Tertiary Coals in South Texas: Anomalous Cannel-Like Coals of Webb County (Claiborne Group, Eocene) and Lignites of Atascosa County (Jackson Group, Eocene) - Geologic Setting, Character, Source-rock and Coal-bed Methane Potential

FIELD TRIP GUIDEBOOK

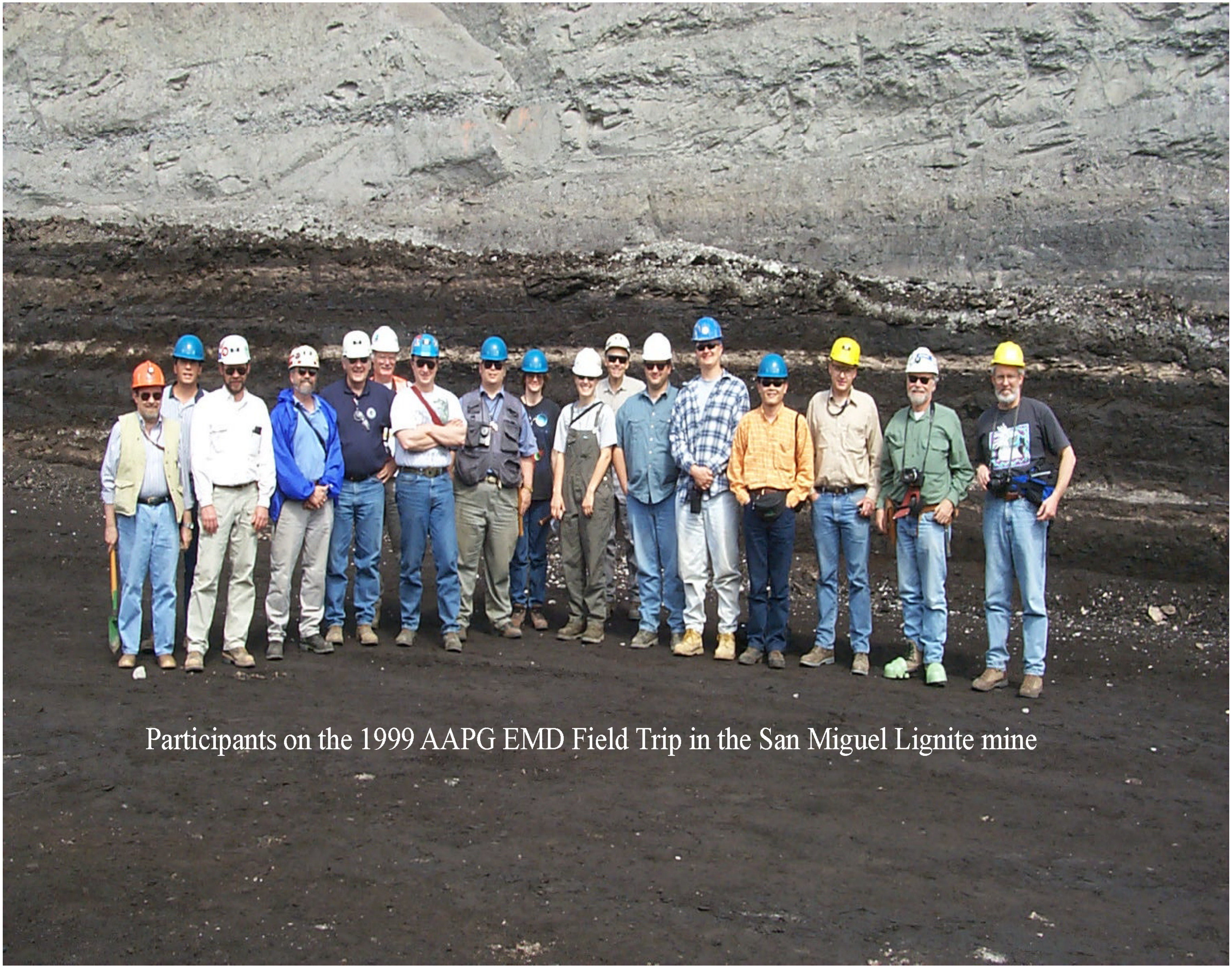
The 1999 AAPG Annual Convention
Energy Minerals Division
Field Trip # 15

April 14-15, 1999

Field Trip Leaders:
Peter D. Warwick, U.S. Geological Survey, Reston, VA
Robert W. Hook, Consultant, Austin, TX
John R. SanFilipo, U.S. Geological Survey, Reston, VA

Edited by P.D. Warwick, C.E. Aubourg, and J.C. Willett

U.S. Geological Survey Open-File Report 99-301



Participants on the 1999 AAPG EMD Field Trip in the San Miguel Lignite mine

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Introduction

Tertiary coals in South Texas: Anomalous cannel-like coals of Webb County (Claiborne Group, Eocene) and lignites of Atascosa County (Jackson Group, Eocene) (AAPG - EMD Field Trip, April 14-15, 1999)

By Peter D. Warwick, Robert W. Hook*, and John R. SanFilipo

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The coal-bearing Gulf of Mexico Coastal Plain of North America contains a variety of depositional settings and coal types. The coal-bearing region extends westward from Alabama and Mississippi, across Louisiana to the northern part of the Mississippi Embayment, and then southward to eastern Arkansas, Texas and northern Mexico (fig. 1). Most of the coal currently mined in Texas is lignite from the upper part of the Wilcox Group (Paleocene-Eocene) and, in Louisiana, lignite is mined from the lower part of the Wilcox (fig. 2). Gulf Coast coal is used primarily as fuel for mine-mouth electric plants. On this field trip we will visit the only two non-Wilcox coal mining intervals in the Texas-Louisiana Coastal Plain; these include the San Pedro - Santo Tomas bituminous cannel-like coal zone of the Eocene Claiborne Group, and the San Miguel lignite coal zone of the Eocene Jackson Group (fig. 2). Other coal-mining areas in northern Mexico are currently producing bituminous coal from the Cretaceous Olmos Formation of the Navaro Group (fig. 2).

The Claiborne-Jackson coal-bearing intervals of south Texas are very different from the Wilcox coal-bearing intervals found in central and northeastern Texas and northwestern Louisiana. The cannel-like coal deposits of south Texas are unique and are one of the few mined cannel-like coal deposits in the world. This field guidebook contains papers that focus on the regional geologic setting of south Texas (Chapter 1), and papers on the Santo Tomas and San Pedro coal deposits and San Miguel lignite deposits (Chapters 2 and 3). Finally, there is an overview paper on the anomalous coal-rank changes of south Texas, and a discussion of the source-rock and coal-bed methane potential for the south Texas coal fields (Chapter 4).

The field trip will visit two active mines in South Texas and will provide the participants an opportunity to observe the mining operations and coal geology of the surface mines. The older Claiborne Group coals that occur near the U.S.-Mexico border (fig. 1), are long-known for their cannel-like character and will be seen in workings of the Farco Mining Company. These unusual nonbanded coals have high calorific values (3800 to 6000 kcal/kg or 6800 to 10,800 btu, dry basis) and substantial oil and gas yields upon distillation. Recent petrographic and geochemical investigations have shown that these coals are bituminous in rank, hydrogen

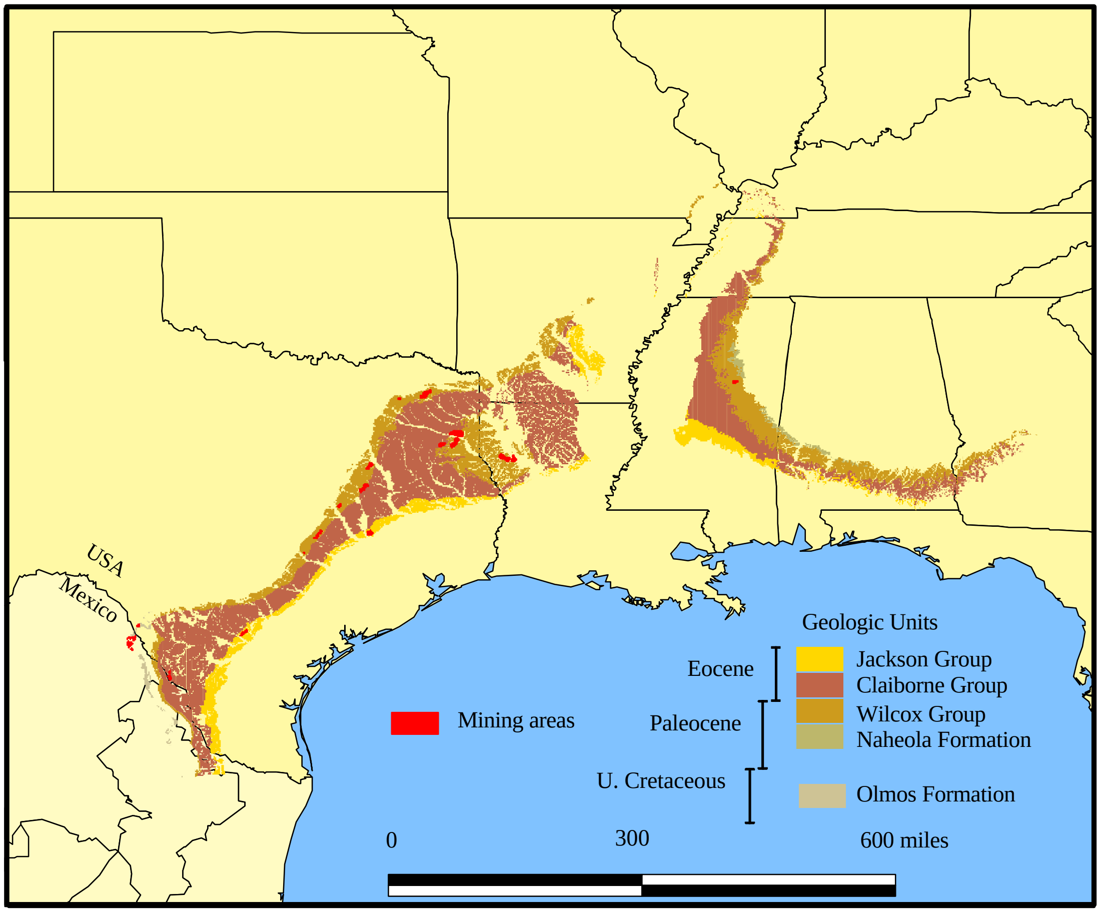

Figure 1. Map showing outcrop of coal-bearing formations in the U.S. Gulf of Mexico coastal area. Active, recent and proposed mining areas are shown in red.

rich, contain abundant green algae remains, and are potential sources of hydrocarbon. The field trip leaders will discuss the depositional setting, petrology, geochemistry, and regional geology of these coal deposits.

The lignites of the San Miguel deposit (Jackson Group, Eocene), differ greatly from the coals of the border area. Four principle lignite beds comprise the San Miguel deposit. The beds are separated by reworked volcanic ash partings (generally less than 0.25 m or 0.75 ft thick). Drill records and in-mine studies indicate that these lignites were deposited in environments that were partially marine influenced. The geochemistry and depositional setting for these lignites, and regional South Texas/Northeastern Mexico coal geology will be discussed. The field trip will spend the first night in Laredo, a U.S.-Mexico border town, and will visit the two surface mines the next day.

ITINERARY

This is a tentative schedule based upon ideal weather and traffic conditions.

<u>Wednesday, 14 April</u>

4:30 PM - depart H.B. Gonzalez Convention

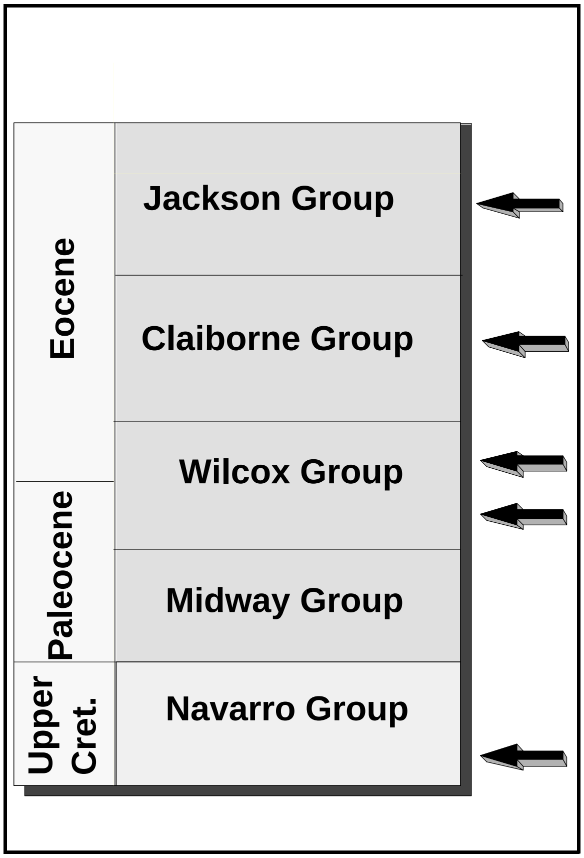

Figure 2. Simplified stratigraphy of coal-bearing intervals in the U.S. Gulf of Mexico Coastal Plain. Arrows indicate stratigraphic position of major coal-bearing intervals.

Center in San Antonio for Laredo, a nonstop drive of approximately 2.5 hours.

7:00 PM - check-in at La Posada Hotel, downtown Laredo.

7:30 PM - short (less than 30 min.) meeting at La Posada. We will provide an overview of South Texas coal geology and give suggestions for dinner.

<u>Thursday, 15 April</u>

7:00 AM - depart La Posada for Palafox, an approximately 30 minute drive.

8:00 AM - arrive at Farco Mining's Palafox Mine Office. David Wadsack and Gustav Holm, hosts. Safety training in office.

Stop 1: Trevino Mine. Observe San Pedro Coal (Bigford Formation) and overlying tidal deposits. Discuss unique mining methods.

Stop 2: Palafox Mine. Observe San Pedro Coal, overlying sandstone and mudstone deposits, and thin coal seam.

Stop 3: Coal yard. Discuss coal preparation and utilization.

10:30 AM - return to Farco office for convenience stop; depart for San Miguel Mine at 10:45 AM.

Optional Stop A: FM 1472 roadcut east of Santo Tomas. Observe coastal-barrier facies in El Pico Clay (10 minutes).

12:15 PM - lunch stop (30 minutes), Picnic Area south of Cotulla at Mile Marker 59 on I-35 North. This is a no-toilet rest area.

1:00 PM - convenience and gas stop (15 minutes) at Mobil station in Cotulla at junction of Business I-35 and Texas Route 97.

2:15 PM - arrive North American Coal's San Miguel Mine Office. Roger Fish, Engineering Manager, host. Safety certification and mine overview at office.

Stop 4: E area final pit. Observe completed highwall exposure of Jackson Group from spoil bank. Discuss lithofacies overlying coal, ash disposal, and reclamation methods.

Stop 5: E area, active pit. Observe coal seams and splits, discuss unique mining methods.

Optional Stop B: B area.

4:30 PM - depart San Miguel Mine for San Antonio.

OTHER INFORMATION

Both Farco Mining and North American Coal require hard hats, safety glasses, and steel-toe boots.

Exercise extreme caution at all times when on mine property. *Do not approach highwall exposures without the consent of company personnel.*

Coal sampling and photography are permitted by both operators. Later publication of coal-quality data or mine photographs requires company consent and acknowledgment.

We will stop at a mandatory U.S. Border Inspection station north of Laredo on Thursday morning. *No illegal substances or firearms should be on your person or in your belongings.* Non-U.S. citizens should have the appropriate travel papers available for presentation.

CHAPTER 1

Regional geologic setting of South Texas and the Santo Thomas coal deposits

By Thomas E. Ewing

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INTRODUCTION

This paper supplements the work that the U.S. Geological Survey has recently conducted in South Texas on the coal geology of the Eocene Claiborne Group of the Laredo area (Warwick and Hook, 1995) and the Jackson Group of the San Miguel lignite mine area (Warwick and others, 1996). I will first present a general overview of the trip route in relationship to the major structural and stratigraphic features of South Texas. Then I will present subsurface well log data to show the correlation of the coal zones into the subsurface, and place them in a regional context.

GENERAL OVERVIEW OF THE FIELD TRIP ROUTE

When we leave San Antonio, we will proceed southwest along Interstate 35 towards the city of Laredo. San Antonio is an oasis city, built around springs and deep wells drawing water from the Lower Cretaceous Edwards Aquifer along the (Miocene-age) Balcones fault zone. The city is built on rocks ranging in age from Albian (Edwards Limestone) to Paleocene (lower Wilcox Group), with younger rocks generally to the southeast.

Tectonically, the San Antonio area lies on the southwest flank of the San Marcos Arch (fig. 1), a broad southeast-trending area of lesser subsidence than surrounding areas during Mesozoic and Cenozoic time. During the Early Cretaceous, the area was repeatedly occupied by extensive carbonate platforms (the Sligo Limestone of Aptian age and the Edwards Group carbonates of Albian age; fig. 2). As regional sedimentation shifted from carbonates to siliciclastic material in the Late Cretaceous (Campanian - Maastrichtian), the San Antonio area lay east of the major San Miguel and Olmos wave-dominated deltas of South Texas, and mainly marine shales and thin sandstones were deposited. In the Paleogene, Wilcox, Carrizo and younger sandstones were deposited in the San Antonio area, which lay in the transition between the largely strike-oriented strandplain, wave-dominated delta and bar - lagoon systems of South Texas and the fluvial-deltaic deposits of East Texas.

As we drive southwest toward Laredo, we cross the Rio Grande Embayment, a broad synclinal area between the San Marcos Arch of Central Texas and the Laramide fold systems of Mexico (fig. 1). The present Rio Grande flows along the southwest side of this embayment. The road slowly climbs the stratigraphic section, reaching the late middle Eocene ("Laredo Formation," Sparta and Cook Mountain equivalent; fig. 2) at Laredo. South of Cotulla (fig. 1), the road crosses the buried Stuart City Reef margin of the Edwards Group carbonate platform. The reef margin is gas-productive, and also controls faulting and

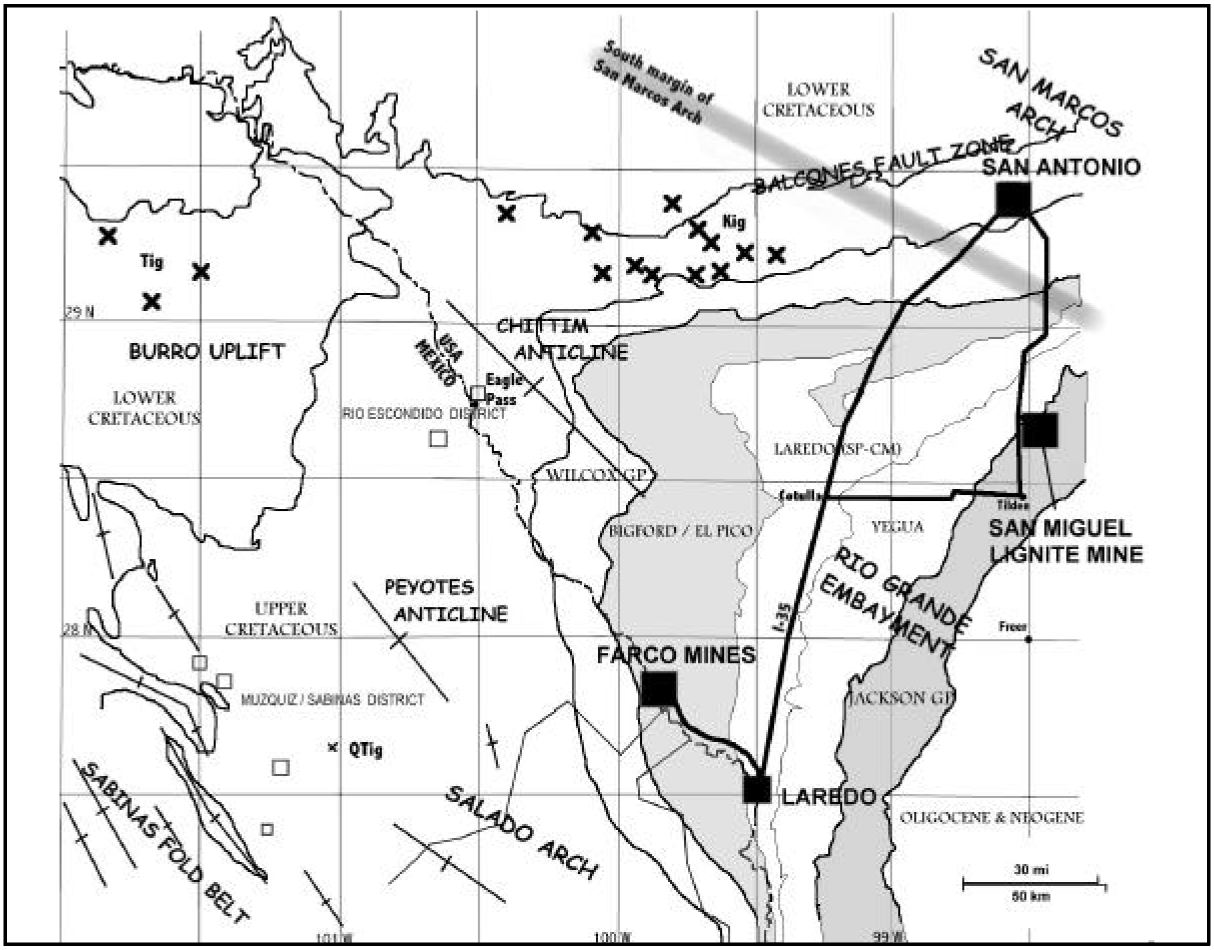

Figure 1. Route of the 1999 EMD field trip, with major tectonic features and outcrop belts shown. Open boxes represent locations of Upper Cretaceous coal deposits; "X" represents igneous rocks; Kig, Tig, QTig = Cretaceous, Tertiary, and Quaternary igneous rocks.

shallower marine sandstone development in the Olmos Formation. At Laredo, the position of the buried Sligo reefal shelf margin is reached. This reef contains a major gas field just across the river in the western part of Nuevo Laredo (Totonaca field) at depths of some 13,000 ft.

Jose de Escandon founded Laredo, the chief port of entry from Mexico into Texas, in the 1750s as the northernmost city of the new province of Nuevo Santander (the lower Rio Grande valley). The early trade routes from Monclova to San Antonio passed north of the Laredo area, but the location of Laredo on the shortest route from Monterrey to San Antonio, coupled with the main rail links to both cities and to the port of Corpus Christi, ensured Laredo's economic growth.

Laredo, and the Santo Tomas district to its northwest, lie on the southwest flank of the Rio Grande Embayment. Dips are generally one degree or higher to the east in outcrops near the river. Southwest into Mexico, the dips continue until the base of the

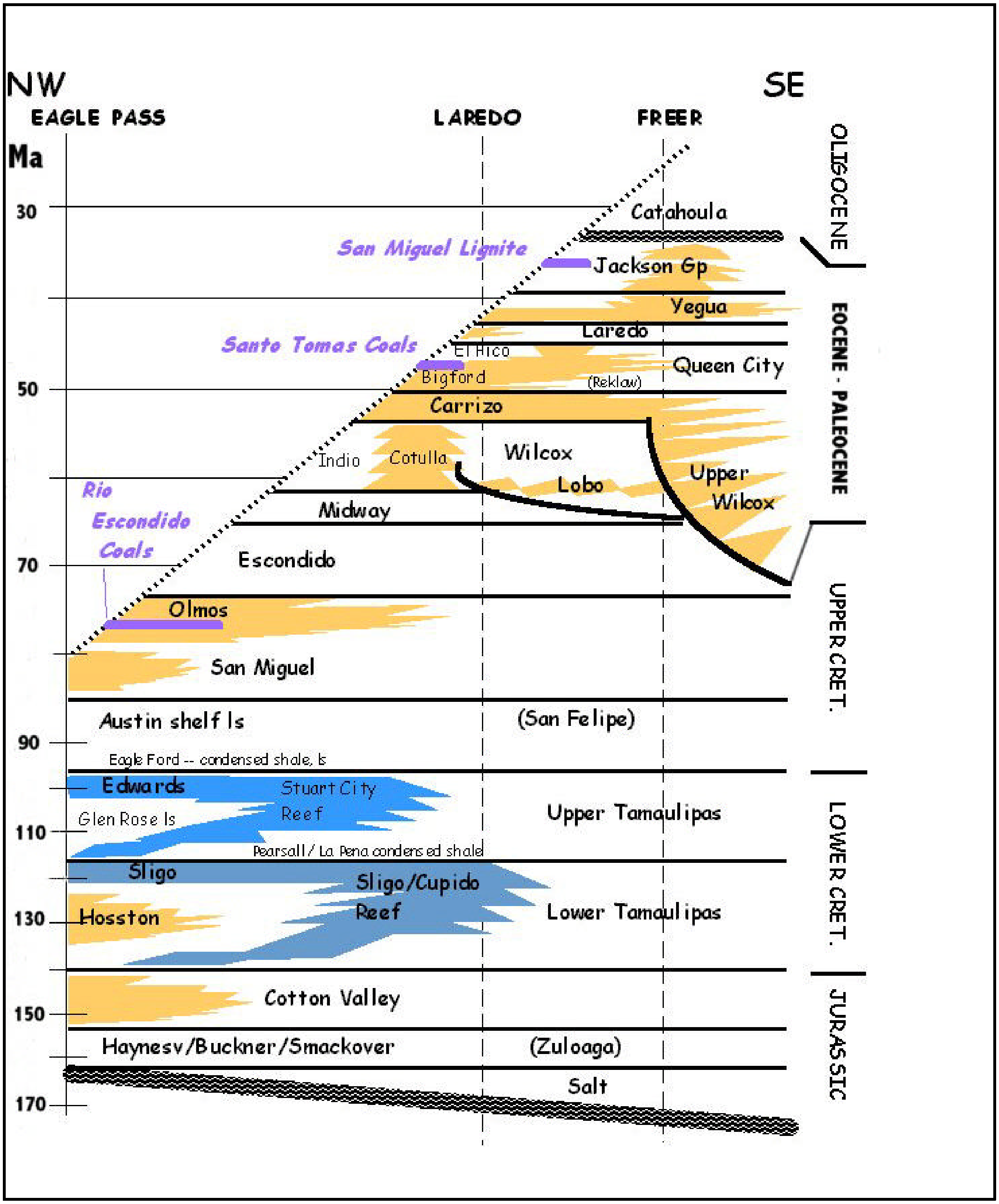

Figure 2. General northwest-southeast stratigraphic section of Mesozoic and Paleogene strata along the Rio Grande, from Eagle Pass to Freer (fig. 1). The stratigraphic location of significant coal and lignite deposits are shown.

Tertiary outcrops about 12.5 mi into the interior. Several anticlinal axes, collectively referred to as the "Salado arch" or the "Burro-Peyotes arch", trend southeastward, with intermittent exposures of Austin limestone on anticlines. The east to northeast dip off the flanks of the arch towards the Rio Grande is easily visible on satellite photography. Secondary folds are seen in some areas.

After visiting the Santo Tomas area, we will travel back to the north to Cotulla, turning east to Tilden, then north to the San Miguel lignite mine (fig. 1). The trip east from Cotulla to Tilden proceeds over younger rocks than any other part of the trip. Sandy Yegua Formation deposits are overlain by the lignite-bearing Jackson Group. The hills east of Tilden are underlain by the largely volcaniclastic Catahoula (or Gueydan) Formation of Oligocene age. Zeolites have been mined from the basal Jackson strata just west of Tilden, and used as kitty litter. North of Tilden, we cross San Miguel Creek (with natural lignite exposures in its banks) and proceed to the San Miguel mine. After this classic Gulf Coast lignite deposit is viewed, we will travel back to San Antonio across Eocene and Upper Cretaceous rocks.

STRUCTURAL AND STRATIGRAPHIC SETTING OF THE SANTO TOMAS DISTRICT

The coal beds of the Santo Tomas district lie within the Bigford Formation - El Pico Clay succession of the Rio Grande Embayment. These two formations correlate with the Queen City cycle of the Claiborne Group, and are early Middle Eocene in age (fig. 2). In South Texas, the Queen City sandstones were deposited in a mixed wave-dominated deltaic and barrier bar environment, with a strike-oriented sandstone maximum in eastern Webb County about 30 miles east of Santo Tomas (Guevara and Garcia, 1972). Northwest of the sand maximum, the upper part of the cycle contains a low percentage of sandstone and much lagoonal shale; this has been called the El Pico Clay by Eargle (1968). The lower part of the cycle contains high percentages of sandstone (Bigford Formation as redefined by Eargle from Trowbridge, 1923), and rests directly on the Carrizo Formation and upper Wilcox sandstones with very little break. The downdip marine Reklaw formation passes westward into the Bigford shoreline sandstones.

The contact between Bigford Formation and El Pico Clay is gradational. Sandstones do occur in the El Pico "Clay", and may become more abundant northward away from the Rio Grande. The transitional beds between Bigford and El Pico are intimately associated with the San Pedro and Santo Tomas coal zones, as we will see.

To better understand the location of the Santo Tomas coal deposits within the stratigraphic section, a pilot study was undertaken of well logs in the area around and east of the mines. The area has been extensively drilled for gas reserves in the Wilcox Group sandstones (Palafox field) and in the Olmos Formation (Las Tiendas, Booth Ranch, and La Cruz fields); gas has also been found in reefal Edwards carbonates in Galan field, just south of the Rachal Mine (fig. 3). Many of these well logs have been released, and most were logged to within a few hundred feet of the surface. A regional shale which correlates to the Middle Wilcox can be identified on all logs, and forms a good structural datum. The structure map (fig. 3) shows structural dip of 1.0-1.4 degrees to the

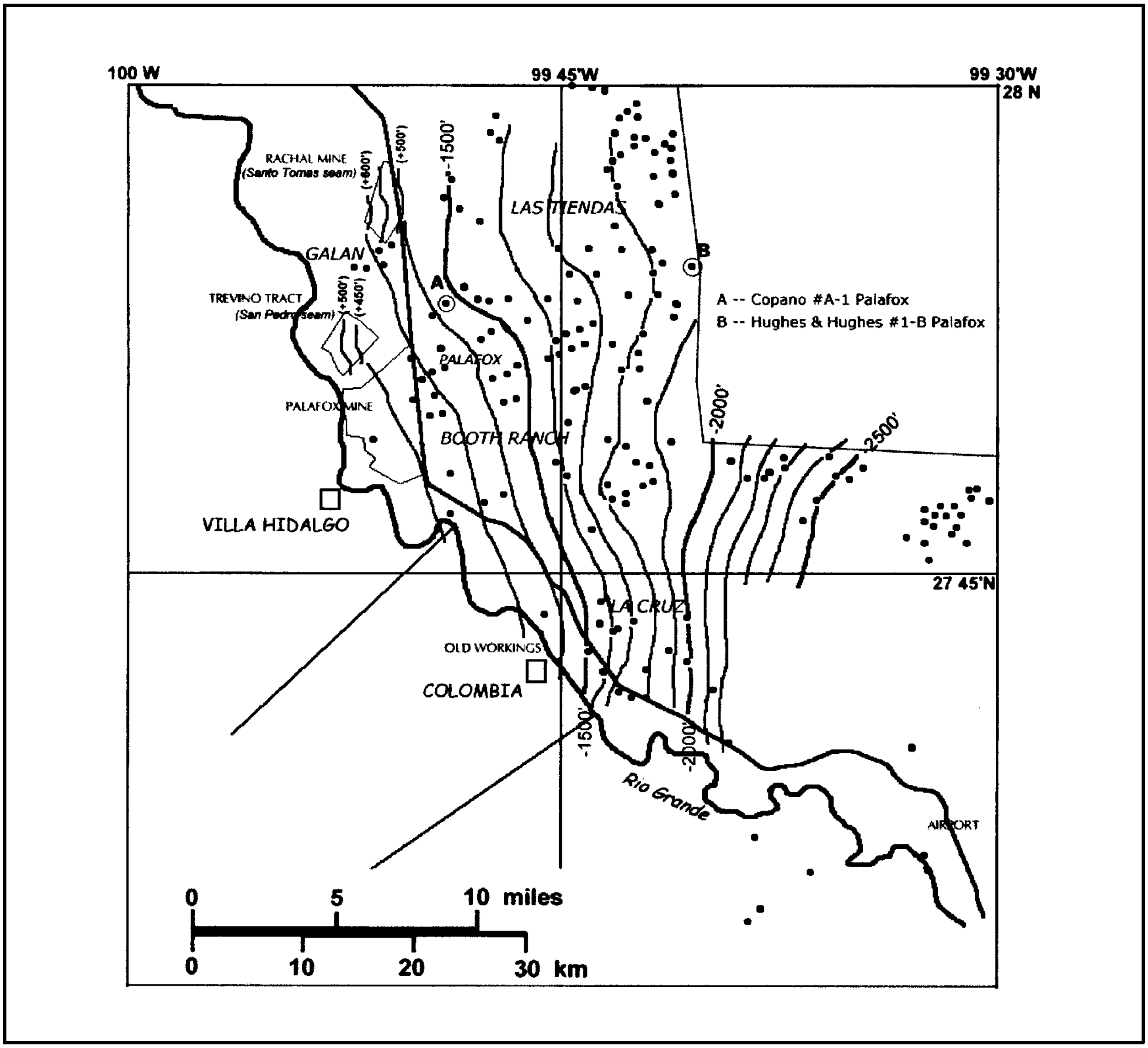

Figure 3. Subsurface structure, Top Middle Wilcox marker, Santo Tomas area. The contoured data on the Santo Tomas and San Pedro coal beds are from Warwick and Hook (1995). Gas field names are also shown.

east or east-northeast on the Middle Wilcox marker. This corresponds well to the 0.9-1.2 degrees of dip seen in the Trevino and Rachal mine areas (data from Warwick and Hook, 1995). From comparison of the Middle Wilcox data and the mine elevations, the Santo Tomas bed at the Rachal Mine lies 1900±20 ft above the Middle Wilcox marker. Less certainly, the San Pedro seam at the Trevino lease lies about 1600-1650 ft above the marker, or 250-300 ft below the Santo Tomas. Elsewhere, however, the San Pedro is only 90 ft below the Santo Tomas. This suggests that the San Pedro beds are not

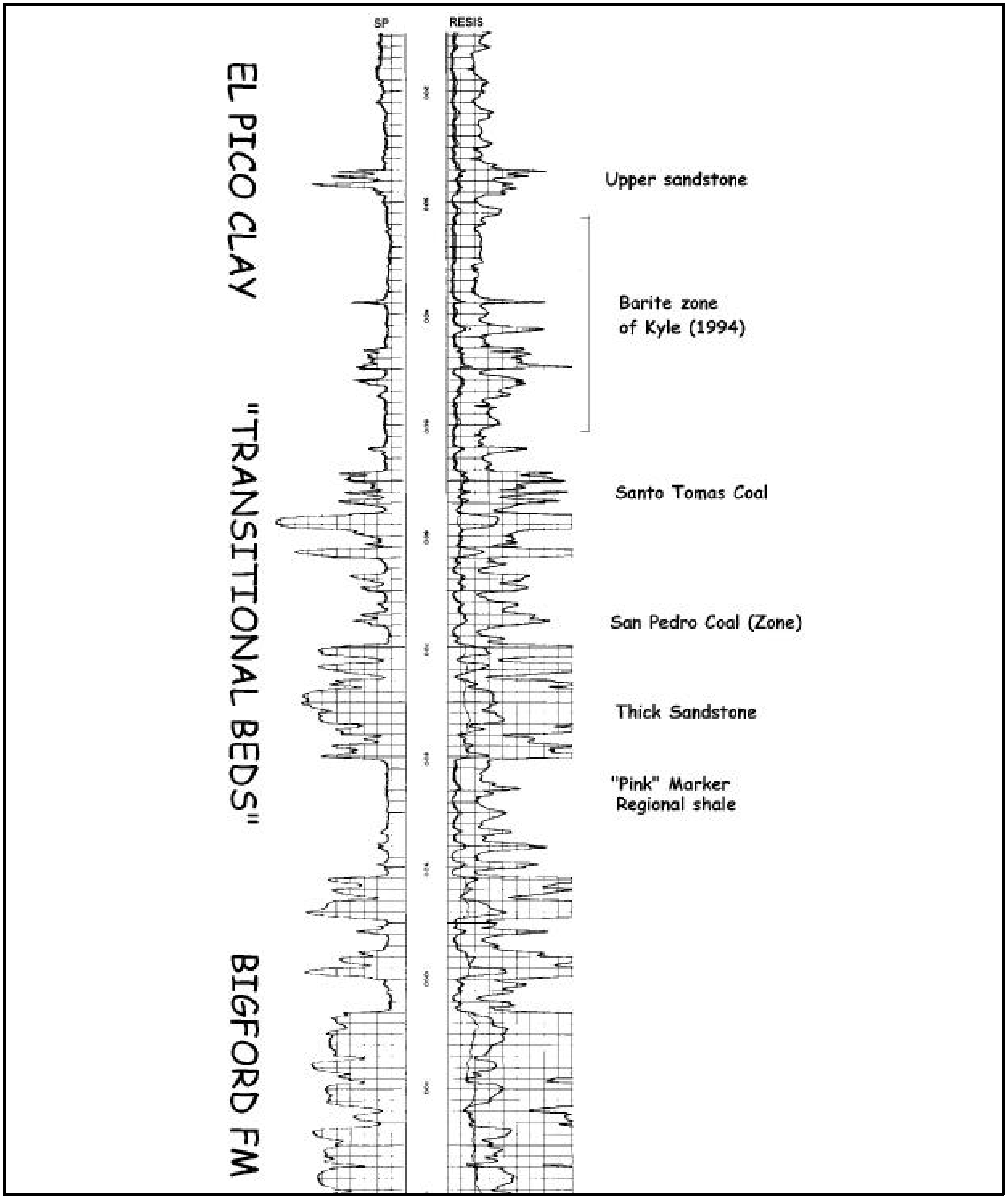

Figure 4. Electric log, Hughes & Hughes #1 Palafox Exploration "B", showing the correlation from surface mines to subsurface stratigraphy. Location of well shown on figure 3. Vertical log scale in ft.

wholly correlative, although there may be other solutions.

There is slight thickening of some stratigraphic units to the northeast, perhaps indicating structural growth on the Salado folds during Eocene time. However, the total amount of growth is not more than 100-150 ft.

The coal beds in the Rachal area can be confidently projected into the Copano #A-1 Palafox Exploration well, an Edwards test drilled in 1962 about 3 miles SSE of the Rachal mine (fig. 3). The correlation indicates that the coal beds correlate to a thin-bedded interval lying above a 60-ft thick sandstone and below a 100-ft thick shale unit. This shale ("Pink" Marker) can be observed on logs throughout the area mapped, and continues downdip at least to the Laredo airport (fig. 3). The sequence can be correlated to the east into the Hughes and Hughes #1-B Palafox Exploration well, where the overlying clay-rich sequence is also logged (fig. 4). The Pink Marker and the overlying sandstone can also be correlated to lithologic logs presented by Lonsdale and Day (1937) and Warwick and Hook (1995). Although the individual coal beds cannot be definitely located on the well logs (the coal may have some SP response?), the interval is reliably picked, and can be carried throughout the area. Downdip past the old workings towards Laredo, the interval becomes sand-rich and loses its thin-bedded, resistive character.

Due to the density of drilling in the Las Tiendas area of northwest Webb County, it should be possible, with detailed study of the subsurface logs, to more closely define the depositional geometry of the algal coals of the Santo Tomas district and estimate their resource potential.

As an added point of interest in the area, Kyle (1994, p. 41-46) has described a significant surface occurrence of barite in the Pinto Creek drainage, just northeast of the Rachal mine. The barite occurs in clays that lie 80-250 ft above the Santo Tomas seam.

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CHAPTER 2

The San Pedro and Santo Tomas Coal Beds (Claiborne Group, Eocene) of Webb County, Texas

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INTRODUCTION

The San Pedro and Santo Tomas coal zones of Webb County, Texas, are unique within the realm of Gulf Coast coal geology. Coal beds within these zones are distinguished by calorific yields and vitrinite-reflectance values that indicate a rank as high as high-volatile bituminous C, which is considerably greater than other Tertiary coals within the Gulf Coastal Province. In the past, the San Pedro and Santo Tomas were identified as cannel coal because of their blocky, nonbanded character, and conchoidal fracture (Vaughan, 1900; Ashley, 1919; Lonsdale and Day, 1937). Unlike true cannel coal known from the Upper Carboniferous of the Appalachians and Europe, the Webb County deposits are not particularly rich in spores or cuticular material and are not restricted to local channel fills. Rather, the San Pedro and Santo Tomas coals contain abundant green-algae fructifications and occur as multiple tabular coal beds within zones that extend for tens of miles along strike (Warwick and Hook, 1995).

Recent work has addressed the depositional origin, petrography, and geochemistry of the San Pedro and Santo Tomas coal beds, but several basic questions remain. The full extent of these deposits has not been determined. In adjacent parts of Mexico, numerous cannel-like beds occur within the Claiborne Group (SPP, 1989), but no comparable deposits are known elsewhere in Texas outside of Webb County. The question of rank also cannot be resolved at this time. Previously, we attributed the high rank of the San Pedro and Santo Tomas to geothermal influences (Warwick and Hook, 1995). Although the suggestion of geothermal influence is consistent with data that indicate an elevated rank of Wilcox coal deposits in adjacent counties, additional study is required to confirm the origin and delineate the extent of such alteration. Likewise, the significance of abundant green-algae fructifications in these coals, identified only from petrographic study of polished blocks, cannot be judged fully at this time because comparable polished block petrographic data do not exist for the great majority of other Tertiary coals.

GEOLOGIC SETTING AND STRATIGRAPHY

The Farco mine complex of Webb County lies within the outcrop of the southwestern flank of the Rio Grande Embayment, which extends southwesterly through Coahuila, Nuevo León, and

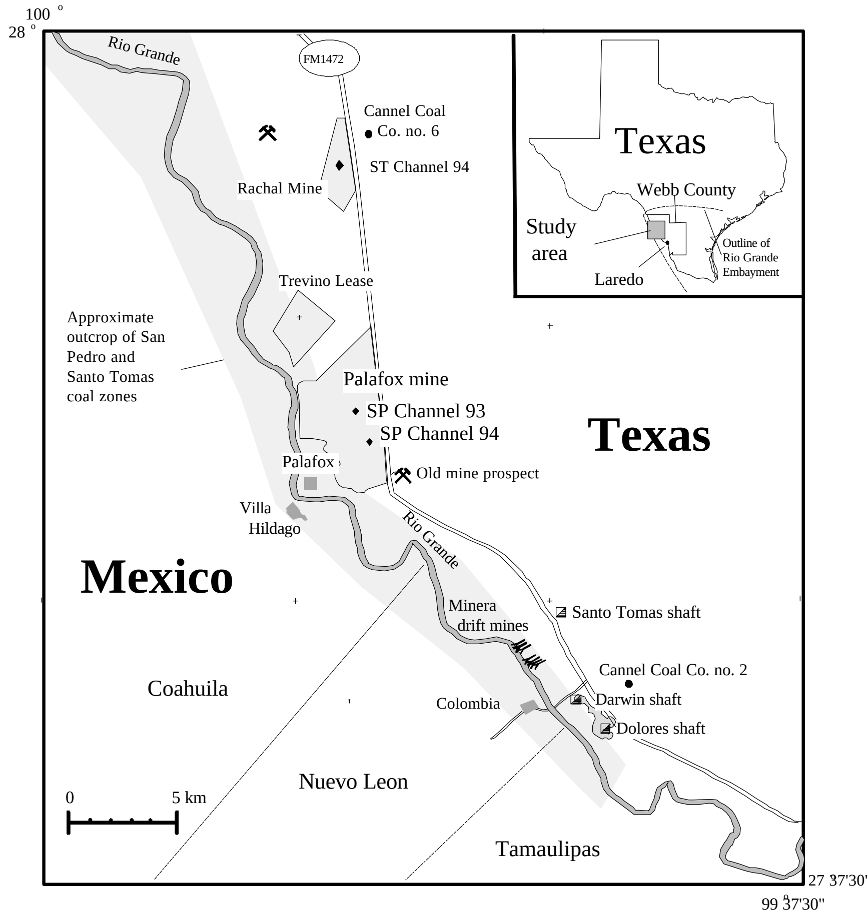

Figure 1. Location of study area, underground mine entries and prospects, Cannel Coal Company coreholes 2 and 6, surface mines, and sample sites. Inset shows location of study area, Webb County, and Rio Grande Embayment in South Texas. From Warwick and Hook (1995).

Tamaulipas in Mexico (fig. 1). Within the Rio Grande Embayment, the lower to middle part of the Claiborne Group consists of marine mudstones (Reklaw Formation) in the east and northeast, and sandstones and mudstones (Bigford Formation) in the south and southwest (fig. 2). The marine mudstones coarsen upward into the fluvialdeltaic Queen City Sand, which prograded gulfward across eastern and central Texas. To the west and southwest, the interval overlying the Bigford Formation becomes less sandy and claystones of the El Pico Clay Formation predominate. The San Pedro and Santo Tomas coal zones occur within the fining-upward transition from sandstone-dominated rocks to mudstone-rich deposits. The coal beds dip approximately 2° to the northeast, toward the synclinal axis of the embayment.

The San Pedro coal zone ranges up to 10 m (33 ft) in thickness and contains as many as five organic-rich beds that vary from carbonaceous mudstone to nonbanded coal in composition. The thinner Santo Tomas coal zone occurs approximately 25 to 35 m (82 to

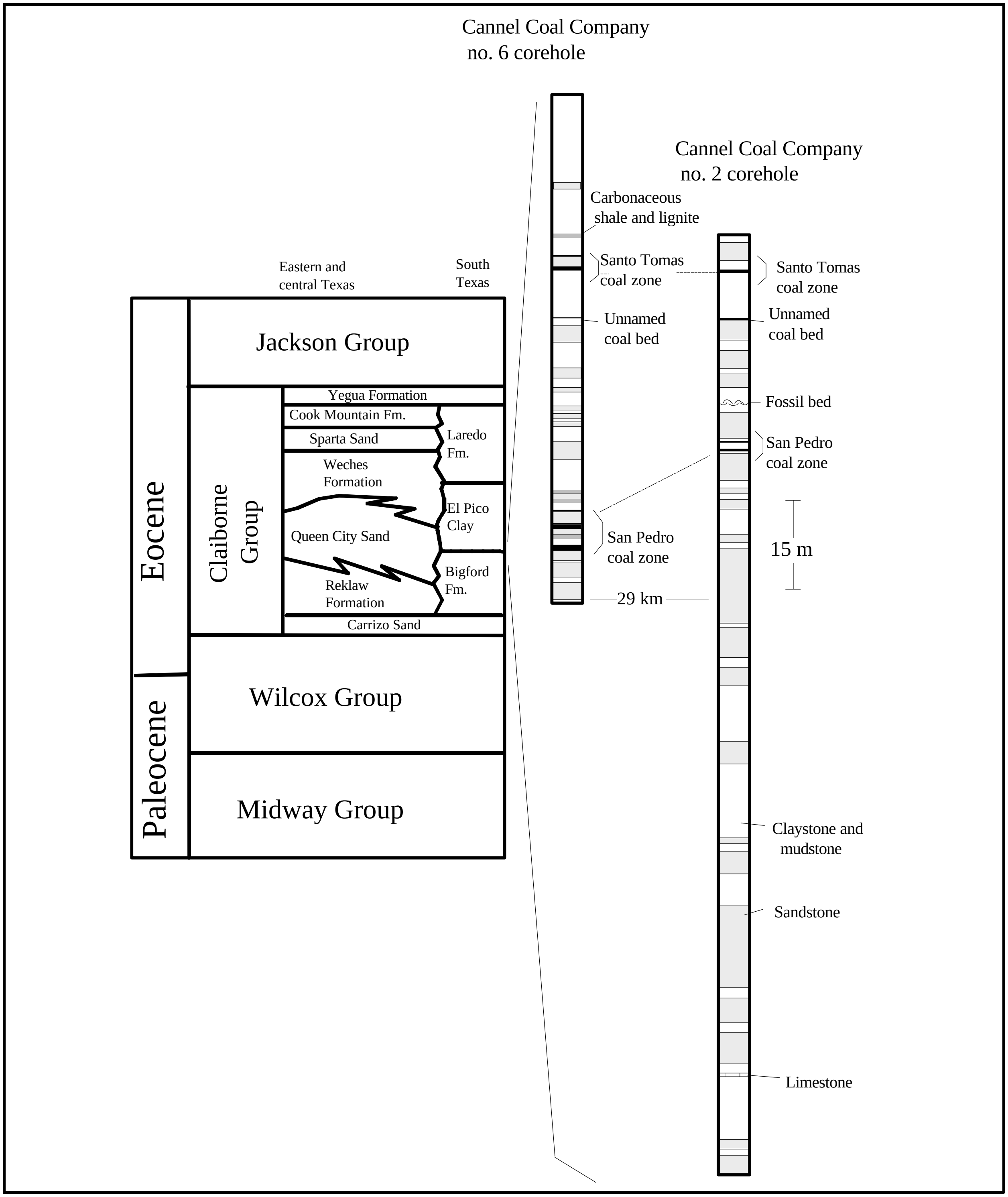

Figure 2. Representative corehole records from Vaughan (1900) that include both coal zones. Approximate locations shown on figure 1. Regional stratigraphy after Eargle (1968) and Guevara and Garcia (1972). From Warwick and Hook (1995).

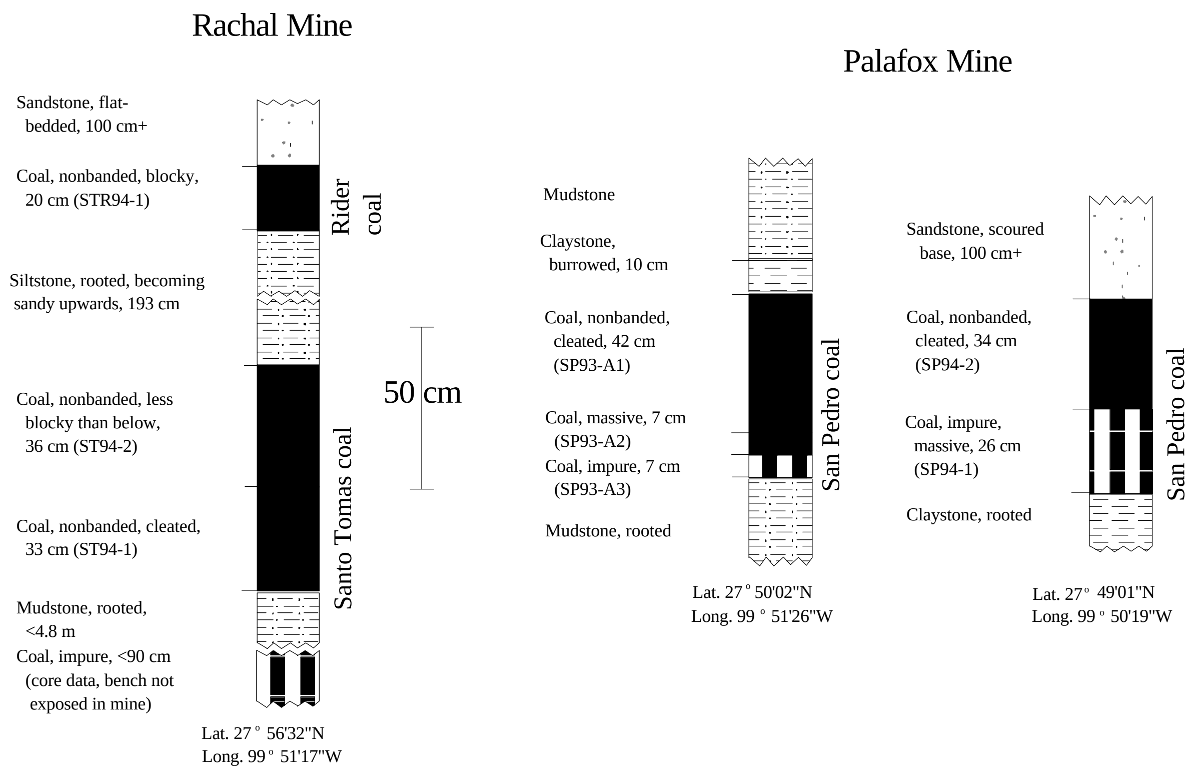

Figure 3. Bed sections and sample intervals of the San Pedro, Santo Tomas, and Santo Tomas rider coal beds. Sample numbers are in parentheses. Approximate locations are shown in Figure 1. From Warwick and Hook (1995).

115 ft) above the San Pedro zone, averages approximately 2.4 m (7.9 ft) in thickness, and consists of a lower main bed and an overlying rider, both of which may occur as nonbanded coal, impure coal, or carbonaceous mudstone (fig. 3). Within the Farco property and leases, coal beds of the San Pedro zone are mined at the Palafox and Trevino mines, and the Santo Tomas zone is developed at the Rachal mine (fig. 1).

MINING HISTORY

The Santo Tomas coal zone of Webb County was first mined commercially by the Rio Grande Coal and Irrigation Company between 1881 and 1914 in modest drift openings in the vicinity of Minera (fig. 1). By 1895, the Cannel Coal Company had completed a shaft and had driven mains in both the Santo Tomas and San Pedro zones at Darwin (fig. 1). The company, which employed several hundred miners, was directed by David Darwin Davis, a mining engineer from Wales (Hopson, 1975). A second shaft of the Cannel Coal Company at Dolores also mined both coal zones. The Santo Tomas Coal Company opened a shaft to the Santo Tomas coal bed between 1910 and 1912 near the village of Santo Tomas. This operation ceased in 1918 after a mine fire. The Darwin mines were abandoned in 1921, and the Dolores mines closed in 1939.

In 1979, Farco Mining Company of Texas, Inc., initiated surface mining at Palafox (fig. 1). The Rachal and Trevino mines began production in 1983 and 1996, respectively. Cumulative production from 1979 through 1997 totaled approximately 6 million short tons. The coal is washed and sized at a cleaning plant at Palafox. A significant amount of the coal is exported to the Republic of Ireland as lump coal for domestic use, and other production is consumed by local cement plants. Kelmac, Inc., a subsidiary of Chevron Corporation, recently acquired the Webb County mines of Farco Mining Company of Texas and operates currently under the name Farco Mining, Inc.

DEPOSITIONAL SETTING

The coal-bearing portion of the lower to middle Claiborne Group of Webb County is a fining-upward sequence situated above a thick, sandstone-dominated section that contains poorly preserved marine invertebrates, and below a mudstone-rich section that yields mainly nonmarine fossils. Corehole records and natural exposures show that the San Pedro coal zone overlies a barren interval dominated by thick (7.6-10.7 m or 25-35 ft), predominantly flat-bedded, sandstone deposits.

At Palafox, the San Pedro coal zone consists of a thick ($\leq$ 0.85 m or 2.9 ft), nonbanded upper bed and a thin, impure bed approximately 3 m (9.8 ft) below; additional thin coal beds and carbonaceous mudstones occur in the lower part of the coal zone but are not mined (fig. 3). The upper coal bed is underlain by a dark gray, root-penetrated, silty claystone, and the uppermost portion of this coal bed contains mud-filled invertebrate burrows and trails. As seen in-mine, the contact between this coal and overlying mudstone or sandstone generally is sharp.

The interval immediately above the San Pedro coal zone consists mainly of sandstone, a slightly smaller proportion of mudstone, a minor intraformational conglomerate, local fine-grained limestone nodules or bands, and thin (< 0.45 m or 1.5 ft), discontinuous coal beds that range from nonbanded coal to clay or silt-rich impure coal. The sandstones are calcareous and are composed chiefly of fine to very fine, subangular to rounded quartz grains; individual beds are massive, cross bedded, streaked or interbedded with mudstone, rippled, or rooted or otherwise biotrubated. An en echelon pattern characterizes sandstone bodies above the San Pedro coal zone in the Palafox Mine. These sandstone bodies are flat botttomed, flat to ripple bedded, and exhibit characteristics of mouth-bar to crevasse-splay sands deposited in shallow water. Between the main coal bed and these sandstone deposits, coarsening-upward, rhythmically interbedded mudstones and sandstones contain flaser bedding suggestive of tidal influences. A few zones of poorly preserved marine invertebrate fossils (pelecypods, gastropods) occur above the San Pedro coal zone (Lonsdale and Day, 1937).

At the Rachal Mine (fig. 1), the Santo Tomas coal zone consists of a thick (0.69 m) nonbanded main seam, a clastic interval that ranges from 0.91 to 1.98 m (3 to 6.5 ft) in thickness, and a thin (0.20 m or 0.6 ft) rider coal bed (fig. 3). Both beds are underlain by paleosols, and the top of the main bed contains invertebrate burrows and trails. The interval between these coal beds consists of flat-bedded siltstone and fine to very fine grained, noncalcareous sandstone that fine laterally into coarsening-upward mudstone deposits. These mudstones lack the flaser-bedded sandstone interbeds that occur above the San Pedro coal bed at Palafox. Channel-form deposits within this interval are small (0.25 m or 0.8 ft thick, 1 m or 3.3 ft wide), few in number and limited to the top of thick sandstone deposits. Overall, the interval between the main Santo Tomas coal bed and rider bed records the drowning of an initial mire, infilling of the resulting floodbasin by minor crevasse splays, and re-establishment of mire conditions.

The presence of several thin coal and carbonaceous shale beds a short distance above the Santo Tomas rider bed indicates that clastic-rich mires persisted locally. Overlying coarsening-upward sequences represent the terminal flooding and clastic infilling of the floodbasin. Lonsdale and Day (1937) reported thin sandstone beds in the area of Darwin that contained poorly preserved nonmarine molluscs and abundant green algae fructifications. Although they interpreted these fossil occurrences as a unique bed of considerable persistence, Gardner (1945), who measured and collected many of the fossiliferous sections reported by Trowbridge (1923, 1932) and Lonsdale and Day (1937), stated clearly that several such beds occur. The presence of these locally rich beds of nonmarine aquatic fossils above the Santo Tomas coal zone indicates that lacustrine settings may have been common within the floodbasin.

COAL CHARACTERISTICS

The nonbanded coals that are mined in Webb County are extremely hard, fracture conchoidally, and have cleats developed at a scale similar to that of bituminous nonbanded coals. The lower part of the San Pedro coal bed at Palafox is very massive and breaks into blocks that average 0.5 m (1.6 ft) in width; to a lesser extent, the main Santo Tomas coal bed becomes more massive and less fractured downward.

Physical and geochemical analyses (fig. 4) reported by us previously (Warwick and Hook, 1995) are comparable to earlier analyses of these coal beds (Evans, 1974; Mukhopadhyay, 1989). All the San Pedro and Santo Tomas samples have relatively high ash yields (9.5-18% dry basis) at their base. Total sulfur content (0.8-2.0%, dry basis) generally increases upward, and organic sulfur is predominant. Calorific values increase upward within each coal bed, with a maximum of 7,434 kcal/kg (13,371 Btu, dry basis) found in the top part of the main San Pedro bed at Palafox. Hydrogen content follows calorific values, ranging from 5.4 to 6% (dry basis). Additional physical and geochemical data, including trace-element analyses, are reported in Warwick and Hook (1995).

Petrographic study of particle pellets and unetched polished blocks from San Pedro and Santo Tomas coal samples (Warwick and Hook, 1995) indicate that a highly degraded groundmass composed of eugelinite is the main organic component (approximately 71%, mineral-matter-free basis). An enriched liptinite fraction (approximately 23%) accounts for a portion of the high calorific

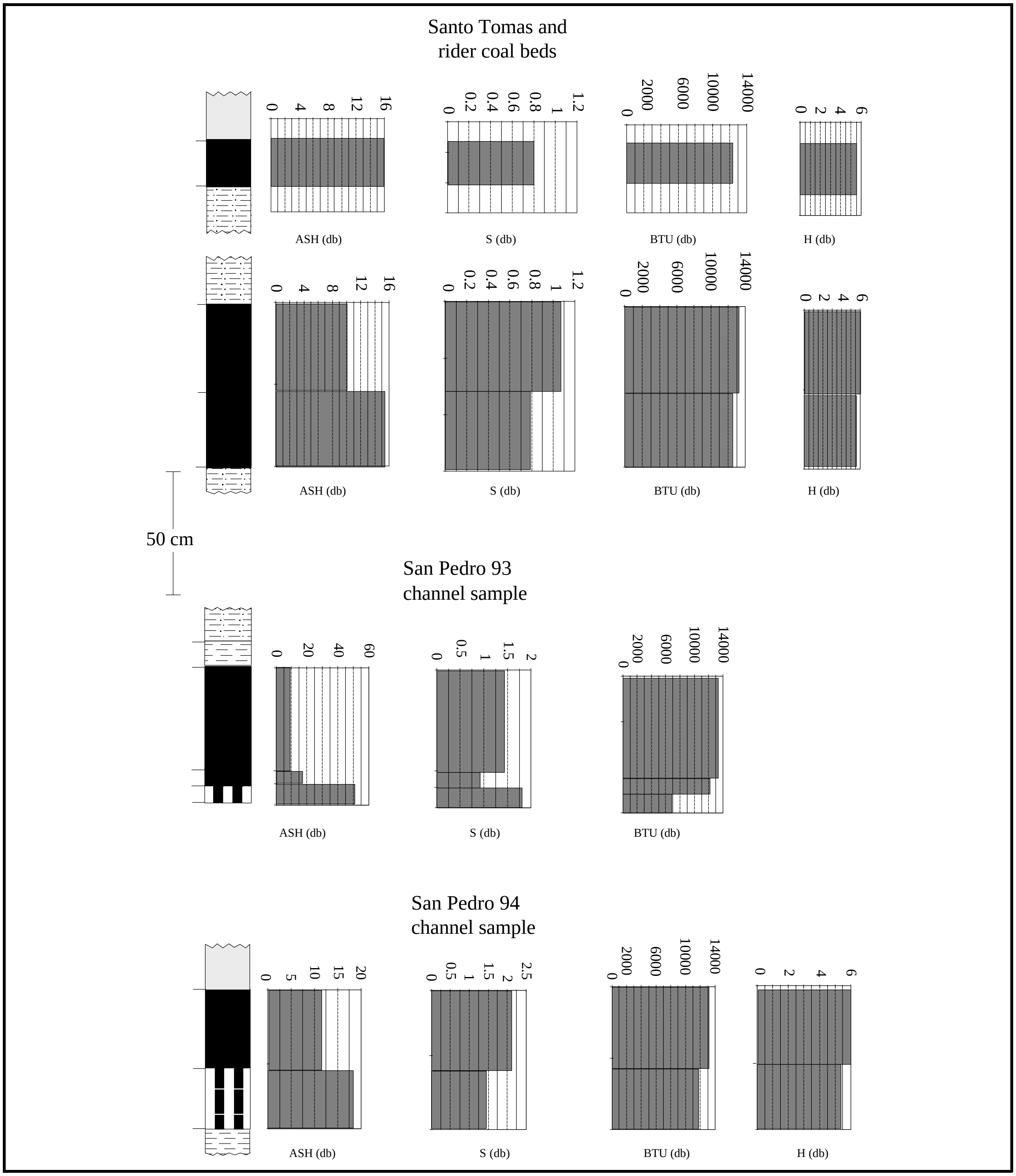

Figure 4. Selected proximate and ultimate data. Sample descriptions and symbols are the same as those used in figure 3. All values as percentages except Btu. Sample locations are shown in Figure 1. Complete sample data are given in Warwick and Hook, 1995. From Warwick and Hook (1995).

values that distinguish these coals. Most of this enrichment represents fusiform green-algae fructifications, which because of their size (up to 2 mm or 0.1 in. in length), cannot be identified or quantified readily by conventional coal petrography techniques or palynologic preparations that involve acidification. There is a negligible proportion of inertinite macerals in these coals.

Average maximum vitrinite reflectance (Ro_{max}) values for San Pedro and Santo Tomas coal samples reported previously by us was 0.53. This was comparable to the Ro_{max} reported by Mukhopadhyay (1989) for one San Pedro sample. Compared to standard rank parameters, the San Pedro and San Tomas coal deposits fall within the range of subbituminous A to high-volatile bituminous C coal.

SUMMARY

The unusual coals of the San Pedro and Santo Tomas coal zones of the Claiborne Group in Webb County, Texas, are distinguished by physical, petrographic, and

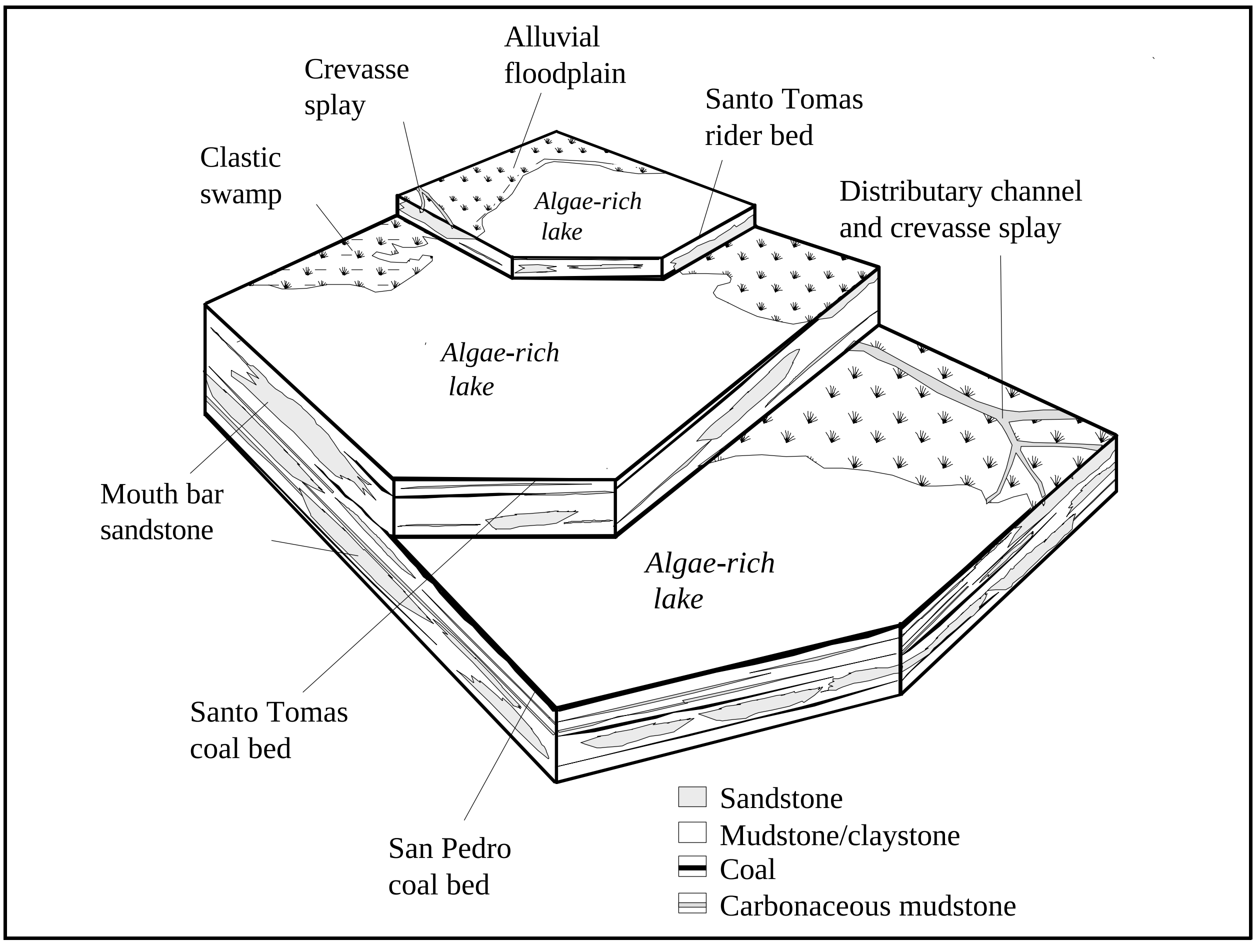

Figure 5. Schematic block diagram of depositional environments for the San Pedro and Santo Tomas coal zones in the middle part of the Claiborne Group. No scale implied. The geometric distribution of lithologies on the panels is inferred from borehole and mine highwall data. From Warwick and Hook (1995).

geochemical characteristics unlike those of other Gulf Coast Tertiary coal deposits. Whereas the San Pedro deposits accumulated in marine-influenced lower delta plain settings, the overlying Santo Tomas interval represents a nonmarine, mudstone-dominated sequence (fig. 5). Mineable coal beds within both coal zones contain an abundance of green algae fructifications, which account in part for the anomalously high calorific value. Data from Mexico (SPP, 1989), however, record Quaternary igneous intrusive rocks less than 100 km (62 mi) west of the Rio Grande area, and coal-quality data from coal beds in the underlying Wilcox Group of Texas counties bordering Webb County indicate increased rank. Additional work is required to determine the postdepositional history of the coal deposits of South Texas.

ACKNOWLEDGMENTS

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CHAPTER 3

The San Miguel lignite deposit, Jackson Group (Eocene), South Texas

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INTRODUCTION

The San Miguel lignite deposit (late Eocene, lower Jackson Group) of South Texas is mined by the North American Coal Corporation, at the San Miguel Mine near Jourdanton, Texas (fig. 1). The deposit consists of four or more thin (generally < 1 m or 3.3 ft thick) lignite benches that are separated by claystone and mudstone partings (fig. 2). The partings are composed of altered volcanic air-fall ash that has been reworked by tidal or channel processes associated with a back-barrier depositional environment (Snedden and Kersey, 1981; Gowan, 1985; Ayers, 1986; Senkayi and others, 1987; and Warwick and others, 1996). The field trip stop at the San Miguel Mine will include a trip into the working opencast pit. We will be able to observe mining methods, and the rocks associated with the coal-bearing interval. This summary of the geology of the San Miguel deposit is based largely on Warwick and others (1996), which focuses on the petrology and geochemistry of the lignite deposit.

GEOLOGIC SETTING

The San Miguel lignite deposit is in the undivided lower Jackson Group of South Texas (fig. 2). In the mine area, the Jackson strata dip to the southeast about 17 m/km (90 ft/mi) (Ayers, 1986). The mine is located updip of a strike-elongated sand complex that has been interpreted as a barrier-bar/strand plain complex by Kaiser and others (1980) and Gowan (1985). Gowan (1985) and Ayers (1986) suggest that the mud-dominated sediments the comprise the floor, partings, and roof of the San Miguel lignite deposit originated in lagoonal mires landward (west) of the sandstone-dominated barrier island complex. The lignite-bearing interval is laterally persistent along strike for more than 40 kilometers (25 mi) (Ayers, 1986, 1989; Tewalt and others 1983). More detailed descriptions of the geological setting of the area can be found in McNulty (1978), Snedden (1979), Snedden and Kersey (1981), Tewalt and others (1983), Gowan (1985), and Ayers (1986, 1989).

The San Miguel lignite interval consists of four (or more) thin (generally <1 m or 3.3 ft thick) lignite benches that are separated by claystone and mudstone partings. The upper bed is designated as the A bed and is underlain by the B, C, and D beds (figs. 2, 3a) (Gowan, 1985). Tewalt and others (1983) referred to this interval as South Jackson seam no. 10. The rocks above the lignite beds are dominated by fine siltstone and claystone with occasional thin layers of gastropod and bivalve shells.

Kaiser (1982), Gowan (1985), and Ayers (1986, 1989) suggested that the rock partings within the San Miguel lignite deposit

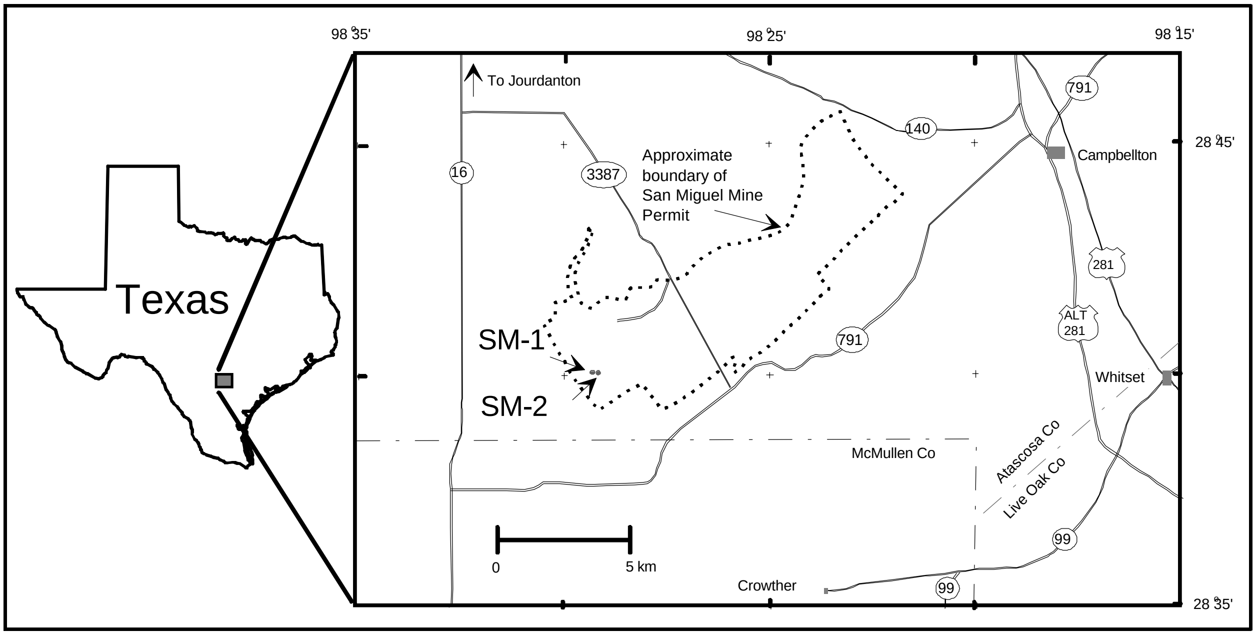

Figure 1. Index map of the San Miguel Mine area showing towns, roads, and sample sites. Mine outline from the San Miguel Lignite Mine Permit Application, on file at the Texas Railroad Commission in Austin, Texas. From Warwick and others (1996).

are composed of volcanic air-fall ash that has been reworked by possibly tidally influenced channel processes. Senkayi and others (1987) examined the partings in detail and found that most contained altered kaolinite and mixed detrital and volcanic quartz grains, thereby supporting the interpretation of a volcanic origin and subsequent detrital mixing of the sediment that forms these layers. These findings are consistent with the conclusions of Warwick and others (1996) (see below).

LIGNITE RESOURCES AND MINING

Jackson Group lignite resources for the South Texas area have been estimated to be about 6 billion short tons (5.4 metric tons) with 750 million tons (680 metric tons) occurring near surface and the remainder classified as deep-basin deposits (Kaiser and others, 1980). Surface mining operations at the San Miguel Mine began in 1980 and the 1997 annual production was about 3.5 million tons (3.2 metric tons) (data from the U.S. Department of Energy, Energy Information Agency and the Railroad Commission of Texas). Since 1997, the San Miguel Mine has been operated by the North American Coal Corporation; prior mining was carried out by the Atascosa Mining Company. The Keystone Coal Industry Manual (PRIMEDIA Intertec, 1999) reports the total reserves for the North American Coal Corporation in the San Miguel Mine area to be about 42 million tons with 35 million tons recoverable (38.2 and 32 million metric tons respectively). Average overburden is about 30 m (98 ft), with a stripping ratio of 7:1. Overburden is removed by dragline methods. The coal is removed by Easi-Miners (a modified asphalt stripper) and front-end loaders. The lignite is

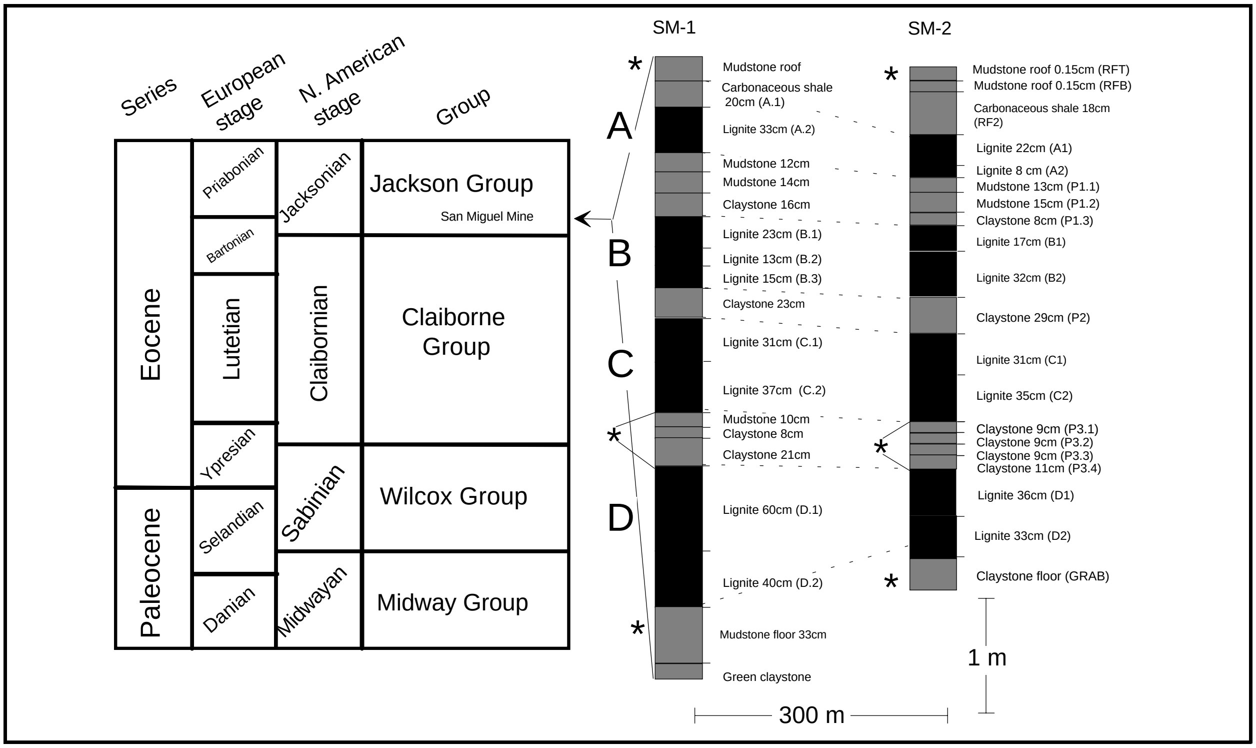

Figure 2. Generalized stratigraphy and stratigraphic sections of the coal-bearing interval at the San Miguel Mine. Sample numbers are in parentheses, and channel sample sites are shown on figure 1. The approximate positions of the volcanic ash beds identified by Senkayi and others (1987) are indicated by an asterisk. Stratigraphy is after Breyer (1991). From Warwick and others (1996).

moved by truck and used as steam coal in the mine-mouth 409 megawatt San Miguel Power Plant operated by the San Miguel Electric Cooperative (PRIMEDIA Intertec, 1999).

Some mining problems that are encountered in the San Miguel Mine include floor heaves, mudstone dikes, and channels within the coal interval. Some of these features may be observed during our field trip. In some areas, a greenish mudstone located 1-2 meters (3.3-6.6 ft) below the D bed (fig. 2) intrudes into the floor of the open pit causing problems with pit traffic and general mining operations (fig. 3a). Ayers (1986) described clastic dike intrusions that originate primarily from the partings between beds C and D. The intrusions are generally no more than a few meters in length and are less than 0.5 m (1.6 ft) wide. Minor faulting is usually associated with these dikes. Ayers (1986) suggested that emplacement of these dikes may be related to loading and dewatering processes. Another interesting feature that is often observable in the San Miguel Mine are small interseam channels that usually scour into lignite beds C or B and are filled with inter-seam parting material. The channels are usually no more than a few meters (several ft) wide and are confined to a single clastic parting zone within the A-D coal bed complex. Ayers (1996) described these channels in detail and suggests that were formed by marsh drainages that occupied the area between periods of peat accumulations.

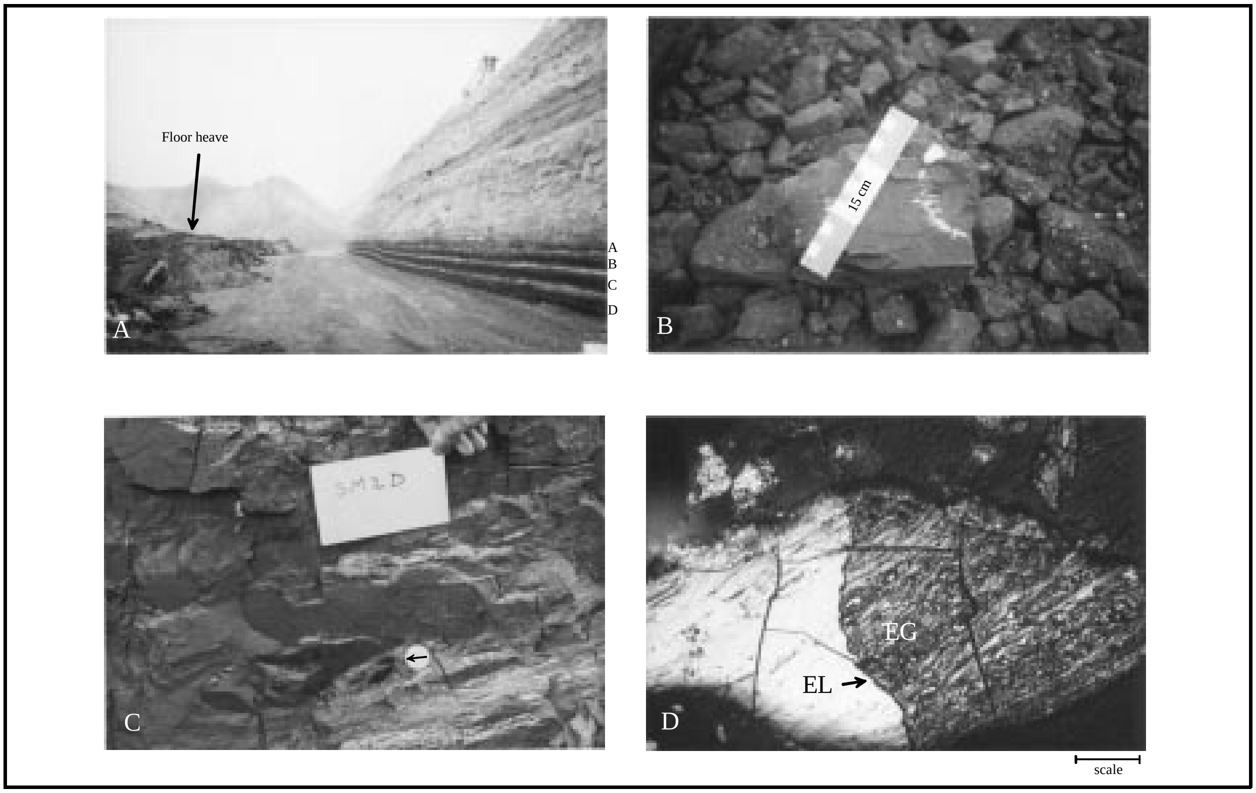

Figure 3. Representative photographs and photomicrographs of outcrops and samples from the San Miguel lignite interval. (a) View of a highwall with A (upper), B, C, and D beds and the partings. Note that the debris on the mine floor seen on the left of the photograph is due to floor heaves. (b) Clay-filled burrows are common in the San Miguel lignite. Scale = 15 cm. (c) Arrow points to a compressed log in the D bed. (d) Typical photomicrograph of an etched and unetched surface of a polished pellet of San Miguel lignite. EG = eugelinite, EL = etch line. Scale bar = 25µm. From Warwick and others (1996)

CHARACTER OF THE SAN MIGUEL LIGNITE

Megascopic characteristics

As described by Gowan (1985), the San Miguel Lignite interval has been extensively reworked by burrowing organisms. This is apparent from the lithologic descriptions of the channel sample sites described by Warwick and others (1996) (fig. 3b). Some of the burrows near the top of the A lignite bed were identified as *Gyrolithes* by Gowan (1985) and probably were formed by organisms that lived in the water that encroached over the top of the peat deposit. The burrows, usually filled with a mixture of organic material and kaolinitic claystone, is one source of ash in the lignite beds (fig. 3b). Individual lignite beds generally exhibit a dull, somewhat massive texture near their base and grade upward into attrital-rich lignite with increasing xylinitic bands (3-4 cm or 1.2-1.6 in thick) towards the top of the individual bed. Xylinitic bands can compose up to 30% of individual lignite beds. Occasionally, compressed logs are exposed in

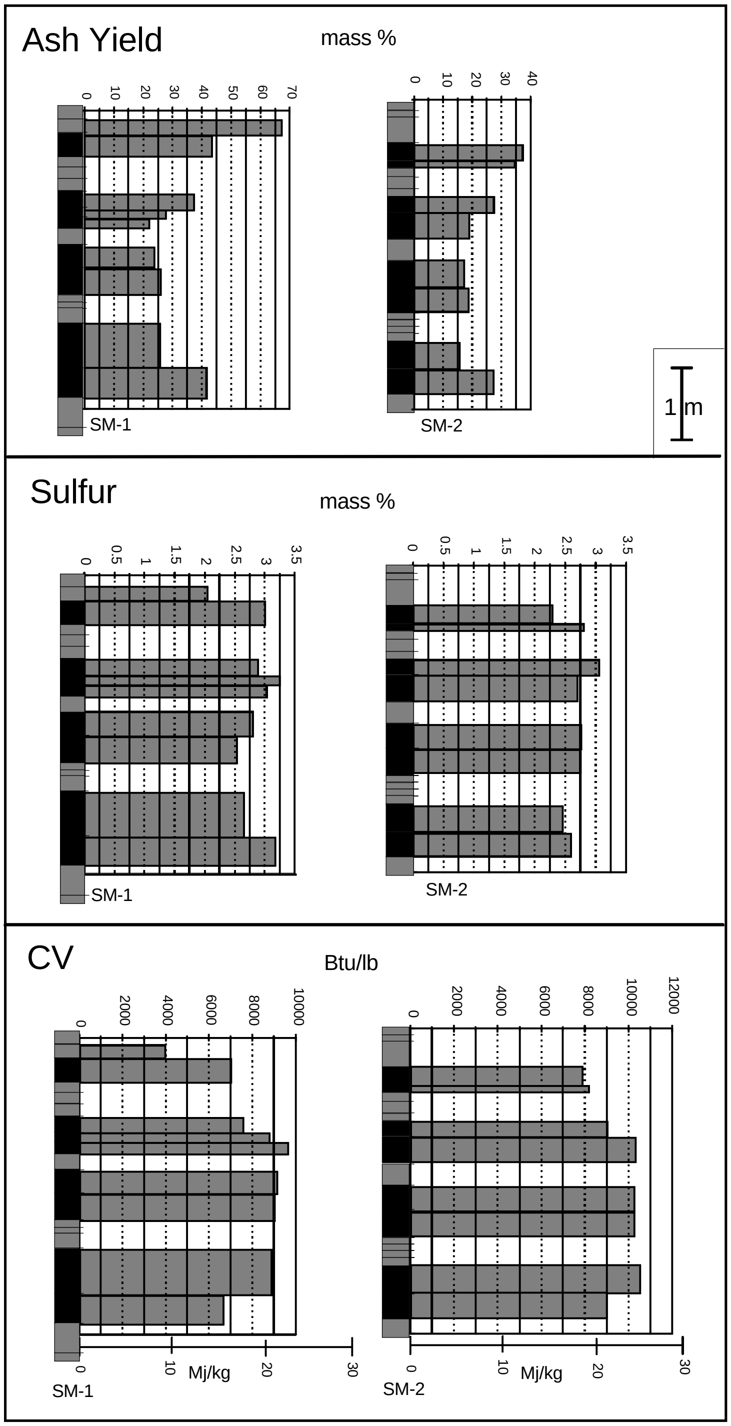

Figure 4. Bar graphs showing concentrations of ash yield, total sulfur, and calorific value (CV, dry basis) for the sample sets SM-1 and SM-2. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. Distance between sample sites is about 300 m. From Warwick and others (1996).

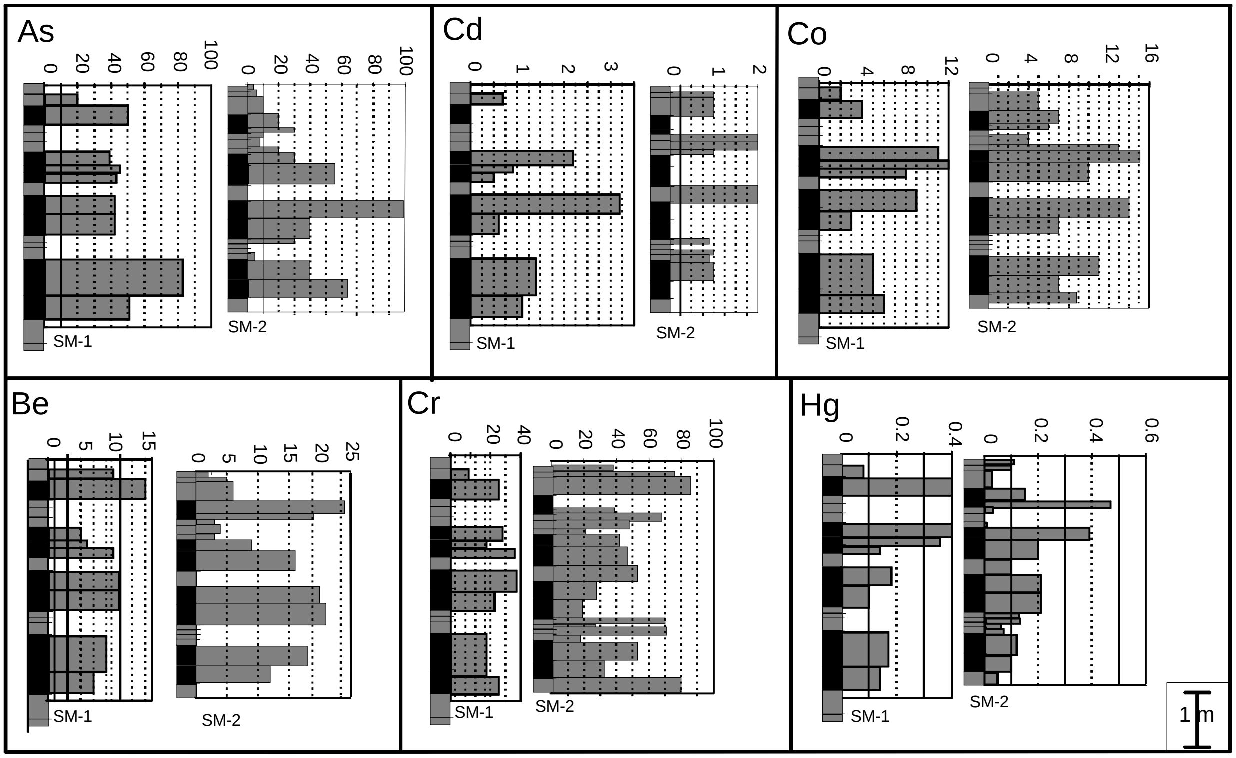

Figure 5. Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for twelve potentially environmentally sensitive elements identified by the 1990 U.S. Clean Air Act Amendments. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. All values are parts per million (ppm). From Warwick and others (1996).

cross section on the exposed face of the lignite bench (fig. 3c). The middle lignite beds (B and C) appear to contain the greatest percentage of xylinitic banding when compared to the upper and lower beds (A and D).

Proximate analyses

Chemical and physical data obtained from San Miguel lignite samples have been reported on an individual bed basis (5 samples; Mukhopadhyay, 1989) and on a combined bed basis (23 samples; Tewalt, 1986). From these data, the dry ash yields of samples range from 25 to 55% (avg 38%; Tewalt, 1986) with the A bed having the greatest average ash yield (39%, Mukhopadhyay, 1989). Equilibrium moisture values range from 27 to 33% (Tewalt, 1986). Total sulfur contents (on a dry basis) range from 1.5 to 3.1% (Tewalt, 1986). Organic sulfur is the dominant sulfur type. Calorific values (on a moisture-free basis) for the San Miguel samples range from 5384 to 8690 Btu/lb (12.5-20.2 Mj/kg) (Tewalt, 1986). Tewalt (1986) and Mukhopadhyay (1989) report that the rank of the Jackson Group and the San Miguel lignites is lignite A.

Warwick and others (1996) reported proximate analyses for 17 lignite samples collected from the San Miguel deposit (fig. 4). The data indicate that dry ash yields average 30.16%; total dry sulfur content averages 2.76% (dominated by organic sulfur, 2.04%);

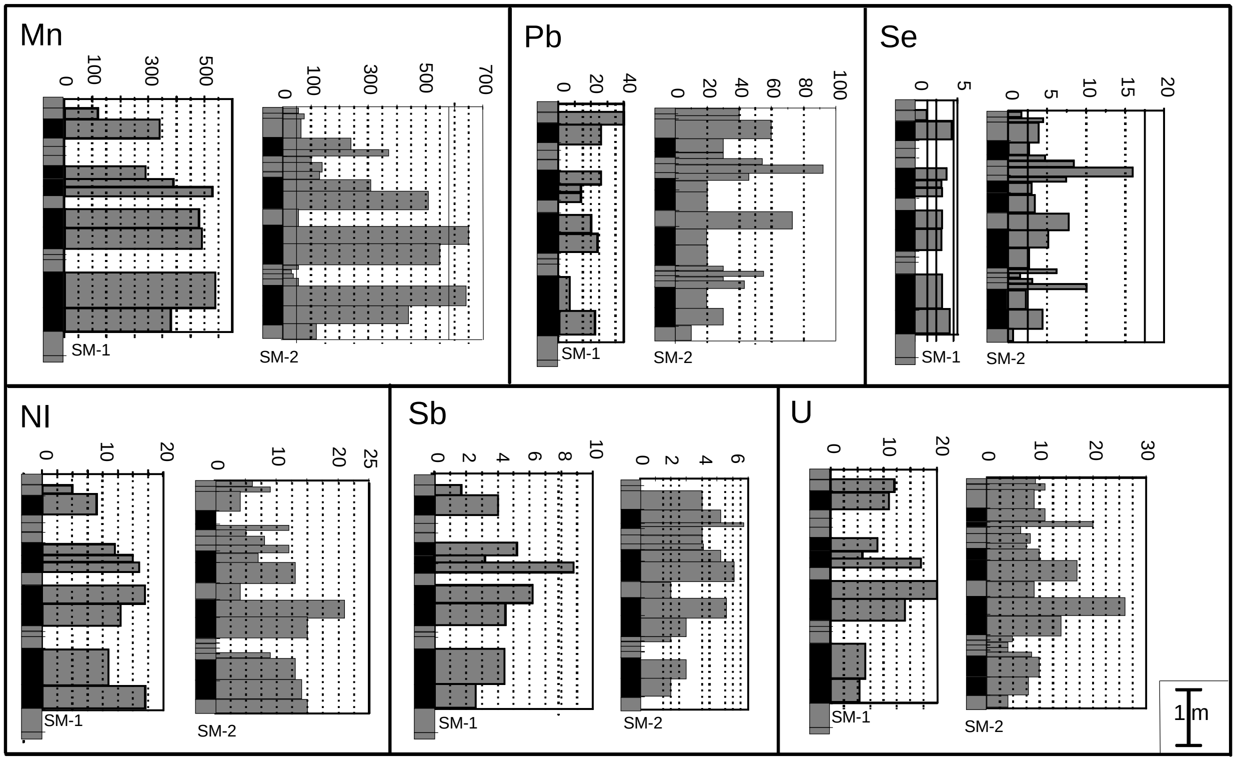

Figure 5. Continued - Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for twelve potentially environmentally sensitive elements identified by the 1990 U.S. Clean Air Act Amendments. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. All values are parts per million (ppm). From Warwick and others (1996).

and dry calorific values average 8611 Btu/lb (20 Mj/kg) (fig. 4). As-received moisture content averages 33.4% for the SM-2 channel sample set. At both sample sites, ash yields were greatest from the upper and lower lignite benches. Total sulfur content is fairly uniform both within and between each sample site (fig. 4).

Major, Minor, and Trace element data

Tewalt (1986) reported major oxide and trace-element data for the San Miguel lignite interval. She found that the San Miguel lignite interval contains greater amounts of Na_2O (avg 3.67%; N=66) as compared to other lignite deposits of Texas (range of averages: 0.41-1.22%), and suggested that this enrichment was either the result of sodium sorption from saline waters during and after deposition, or of sodium cation exchange with present-day ground water. Tewalt (1986) reported trace-element concentrations for fifteen elements (As, B, Be, Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, U, V, Zn) that were obtained from two samples from the San Miguel deposit. Based on the results from other Jackson Group lignites of East Texas, Tewalt suggested that the Jackson lignites contain greater amounts of B, Be, Mn, and Zn

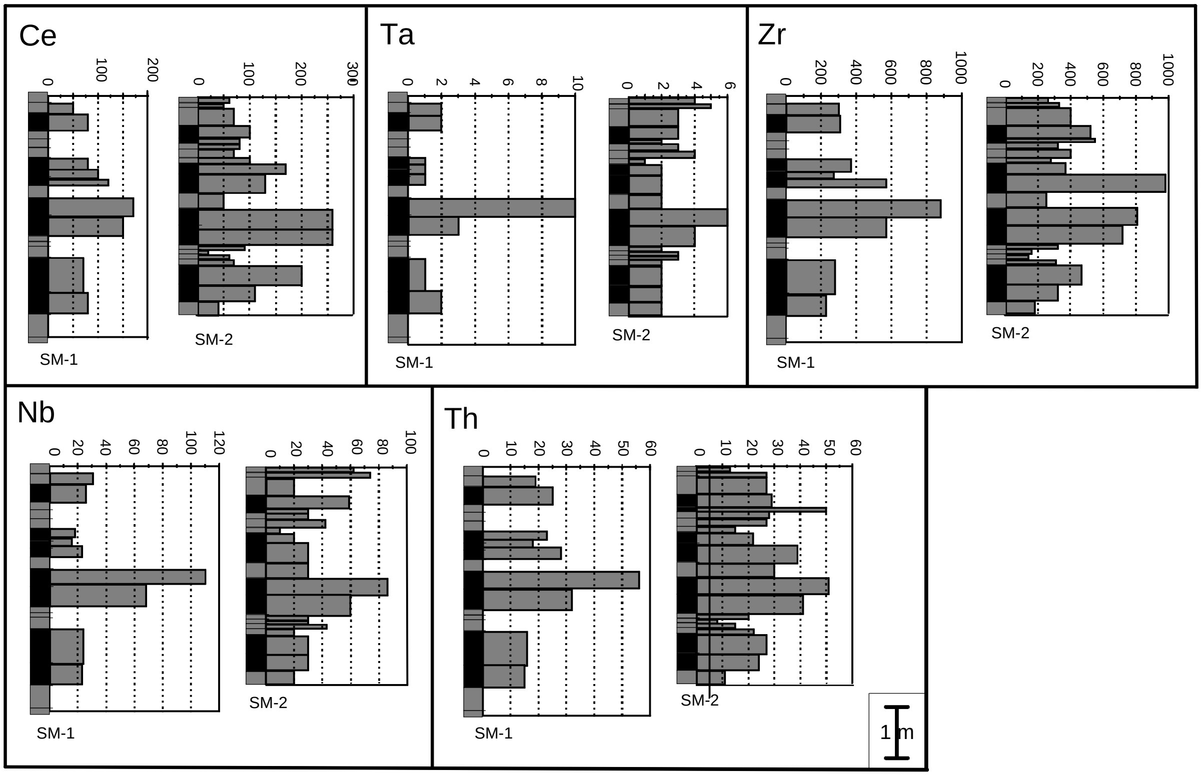

Figure 6. Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for those elements inferred to be derived from volcanic ash. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. All values are parts per million (ppm). From Warwick and others (1996).

than the older Wilcox lignites of eastern Texas.

Warwick and others (1996) reported trace element data obtained from two channel samples taken from the San Miguel mine (figs. 1, 2). Of particular interest for this study was the distribution of 12 environmentally sensitive elements that were described by the 1990 U.S. Clean Air Act Amendments. A summary of the trace element data (on a dry, ash basis) for both sample sites is plotted on figure 5. Visual analysis of the SM-2 bar graphs shows that some of the elements are concentrated in the organic-rich (or lignite) samples. Linear correlations between ash yield and the concentrations of the environmentally sensitive elements on an ash basis for those samples containing less than 50% ash (i.e. what is normally mined) showed that only Mn has a strong negative ($r < -0.5$) relationship to sample ash yield. On a whole-coal basis (for those samples containing less than 50% ash) a strong positive correlation ($r > 0.5$) was found between ash and Pb, Se, and Na_2O.

Warwick and others (1996) also plotted bar graphs for both San Miguel rock and lignite samples to show the vertical distribution of elements that may be associated with volcanic ash partings (fig. 6). Mean concentrations are: Ce, 117 ppm: Nb, 36 ppm; Ta, 2.4 ppm; Th, 29 ppm; and Zr, 477 ppm (all concentrations in coal on an ash basis) (fig. 6). Concentrations of these elements are generally enriched in the B and C lignite beds. Previous work has indicated that concentrations of these elements in coal can be enriched by incorporation of volcanic ash in peat or by leaching from volcanic ash beds (Zielinski, 1985; Crowley and others, 1989). In coal samples from intervals adjacent to altered volcanic ash partings in the Cretaceous C coal bed of Utah, Crowley and others (1989) reported mean concentrations (on an ash basis) of elements having a volcanic origin as follows: Zr (752 ppm), Nb (57 ppm), Th (60 ppm), and Ce (246 ppm). Although the mean concentrations of these elements in the San Miguel samples do not reach the reported averages for the Utah C coal bed, specific samples from SM-1 and SM-2 exceed the Utah averages for Zr, Nb, and Ce.

Mineralogy of San Miguel partings

Warwick and others (1996) reported results from preliminary examination of San Miguel rock parting samples based upon scanning electron microscopy (SEM) and energy-dispersive X-ray analyses (EDXA). These analyses indicate that the upper part of the mudstone parting below the A bed (SM-2 P1.1, fig. 2) is composed primarily of kaolinite with some mixed-layer clay present. Vermicular kaolinite is present throughout the sample, as are small (<50µm) K-feldspars. Isolated plagioclase, quartz, barite, framboidal pyrite, anatase, and a single Al-phosphate were also observed. The mudstone is very organic rich. Although individual organic stringers are rare, irregular pieces of coaly material are found throughout the sample.

The matrix of the claystone below the B bed (sample SM-2 P2, fig. 2) is composed primarily of mixed-layer clay and abundant organic material. Both alkali and plagioclase feldspars were observed throughout the sample, but they are rare. Quartz, pyrite, and Ca-Al phosphate (crandalite group?) are present in trace amounts.

Examination of samples from the claystone parting between the C and D beds (P3.1, P3.2, P3.3, and P3.4, fig. 2), which was described as a major ash bed by Senkayi and others (1987), shows that the matrices are composed primarily of mixed-layer clays. Kaolinite is present as cell-fillings, vermicular clasts, and rarely as matrix material. Accessory grains are uncommon. The dominant accessory minerals are subhedral and often etched alkali feldspars. Plagioclase is also present but not as abundant as the alkalies. Barite and pyrite, and rare subrounded quartz and euhedral zircons were observed in each of the examined samples.

Palynology and Organic Petrography

Gennett (1985) and Gennett and Raymond (1986) examined incremental bench samples from a core of the San Miguel lignite and found that the lower D bed had pollen derived from marsh ferns and palms which suggested a brackish-water influence on the deposition of the D bed paleo-mire. Pollen types found in the overlying beds showed fresh-water associations as indicated by a vertical transition from *Nyssa* (tupelo) to *Engelhardia* (walnut family) and *Fagaceous* (oak family) types. Mukhopadhyay (1989) reported that beds B and D contain marsh pollen types and suggested that the San Miguel lignites are dominated by *Engelhardia/Juglandaceae* and herbaceous(?) monocots.

Mukhopadhyay (1986, 1989) examined the petrographic characteristics of channel and lithotype samples from each of the four major lignite beds exposed at the San

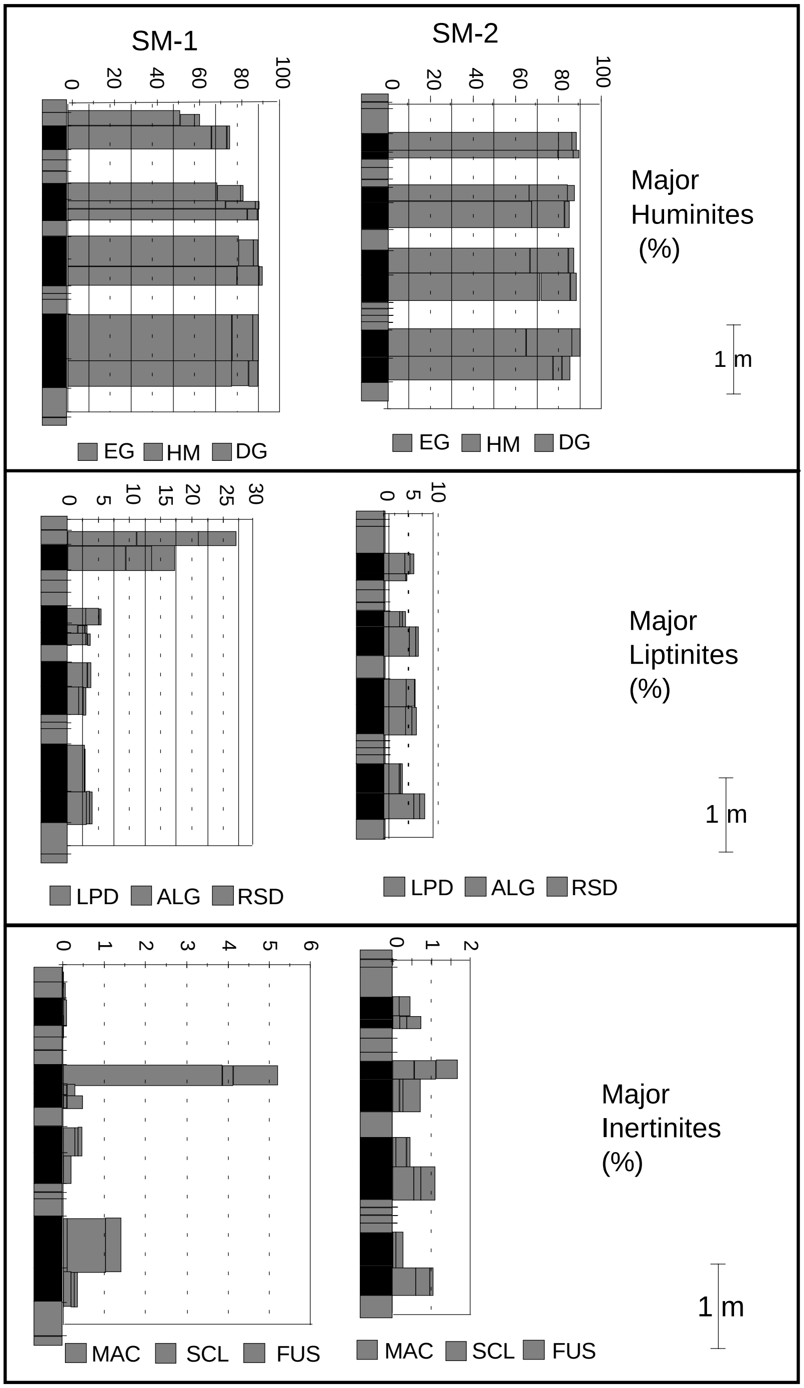

Figure 7. Bar graphs of the major petrographic constituents for the channel-sample sets SM-1 and SM-2. Location of samples are shown on figure 1 and lithologic symbols refer to figure 2. Abbreviations are as follows: EG = eugelinite, HM = humotelinite, DG = detrogelinite, LPD = liptodetrinite, ALG = alginite, RSD = resinite in attritus, MAC = macrinite, SCL = sclerotinite, FUS = fusinite. From Warwick and others (1996)

Miguel mine. Mukhopadhyay's channel sample data indicate that bed A (fig. 2) contains greater amounts of liptinite macerals (32%, primarily sporinite and liptodetrinite) than the huminite-rich middle lignite beds. Bed C contains the greatest amount of huminitic material (85%, primarily ulminite and attrinite/densinite) when compared to the other beds. Inertinite content for the beds range from 1 to 4% and is primarily in the form of sclerotinite and fusinite. The D bed contained a few marine dinoflagellates (algal cysts).

Warwick and others (1996) reported that the San Miguel lignite deposit is dominated by the huminite maceral group (89%) followed by the liptinite (10%), and inertinite (1%) maceral groups (figs. 3d and 7). The three dominant huminite maceral subgroups in decreasing order of abundance are: eugelinite (73%), humotelinite (11%), and detrogelinite (3%). The liptinite maceral group is dominated by liptodetrinite (4%), followed by alginite (2%) and resinite in attritus (1%). The inertinite maceral group is composed of macrinite, sclerotinite, and fusinite.

Vertical and lateral variations in maceral composition can be observed in the petrographic data (fig. 7). Channel-sample set SM-1 contains similar amounts of huminite macerals as found in SM-2 samples, but SM-1 samples have markedly less liptinite and inertinite components. Vertical trends in the petrographic data include slightly increased liptodetrinites in samples from the top and bottom of the lignite interval and a sharp increase in inertinite (primarily macrinite and fusinite, fig. 7) in the lignite samples directly below the parting between the A and B beds. Humotelinite content increases, although slightly, in the upper part of each bed. This finding is in agreement with megascopic descriptions of the coal in the field.

RELATIONSHIP BETWEEN ASH YIELD, AND PETROGRAPHIC AND GEOCHEMICAL CHARACTERISTICS OF THE SAN MIGUEL LIGNITE DEPOSIT

Warwick and others (1996) examined the relationship between the ash yield and the petrographic and geochemical characteristics of the San Miguel lignite as mined. The major conclusions of their study are as follows: (1) The distribution of Mn is inversely related to the ash yield of the lignite samples. This indicates an organic affinity, or an association with finely disseminated minerals in the lignite that contain this element. (2) On a whole-coal basis, the concentration of the environmentally sensitive element Pb is positively related to ash yield in lignite samples. This indicates an inorganic affinity for Pb. (3) Average whole-coal concentrations of As, Be, Sb, and U in the San Miguel samples are greater than published averages for these elements in other U.S. lignites. (4) The upper and lower lignite benches of the San Miguel deposit are both ash- and algal-rich, indicating that these intervals were probably deposited in wetter conditions than those in which the middle intervals formed. (5) The dominance of the eugelinite maceral subgroup over the huminite subgroup indicates that the San Miguel lignites were subjected to peat-forming conditions (either biogenic or chemical) that enabled degradation of wood cellular material into matrix gels, or that the plants that formed these lignite benches were less woody and more prone to formation of matrix gels. (6) An inertinite-rich layer (top of the B bed) might have formed from widespread oxidation of the San Miguel peat as a result of a volcanic ash fall that was subsequently reworked.

SUMMARY

There have been numerous studies conducted through the years detailing the geology of the San Miguel lignite deposit. The depositional setting of the lignite deposit is interpreted to have originated in back-barrier lagoonal mires (Snedden and Kersey, 1981; Kaiser and others,1980; Gowan,1985; Ayers, 1986). The deposit consists of four or more thin (generally < 1 m or 3.3 ft thick) lignite benches that are separated by claystone and mudstone partings (fig. 2). The partings are composed of altered volcanic air-fall ash that has been reworked by tidal or channel processes associated with a back-barrier depositional environment (Snedden and Kersey, 1981; Gowan, 1985; Ayers, 1986; Senkayi and others, 1987; and Warwick and others, 1996).

Individual lignite beds generally exhibit a dull, somewhat massive texture near their base, which grades upwards into attrital-rich lignite with increasing xylinitic bands (3-4 cm or 1.2-1.6 in thick) towards the top of the individual bed. Proximate data indicate that dry ash yields from the San Miguel deposit average 30.16%; total dry sulfur content averages 2.76% (dominated by organic sulfur, 2.04%); and dry calorific values average 8611 Btu/lb (20 Mj/kg) (Warwick and others 1996). Petrographically, the San Miguel lignite deposit is dominated by the huminite maceral group (89%) followed by the liptinite (10%), and inertinite (1%) maceral groups (Warwick and others, 1996). Average whole-coal concentrations of As, Be, Sb, and U in the San Miguel samples are greater than published averages for these elements in other U.S. lignites (Warwick and others, 1996).

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CHAPTER 4

Some speculations on coal-rank anomalies of the South Texas Gulf Province and adjacent areas of Mexico and their impact on coal-bed methane and source rock potential

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INTRODUCTION

There are two known occurrences of bituminous coal within the generally lignitic Gulf of Mexico Coal Province. One occurs in the Olmos Formation (Maastrictian) and the other occurs in the lower-middle part of the Claiborne Group (middle Eocene, fig. 1). Both occur within the Rio Grande vicinity of south Texas and Mexico, and each can be considered somewhat anomalous in rank in comparison with typical U.S. coals of similar age, which are generally less mature.

CRETACEOUS BITUMINOUS COALS

The Olmos Formation coals, which will not be visited on the field trip, occur in the Eagle Pass area of Maverick County, Texas, where a permit to mine is pending (Dos Republicas permit, fig. 2). This deposit extends into the Sabinas Basin of Mexico, where high-volatile C bituminous coal is being mined for electrical power generation by the Minera Carbonifera Rio Escondido (MICARE) for the Comission Federal de Electicidad (CFE) Carbon I and II projects (fig. 2). Core samples of these high-ash coals from the Eagle Pass area are typically about 7500 Btu/lb on an as-received (AR) basis and about 12,000 Btu/lb on a moist, mineral matter-free (MMmF) basis. Samples from Carbon I and II are reported to have an average (Rm?) vitrinite reflectance of 0.58% (Verdigo and Arciaga, 1991). These and other rank parameters for Sabinas Basin coals are somewhat higher than those for most shallow occurrences of Upper Cretaceous coals of the southern Rocky Mountain Province, for example the southern part of the San Juan Basin of New Mexico, but they are consistent with rank-elevated coals towards basin interiors or near igneous provinces on basin margins. The rank elevation of the Olmos Formation coals can probably be attributed to residual heat flow from slightly younger shallow intrusive activity of the Balcones igneous province, or much younger igneous activity within Mexico (fig. 2).

TERTIARY BITUMINOUS AND RELATED COALS

The second documented occurrence of bituminous coals in the Gulf Province is the Santo Tomas coal field in Webb County, Texas, which will be visited on the field trip. Here the Farco Mining Company (fig. 2) is mining high-volatile A bituminous coal from the lower-middle part of the Claiborne Group

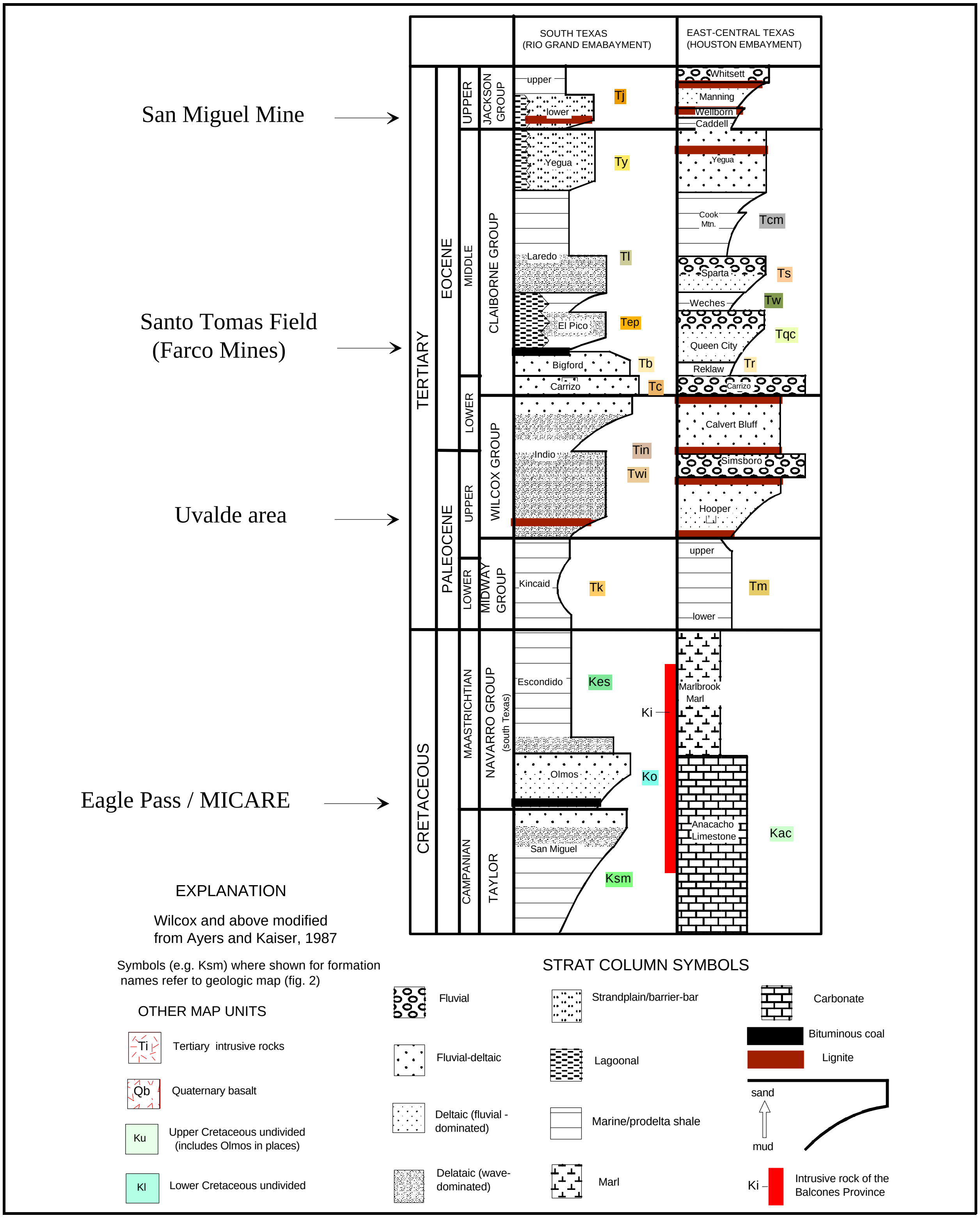

Figure 1. Generalized columnar section for south Texas coal areas and adjacent areas of Mexico.

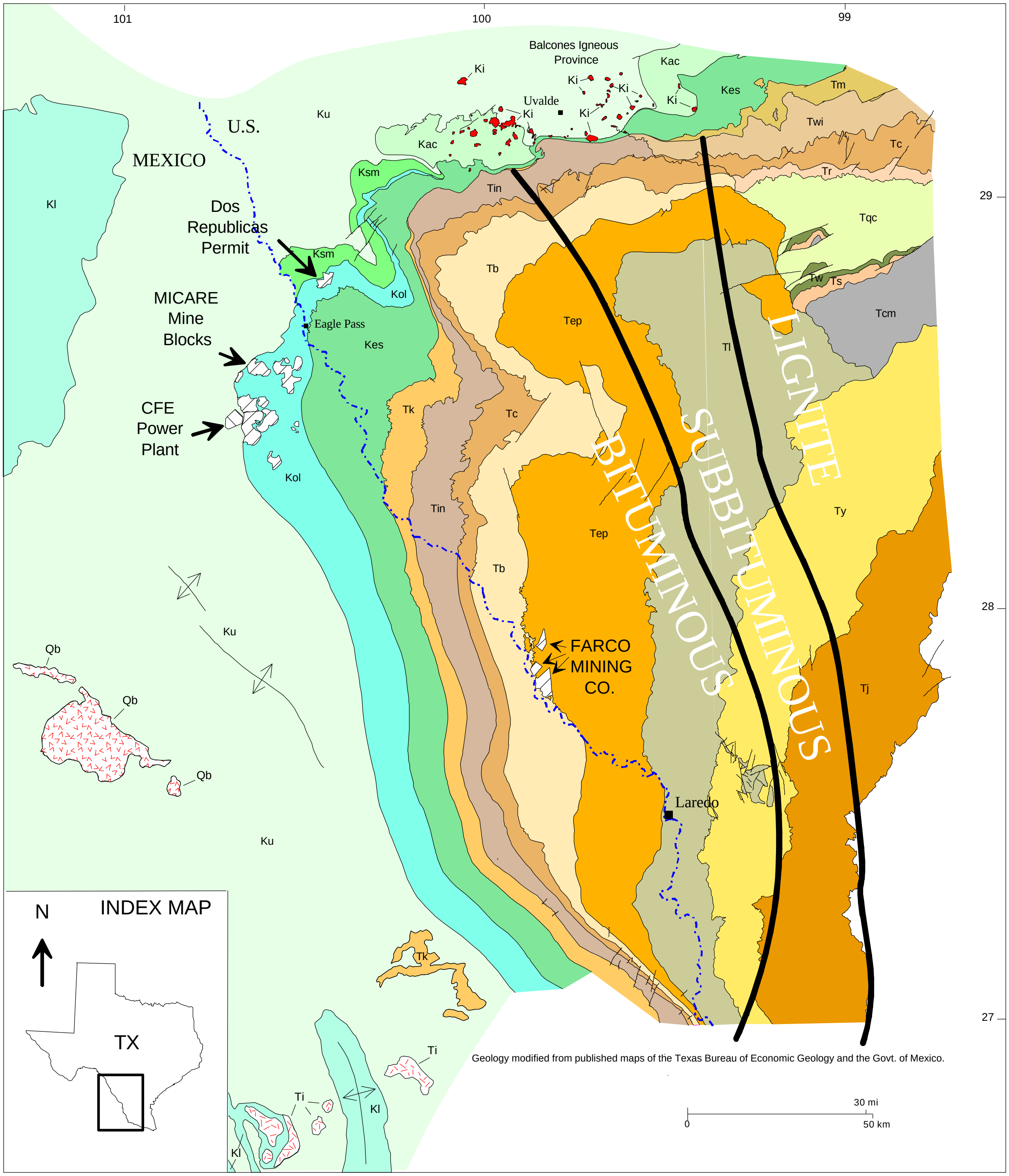

Figure 2. Regional geology and location of bituminous coal deposits of south Texas and adjacent areas of Mexico. See figure 1 for map units. Also shown are speculative boundaries of coal-rank changes.

for use in local cement plants and for export as lump coal for use in the Republic of Ireland. The coal occurs in two primary zones, the San Pedro and Santo Tomas zones, near the ill-defined contact of the Bigford and overlying El Pico Formations, about 3,000 ft stratigraphically higher than the Olmos Formation (fig. 1). Speculations on the cause of the relatively high rank of these coals are more problematic than those for the Olmos coals. Because these coals occur higher in the section than Wilcox Group coals from the same general area, which have traditionally been described as lignite (Maxwell, 1962, Breyer and McCabe, 1986), depth of burial would presumably not account for the rank elevation. Numerous lignite beds have also been described as intercalated within the San Pedro – Santo Tomas canneloid coals themselves (Lonsdale and Day, 1937), which would also presumably rule out depth of burial or local thermal gradients as the cause of rank elevation.

Based on these considerations, it would be logical to assume that the highly sapropelic nature and enriched liptinite content (reported to be 23% in Warwick and Hook, 1995) of these coals could account for their anomalously high heating value (~12,000 Btu/lb AR, 14,000 MMmF, figs. 3 and 4), without an added thermal factor. A re-examination of nearby Wilcox coals suggests, however, that a much wider area and stratigraphic range of South Texas has been subjected to elevation in rank, probably by local heat flow, than previously thought. Recalculating the Wilcox coal quality parameters for the Uvalde area (fig. 2) from Maxwell (1962, tables 30, 31, and 32) gives a range of MMmF Btu/lb from 10,494 to 11,893, (i.e. subbituminous A to high-volatile C bituminous). Note that sample no. 1-A from Maxwell's table 30, which is lignite on an MMmF basis, is clearly weathered, and some other samples from his tables appear to have lost moisture; normalizing to 15% moisture consistent with table 32 results in an apparent rank of subbituminous B to high-volatile C bituminous. Proprietary analytical data recently made available to the USGS for the National Coal Resource Assessment supports these determinations. Together they indicate that on the basis of heating value, the Wilcox coals range from subbituminous B just east of Uvalde to high-volatile bituminous A towards the west, although even the most mature of these coals is generally described as lignite in company drilling records. An average reflectance value of 0.37% (Rm; range 0.30-0.45%) reported by Breyer and McCabe (1986) from an area just east of Uvalde is somewhat equivocal, but consistent with subbituminous coals of the Powder River Basin of Wyoming (R.W. Stanton, USGS, personal communication). These values can be compared with some previously unpublished rank parameters and standard analysis of the Santo Tomas and San Pedro coal zones and typical Wilcox lignites from the Sandow mine near Austin, approximately 250 mi northeast of the Santo Tomas field, in figures 3 and 4.

To the author's knowledge, no published analysis of the intercalated "lignites" of the Bigford-El Pico interval exist. One highly weathered sample of a banded, somewhat splintery, stray bed that occurs within the San Pedro interval about 40 ft above the main bed at the Farco Trevino Mine has been analyzed by the USGS with equivocal results (sample SP-UN-96-1, figs. 3 and 4). On a Btu basis, this coal would seem to be classified as lignite; however, an average Rmax of 0.74% and extremely high

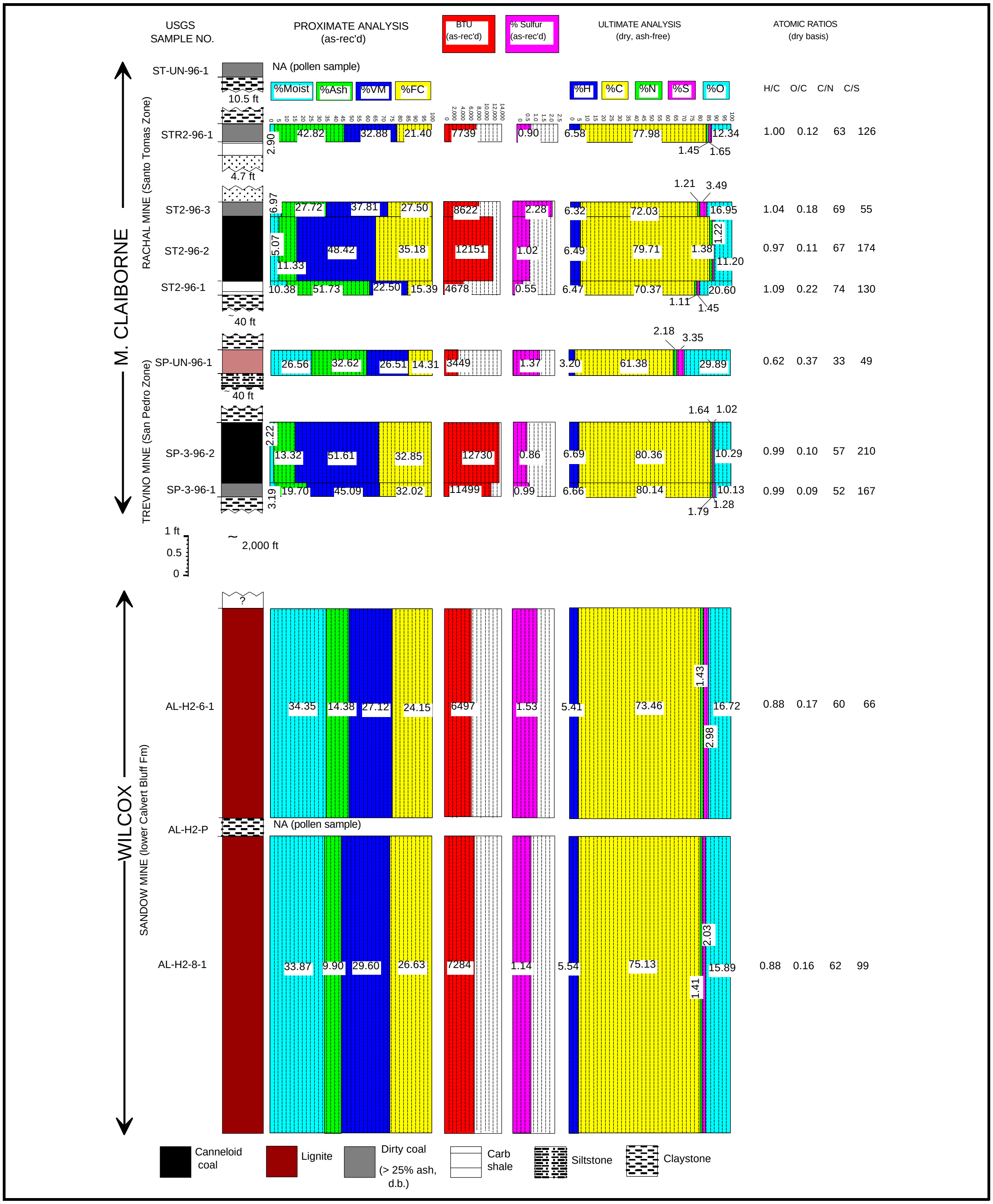

Figure 3. Standard analysis and elemental ratios for selected samples from the Santo Tomas coal field (middle Claiborne) and Sandow Mine (Wilcox).

volatile-matter content imply a rank more similar to the canneloid coals. Other maturation parameters (apparent specific gravity, residual moisture, agglomerating character, etc.) are more consistent with Wilcox lignite, although the weathered nature of the sample is readily apparent form the high oxygen content, and none of these results can be considered definitive. The higher reflectance value for the stray bed versus the main San Pedro – Santo Tomas beds as shown in figure 4 may be attributable to weathering-related diminution of the vitrinite suppression typical in canneloid coals. This sample fluoresces when examined under blue light and shows algal cell structures similar to the San Pedro and Santo Tomas canneloid coals (P.D. Warwick, USGS, personal communication).

EXTENT OF THE COAL-RANK ANOMALY AND ITS POSSIBLE IMPACT ON HYDROCARBON GENERATION

As previously stated, it now appears that a much wider area of South Texas has been subjected to coal-rank elevation than has previously been recognized. Early versions of the "Coal Fields of the United States" map (e.g. Campbell, 1908, through Trumball, 1960) showed small pods of bituminous coal within the overall lignite trend, and no intervening subbituminous halos. The area of hypothesized rank elevation was slightly expanded for a preliminary revision to this map (Tully, 1996), without the benefit of most of the new data or rank recalculations cited herein. Based on the information currently available, additional revisions to the map that will show a much wider and more graduated area of rank elevation in South Texas are being proposed, as shown in figure 2. Any such revisions are speculative, however, without analysis of fresh samples of the intercalated stray beds in the El Pico – Bigford interval and additional reflectance values and analyses from the Wilcox, Jackson and Yegua intervals (figs. 1 and 2).

Coal-bed methane (CBM) shows have been recorded in some gas wells in Maverick and Dimmit counties, and a number of gas fields occurring in the general area produce from Olmos and Wilcox sandstones (see Ewing this volume). The extent of the coal-rank variation within South Texas can therefore be considered particularly important from the consideration of the CBM and conventional source-rock potential. The H/C and O/C ratios from figures 3 and 4 are plotted on a Van Krevelen diagram in figure 5, along with data for Olmos Formation coals derived from various sources (Evans,1974, table 5; Miller and others, 1998; and unpublished USGS files). A few examples of Jackson Group coals, which are generally not discussed in this paper, but will be seen on the field trip, are also shown for completeness; these are from unpublished USGS sampling of the San Miguel Mine. As to be expected, the Wilcox, Olmos, and Jackson coals plot within the type III kerogen path, and the less humic Santo Tomas and San Pedro coal zones plot closer to the type II field. The Santo Tomas coals, which appear slightly more oil prone on the diagram, yielded 52 gal/ton oil and 5672 SCF per ton gas from low-temperature distillation done by the U.S. Bureau of Mines (Ashley, 1919). Rock-Eval pyrolysis for one Santo Tomas sample by Mukhopadhyay (1989, fig. 28a), which yielded 66% total organic carbon and very high and low hydrogen and oxygen indices respectively, placed these coals directly on the type II kerogen field.

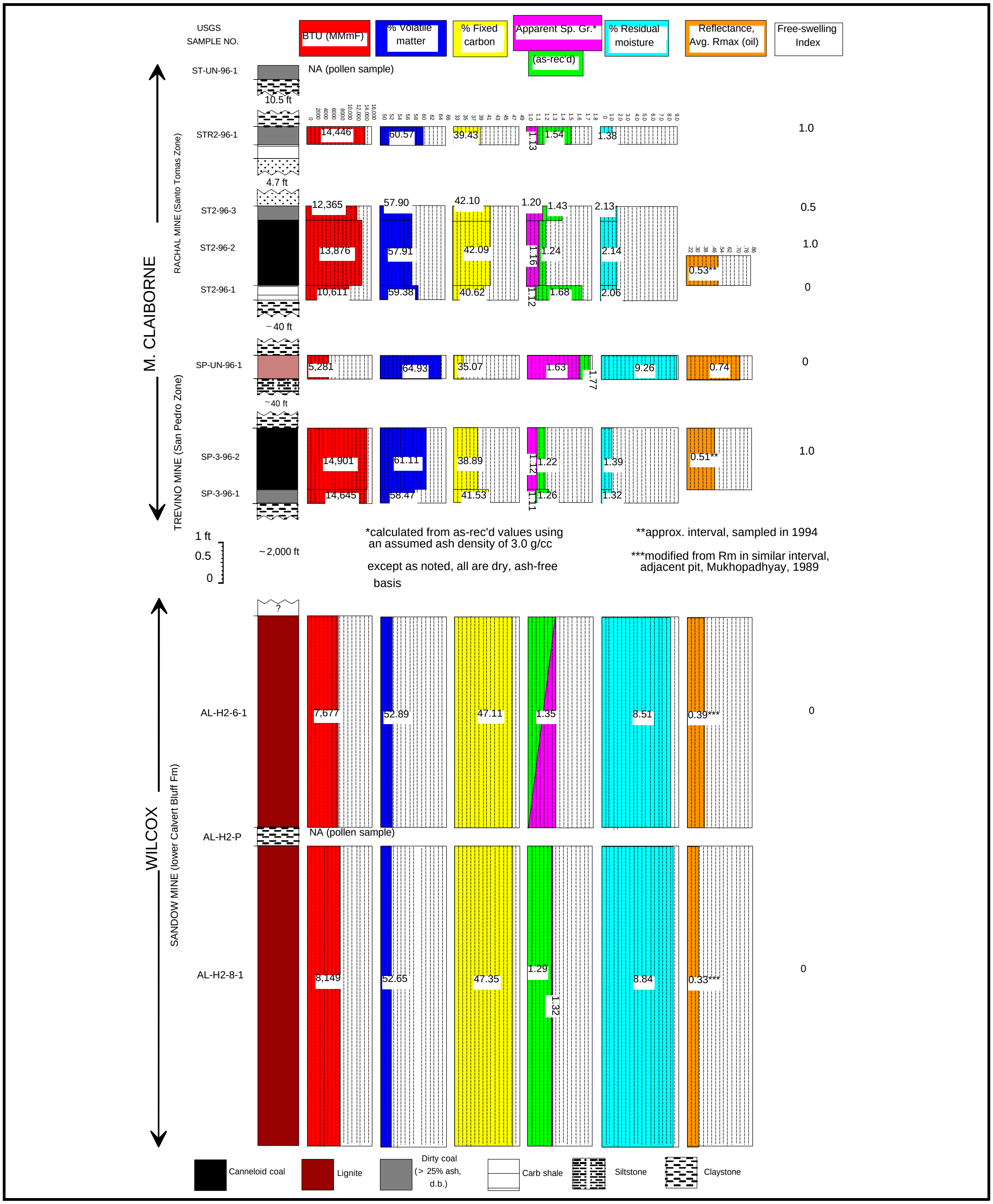

Figure 4. Selected rank parameters for selected samples from the Santo Tomas coal field (middle Claiborne) and Sandow Mine (Wilcox).

The remarkable ease of ignition that enables these coals to be exported in considerable quantities for domestic use is further evidence of their oil-generating potential. Most of the Olmos data shown on figure 5 approaches the lower limits of hydrocarbon generating maturity. In addition to being somewhat oil-prone in composition, these coals may lack the permeability to adsorb gas or produce CBM commercially.

The Olmos Formation data shown on figure 5 is generally consistent with that of a somewhat more mature humic coal than the other samples. Available coal-quality data for the Olmos Formation is, however, scarce and somewhat questionable. The data shown on figure 5 from the MICARE mine samples (Miller and others, 1998) shows consistently lower oxygen values than the other Olmos samples, and thus more apparent maturation, placing them well beyond fluid hydrocarbon generation thresholds. While this conceivably could reflect increasing rank towards local igneous activity, it seems more probable that this is an analytical bias. Other data from the MICARE mines (Verdigo and Arciaga, 1991, table 2) show higher average oxygen values, but the reporting basis is not clear. The Dos Republicas sample analysis appears to be reliable, but these and other recent analyses from the Eagle Pass area show a very wide range of ash, and corresponding elemental values where available, that may be attributable to sampling techniques. The "old Eagle Pass" samples on figure 5 came from a variety of mine sources sampled before 1912 (see Evans, 1974), including unwashed and washed samples, with some apparent drying, and possibly weathered. The available data on heating value for the MICARE coals is also inconclusive in this regard. The Olmos data shown on figure 5 represent an attempt to select "typical" samples with relatively similar ash values from the various data sets, with the exception of the "old" samples, where the widest range is shown. The two San Miguel samples selected for the diagram are probably slightly atypical, in that they are at the higher end of the recorded heating values for USGS samples from that mine. These and the Sandow samples shown on the diagram fall in the relatively less mature end of the humic pathway as expected. All of the oxygen values used for figure 5 are by difference rather than direct measurement, with the possible but unlikely exception of the "old Eagle Pass" samples.

No elemental data is currently available to the USGS for Wilcox, Yegua, or Jackson coals from the higher rank areas shown in figure 2. Based on their location, at least some of the reported CBM shows in the area are without question from Olmos Formation coals. It appears likely that a considerable area of Wilcox coals may also have reached thermal-gas-generating maturity in the South Texas area. Although highly speculative, based on the extent of Tertiary volcanism in nearby areas of Mexico, it appears that Yegua and Jackson coals could have been similarly elevated in rank as far south as Falcon Reservoir (about 90 mi southeast of Laredo, fig. 2). In a detailed study of the petrology and organic geochemistry of Texas coals, Mukhopadhyay (1989) suggested that many Texas coals are enriched in liptinite relative to other coals of similar rank and may have generated liquid hydrocarbons earlier on the maturation pathways than is normally expected. Although very few of his samples are from South Texas, where the maturation potential would seem highest, he suggests (p. 102) that some of the oil produced from the

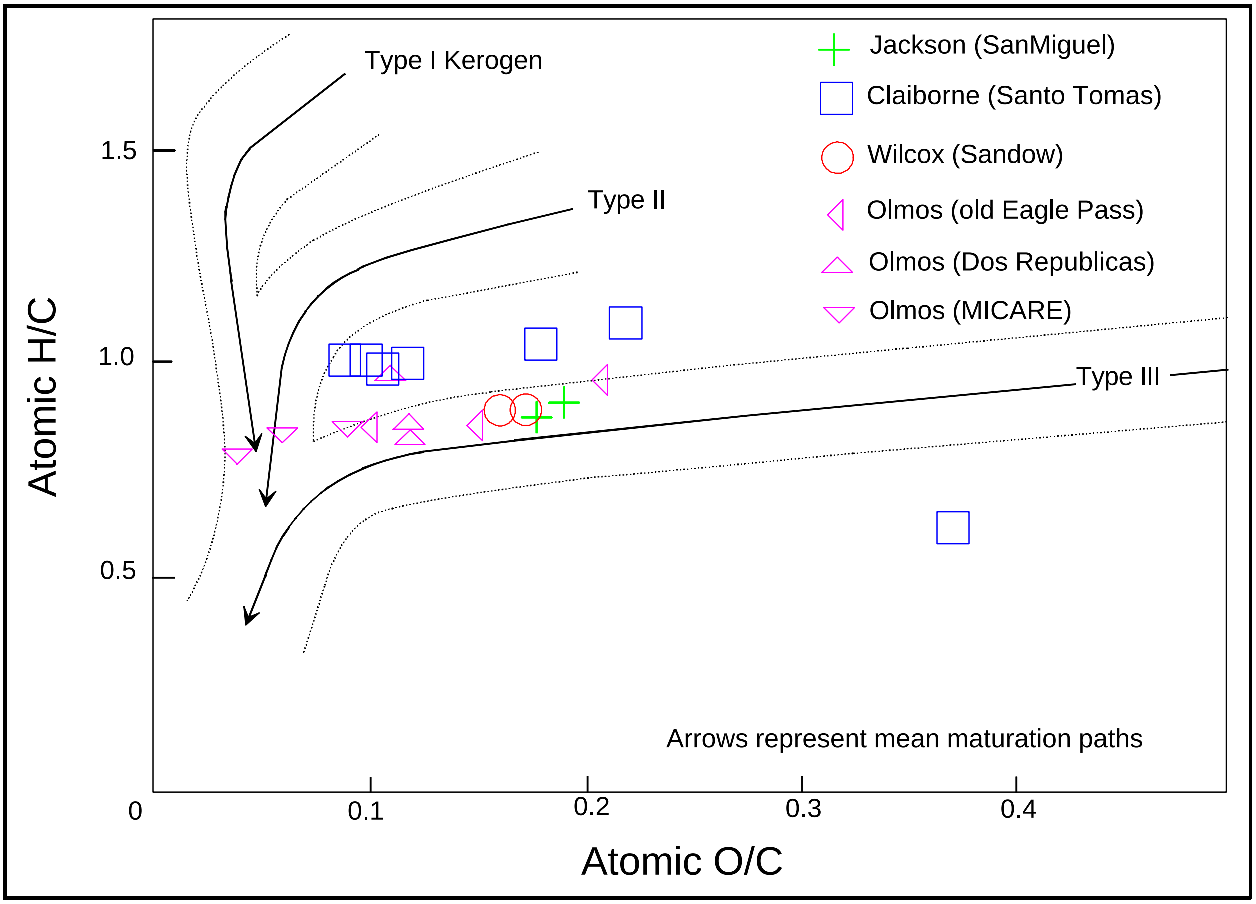

Figure 5. Van Krevelen-type diagram for various coal types of South Texas and vicinity.

Wilcox and Claiborne intervals of South and East Texas may be sourced in the Wilcox.

One potential constraint on commercial CBM viability in South Texas may be the thickness of the coal beds, which for individual beds is generally less than ten feet thick. There are multiple beds in each of the coal-bearing intervals, however, and in general coal thicknesses beyond shallow (i.e. mineable) depths have not been thoroughly investigated. It should be noted that nothing in this paper addresses the potential for early or late biogenic gas occurrences in Texas coals, which should be considerable based on recent activity in the Powder River Basin of Wyoming. It is also worth noting that although the coal-bearing facies of the Olmos Formation is mapped with an eastward pinch-out into marine rocks a few miles southwest of Uvalde (fig. 2), anecdotal evidence presented in Maxwell (1962, p. 90) suggests that Cretaceous coal-bearing rocks may be present somewhat farther east and north.

CONCLUSIONS

Available information based on limited and poorly controlled sampling and analysis suggests that the coal rank anomalies recognized in the Olmos Formation and middle Claiborne Group of South Texas and adjacent areas of Mexico may extend to a considerably wider area and stratigraphic range. Additional sampling and analysis of the entire interval from the Upper Cretaceous Olmos Formation through the upper Eocene Jackson Group would be useful in refining the known extent of rank variation. Coal-bed desorption and drill-stem or more sophisticated down-hole testing would help determine the methane-producing potential of these coals. Biomarker and stable isotope studies of hydrocarbons produced from more conventional reservoirs in the area may also provide useful information on the source-rock potential of these coals.

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