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

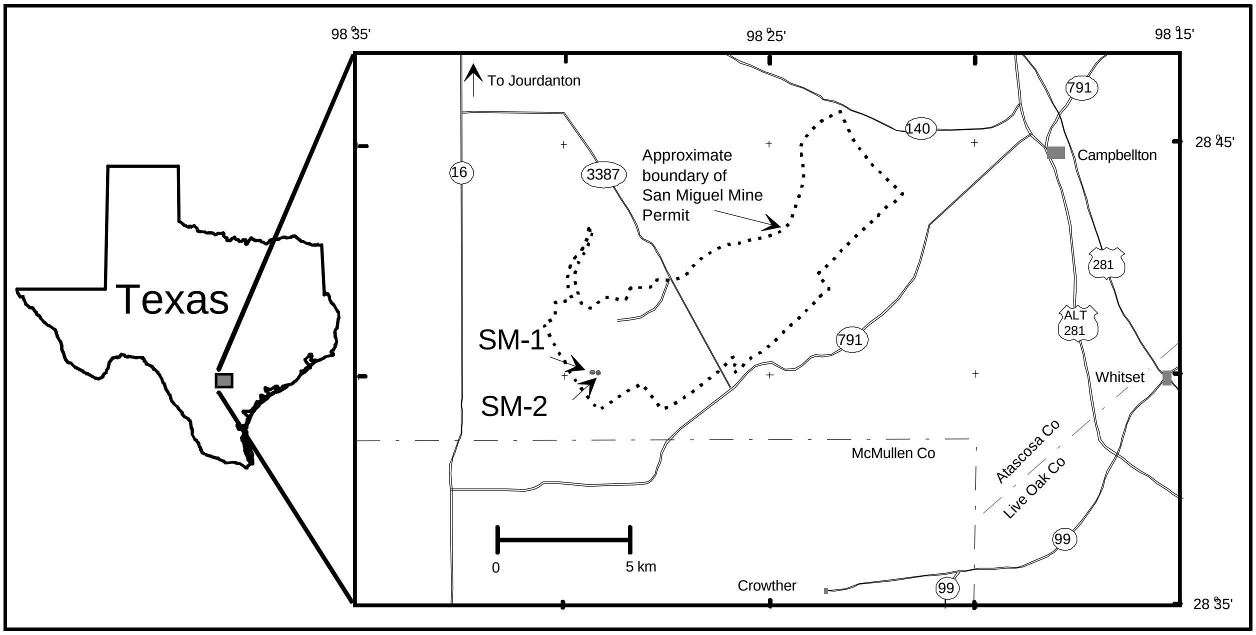

Figure 1. Index map of the San Miguel Mine area showing towns, roads, and sample sites. Mine outline from the San Miguel Lignite Mine Permit Application, on file at the Texas Railroad Commission in Austin, Texas. From Warwick and others (1996).

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

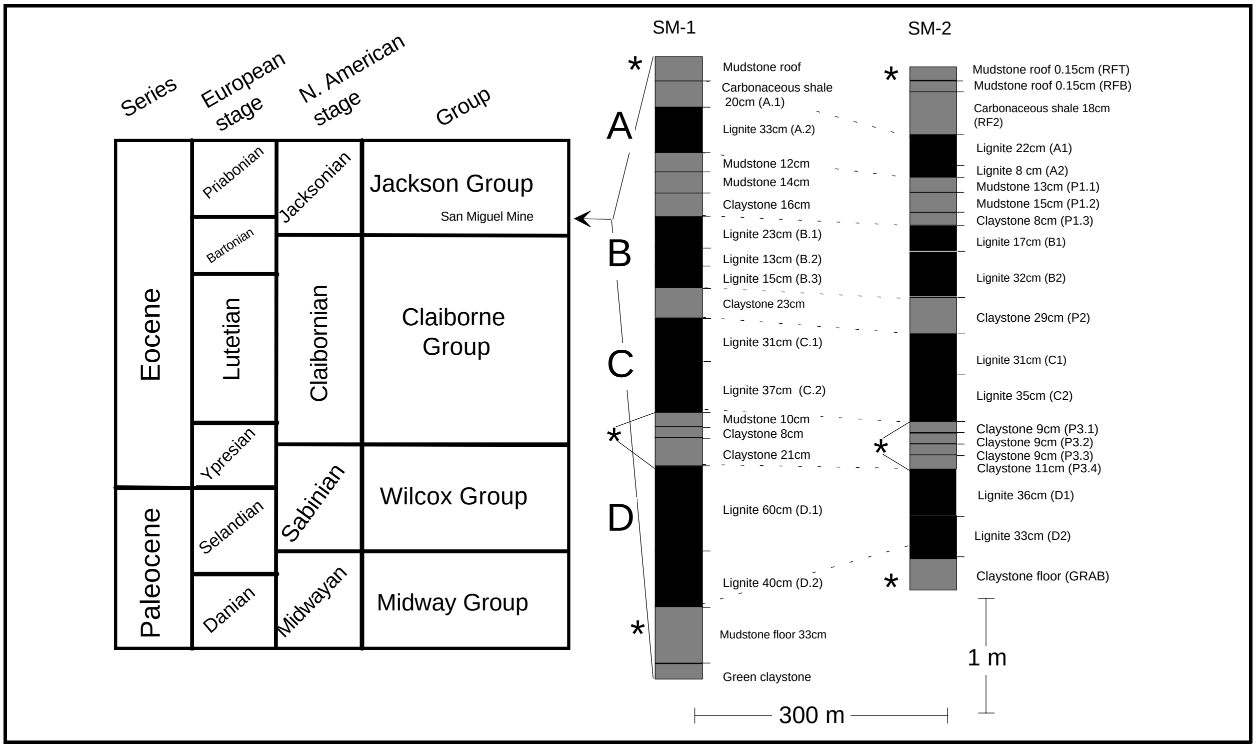

Figure 2. Generalized stratigraphy and stratigraphic sections of the coal-bearing interval at the San Miguel Mine. Sample numbers are in parentheses, and channel sample sites are shown on figure 1. The approximate positions of the volcanic ash beds identified by Senkayi and others (1987) are indicated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

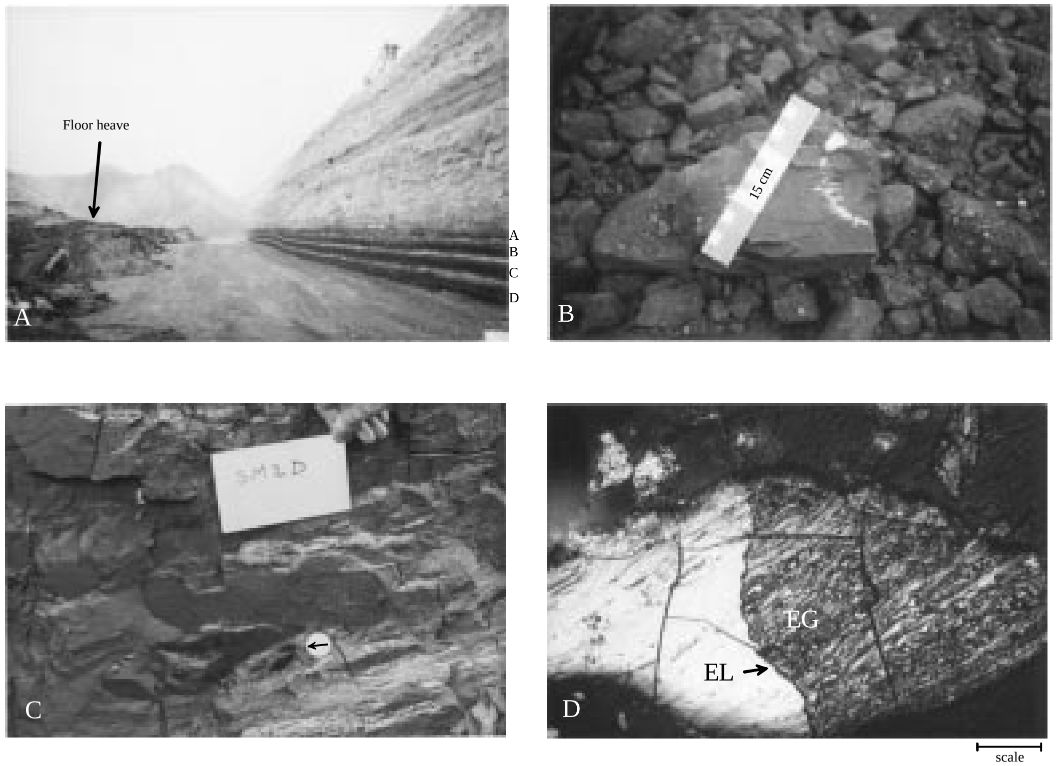

Figure 3. Representative photographs and photomicrographs of outcrops and samples from the San Miguel lignite interval. (a) View of a highwall with A (upper), B, C, and D beds and the partings. Note that the debris on the mine floor seen on the left of the photograph is due to floor heaves. (b) Clay-filled 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

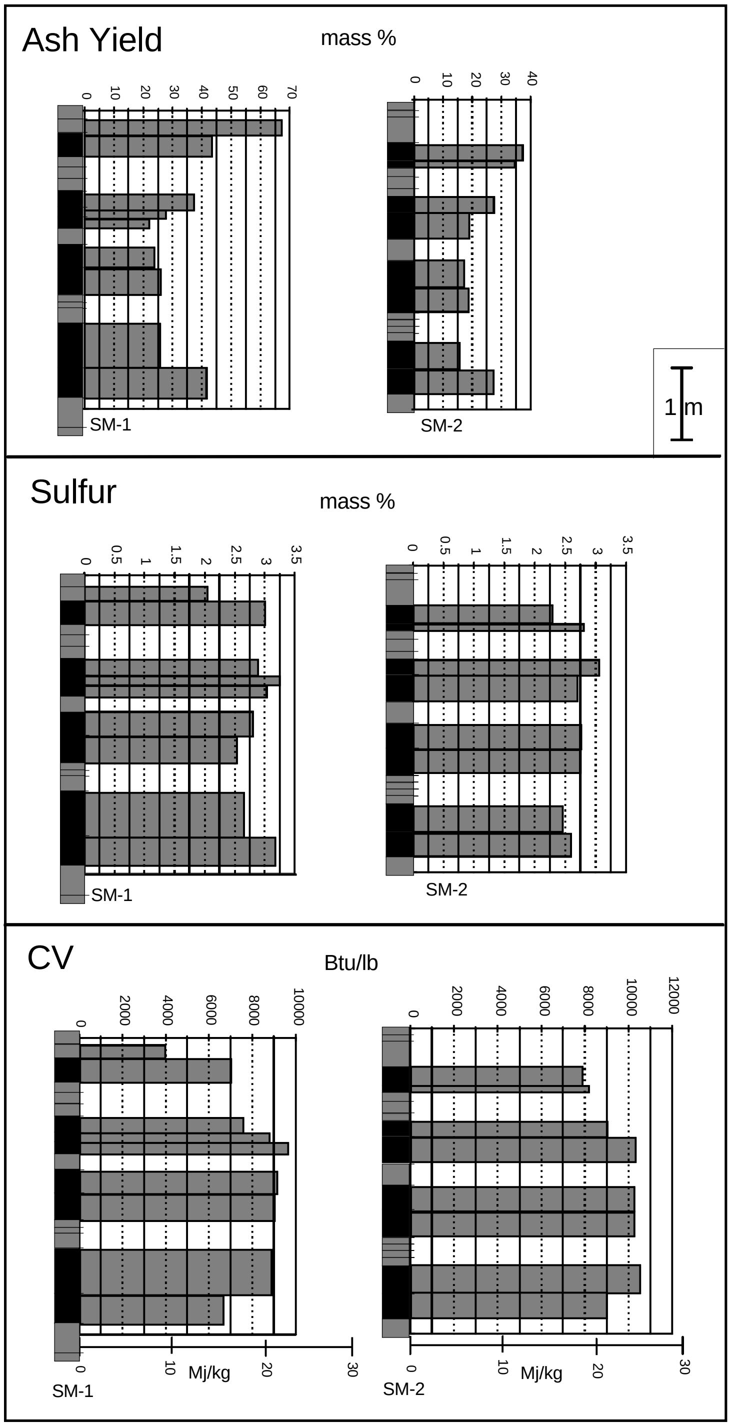

Figure 4. Bar graphs showing concentrations of ash yield, total sulfur, and calorific value (CV, dry basis) for the sample sets SM-1 and SM-2. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. Distance between sample sites is about 300 m. From Warwick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

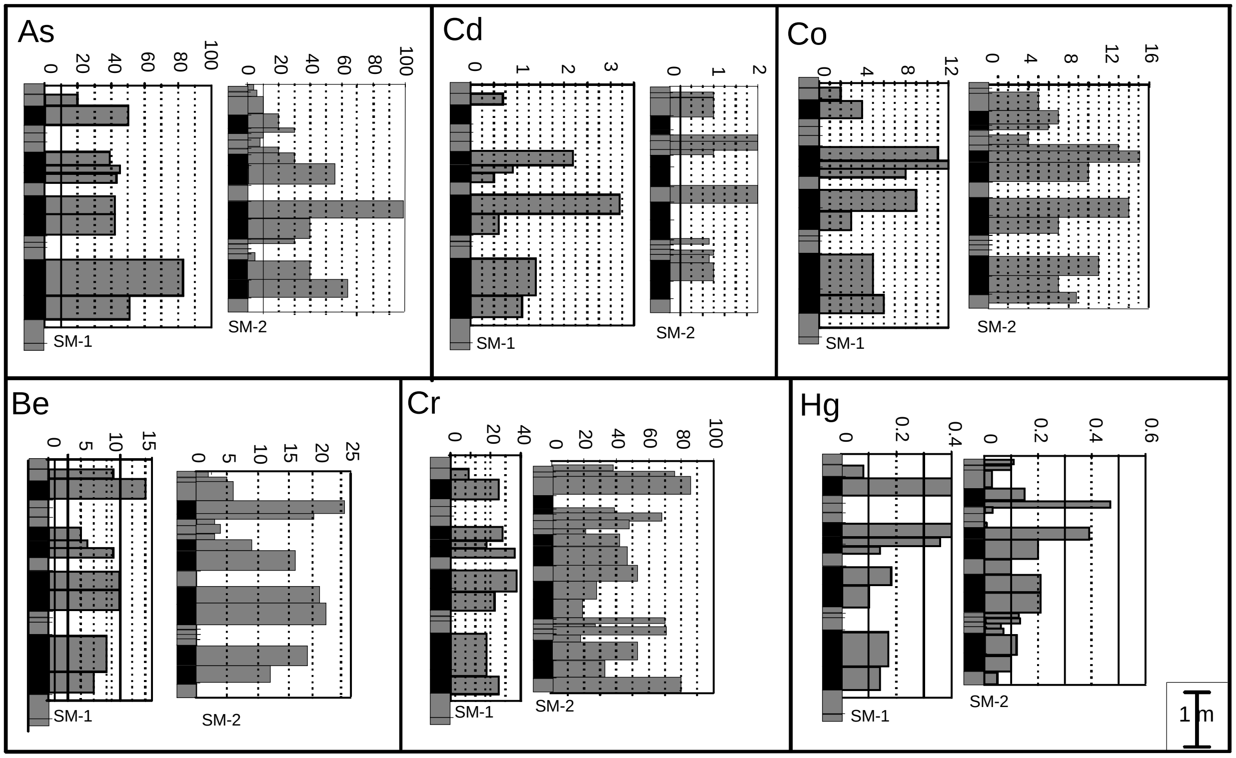

Figure 5. Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for twelve potentially environmentally sensitive elements identified by the 1990 U.S. Clean Air Act Amendments. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 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%);

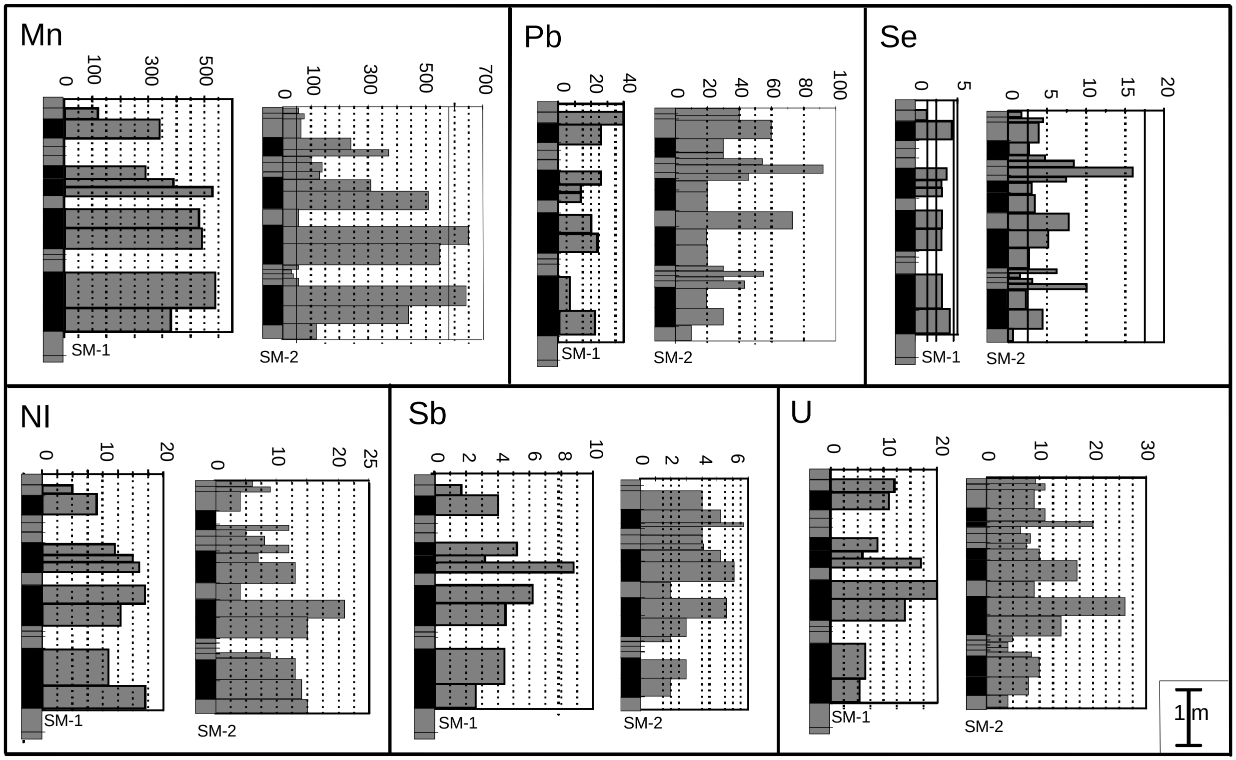

Figure 5. Continued - Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for twelve potentially environmentally sensitive elements identified by the 1990 U.S. Clean Air Act Amendments. Location of samples are shown on figure 1 and lithologic symbols are the same 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

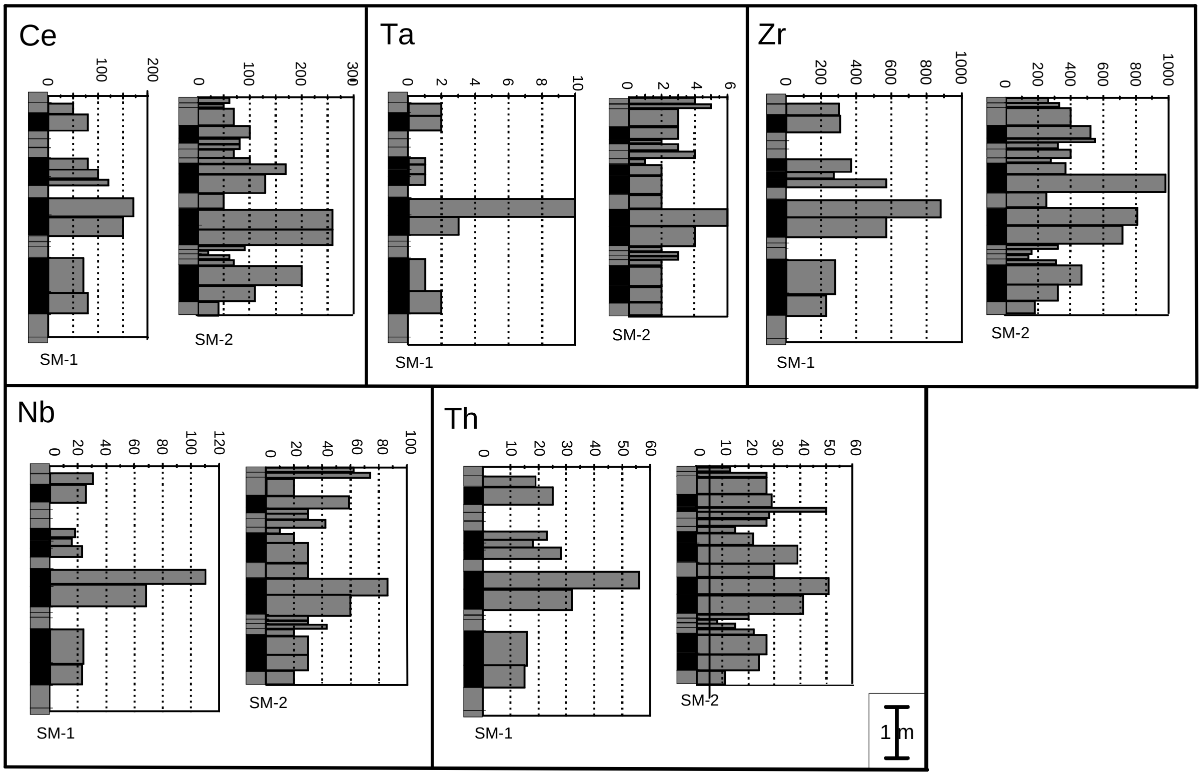

Figure 6. Bar graphs showing the distribution of trace element concentrations (dry USGS ash basis) for those elements inferred to be derived from volcanic ash. Location of samples are shown on figure 1 and lithologic symbols are the same as used on figure 2. All values are parts per million (ppm). From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

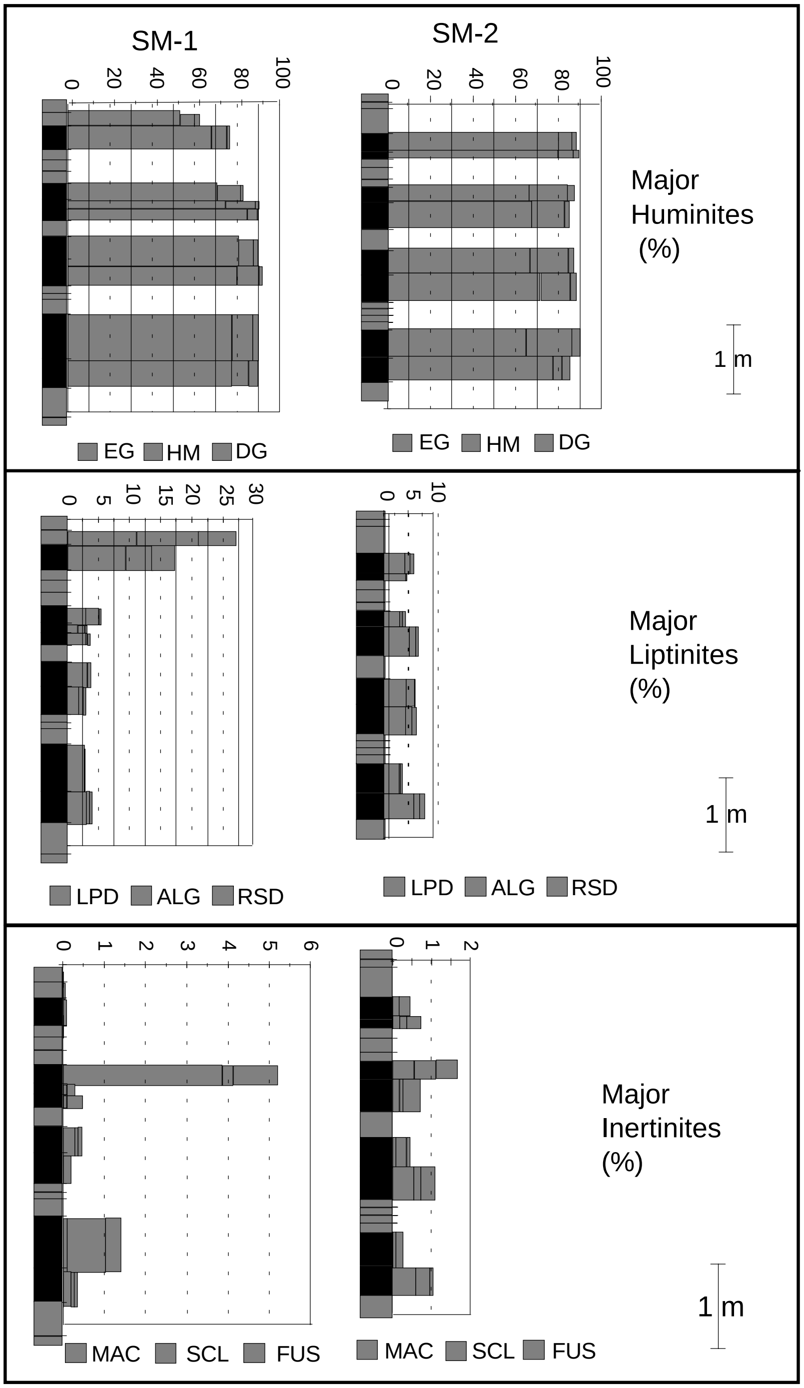

Figure 7. Bar graphs of the major petrographic constituents for the channel-sample sets SM-1 and SM-2. Location of samples are shown on figure 1 and lithologic symbols refer to figure 2. Abbreviations are as follows: EG = eugelinite, HM = humotelinite, DG = detrogelinite, LPD = liptodetrinite, ALG = 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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