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GROUND-WATER GEOCHEMISTRY AS A GUIDE TO AQUIFER INTERCONNECTION ABOVE TATUM SALT DOME, MISSISSIPPI

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ABSTRACT

Tatum Salt Dome, the site of two underground nuclear detonations in the mid 1960's, is overlain by five semi-confined to confined fresh-water aquifers of Miocene age. Differential head values in the aquifers indicate the potential for interaquifer ground-water flow, a possibility supported by the interpretation of existing ground-water geochemical data. Strontium occurs in elevated concentrations in the lowermost two aquifers overlying the dome. The presence of abundant celestite ($SrSO_4$) and strontianite ($SrCO_3$) in the salt dome caprock probably controls the solubility of Sr and indicates that there is hydrologic communication with the lowermost aquifers. Interpretation of the results of pump tests conducted by the U.S. Department of Energy supports this conclusion. In addition, these pump tests indicate some degree of hydrologic connection between the three upper aquifers. Evaluation of the available ground-water geochemical data, site geology, pump test results, and the general structural setting above this shallow salt dome indicates that faulting is the most plausible mechanism of interaquifer connection.

INTRODUCTION

Tatum Salt Dome was the site of two underground nuclear tests conducted by the U.S. Atomic Energy Commission (AEC) during the mid 1960's. Pre- and post-test hydrologic monitoring programs were established to evaluate: 1) the general hydrogeology of the site; 2) baseline ground-water geochemistry; and 3) the possibility of migration of radionuclides into the surrounding fresh water aquifers. Pump tests conducted in the aquifers over the dome have suggested the possibility of vertical connection between the porous salt dome caprock and at least one of the overlying aquifers. Hydraulic connection between the caprock and the overlying or adjacent aquifers could potentially provide a migration path for contaminants away from the dome if leakage from the salt stock occurred.

Caprock at Tatum Dome contains abundant amounts of the strontium minerals celestite ($SrSO_4$) and strontianite ($SrCO_3$), locally up to 50% (Schlocker, 1963; Saunders, 1988; Saunders et al., 1988). Because these minerals are not known to be present in the aquifers, dissolved strontium provides a natural tracer to evaluate the possibility of hydraulic connection between supradomal aquifers and the caprock. The object of the present study is to interpret available ground-water chemistry and aquifer pump test results to evaluate which aquifers may be connected. In addition, all of the available geologic logs generated from AEC drilling and earlier sulfur exploration wells of Freeport Sulphur Company were evaluated in an attempt to identify the mechanism by which the aquifers are connected.

Tatum Dome is a shallow piercement salt dome that presently lies in close proximity to fresh-water Coastal Plain aquifers that are extensively utilized in the region. For this reason, the site hydrogeology and geochemistry provide a useful case history to consider as other salt domes are evaluated as potential repositories of low-level radioactive or chemical wastes.

GEOLOGIC AND HYDROLOGIC SETTING

Tatum Salt Dome is located in Lamar County, Mississippi, approximately 22 miles southwest of Hattiesburg, within the Mississippi Salt Basin (Figure 1). The top of the caprock lies approximately 900 feet below ground surface. The dome is roughly circular in outline, and is approximately 5000 feet in diameter (Figure 1). The caprock of Tatum Dome is approximately 600 feet thick over the dome crest (Figure 2) and is lithologically zoned in a fashion similar to other Gulf Coast salt domes (e.g., Halbouty, 1979). The caprock consists of a massive anhydrite ($CaSO_4$) zone up to 450 feet thick at the base, which is overlain by a gypsum zone 2 to 20 feet thick, which in turn is overlain by vuggy and porous limestone up to 150 feet thick (Eargle, 1964; Saunders, 1988). The top of the caprock penetrates the Upper Oligocene-Miocene Catahoula Formation (Figure 2). The dome must have been close to the surface during deposition of the Catahoula, because lignite deposits with interbedded sands and clays up to 132 feet thick are locally present immediately above the caprock. No lignite is present in wells located away from the dome, which indicates that the dome influenced drainage patterns and topography locally. The Miocene Pascagoula and Hattiesburg formations overlie the Catahoula Formation, and have been arched at least 500 feet over the dome (Eargle, 1968). Sand and gravel of the Plio-Pleistocene Citronelle Formation were arched and removed from the surface above the dome by Late Pleistocene to Recent erosion (Eargle, 1968), suggesting Quaternary uplift of the salt stock occurred.

A number of aquifers have been identified adjacent to or above Tatum Dome (Figure 2). The aquifer designations used by the AEC (now U.S. Department of Energy, DOE) are: aquifer 5, within the Eocene Claiborne Group; aquifer 4, within a limestone unit of the Oligocene Vicksburg Group; aquifer 3B and 3A, within the Catahoula Formation; and aquifers 2B, 2A, 1, and Local aquifers within sands of the Pascagoula and Hattiesburg formations. In addition, the limestone caprock is

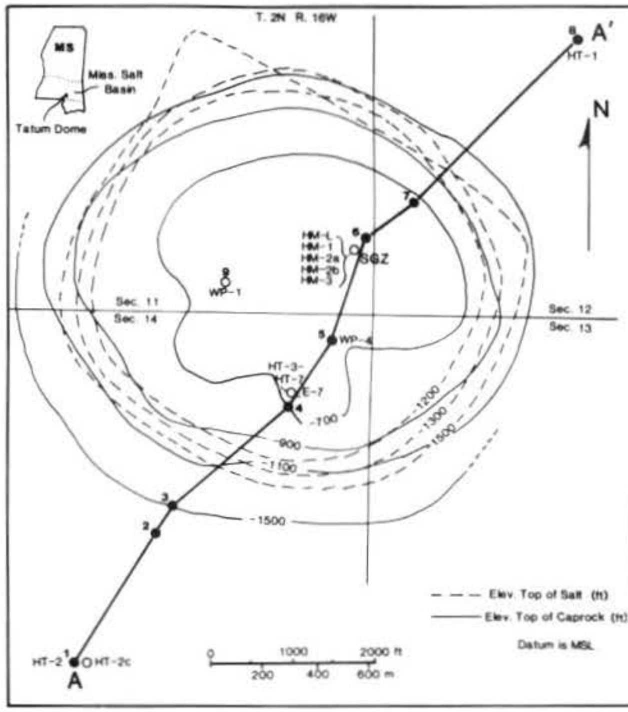

Figure 1. Well locations and structural contour map showing the configuration of the top of salt and caprock at Tatum Salt Dome, Mississippi. Location of geologic cross section A-A' is also shown. Modified from Taylor (1964) and Saunders (1988).

saturated and is referred to as the caprock aquifer. In the vicinity of Tatum Dome, the aquifers are confined and artesian. However, on a more regional scale, they apparently interfinger and coalesce to form a large interconnected aquifer system (Taylor, 1964; Fenske, 1987). Parallel declines of water levels of approximately 1 foot/year in aquifers 3, 2, 1, and the caprock at Tatum Dome have occurred since the early 1960's, reflecting the increased pumping for industrial and municipal purposes (Fenske, 1987). Fenske and Humphrey (1980) estimated that 26.4 million gallons/day are pumped from the Miocene aquifers in the general region around Tatum Dome. The regional dip of this aquifer system is approximately 40 feet per mile to the south-southwest (e.g., Eargle, 1968). The original ground-water flow was in this direction; however, present day flow in aquifers 1, 2A, 2B, and 3A is east-northeast in the direction of the high capacity wells near the towns of Purvis and Hattiesburg (Fenske and Humphrey, 1980; Fenske, 1987). Brine injection in aquifer 5 at the Baxterville oil field, six miles southwest of Tatum Dome, has reversed the flow direction in that aquifer as well (Fenske and Humphrey, 1980).

SITE HISTORY

In 1964, a 5.3 kiloton-yield nuclear device was detonated

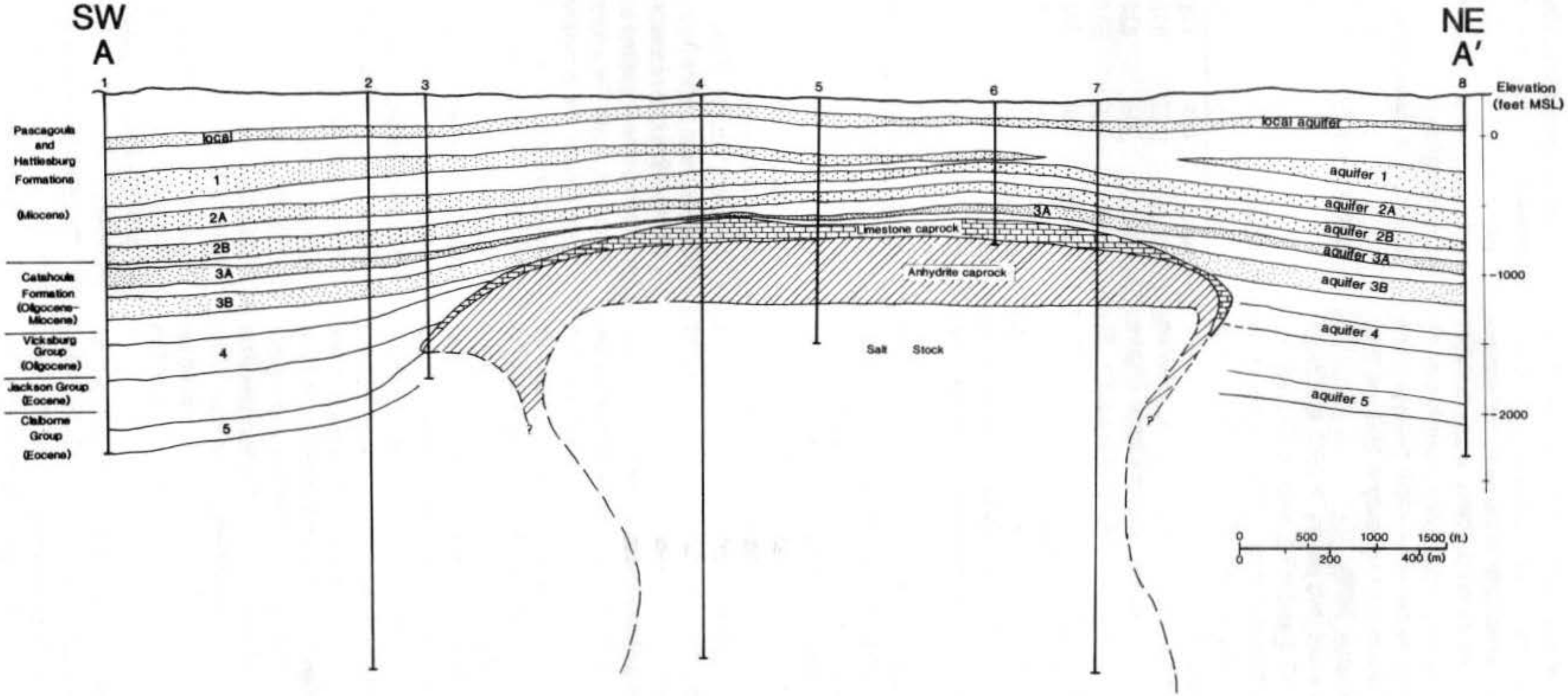

Figure 2. Geologic cross section A-A' through Tatum Salt Dome. Fresh-water aquifers are stippled. Modified from Taylor (1964).

(Salmon event) in the salt stock 2710 feet below ground surface. The explosion produced a hemispherical-shaped cavity approximately 114 feet in diameter at the base, and approximately 88 feet high at the center. In 1966, a 380 ton-yield device was detonated (Sterling event) in the cavity formed by the Salmon event. In addition, two non-nuclear gas explosions were produced in the Salmon/Sterling cavity in 1969 and 1970 (U.S. Department of Energy, 1978).

Prior to the Salmon event, two deep (> 2600 feet deep) hydrologic test holes, HT-1 and HT-2, were drilled approximately 2000 feet away from the dome in the probable updip and downdip directions, respectively (Figure 1). Pump tests were conducted on each of the aquifers penetrated and aquifer characteristics were determined. In addition, a series of wells were screened in the aquifers over the dome (Figure 1): HT-4 in aquifer 1, HT-5 in aquifer 2A, HT-6 in aquifer 2B, and HT-7 in aquifer 3A. The results of the aquifer tests conducted on these wells are summarized by Taylor (1964): "Pumping tests at the four closely spaced wells (HT-4 through HT-7) showed hydraulic communication between the aquifers. Pumping from one aquifer caused drawdown in the water level of the other aquifers."

After the Salmon event of 1964, a hole was drilled at the surface ground zero (SGZ) by the AEC into the cavity formed from the detonation. Drilling returns from this hole flowed into an unlined mud pit, apparently resulting in the release of tritium, locally exceeding drinking water standards, into the unsaturated zone below and the shallow unconfined "surficial" aquifer (U.S. Department of Energy, 1978). In light of the conclusion of Taylor (1964) that the supradomal aquifers are hydraulically connected, the State of Mississippi requested that additional wells be drilled into the supradomal aquifers in the vicinity of SGZ to verify that no radionuclides were being released from the salt dome and to provide additional data on the source of the tritium in the shallow ground water. As a result of this request, DOE drilled a series of new wells in 1979 designated HM-L, HM-1, HM-2a, HM-2b, HM-3 into the aquifers over the dome (Figure 1). Pump tests were conducted on the aquifers and an extensive water sampling program was carried out to determine the presence of any radionuclides and the general water quality of each of the aquifers. Elevated tritium values were found in the deeper Local aquifer in this study, although Fenske and Humphrey (1980) concluded that the tritium leaked from the surficial aquifer along the outer casing of one of the holes drilled in 1979. The interpretation of data generated from this program (Fenske and Humphrey, 1980) supported the earlier interpretation of DOE that no radionuclides are leaking from the dome into the overlying aquifers.

The 1979 hydrologic testing program apparently yielded different results than the earlier study reported by Taylor (1964). During the pumping of each supradomal aquifer, the water level was monitored in the other aquifers. According to Fenske and Humphrey (1980): "No obvious changes in water levels of adjacent aquifers were noted during the tests." However, the drawdown in the pumped wells (Figure 3) was very minor (< 0.4 feet), suggesting that the aquifers were not pumped at a rate sufficient to stress the aquifers. Fenske and Humphrey (1980) presented water level data for each of the aquifers (Table 1) and noted the potential for interaquifer

TABLE 1. WATER LEVELS IN WELLS OVER TATUM DOME SUMMER, 1979

WELL	AQUIFER	ELEVATION (ft MSL)
HM-L	L (local)	157.84
HT-2c	L	159.11
HM-1	1	158.50
HT-4	1	161.18
HM-2a	2A	141.04
HT-5	2A	142.08
HM-2b	2B	138.25
HM-3	3A	155.27
E-7	caprock	149.78

Reference: Fenske and Humphrey (1980).

flow based on hydraulic head differences. In addition, pumping of each aquifer resulted in a response typical of an unconfined aquifer (Fenske and Humphrey, 1980), where delayed yield comes from gravity drainage. Figure 3 is an example of this type of response for two of the pump tests, where pumping time is plotted on a log scale and drawdown on an arithmetic scale. For a homogeneous, isotropic, nonleaky, confined aquifer, the drawdown-time curve should be a straight line as predicted from the Theis nonequilibrium condition (Fetter, 1988). Fenske and Humphrey (1980) proposed that departure from the conventional drawdown response was due to one or more of the following: 1) aquifer leakage; 2) aquifer consolidation; or 3) entrainment of natural gas in the water. However, because repetitions of pump tests produced the same results, Fenske and Humphrey (1980) concluded that aquifer leakage was the most probable cause of the observed aquifer response, corroborating the earlier interpretation of Taylor (1964). If this conclusion is valid, then the lack of observable water level declines in the adjacent aquifers might have been a result of the low pumping rate relative to the available yield from the leaky aquifers.

GROUND-WATER GEOCHEMISTRY

The present study was undertaken to determine if ground-water geochemistry could be used to provide additional evidence of interconnection of supradomal aquifers, and to identify which are interconnected. To that end, available water

TABLE 2. GROUND-WATER GEOCHEMISTRY - TATUM DOME AREA

	Over Dome				Off Dome					
Well	HM-1	HM-2A	HM-2b	HM-3	HT-2c	HT1-1	HT1-2	HT2-2	HT1-3	HT1-4
Aquifer	(1)	(2A)	(2B)	(3A)	(L)	(1)	(2A+B)	(2A)	(3A)	(4)
SiO2	31	21	9.4	9.4	16	11	22	22	9.2	22
Fe (tot)	0.31	0.94	0.05	< 0.05	1.6	0.60	1.8	1.5	0.29	0.11
Ca	11	2.2	11	12	7.5	5.2	6.2	5.4	14	5.4
Mg	1.7	0.68	1.5	0.69	1.5	0.3	1.1	1.1	1.7	2.6
Sr	0.10	0.06	0.86	2.5	0.06	ND	ND	ND	ND	ND
Na	34	13	85	240	40	58	8.5	7.8	126	483
K	3.0	2.8	2.4	4.8	1.3	1.8	2.9	2.9	3.9	7.8
HCO3	73	41.5	163	400	138	154	32	27	226	613
SO4	10	10	61.0	29.0	10	7.4	9.6	10	99	1.4
Cl	19.2	3.8	13.8	178	4.1	4.5	4.1	4.5	21	412
F	0.2	< 0.1	0.65	2.5	0.02	0.0	0.1	0.0	0.9	6.0
TDS	184	96	348	880	220	243	88	82	502	1553
Temp.	25	29	32	34	22	25	26	ND	29	33
pH	6.7	6.1	7.9	7.7	7.5	8.2	6.4	6.2	7.4	8.1
SpC	185	98	510	1120	215	261	85.3	81.4	675	28900
Date	7-79	7-79	8-79	8-79	8-79	5-61	5-61	5-61	5-61	4-61
SI-cal	-1.76	-3.21	-0.21	-0.02	-0.91	-0.30	-2.62	-2.96	-0.52	0.14
SI-dol	-3.99	-6.54	-0.85	-0.84	-2.20	-1.48	-5.63	-6.27	-1.55	0.42
SI-cel	-3.58	-3.72	-1.98	-1.96	-3.80	—	—	—	—	—
SI-str	-3.36	-4.35	-0.91	-0.30	-2.54	—	—	—	—	—
SI-fl	-2.72	—	-1.87	-0.77	-2.86	—	-3.53	—	-1.50	-0.46

Note: Units for dissolved species are in mg/l

Abbreviations: ND - not determined; SI - saturation index; cal - calcite; dol - dolomite; cel - celestite; str - strontianite; fl - fluorite; SpC - specific conductance in micromhos.
Reference: Data from wells over the dome from Fenske and Humphrey (1980); Off dome well data from Armstrong et al. (1961).

quality data, principally from Armstrong et al. (1961) and Fenske and Humphrey (1980), were compiled and interpreted in light of previous hydrologic tests and the caprock mineralogy at Tatum Dome.

Aquifer 5 is the deepest aquifer penetrated by hydrologic test wells at Tatum Dome (Figure 2). It contains saline Na-Cl ground water with approximately 18,000 mg/l TDS at HT-2 and 11,000 mg/l TDS at HT-1 (Taylor, 1964). This chemical difference may reflect salt dome dissolution along the path of historic ground-water flow, or increased salinity due to the brine injection to the southwest, or both. Aquifer 4 is brackish, with a TDS content of approximately 1550 mg/l at HT-1. It is primarily a Na-HCO_3 type, but significant chloride is also present (Table 2). Analyses from aquifer 4 in HT-2 have higher chloride contents than at HT-1 (up to 522 mg/l), suggesting some degree of salt dome - ground water interaction along the probable southwesterly flow direction. No complete analyses of water in the caprock aquifer are available, but Taylor (1964) described it as saline (TDS=2530 mg/l), containing 465 mg/l Ca, 1260 mg/l SO_4, and lesser amounts of Na and Cl. No chemical data are available for aquifer 3B. Taylor (1964) concluded that aquifers 4, 3B, and the caprock are hydraulically connected because pumping of aquifer 3B and the caprock produced water level declines in aquifer 4.

All of the aquifers above the dome contain fresh Na-HCO_3 water (TDS < 1000 mg/l TDS) and are of the Na-HCO_3 type typical of many Coastal Plain aquifers (e.g., Lee, 1985). However, aquifer 3A at HM-3 contains elevated amounts of chloride compared to HT-1 (178 mg/l versus 21 mg/l), once again apparently indicating a salt dome mineralizing effect. Another obvious difference between aquifer 3A over and away from the dome is the higher temperature over the dome. At HM-3, the water temperature is 34°C compared to 29°C at HT-1 (Table 2), reflecting a thermal anomaly associated with the high heat flow of salt domes (e.g., O'Brien and Lerche, 1987a). In contrast, aquifer 2A at HM-2a over the dome is very similar to HT-2. Pumping of 2B at HT-1 produced little water and no analyses were performed exclusively on 2B off the dome. An analysis from HT-1 screened in both 2A and 2B is very similar to the 2A-only analyses, indicating that either there was only a minor contribution from 2B or that the aquifers are chemically similar away from the dome. However, over the dome at HM-2b, 2B has greater pH, TDS, sulfate, chloride, sodium, and calcium contents than off the dome. Water analyses from aquifer 1 over and off the dome are fairly similar, although the pH at HM-1, over the dome, is significantly lower than off the dome.

To further characterize the ground-water geochemistry in the vicinity of Tatum Dome, the computer program WATEQF (Plummer et al., 1976) was used to calculate the saturation indices (SI) for various minerals that are important in controlling the concentrations of dissolved species. WATEQF calculates mineral saturation indices for an aqueous solution using the chemical analysis and the thermodynamic stability data for both minerals and aqueous species. The SI is defined as log (IAP/Kt), where IAP is the ion activity product from the input chemical analysis, and Kt is the mineral equilibrium constant at the input temperature of the solution. A solution that is theoretically saturated with respect to a particular mineral will have a SI=O; SI is negative for undersaturation, and positive for supersaturation. For example, the analysis of ground water from the limestone aquifer 4 at HT-1 (Table 2) has a SI for calcite of 0.14, indicating a theoretical supersaturation with respect to calcite.

WATEQF was used to calculate SI values for calcite, dolomite, celestite, strontianite, and fluorite for water analyses over the dome, and for calcite, dolomite, and fluorite where the data were available for wells off the dome (Table 2). The SI values for the strontium minerals are particularly useful, because the caprock aquifer contains an abundance of these minerals in addition to abundant calcite and minor amounts of dolomite. Unfortunately, no data are available on the Sr content of ground water in the caprock aquifer. However, using the partial chemical analysis presented above and assuming saturation with respect to celestite, which is much more soluble than strontianite, WATEQF was used to estimate a Sr content of 22 mg/l for the caprock aquifer. Strontium values of 2.5 and 0.86 mg/l for aquifers 3A and 2B, respectively, are anomalously high compared to typical ground waters in the region. Skougstad and Horr (1963) analyzed more than 160 samples of ground water used for public water supply in the United States for strontium. They found that 60% of the samples contained less than the 0.2 ppm lower detection limit. Values reported for Mississippi and Louisiana ground waters were all less than or equal to 0.2 ppm. Although the Sr content of 2B is less than 3A, the SI values for celestite are remarkably similar, partially due to the higher sulfate content of 2B. In addition, 3A and 2B are both within 1 log unit of saturation with respect to calcite and dolomite even though the host formations are sands.

The geochemical data indicate that Sr-rich ground water migrated upward and out of the caprock and mixed with water in 3A and 2B. This apparent hydraulic connection is consistent with the hydraulic gradient between 3A and 2B (Table 1), although seemingly at variance with a lower head reported for the caprock in well E-7. However, E-7 is 1800 feet south-southwest of HM-3, and the water level of E-7 in 1961 was identical to that for HT-7 screened in 3A at that location (Taylor, 1964).

Water chemistry for 2A, 1, and the Local aquifer are generally similar both over and off the dome and are distinctly different than 3A and 2B. This chemical difference suggests that either there is no hydraulic connection between 2B and 2A or that any contribution from below is greatly diluted. Water level data (Table 1) are consistent with the former. The chemical similarity of water in 2A, 1, and the Local aquifer could indicate hydraulic connection between them, and the water levels suggest a potential for downward flow between these aquifers (Table 1).

The interpretation of the water chemistry presented here suggests that aquifers 3A and 2B are hydraulically connected to the caprock, whereas 2A, 1, and the Local aquifer may be interconnected but isolated from the lower aquifers in the vicinity of SGZ. Accepting this hypothesis, the following can explain the 1979 pump tests in the vicinity of SGZ. Pumping of aquifer 3A induced water flow from the underlying caprock; pumping of aquifer 2B induced flow from the underlying aquifer 3A and possibly the caprock; pumping of 2A induced downward flow from 1; and pumping of 1 induced flow from the Local aquifer and possibly from 2A below. However, this may only apply to the SGZ area, for the 1961 pump tests of HT-4 through HT-7 indicated hydraulic connection between all of the supradomal aquifers.

PROPOSED MECHANISM OF AQUIFER CONNECTION

Aquifer leakage above Tatum Dome could be the result of water supplied from the less permeable confining layers, either directly from storage or indirectly from water supplied by the adjacent aquifer(s) above or below. However, the rapidity and the magnitude of the departure from the ideal nonequilibrium drawdown response (Figure 3) argues for a more direct connection between aquifers. Faults are exceedingly common in formations overlying salt domes (e.g., Halbouty, 1979; O'Brien and Lerche, 1987b), and faulting appears to be the most likely source of aquifer connection above Tatum Dome.

It is difficult to evaluate the existence of supradomal faulting at Tatum Dome from the available data. Some of the arching of formations over the dome shown in Figure 2 could be interpreted as a result of faulting. In addition, the undulation of aquifer 1 between wells 4 and 5, and its apparent absence in well 7, could also be caused by faulting.

In an attempt to locate any potential faults over the dome, the geologic logs of the nine exploration wells drilled in the 1940's by Freeport Sulphur Company were evaluated along

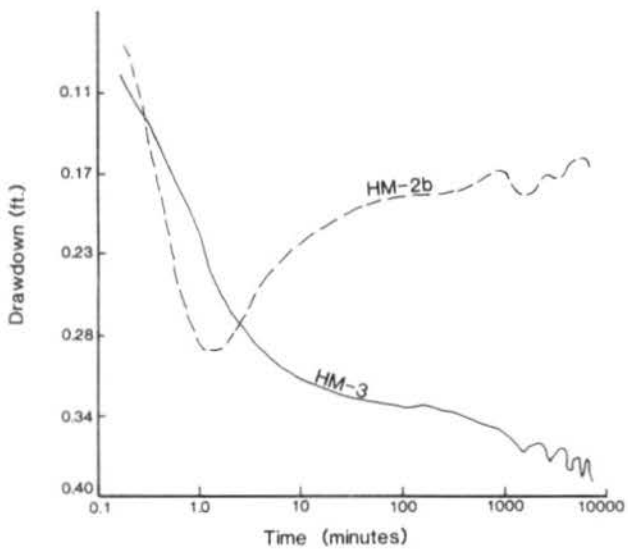

Figure 3. Semilogarithmic plot of drawdown data for pump tests of HM-2b screened in aquifer 2B and HM-3 screened in aquifer 3A. Pump discharge rates are 196.8 gallons per minute (GPM) and 192.7 GPM, respectively. From Fenske and Humphrey (1980).

with the detailed geologic logs from AEC wells WP-1 and WP-4 (Eargle, 1962a,b). The entire sequence of units above the dome consists predominantly of alternating sands and clay, and precise correlation between wells was not possible from the available data. However, the presence of lignite over the dome provides a useful and easily recognizable marker horizon. A sequence of lignite interbedded with sands and clays reaches a maximum observed thickness of 132 feet at a depth of 784-916 feet in WP-4 (Eargle, 1962b) and is absent from WP-1 approximately 1500 feet to the west-northwest. Eargle (1962b) stated "the conspicuous differences between the sections immediately above the caprock in the two holes are most probably due to faulting followed by erosion..." Lignite was encountered in four of the Freeport holes, but absent in the remainder, providing further support for Eargle's conclusion about faulting.

CONCLUSIONS

The combined geochemical, hydrologic, and geologic data support the conclusion that aquifers above Tatum Dome are interconnected by faults to varying extents. At SGZ, the caprock, 3A, and 2B aquifers are connected but separated from the overlying, apparently interconnected, 2A, 1, and Local aquifers. However, 1800 feet south-southwest of SGZ, all of the aquifers may be connected. These interpretations suggest that aquifer-fault relationships in the three dimensions are complex, as would be expected over the crest of a shallow salt dome. That being the case, additional hydrologic tests probably are necessary to fully characterize the hydrogeology in this type of setting.

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NEW PUBLICATION BY THE BUREAU OF GEOLOGY

PRELIMINARY EVALUATION OF COAL AND COALBED GAS RESOURCE POTENTIAL OF WESTERN CLAY COUNTY, MISSISSIPPI

The Bureau of Geology announces the publication of Report of Investigations 1, "Preliminary Evaluation of Coal and Coalbed Gas Resouce Potential of Western Clay County, Mississippi," by Kevin S. Henderson and Conrad A. Gazzier.

This publication describes an investigation of Pottsville Formation coalbed gas resources of western Clay County, Mississippi. The study documented the presence of four coal groups within 3700 feet of the surface. These four groups consist of as many as 17 individual seams with thicknesses varying from two to six feet. Aggregate thicknesses of all coal seams in these four groups may exceed 25 feet, with 16 feet being the average. It is estimated that the study area has bituminous coal resources in excess of 5.2 billion tons at depths shallower than 3700 feet. Using the somewhat conservative estimate of 200 cubic feet of gas per ton of coal, the total coalbed gas reserves are estimated to exceed one trillion cubic feet of gas.

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FOSSIL PALM STEM FROM BAYOU PIERRE, COPIAH/CLAIBORNE COUNTIES, MISSISSIPPI

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INTRODUCTION

In a survey of fossil (silicified) wood occurring in the Bayou Pierre drainage, Copiah and Claiborne counties, Blackwell and others (1983) reported a variety of woods, including predominantly dicotyledonous woods, but with some coniferous woods and also fossil palm being found. In contrast to the majority of the dicot and conifer petrifactions (these considered to be associated with Pleistocene pre-loess terrace gravels), the fossil palm was interpreted as having a probable derivation from the Oligo-Miocene Catahoula Formation, through which the Bayou Pierre drainage cuts. Specimens (large and small) of the silicified palm, found mixed with the fossil dicot and conifer woods, were interpreted as being reworked by stream action into the Pleistocene gravel deposits. The inclusion of palm in our paper (1983) was based on several specimens collected personally and on a larger collection of specimens from the vicinity (Copiah/Claiborne County line) donated to the authors by the Schabilion family of the Mississippi Petrified Forest at Flora, Mississippi. In essence, the occurrence of fossil palm was simply listed in the paper, and designated by the rather generalized descriptor, *Palmoxylon*.

Subsequently, Blackwell (1984) presented information on the Bayou Pierre material regarding means of determining, for fossil palm specimens found, the possible horizontal and vertical positions which they originally occupied in the stem of the once-living palm; information was also presented to assist in deciding with assurance whether or not petrified stem material discovered is in fact fossil palm (aided by Tomlinson, 1961, and Tomlinson, personal communication), as opposed to belonging to some other plant group (including other groups of monocots). It should be realized by the reader that palm "wood" is not truly wood (which is secondary vascular tissue), but is composed of a variety of tissues, the cells of which are totally of primary origin -- very much comparable to the stem tissues of a corn plant (see Tomlinson, 1967).

At the present time, it is possible in light of historical studies to make cautious statements regarding the classification (perhaps even the "systematic relationships") of fossil palm stem material found at Bayou Pierre. The study of fossil palm from Bayou Pierre (and elsewhere in the Southeast) has a long though decidedly intermittent history. In 1916, Berry presented his study of the "flora" of the Catahoula Sandstone, examined from outcrop (or outwash from outcrop) in Mississippi, Louisiana, and Texas. Berry recognized a total of seven species of *Palmoxylon*, all previously described: viz., *P. ovatum, P. mississippense, P. texense, P. lacunosum, P. cellulosum, P. remotum*, and *P. microxylon*. These species were distinguished, as viewed in microscopic cross-section, by technical features of or relating to the fibrovascular bundles, the auxiliary sclerenchyma bundles (i.e., those possessing fibers but not vascular tissue), and ground tissue features (e.g., ground tissue "expanded" and hence showing intercellular space, or else not so). Of these species, Berry listed the occurrence of only *P. cellulosum* from Bayou Pierre, a species lacking auxiliary bundles; *Palmoxylon cellulosum* had been previously described by Knowlton (1888) from Rapides Parish, Louisiana. Berry did, however, indicate the occurrence of other species of *Palmoxylon* from Mississippi, including *P. ovatum*, from Adams County. *Palmoxylon ovatum* had been described (from Mississippi) by Stenzel in his masterful monograph of fossil palms published in 1904.

RESULTS AND DISCUSSION OF CLASSIFICATION

Sectioning of the Bayou Pierre specimens available to me personally (including the Schabilion collection) did not reveal a form definitely comparable to *Palmoxylon cellulosum*. However, material quite comparable to *P. ovatum* and also to *P. lacunosum* (Unger) Felix (1883) was discovered (Figures 1-6). *Palmoxylon lacunosum* (Figures 1-4), listed by Berry (1916) from Rapides Parish, Louisiana, is distinguished from *P. cellulosum* by the presence (in *lacunosum*) of auxiliary (fibrous only) bundles, and perhaps by a greater percentage of vascular tissue in the fibrovascular bundles. *Palmoxylon ovatum* is distinguished from either (*lacunosum* or *cellulosum*) by a ground tissue lacking intercellular space (composed as it is of more or less isodiametric cells) and by apparently unitary fibrous strands (appearing as dark dots in photograph, Figures 5-6) – as opposed to either the presence of compound fibrous bundles or else the total lack of such bundles.

Since this writer has no reason to doubt Berry's determination of *P. cellulosum*, the determination being a relatively clear-cut matter, at least three species of fossil palm (*P. cellulosum, P. ovatum*, and *P. lacunosum*) seemingly occur in the Bayou

Pierre drainage (and the ultimate discovery of additional forms would not be surprising). In collections available to me, specimens identifiable as *P. lacunosum* were found to be common. The question of correspondence of any or all of these fossil palm species to extant palms is a difficult one to answer. Tomlinson (personal communication) cautions as to the unprofitability of equating most fossil palm stem section material with that of extant genera and species of palms. In spite of a great deal of recent work on palm taxonomy (e.g., Uhl and Dransfield, 1987), the systematic anatomy of palms remains clouded. The uncertainty of meaning, taxonomically, of much palm structural material relates to the potentially great internal anatomical variability of palm stems of various types, both vertically and horizontally (Kaul, 1960; Tomlinson, 1961; Mahabale, 1966) as well as to difficulties in sectioning (Kaul, 1960; Tomlinson, 1967). Reliable patterns of stem anatomy (especially ground tissue or "expanded" ground tissue patterns), if present at all, are to be sought in the very mature stem (Schoute, 1912; Kaul, 1960), i.e., toward the stem base. Because of the tropical location (inaccessibility) of most palms, and difficulties of obtaining tissue from the internal stem base even when field access to palms is gained, suitable comparative extant anatomical material is often not available.

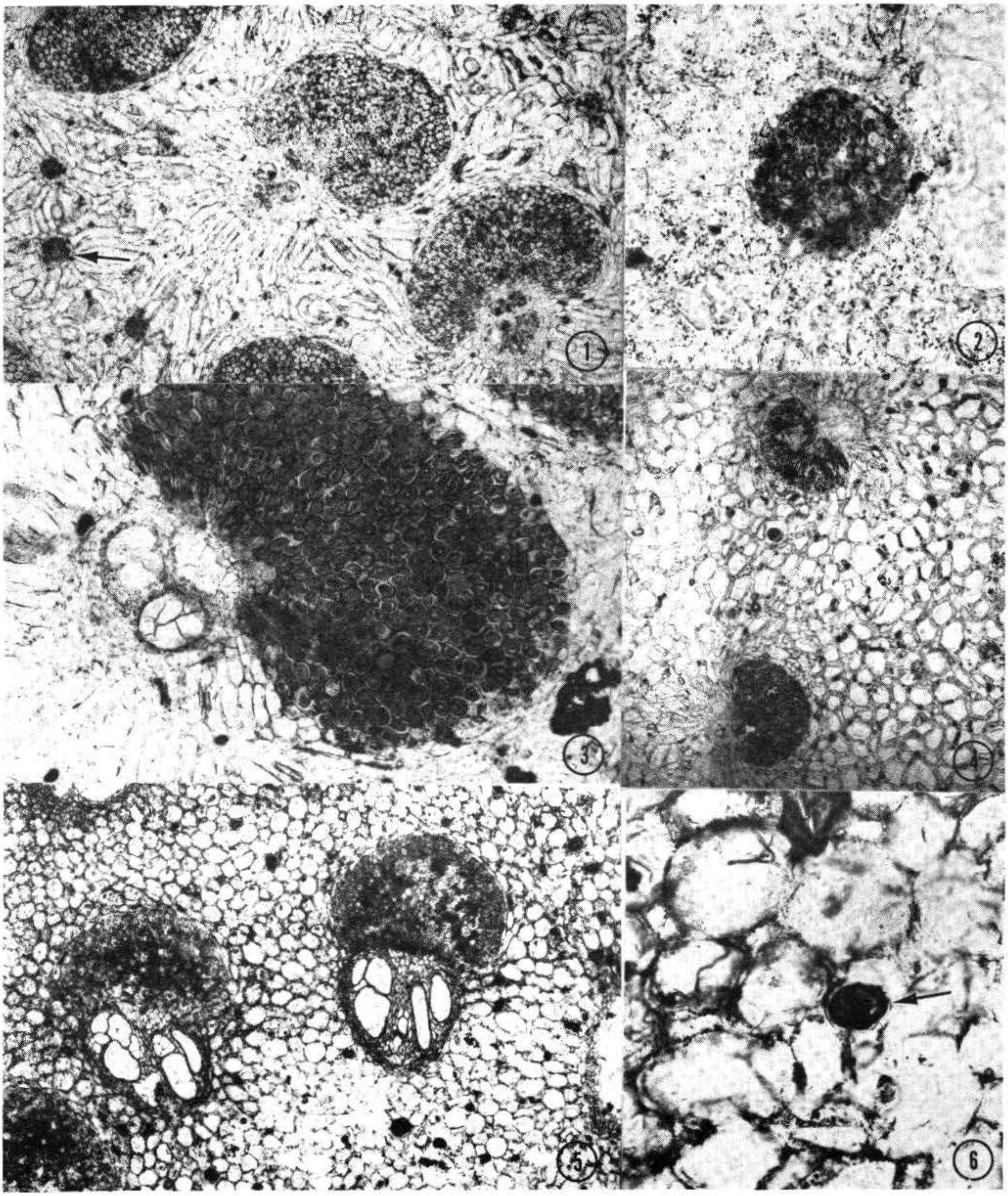
In spite of the above pessimism, it is feasible to make some suggestions as to the classification and even the relationships of specimens of petrified palm stems. In general, an artificial but nonetheless useful classification of palm stem material into three general categories, based on cross-sectional appearance, has been employed (Stenzel, 1904; Kaul, 1960; Sahni, 1964). These three categories are named broadly after palm genera considered representative of each of the categories; these are, *Mauritia*-like, *Corypha*-like, and *Cocos*-like stem cross-sectional appearances. Of the three, *Mauritia*-like stems are uncommon compared to the other two types (see Sahni, 1964). Based on fibrovascular bundle distribution and configuration, and ground tissue expansion (appearance), *P. lacunosum* and *P. cellulosum* would be considered definitely "*Corypha*-like," and *P. ovatum* would be "*Cocos*-like." Categorization of fossil palm stem specimens found at Bayou Pierre (and elsewhere) into one or more of these three general types typically presents no real problem. It is only when one attempts a much more precise identification, i.e., a true comparison to extant taxa, that great difficulty is encountered.

In consideration of various features, including reasonably abundant fibrous (auxiliary) bundles in the stem periphery (Figures 1-2), material classified as *P. lacunosum* is not inconsistent with the modern "coryphoid" genus *Washingtonia*, a desert fan palm with two species found today in western Arizona, southeastern California, and parts of northwestern Mexico. Based on a ground tissue lacking expansion, and simple fibrous strands (dark dots, as seen in cross-section, Figures 5-6), *P. ovatum* is generally comparable to stem material of *Cocos nucifera* (coconut palm). However, these statements are *not* to be construed as determinations of the true identity of *P. lacunosum* and *P. ovatum*, respectively, but rather only as tentative suggestions of similarity to extant forms. It is even more difficult to suggest what *P. cellulosum* could possibly be, especially since I have not directly observed any specimens of this taxon. However, the modern coryphoid genus *Sabal* might be considered as a possibility for eventual comparison, based on the absence of fibrous bundles in this genus (as opposed to the presence of such in *Washingtonia*). Quite circumstantially, Berry (1916) did report leaf material of *Sabalites* from the Catahoula "flora."

As alluded to earlier, it is possible to assess characteristics of petrified palm stem specimens, related but additional to their taxonomy. If, for example, one examines the photographs of *P. lacunosum*, it is perceivable, based on spacing of vascular bundles and relative expansion of ground tissue, that the specimen represented in Figure 4 is probably from a more inner portion (position) of the stem than is the specimen illustrated in Figure 1. In this regard, Kaul (1960) presents a helpful account of characteristics of different horizontal regions of a palm stem. Furthermore, the thickened walls of the fibers of the fibrovascular bundle seen in Figure 3 suggest that this specimen came from the base (very mature portion) of the stem (Tomlinson, personal communication). Hence, features observable in fossil stem pieces (specimens) may provide information as to the initial horizontal and vertical position of occurrence of these specimens in the once living palm trunk.

Legend for Figures

Figures 1-4, *Palmoxylon lacunosum*: (1) Cross-section through stem sample probably originating from outer region of fossil palm trunk (X 30); note rather closely spaced vascular (fibrovascular) bundles (one featured immediately to the left of the number one), ground tissue with limited air spaces (center-left), and auxiliary (fibrous only) bundles (one pointed out with arrow). (2) Auxiliary (sclerenchyma) bundle enlarged (X 260). (3) One vascular bundle enlarged (X 85); note large region (dark area to right) of fibers, each fiber showing a thickened wall; two large metaxylem vessels are evident to left in the bundle. (4) Cross-sectional area of specimen probably originating toward center of fossil palm trunk (X 12); note regular air spaces formed in "expanded" ground tissue between and around the more widely spaced vascular bundles. Figures 5-6, *Palmoxylon ovatum*: (5) Cross-section of sample (X 30) demonstrating the lack of air spaces in the ground tissue (composed of more or less isodiametric cells) and the unitary fibrous strands (dark dots). (6) Unitary fibrous strand (arrow) enlarged (X 260); note definitive border around strand.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GEOLOGICAL ASSOCIATION

Of the possible formations from which the fossil palm material could be associated in the Bayou Pierre drainage in Copiah and Claiborne counties, the only plausible choices seem to be either the pre-loess terraces (gravels) of Pleistocene age, or else the Oligocene or Miocene (depending on interpretation) age Catahoula Formation (Matson, 1916; Bicker and others, 1966, 1969). As in our 1983 paper (Blackwell et al.), we still favor an interpretation of association of fossil palm material with the Catahoula Sandstone. Reasons for favoring an Oligo-Miocene (vs. Pleistocene) age for the palms include: 1) Berry (1916) was able to relate all species of palms recognized in his manuscript, from Mississippi to Texas, to the Oligo-Miocene Catahoula Formation. 2) Stenzel (1904) considered *Palmoxylon ovatum* to be related to a species of fossil palm described from the Lower Oligocene or Upper Eocene of Libya. 3) Fossil palm is reported in geological horizons from the Upper Cretaceous to the Pliocene (see Mahabale, 1958; Kaul, 1960; Sahni, 1964; Daghlian, 1981). Authentic Pleistocene reports are apparently lacking; however, potential (eventually discovered) Pleistocene occurrences cannot be ruled out (since, after all, palms are very much with us in the present day). 4) The very tentative determination of *Palmoxylon ovatum* as "*Cocos*-like" would, if correct, be indicative of plants inhabiting a marine borderland environment. This environment would be more consistent with conditions possibly existing in the Oligocene or early Miocene environment of Copiah/Claiborne counties, than with Pleistocene (even Pleistocene interglacial) conditions there. In this connection, Berry (1916) considered the Catahoula "flora" in general to have coastal-tropical rather than "upland" or "inland" affinities. 5) Fossil palm, common at Bayou Pierre, is not common (Dockery, 1987) in similar Pleistocene drainages (Pleistocene gravels) in Mississippi (such as Thompson Creek) located to the north of Bayou Pierre; yet dicot and even coniferous wood is common in these drainages as it also is at Bayou Pierre (Blackwell and Dukes, 1981; Blackwell and others, 1983). Thus, a potentially different (non-Pleistocene) source for the Bayou Pierre palm would seem to be indicated. 6) Very subjectively, specimens of fossil palm examined typically bear a similarity in appearance to weathered chunks of the Catahoula Sandstone; whereas, the fossil dicot and coniferous material is quite diverse in appearance, and generally similar to that in the Thompson Creek drainage, for example. 7) I found one specimen of fossil palm immediately adjacent to and apparently weathered from an outcrop of the Catahoula at Bayou Pierre; however, it was not possible to make a definite connection in that case. To answer the question of the probable association of the Bayou Pierre palm material with the Catahoula Formation conclusively, professional and amateur collectors alike should be encouraged to be on the lookout for any specimen of fossil palm still possibly occurring in place in the Catahoula Sandstone.

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The search for knowledge is the noblest endeavor of mankind. The great strength of mind that has fueled men in the enterprise of science must never be diminished by any special definition of its goals. There is only one science and that is basic science. This means we must look at what is there to see and what the universe is about - piloting in uncharted waters, exploring, and learning.

Kevin C. Spencer
1987

Knowledge is unique in that it is our only resource that increases with use - the more we use it, the more we have.

Dixy Lee Ray
1989

MISSISSIPPI PLACE-NAMES TRIVIA

Michael B.E. Bograd
Mississippi Bureau of Geology

One interesting aspect of work at the Bureau of Geology is dealing with curious place-names. Many names come to light during our routine work throughout the state; others are spotted on old maps or on the hundreds of topographic maps we stock for sale. Still other names come to our attention when visitors inquire about names of obscure places, both extant and extinct.

Sources of information about place-names include Brieger (1980), topographic maps published by the U.S. Geological Survey, a card file at the Mississippi Department of Archives and History, several articles (Gannett, 1902; Phelps and Ross, 1952; and Mauney, 1985), and numerous articles in the state's newspapers.

This article addresses just one aspect of place-names trivia - a comparison of town names with Mississippi counties of the same name. Table 1 is a list of places that are found in the county of the same name (e.g., the town of Newton is in Newton County). Table 2 is the same thing, but the town names are some variation of the county name (e.g., Calhoun City is in Calhoun County). Table 3 is a list of places that share a name with a Mississippi county but are located in another county (e.g., places called Smith are located in Covington, Lauderdale, Newton, and Pearl River counties, but not in Smith County). Table 4 is the same as Table 3, but with spelling variations.

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Table 1. Places in County of Same Name

Attala (now Kosciusko)
Bolivar
Carroll
Coahoma
Franklin (now Meadville)
Grenada
Lauderdale
Madison
Neshoba
Newton
Panola (extinct)
Pontotoc
Rankin
Sunflower
Tishomingo
Tunica
Wilkinson
Winston (?)

Table 2. Places in County of Same Name (Variations)

Attalaville (extinct)
Calhoun City
Carrollton
Chickasaw Switch
East Lincoln
Lafayette Springs
Leakesville (now Carthage)
Madisonville (extinct)
North Carrollton
Union Hill
Warrenton
Waynesboro
West Lincoln
Yazoo Junction (extinct)
Yazoo City

Table 3. Places in County of Different Name

Adams (extinct), Pearl River Co.
Adams, Hinds Co.
Alcorn, Claiborne Co.
Benton, Yazoo Co.
Calhoun, Jones Co.
Calhoun, Newton Co.
Calhoun, Winston Co.
Choctaw, Bolivar Co.
Choctaw, Holmes Co.
Claiborne, Hancock Co.
Clay, Itawamba Co.
DeSoto, Clarke Co.
Forrest, Attala Co.
Franklin, Holmes Co.
George (extinct), Rankin Co.
George, Yazoo Co.
Humphreys (extinct), Claiborne Co.
Issaquena, Sharkey Co.
Jackson, Hinds Co.
Jefferson (now Hernando), DeSoto Co.
Jefferson, Carroll Co.
Jones (now Gift), Alcorn Co.
Jones, Chickasaw Co.
Lamar, Benton Co.
Lawrence, Newton Co.
Lee (extinct), Bolivar Co.
Lee (extinct), Jefferson Davis Co.
Leflore, Grenada Co.
Marion, Lauderdale Co.
Monroe (now Maybank), Forrest Co.
Monroe, Franklin Co.
Montgomery (now Pickens), Holmes Co.
Montgomery, Holmes Co.
Montgomery, Lincoln Co.
Perry (extinct), Stone Co.
Prentiss (extinct), Bolivar Co.
Prentiss, Jefferson Davis Co.
Quitman, Clarke Co.
Rankin, Holmes Co.
Scott, Bolivar Co.
Sharkey, Tallahatchie Co.
Smith, Covington Co.
Smith, Lauderdale Co.
Smith, Newton Co.
Smith, Pearl River Co.
Stone (extinct), Neshoba Co.
Stone or Stone's Switch (extinct), Chickasaw Co.
Stone, Panola Co.
Tallahatchie (extinct), Panola Co. - named for river
Tate (extinct), Pearl River Co.
Union (extinct), Simpson Co.
Union (now Friar's Point), Coahoma Co.
Union, Greene Co.
Union, Jones Co.
Union, Lee Co.
Union, Newton Co.
Walthall (Gatewood), Yalobusha Co.
Walthall, Webster Co.
Washington (now Neely), Greene Co.
Washington, Adams Co.
Webster, Winston Co.
Wilkinson (extinct), Lincoln Co.
Yalobusha, Leflore Co. - named for river

Table 4. Places in County of Different Name (Variations)

Calhoun Station (now Gluckstadt), Madison Co.
Carrollville (extinct), Prentiss Co.
Clayton, Tunica Co.
Claytown, Winston Co.
Forreston (extinct), Lowndes Co.
Georgetown, Copiah Co.
Georgeville (extinct), Holmes Co.
Grenada Junction (extinct), Leflore Co.
Holmesville, Pike Co.
Ittawamba (extinct), Marshall Co.
Jackson Landing, Pearl River Co.
Jackson Springs (extinct), Lauderdale Co.
Jackson's Point (extinct), Coahoma Co.
Jacksonville (extinct), Kemper Co.
Jones Crossing, Holmes Co.
Jones Mill, Harrison Co.
Jonesboro (now Chalybeate), Tippah Co.
Jonestown, Coahoma Co.
Jonestown, Warren Co.
Leake's Switch (extinct), Covington Co.
Leakesville, Greene Co.
Marion Landing (now Sidon), Leflore Co.
Newtonville (extinct), Attala Co.
North Union, Attala Co.
Old Union, Lee Co.
Perryville (now Bryant), Yalobusha Co.
Pikeville (now Egypt), Chickasaw Co.
Piketon, Scott Co.
Sunflower Landing (extinct), Coahoma Co.
Union Church, Jefferson Co.
Union Hall, Lincoln Co.
Uniontown (extinct), Jefferson Co.
West Union, Attala Co.
Winstonville, Bolivar Co.
Yazoo Pass (now Rich), Coahoma Co.

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