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SOUTH TEXAS URANIUM PROVINCE: GEOLOGY AND EXTRACTION

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CONTENTS

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The increasing demand for uranium combined with the improving economics of uranium production have resulted in a significant upsurge in exploration and mining efforts in the South Texas Coastal Plain uranium province. Texas ranks third in U.S. uranium production. Today, potentially commercial deposits have been delineated along an arcuate belt that stretches more than 250 miles from the Rio Grande into the middle Coastal Plain. The extent of these known deposits, both areally and stratigraphically, combined with the large areas that remain little explored suggest an ultimate ore reserve potential that could significantly affect the economy of the State.

HISTORY

Uranium was discovered in the Coastal Plain in 1954 when a radiometric anomaly was discovered in southwest Karnes County during an airborne survey intended to define anomalies over petroleum fields. In the flurry of exploration that followed, several significant shallow deposits were discovered. Mining commenced in 1960 and construction of the first mill by Susquehanna Western Inc. followed in 1961. Deeper, unoxidized uranium deposits were discovered by drilling in 1963, and mining of these deposits opened up the Butler-Weddington trend of western Karnes County. Ultimate production of this ore trend alone totals more than ten million pounds of U_3O_8. Susquehanna Western constructed a second mill near Ray Point in Live Oak County in 1970 to process high lime uranium ore of the Oakville Sandstone trend. In late 1973, Conquista Project (a partnership of Continental Oil Co. and Pioneer Nuclear) went on-stream and is the only surface mining and mill operation currently active in the province. A new phase of uranium extraction began in 1975 with construction of an in-situ leach mining facility by Arco-Dalco-US Steel in Live Oak County.

GENERAL GEOLOGY

Active mining operations lie along a belt that extends from southern Webb County northward to northern Karnes County (fig. 1). This trend follows the strike of the Tertiary stratigraphic units that host the uranium deposits. As shown in figure 2, several different units have proven productive, including sands within the Whitsett (Jackson) Formation of Eocene age, the Catahoula Formation of Oligocene age, and the Oakville Sandstone of early Miocene age. A few ore bodies have also been outlined in the Frio Clay and Goliad Sand. Thus, all principal upper Tertiary sand units, totaling several thousand feet in combined thickness, host uranium reserves.

The internal features of the host units are very complex. The Whitsett sands were deposited along a coastline consisting of numerous small cuspate deltas separated by barrier bars and lagoons, similar in many ways to portions of the modern Texas coastline. Ore occurs in sands of the delta river channels and barrier bars. Deposits in the overlying units occur in river channel or near-channel levee and overbank sands. Host-sand geometry is typically irregular, and the geometry of associated ore trends reflects these variations.

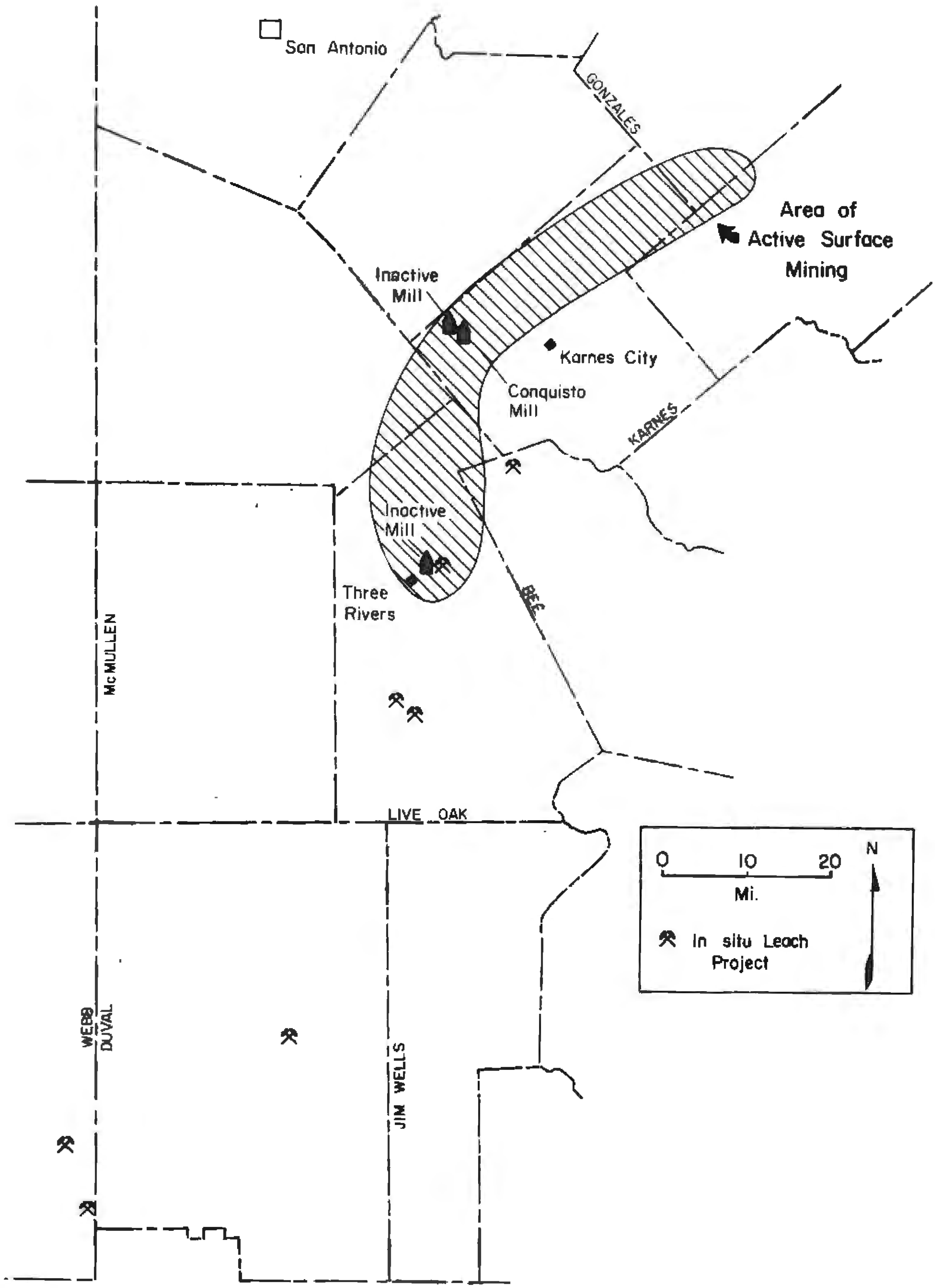

Figure 1: South Texas uranium mining operations

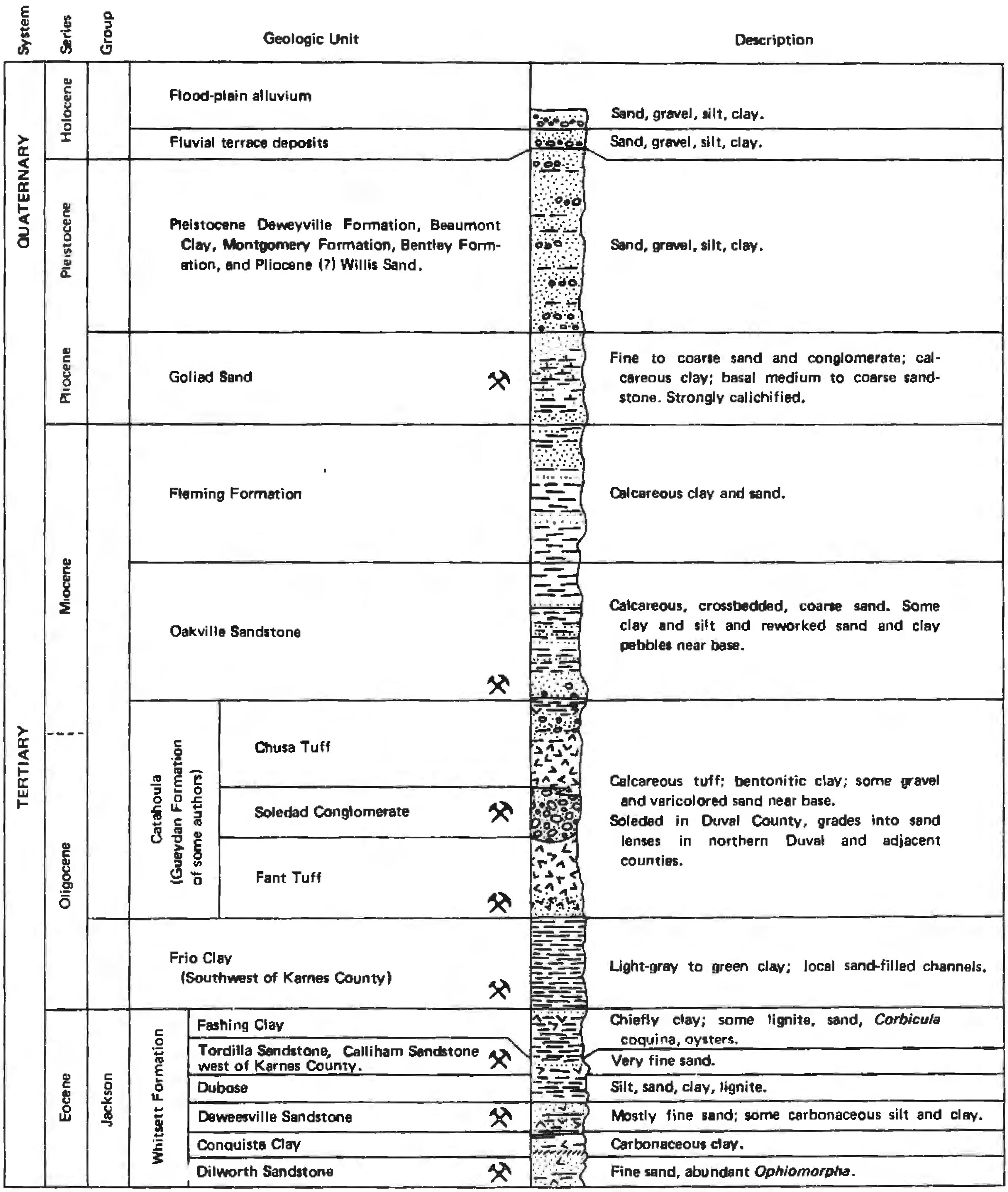

Figure 2: Stratigraphic section in the South Texas uranium province. Crossed picks indicate units from which uranium has been extracted. (Modified from Eargle and others, 1971.)

The structure is relatively simple. Beds dip gulfward at one degree or less. Faulting is prominent in the area of some deposits. Faults have modest displacement of a few tens of feet at the level of the ore hosts, but many are rooted in major fault trends that significantly affect the Cretaceous or early Tertiary section. In addition to influencing the level at which a particular sand unit may be found, faulting at least partially controls the location of some ore bodies, especially in the Oakville trend in Live Oak County.

The water table is shallow, ranging from about 50 to 100 feet below the surface. In addition, local perched water tables are present and may cause some mining problems.

CHARACTERISTICS OF THE ORE DEPOSITS

South Texas uranium ore bodies occur along laterally continuous mineralization fronts. Typically, the fronts separate areas of oxidized or altered sandstone from gray, drab areas of pyritic-reduced sediment. Length of individual, mappable fronts ranges up to several miles with commercial ore bodies strung along the front much as a series of disconnected beads along a string. Ore bodies themselves are usually elongate and sinuous; width of the ore zone rarely exceeds 200 feet and can be much less. A "C"-shaped cross-sectional geometry, the well known ore roll, is typical of many deposits, but variations are common. Where well developed, the nose of the roll points downdip into the reduced sediments.

The uranium was deposited at the transition between pregnant, oxidizing ground waters and depleted, reduced waters. Oxidizing surface water, upon entering the ground-water flow system, encountered an environment containing both intrinsic reductants, such as organic debris, and extrinsic reductants, such as hydrogen sulfide or hydrocarbon gasses, that migrated vertically from deeper horizons. As oxidants in the water were depleted, uranium solubility decreased and it precipitated along a geochemical interface. At the same time, accessory metals such as molybdenum, selenium, and arsenic precipitated.

Common accessory materials in the ore bodies include organic matter, pyrite, zeolite, clay minerals, and calcite. The abundance of each of these determines the efficiency of leaching or milling operations. Volcanic ash that is interbedded with the Tertiary units (particularly the Catahoula) provided the source of uranium.

Texas uranium ores are lean. Ore grades range from a few tenths to a few hundredths of a percent U_3O_8. Thickness of ore grade material is variable, but rarely exceeds twenty feet; most deposits are less than ten feet thick. Core analysis is necessary because the mobility of uranium and its radioactive daughter products in active aquifers, such as most of the Texas host sands, readily produces a disequilibrium between gamma radioactivity and chemical uranium actually present. Chemical uranium may be higher or lower than the amount calculated assuming equilibrium percentages of uranium and all radioactive daughters. Core analysis has turned poor shows into ore bodies (and vice versa).

MINING

Conquista Project is the only currently active surface mine operation. Uranium is removed from open pits ranging in depth from about 50 feet up to a maximum of 300 feet. Surface mining operations extend along a belt centered around the mill site and including northern Live Oak, Karnes, and southern Gonzales Counties (fig. 1). Most mines are in Whitsett sands, but some Oakville and Catahoula ore is mined. Size of individual pits is determined by the geometry of the ore body and dimensions of the lease; however, the life span of a pit rarely exceeds one year. Ore is trucked to the mill site, blended, and processed by acid leaching (fig. 3).

Reclamation

Reclamation of these pits might seem a relatively simple matter involving nothing more than pushing the overburden back into the mine. In reality, the costs of backfilling approach those of removing the overburden during the mining process. This economic strain was not anticipated when uranium sales contracts were negotiated and mining was initiated as there was no mined land reclamation law until 1975. There has been a continuing dialog between Conquista personnel and the Surface Mining and Reclamation Division of the Railroad Commission of Texas aimed at designing an economically rational reclamation plan that meets the requirements of the law. Because the language of the Texas law is more appropriate for area stripping operations than for open-pit mining, these have been interesting discussions.

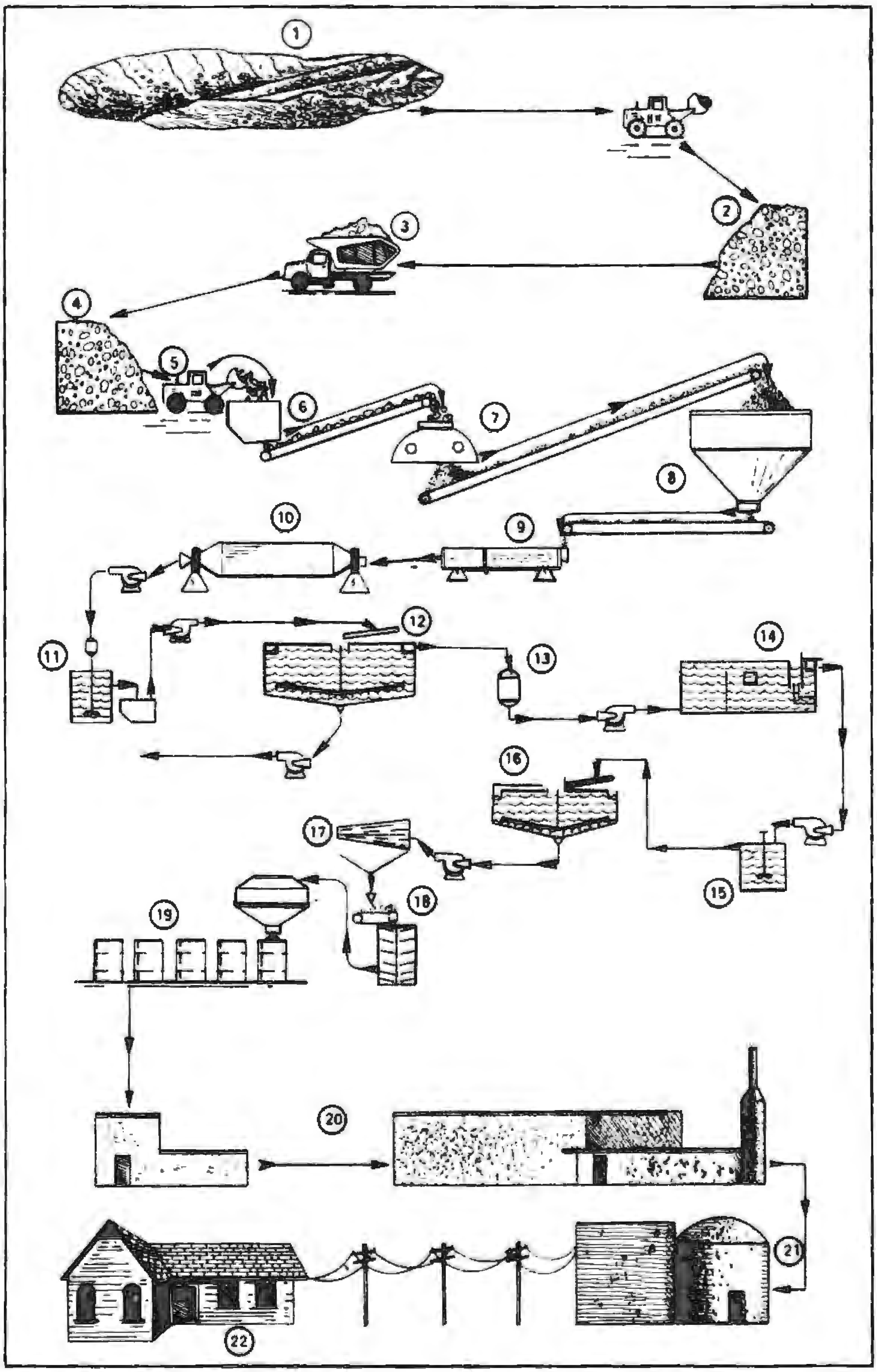

Figure 3: Conquista flowsheet

Figure 3 (see preceding page): Uranium ore from the mine (1) is stockpiled (2) then hauled over the highways (3) to the millsite stockpile (4), where it is sampled and tested. A front end loader (5) picks up the ore and drops it into a hopper and feeder (6), then to a crusher (7), and to storage bins (8). Some ores must be first treated in a roaster (9), but most ores go directly to a rod mill (10) where lumps of sand and clay are broken down by grinding with water. The pulp is pumped to leaching vats (11) where it is mixed with acid and stirred for up to 8 hours to dissolve the uranium coatings. The leached pulp then is pumped to 90 foot wooden tanks called thickeners (12) where it is allowed to settle and be washed in five steps to remove the last traces of dissolved uranium before the washed sand is discarded. The solution is clarified in filters (13) before going to the solvent extraction system (14) where organic solvents are used to extract and concentrate the uranium, which is precipitated (15), then allowed to settle in a thickener (16), dried in a centrifuge (17) and a dryer (18) before being packed in sealed drums (19) for shipment to customers. More than 95 percent of the uranium contained in the ore is recovered and saved. Uranium concentrate (yellow-cake) is purchased by large electric utilities who pay others to have it enriched and treated (20) and eventually manufactured into fuel elements which are used to power generating plants (21) where electricity is produced and distributed to homes (22) and industry.

Present reclamation plans call for grading of spoil piles to reduce slopes and revegetation of the spoil. The pits themselves would be allowed to fill with water and become lakes. Permit applications are being prepared along these lines and until the permitting process is completed, the details of reclamation techniques and standards will be somewhat uncertain.

In Situ Recovery

In addition to surface mining, seven in situ recovery projects are operative or being permitted. Locations extend from Webb County to Bee County

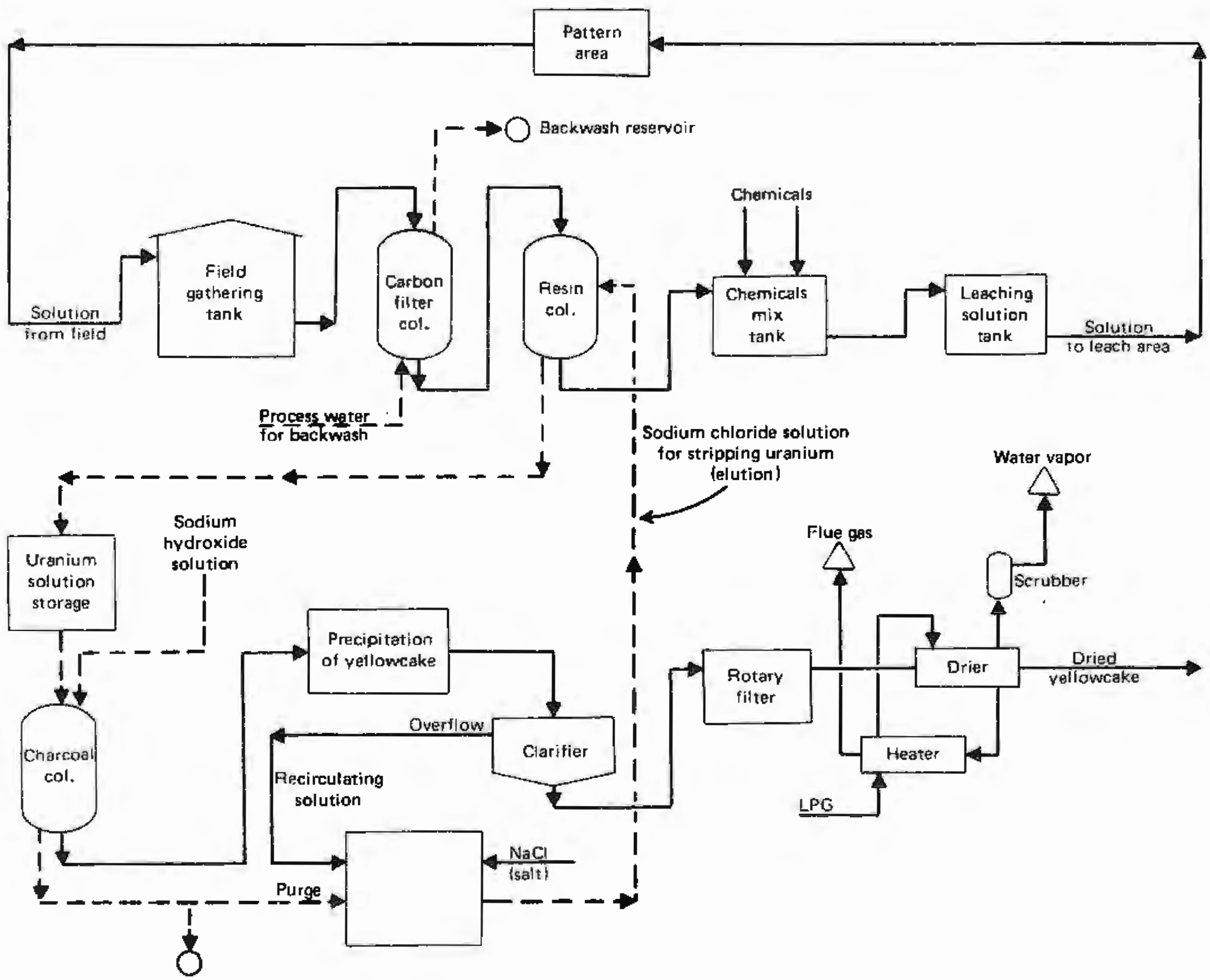

Figure 4: Schematic of a typical in situ leach facility. The leach solution includes an alkaline leach medium, typically ammonium carbonate or bicarbonate, combined with a strong oxidant, commonly hydrogen peroxide. Elution of the exchange resin utilizes sodium or ammonium chloride.

(fig. 1). The four projects in or near Live Oak County tap deposits in the Oakville Sandstone; sites to the south are in the Catahoula (2) and Goliad (1) Formations. In situ extraction of uranium combines mining and milling into a single operation (fig. 4). Uranium is extracted from the host by pumping an oxidizing alkaline leaching solution into injection wells and withdrawing the pregnant liquor through carefully located withdrawal wells. Uranium is stripped from the solution by special resins in exchange columns. Elution of the columns and precipitation of the uranium produces yellow cake ready for shipment.

In situ recovery at a commercial scale is unique to the Texas Coastal Plain. Its advantages, which include lessened surface disruption, broad range of operating depths, and portability of leach units forecast an increasing role of solution mining in development of the multiple, widely dispersed, medium to small ore bodies typical of the Coastal Plain. Environmental monitoring and permitting of leach operations is carried out by the Texas Water Quality Board.

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