigs were active in the area.

Because the individuals and small companies which made the original discoveries did not have the capital to develop mines and build mills, they found it necessary to join with such companies as Kerr-McGee Oil Industries, Inc., The American Metal Co., Ltd. and Phillips Petroleum Co. The Anaconda Copper Co., already the operator of a uranium mill at Bluewater, New Mexico and the Jackpile uranium mine north of Laguna was not interested in developing the Ambrosia Lake deposits, due to the shallow water table.

The first load of ore from the Dysart No. 1 mine was hoisted in December 1955. Some 1500 tons of this ore were shipped to the AEC's pilot plant at Grand Junction, Colorado for metallurgical testing. The AEC concluded that the ore could be processed in a carbonate leach followed by a caustic precipitation more economically than by any other method (Osborne, 1956).

The AEC opened an ore-buying station near Milan on 5 July 1956 to provide a market for the Ambrosia Lake ores while the mill contracts were being negotiated. The initial shipment from the Dysart No. 1 mine was received soon afterwards. During 1956, the Dysart No. 1 mine produced 12,917 tons of ore containing 66,760 pounds U_3O_8 and averaging 0.26% U_3O_8 in grade (Fig. 2). The ore-buying station also provided a market for independent mine operators in the Grants-Gallup area as well as for small uranium producers in central New Mexico.

Early in 1956, two of the small companies, Sabre Uranium and Pinon Uranium, merged to form the Sabre-Pinon Corp. Previously, Pinon had acquired several railroad leases in T14N, R10W from R. D. Bokum, Jr. Sabre-Pinon entered into an agreement with the American Metal Co. Ltd. to develop orebodies on secs. 15, 23 and 25 and build a mill.

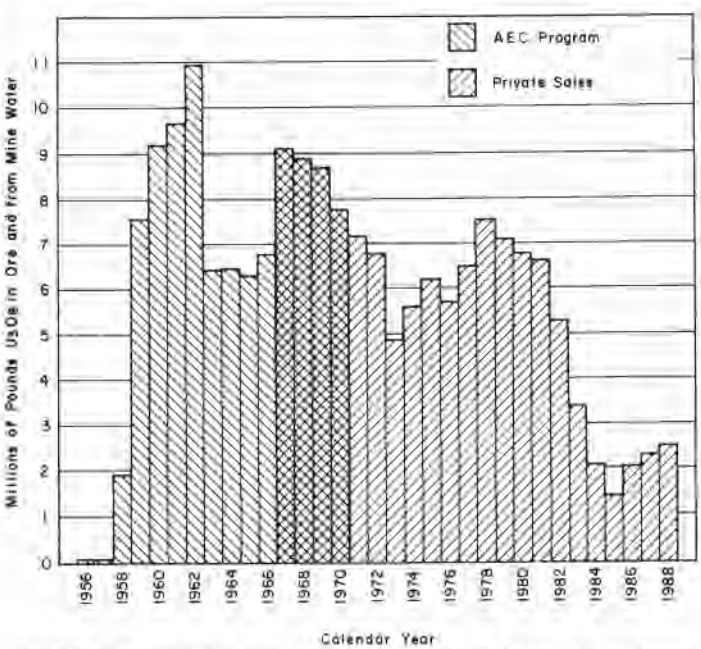

FIGURE 2. Uranium production in ore and mine water, Ambrosia Lake district (1957–1982, U.S. Dept. of Energy; 1983–1987 N.M. Energy, Minerals and Natural Resources Dept.; 1988 estimated).

After drilling a number of check holes and determining that the water table was at shallow depths, American Metals dropped its option (Holmquist, 1970). Subsequently, Homestake Mining Co. was sought as a partner by Sabre-Pinon, and the Homestake-Sapin Partners venture was formed in late 1956. Profits were to be divided as follows: Homestake 25%, Sapin 75% (Holmquist, 1970).

In August 1956, Kermac Nuclear Fuels Corp. was formed as a partnership of Kerr-McGee Oil Industries, Inc., Anderson Development Corp. and Pacific Uranium Mines Co. Kermac was the operator of properties (especially sec. 33, T14N, R9W) held by Ambrosia Lake Uranium Corp. Ambrosia Lake Uranium was a partnership among Kerr-McGee (20%), Anderson (20%), Pacific (10%), Phillips Petroleum (20%) and the Branson Estate (20%).

Late in 1956, Homestake Mining Co. formed another partnership with six limited partners. These were Rio de Oro Uranium Mines, Inc.; United Western Minerals Co.; J. H. Whitney and Co.; White, Weld and Co.; San Jacinto Petroleum Corp.; and Clyde Osborne. This partnership was known as Homestake-New Mexico Partners. In December 1956, this partnership signed a contract with the AEC to produce uranium concentrates (Albrethsen and McGinley, 1982).

Early in 1957, one mine (Dysart No. 1) was producing, and shafts were being sunk on six other sections (10, 14, 22 and 25, T14N, R10W, and sec. 32 and the Ann Lee [sec. 28] in T14N, R9W). Shafts were being planned on eight other sections (15, 23, 24 and 36, T14N, R10W and 30, 33 and the Sandstone [sec. 34] and Cliffside sec. 36, T14N, R9W), and one mill (Homestake-New Mexico Partners) was under construction (Zitting et al., 1957). Of the above listed shafts, Kermac controlled secs. 10, 22, 24, 30 and 33; Homestake-Sapin, secs. 15, 23 and 25; Homestake-New Mexico, sec. 32; Holly Uranium, sec. 14; Vanadium Corporation of America (VCA), sec. 36; and Phillips, Ann Lee, Sandstone and Cliffside (Fig. 1).

Also, in 1957 Kerr-McGee announced ore reserves of 23,000,000 tons of ore averaging 0.32% U_3O_8 in grade, with a potential for an additional 9,000,000 tons on the Kermac properties. Reserves controlled by other companies were estimated at 10,000,000 tons averaging 0.27% U_3O_8 in grade with a potential for an additional 5,000,000 tons (Zitting et al., 1957). This would be equivalent to an in-place reserve of 286,000,000 pounds U_3O_8. These reserves were based almost entirely on the gamma-ray logging of drill holes. It was later found that the factors used to calculate grades and thicknesses needed modification, and the above-listed reserves were reduced.

In April 1957, Homestake-Sapin Partners signed a contract with the AEC to produce uranium concentrates. This was followed by contracts between the AEC and Kermac Nuclear Fuels in May, and between the AEC and Phillips Petroleum in September. The two Homestake mills and the Phillips mill would use a carbonate leach–caustic precipitation process for uranium recovery. The Kermac mill would use an acid leaching process with solvent extraction, and uranium would be precipitated using ammonia (Albrethsen and McGinley, 1982). The Kermac and the Phillips mills were built in the Ambrosia Lake area (Fig. 1). The two Homestake mills were built side by side, south of the mining area, in sec. 29, T12N, R10W.

During 1957, production was obtained at Kermac's Section 10 mine and Holly Uranium Corp.'s Buckey mine (sec. 14) and VCA's Section 36 mine (Fig. 1). Total production from the Ambrosia Lake area was 70,176 pounds U_3O_8 (Fig. 2). Production by VCA in 1957 and 1958 was trucked to Durango, Colorado where the ore was processed at VCA's mill. These shipments totaled 4605 tons which averaged 0.49% U_3O_8 and 0.50% V_2O_5 in grade.

The Dysart No. 1 and the Buckey mines were in dry, firm sandstone which permitted trackless-on-ore-level mining similar to the practice used in the potash mines in the Carlsbad area. However, other companies attempting to use this mining method were plagued with serious problems and many disappointments. The problems resulted from inexperience in mining friable sandstone uranium ore lying below the water table. The mines proved to be too wet and the sandstone too incompetent to support openings without extensive timbering and extensive roof-bolting. Trackless roadways could not be maintained, and the slurry of water and sand created abrasive conditions that made the

costs of maintaining the loading and haulage equipment prohibitive. Many mines eventually went to a below-ore, tracked-drift system so that the orebodies could be drained before mining. The draining of the orebodies prior to mining also resulted in a great increase in the structural strength of the sandstone. This facilitated mining by reducing the tendency for caving. This gain in rock strength was due to the precipitation of calcium minerals in pore spaces between the sand grains. The minerals had a cementing effect on the sandstone.

As the mines were developed, initial inflows of water ranged from 200 gallons per minute in the east-central part of T14N, R10W to 800 gallons per minute in the southeastern part of T14N, R9W (Holmquist, 1970). The amount of water to be pumped would double, and even triple, as the mine workings expanded.

Early disappointments were caused by the fact that the actual geometry of the orebodies was much different when developed underground than the mapped configurations based on surface drill holes. Both the grade and thickness of the ore exposed underground were less than those interpreted from the gamma-ray logs of surface drill holes. In addition, the grade of the mined ore was lower than the sampled grade because of the dilution resulting from wet mining conditions (Kelley et al., 1968). Most of the problems were overcome later with experience, ingenuity and perseverance.

Production in 1958 increased to 1,923,447 pounds U_3O_8 as the Sections 15, 22, 32 and Ann Lee mines attained production (Fig. 2). In May 1958, Kermac let a contract to sink a 848-ft- (258-m-) deep shaft on sec. 33, T14N, R9W, and production began in August 1959. In November 1958, a contractor for Kermac began sinking a new shaft on sec. 17, T14N, R9W; the shaft was bottomed at 938 ft (286 m), and production commenced in January 1960. By the end of 1958, four mills were operating in the Ambrosia Lake area with a combined capacity of 7780 tons of ore per day. The unexpected difficulties encountered in mining the wet, friable sandstones and the resulting changes in mining methods and plans, delayed the schedules for ore production. Consequently, the mills were not able to operate at full capacity until late in 1959.

On 24 November 1958, the AEC announced that after 1 April 1962, it would purchase only uranium concentrates derived from ore reserves discovered prior to 24 November 1958. This announcement all but stopped exploration for new uranium deposits in the Ambrosia Lake area and throughout the western United States. However, development drilling continued in order to delineate the known orebodies prior to mining. The huge discoveries at Ambrosia Lake, and those made concurrently in Wyoming, were mainly responsible for the AEC reducing its uranium procurement program by issuance of the 24 November 1958 announcement. This marked a major turning point in the AEC's domestic uranium program.

Two new shafts in sec. 11, T14N, R10W began production in 1959; Entrada Oil's Mary No. 1 in the NW¼, and Rio de Oro's Dysart No. 2 in the SE¼. Also attaining initial production in 1959 were the Sections 23, 25, 30, 33 and the Sandstone mines. On 9 November 1961, Homestake-Sapin Partners acquired the assets of the Homestake-New Mexico Partners mill including its AEC contract. The New Mexico Partners mill was closed in April 1962, but portions of the circuitry were used later by the Sapin mill. The plants became known as the Homestake-Sapin complex (Albrethsen and McGinley, 1982). The United Nuclear Corp. merged into the Sabre-Pinon Corp. on 2 April 1962, and the surviving corporation was renamed the United Nuclear Corp. That corporation became the limited partner with Homestake.

The annual ore production from the mines at Ambrosia Lake continued to increase year after year. Production reached an all-time yearly high of 10,903,811 pounds U_3O_8 in 1962 (Fig. 2). These pounds were contained in 3,424,241 tons of ore which averaged 0.22% U_3O_8 in grade. Of this uranium, 59% was produced by Kermac, 20% by Homestake-Sapin, 17% by Phillips and 4% by independents. During 1962, the Dysart Nos. 1 and 2 and the Section 10 mines closed.

AEC allocations and stretch-out, 1963–1970

Yearly allocations (market quotas) for the period 1 April 1962 to 31 December 1966 were based on the reserves developed prior to 24 November 1958. Just as the allocation program was underway, the AEC announced, on 17 November 1962, a new program for the period 1 January 1967 through 31 December 1970. The AEC offered the mill operators the option of deferring a portion of U_3O_8 contracted for delivery to the AEC in the 1963–1966 period, and delivering it in 1967 and 1968. In return, during 1969 and 1970, the AEC would purchase an additional quantity of U_3O_8 equal to the amount deferred. This program, known as the "stretch-out," was participated in by all three mills (Kermac, Homestake-Sapin, Phillips) at Ambrosia Lake. Production during the first four years of the "stretch-out" (1963-1966) ranged from 6,282,460 to 6,790,800 pounds U_3O_8 per year (Fig. 2).

United Nuclear Corp. acquired the Phillips mill, mines and AEC contract in February 1963 for a reported $28 million (Holmquist, 1970). The Phillips mill was shut down in March 1963 after United Nuclear arranged to have its ore processed at the Homestake-Sapin Partners mill. By the summer of 1963, only two mills were processing Ambrosia Lake ores: Kermac with a capacity of 7000 tons per day and Homestake-Sapin with 3500 tons per day capacity (Albrethsen and McGinley, 1982).

Early in 1963, Yucca Uranium Co. conducted an in-situ leaching experiment on the Melrich orebody in sec. 32, T14N, R8W. The experiment was apparently unsuccessful as it was abandoned after a few months. This was the first attempt at in-situ leaching in the Ambrosia Lake area and in the greater Grants uranium region. During 1963, both Kermac and Homestake-Sapin Partners began to recover uranium from the water pumped from the mines. United Nuclear began mine-water recovery in 1965. Also, in 1963, both the Mary No. 1 and the Buckey mines were closed. Kermac Nuclear Fuels Corp. was dissolved in 1965, and the Ambrosia Lake operations were taken over by Kerr-McGee Oil Industries, Inc. and later the Kerr-McGee Corp.

Although the AEC permitted the sale of uranium concentrates to private firms as early as 1958, there were no sales until the mid-1960's. In 1967, United Nuclear began ore production for private sales. Sales by United Nuclear-Homestake Partners and Kerr-McGee soon followed. Kerr-McGee finished its AEC contract in 1969, and all of its production in 1970 was for private sales.

These sales, plus the stretch-out program, were responsible for increased production at Ambrosia Lake. Production rates ranged from 8,713,680 to 9,079,360 pounds U_3O_8 per year during the 1967–1969 period, but dropped to 7,781,480 pounds during 1970 (Fig. 2).

Kerr-McGee began sinking a new, 802-ft- (244-m-) deep shaft in the west-central part of sec. 30, T14N, R9W in March 1967. This mine, known as the Section 30 West, began production in 1970. Also in 1967, United Nuclear started producing from the Section 27 mine in T14N, R9W. Sinking of this 850-ft- (259-m-) deep shaft had been started in 1966; sinking of a second shaft, known as Section 27, No. 2 (Fig. 1) was started in the eastern part of the section in June 1969.

In April 1968, Homestake-Sapin Partners became United Nuclear-Homestake Partners (UNC 70%, HMC 30%). In May of the same year, Kerr-McGee began sinking the 1398 ft (426 m) deep Elizabeth shaft on sec. 35, T14N, R9W, the section between the Sandstone and Cliffside mines. A 25-ft- (8-m-) diameter production shaft west of the Sandstone shaft in sec. 34, T14N, R9W was informally named the John Billy shaft (Fig. 1). The control of the Cliffside mine reverted to Moki Oil Co. in 1968, and production temporarily ceased.

Eastward expansion of the Ambrosia Lake district occurred in the fall of 1968 with the discovery of ore at a depth of 2700 ft (823 m) in the Westwater Canyon Member on the Lee Ranch (Fig. 1) northwest of San Mateo by the Fernandez Joint Venture (Kerr Addison Mines, Noranda Mines, Amerada-Hess Corporation). Also, in the east Ambrosia area, Ranchers Exploration and Development Corporation discovered the Johnny M deposit in sec. 7, T13N, R8W in 1969. At about the same time, Kerr-McGee began developing ore on its claims in secs. 9 and 10 and on its Santa Fe lease in sec. 17, T13N, R8W.

Section 19, T19N, R9W was controlled by Stella Dysart long before the uranium boom, and during the 1920's she sold off numerous tracts, some as small as one acre, in an oil promotion scheme. In the 1960's, Kermac started acquiring these tracts, but in some cases the tracts were in litigation or divided among so many heirs that it was impossible to

gain control of them. Kermac sponsored a bill in the New Mexico Legislature to permit a unitization of the tracts so royalty could be credited on an acreage basis to the tracts that Kermac did not control. Royalties for the unknown owners would be put in an escrow fund. After the bill passed in 1969, Kerr-McGee began sinking a 779-ft- (237-m-) deep shaft near the center of the section. This mine did not produce until 1976.

In March of 1970, drilling by the Bokum Resources Corp. penetrated ore-grade intercepts at a depth of 4000 ft (1220 m) on the flanks of Mt. Taylor southeast of San Mateo. Kerr-McGee began mining at the Cliffside mine, now named the Section 36 mine, in 1970. The Cliffside workings provided access to the orebodies in adajcent sec. 1, T13N, R9W. During the same year, United Nuclear closed the Sandstone mine. In spite of the checkerboard ownership of the individual sections, not all sections with orebodies had shafts. Orebodies on ten separate sections were mined from workings in adjacent sections (Fig. 1). For example, the orebodies on sec. 29, T14N, R9W were mined from workings on adjacent secs. 30, 32 and 33 (Fig. 1).

When the AEC program ended on 31 December 1970, the mines in the Ambrosia Lake district had produced 24,014,213 tons of ore averaging 0.21% U_3O_8 in grade and containing 98,767,801 pounds U_3O_8. An additional 893,787 pounds U_3O_8 had been recovered from mine water and 64,833 pounds from the leachate from low-grade orepiles, making a total production of 99,726,421 pounds U_3O_8 (Fig. 2). With the exception of some 14,326,000 pounds produced for private sales, all of the pounds were for AEC contracts. As of 1 January 1971, Section 30 had produced in excess of 15,000,000 pounds U_3O_8, Section 22 in excess of 10,000,000 pounds and Sections 11, 23, 24, 25, 29, and the Ann Lee and Cliffside each in excess of 5,000,000 pounds. Ten other sections (1, 15, 17, 18, 20, 26, 27, 32, 33 and Sandstone) had produced over 1 million pounds each. Five other sections (10, 14, 12, 31, 36) each produced less than a million pounds.

From 1958 through 1970, the four Ambrosia Lake mills produced a combined total of 98,482,931 pounds U_3O_8 in concentrate (yellowcake) for the AEC (Albrethsen and McGinley, 1982). The AEC paid an average price of $7.74 per pound of U_3O_8 for a total price of slightly over $762 million (Albrethsen and McGinley, 1982). Besides the mines at Ambrosia Lake, the mills processed ore from mines in the Gallup area, those in the Poison Canyon trend, Todilto Limestone, Dakota Sandstone and lignite ore from North Dakota, as well as ores purchased at AEC buying stations in New Mexico and Arizona.

The private market, the beginning and boom, 1971–1979

Beginning in 1971, all uranium concentrate produced in the United States was for use in nuclear power plants for the generation of electricity. It was an open market with competition among all producers. At the beginning of 1971, the spot market price for uranium was $6.20 per pound of U_3O_8 in concentrate.

In 1971, Gulf Mineral Resources Co. acquired the Fernandez Joint Venture and the Bokum properties on Mt. Taylor and began an extensive exploration program. By 1974 the ore trends had been well delineated, and the sinking of two 3300 ft (1006 m) deep shafts, 600 ft (183 m) apart, in sec. 24, T13N, R8W, near the village of San Mateo commenced (Fig. 1). Over 120,000,000 pounds of U_3O_8 with an average grade of 0.35% U_3O_8 had been drilled out along a 6-mi- (10-km-) trend (Fig. 1).

Production at Ambrosia Lake continued to decline in 1971 and 1972, as the private market was slow to develop. The large drop in 1973 was due to a long labor strike against Kerr-McGee Nuclear Corp. (Fig. 2). Production increased in 1974 and 1975, but declined by about 500,000 pounds U_3O_8 in 1976, due to decreased production at Kerr-McGee's Sections 29, 30 and 35 mines. Although Kerr-McGee closed the Sections 22 and 33 mines in 1975, this loss of production was more than offset by new production from the Section 19 mine. United Nuclear closed the Ann Lee mine in 1973 but reopened the Sandstone mine the following year. The Johnny M mine in the eastern Ambrosia Lake area began producing in 1976. This 1380-ft- (421-m-) deep shaft is on the section line between secs. 7 and 18, T13N, R8W.

Uranium prices increased markedly in the mid-1970's, and by August 1976 were over $40 per pound of U_3O_8 in concentrate. Production at Ambrosia Lake also increased in response to a strong market and high prices. In 1977, United Nuclear-Homestake Partners began production from a new 550-ft- (168-m-) deep shaft on sec. 13 and from a new decline in the SW corner sec. 15, both in T14N, R10W (Fig. 1). Also in 1977, Spider Rock Mining Co. reopened the Ann Lee mine and began production. The next year, Cobb Nuclear Corp. reopened the Buckey mine and began production from a new shaft in the SW¼ sec. 12, T14N, R10W, in the dry bed of Ambrosia Lake. These mines would close in 1980 and 1982, respectively.

Production at Ambrosia Lake reached a post-AEC period annual high of 7,549,960 pounds U_3O_8 in 1978 (Fig. 2). The increase was short lived as prices began to fall by 1979, mainly due to an oversupply of uranium in the marketplace. In 1978, Perkins (1979) estimated that the total amount of water being pumped from the mines in the Ambrosia Lake district was between 7600–7900 gallons per minute. Some of the water was recirculated in a slurry for sand backfilling and some was used for uranium leaching operations in old stopes.

The domestic market collapses, 1980–present

In 1980, the spot market price for uranium dropped from $40 to $27 per pound of U_3O_8 in concentrate. Only long-term contracts kept the industry alive. However, some mines were forced to close. The Section 15 shaft closed in 1979 followed by the Sandstone in 1980, and the Sections 13 shaft and 15 decline in 1981. Gulf's Mt. Taylor shafts were completed in 1979, and during 1980 some high-grade ore (0.50% U_3O_8) was produced during development work. High rock and water temperatures (125–130°F) and excessive water (4000 gpm) hampered development of the orebody. Additional ore was produced during 1982, but Gulf put the mine on standby in November of that year. Kerr-McGee Nuclear began sinking the 1850-ft- (560-m-) deep Lee shaft in sec. 17, T13N, R8W in the eastern part of the area in 1980 (Fig. 1). Work on this shaft ceased in 1982.

In March 1981, Homestake Mining Co. and United Nuclear Corp. dissolved their joint milling and mining partnership, which included the mill and five mines (Sections 13, 15, 23, 25 and 32). Homestake became the sole operator of the mill and mines. In 1982, Homestake closed the Section 17, 25 and 32 mines. Also in 1982, Spider Rock closed the Ann Lee mine.

In 1983, Kerr-McGee renamed that portion of the Nuclear Corp. that operated the mines and mill at Ambrosia, the Quivira Mining Co. The following year, Quivira closed the Section 24 mine. Early in 1985, Quivira closed all of its mines in the Ambrosia Lake area, which included Sections 19, 30, 30W, 35 and 36 (Cliffside). Uranium continued to be recovered from the water pumped from the mines. With the closure of the Quivira mines, production at Ambrosia Lake in 1985 reached an all-time low of 1,401,000 pounds of U_3O_8 in ore and mine water (Fig. 2). Uranium recovered from mine water in 1985 accounted for 24% of the total production that year. Only Homestake's Section 23 mine continued producing ore in the Ambrosia Lake district.

The Chevron Corp. inherited the idle Mt. Taylor mine when it acquired Gulf Oil in 1984. Chevron Resources Co. reopened the Mt. Taylor mine in March of 1985 and began a 12-month test mining program. After a year of test mining, Chevron increased production to 600 tons per day, and the ore was shipped to the company's Panna Maria mill near Hobson, Texas, via railroad. Production in 1987 was still to be shipped to Texas, and some ore was sent to the Homestake mill for testing. In January 1988, all of the Mt. Taylor ore was being processed at Homestake on a toll basis. However, at the beginning of 1988, the only other mine operating at Ambrosia Lake was Homestake's Section 23 mine. Both Homestake and Quivira continued to recover uranium from mine water. Production at Ambrosia Lake was 2,333,184 pounds U_3O_8 (W. O. Hatchell, written commun., 1988). Some 362,000 pounds U_3O_8, or 16%, was produced from mine water. Production in 1988 is estimated to have been approximately 2,500,000 pounds, with the increase coming from mine water recovery. On 2 September 1988, Rio Algom Ltd. signed a letter of intent to purchase Quivira Mining Co. and Kerr-McGee's Wyoming uranium properties for $28.5 million (Nuclear Fuel, 1988). This sale was finalized in January 1989.

SUMMARY

During the period 1956–1988, mines in 33 sections in the Ambrosia Lake district produced 189,769,000 pounds of U_3O_8, including some 5,301,000 pounds from mine water. This amounts to approximately 19% of the domestic ore production. Currently (February 1989), there are only two mines operating. However, the district contains significant reserves which could be produced if the price of uranium increases to a satisfactory level and the market improves.

Studies by AEC engineers in the 1960's indicated that if it had not been for the checkerboard ownership in the district, the three principal ore trends in the western part of the district could have been mined by open-pit methods. In fact, the mines in these trends are now almost all interconnected by underground workings.

Grade-tonnage relationships, based on a statistical analysis of the Ambrosia Lake district, indicate that at an 0.01% U_3O_8 cutoff grade, the district contained 740,000,000 pounds U_3O_8 at an average grade of 0.06% U_3O_8 (Holen and Finch, 1982). This ranks Ambrosia Lake among the world's giant uranium deposits and, perhaps, it is the largest.

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