FIELD GUIDEBOOK
MINESOIL AND ACID SEEP WORKSHOP

at

Gibbons Creek Lignite Mine
Texas Municipal Power Agency
Carlos, Texas

Participants:
Texas Mining and Reclamation Association (TMRA) and
Railroad Commission of Texas, Surface Mining and Reclamation Division

Prepared by:
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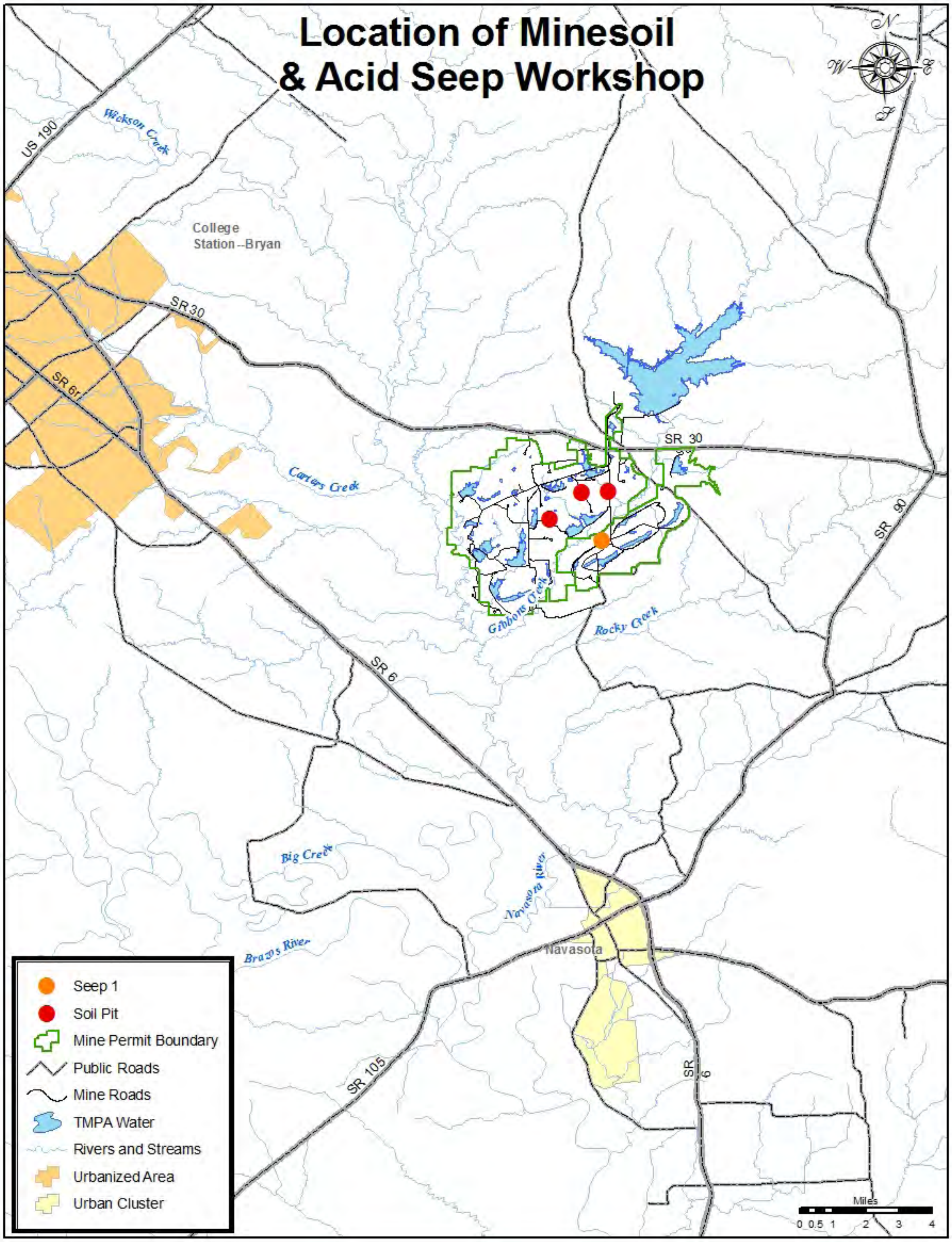
April 8, 2010



Map prepared by Lindy Liles.

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PREFACE

This field workshop developed as a direct consequence of a meeting held between the Texas Mining and Reclamation Association (TMRA) and the Executive Director of the Railroad Commission of Texas (RCT), John Tintera, on September 25, 2009, to discuss a number of surface coal mine reclamation issues. At the meeting, the Executive Director expressed interest in visiting a mine and seeing these issues first-hand.

The primary issues to be addressed in this workshop at Gibbons Creek Lignite Mine are:

- Minesoil reconstruction in relation to pyrite and acid-forming materials.
- Reclamation of acid seeps and final bond release.

The issue of acid-forming materials and pyritic sulfur concentrations was the subject of a report entitled *Evaluation of Texas Minesoils: History and Experience with Acid/Base Calculations and Pyritic Sulfur Concentrations: a Thirty-Year Review* prepared by TMRA and submitted to the RCT Surface Mining Division on July 22, 2008. This submittal was followed by meetings between TMRA and the RCT on July 28, 2008 and November 12, 2008. There were also comments from the RCT dated September 5, 2008, a response by TMRA dated December 3, 2008, and a response with additional comments from the RCT dated January 14, 2009, and a final response by TMRA dated February 2, 2009.

The central theme to pyrite, acid-forming materials, and acid seeps is the natural sulfur cycle. In general, sulfur exists in the natural environment either in the reduced form as sulfide (e.g., pyrite or iron disulfide – FeS_2) or in the oxidized form as sulfate (e.g., gypsum or calcium sulfate – $CaSO_4$). For Gibbons Creek mine, the cycle began 35 million years ago (Ma) in the late Eocene with the reduction of sulfate to sulfide in the sediments that were being deposited. The sulfate came from seawater as the sea encroached onto land. The reduction of the sulfate was facilitated by the highly reducing conditions resulting from the decomposition of vegetation, which scavenged any available oxygen from the environment. The sulfide reacted with available metals in solution, such as iron to form the highly insoluble pyrite, which immediately precipitated out. Where there was not enough iron, the sulfide reacted with hydrogen from water to form hydrogen sulfide (H_2S), to give the very characteristic smell of "rotten eggs" associated with the lignite seams. The formation as a whole remained in this reduced condition for millions of years until it started becoming exposed to oxidizing conditions on the other side of the cycle.

Over the years, as erosion began to remove materials from the surface, oxygen from the atmosphere began to percolate in with rainwater from the surface. This oxidizing process starts from the surface and works its way down resulting in a weathered "rind" of the earth's surface that is on average about 27 feet deep. The oxygen oxidizes sulfide to sulfate and oxidizes the lignite itself. For this reason, lignite is not mined from the surface "outcrop" because it is usually so weathered that it does not have much heat value, but from the subsurface "subcrop" where it is still unweathered. In the oxidation of sulfide, if there are bases present, such as calcium or barium, the sulfate ions combine to form calcium sulfate or barium sulfate, which precipitate out as relatively unreactive minerals. But if there are not enough bases present for complete reaction, the sulfate ions combine with hydrogen ions from water, to form hydrogen sulfate or sulfuric acid (H_2SO_4). This is a natural reaction that may occur in pristine unmined areas as well as in mined areas.

This field workshop investigates primarily the mined areas but discusses these in the context of the chemistry that affects all areas.

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April 8, 2010

1. INTRODUCTION

1.1 Purpose of field workshop

The purpose of this field workshop is to investigate the development of reconstructed minesoils and acid seeps at the Gibbons Creek Lignite Mine over the last two decades. The mine, which is owned by the Texas Municipal Power Agency (TMPA), is located in Grimes County, in east-central Texas.

The Gibbons Creek Lignite Mine is well suited for a study of this nature for the following reasons:

- The three minesoils that were selected for this workshop were reconstructed with mixed dragline overburden (spoil) materials and originally had some of the highest pyrite contents.
- All three minesoils are over 20 years old (the oldest is 26 years old) and have had time to weather and develop incipient soil characteristics.
- Minesoil reconstruction at the oldest site (Grid P19SE) was completed in 1984 before the issuance of minesoil suitability criteria by the Railroad Commission and before the practice of replacing native topsoil at the surface. Within a few years, this grid began to show increasing acidity and in 1991 was treated with lime to a depth of four feet.
- Minesoil reconstruction at the other two sites (Grids U15NW and X14SE) was completed after 1985 and consisted of regrading the mixed overburden material and covering it with a minimum of six inches of native topsoil.
- All three sites have demonstrated revegetation success, as demonstrated by vegetation productivity, cover, and diversity data.
- All three sites have satisfied reclamation standards for Phase I and Phase II bond release (minesoil reconstruction and revegetation success), which the Railroad Commission approved by Order dated December 7, 1999.
- The acid seep that is the subject of this workshop developed about eight years ago and has been closely monitored since.
- There is a good understanding of the geology of the acid seep site both before mining from lignite exploration drill holes and after mining from groundwater monitoring wells.
- The hydrogeology is also well understood, particularly in the context of re-establishment of the groundwater regime in the entire mine block.

1.2 History of Texas Municipal Power Agency

The Texas Municipal Power Agency (TMPA) is a political subdivision of the State of Texas, created by the Texas legislature in 1975 in the wake of the 1973 energy crisis. TMPA's purpose is to provide reliable electric power to its four Member Cities – Bryan, Denton, Garland, and Greenville. As a municipal corporation, the Agency is a non-profit organization and its rates for electricity are designed to cover annual system costs. Surplus funds are refunded to the Member Cities in accordance with the Power Sales Contract at the end of each fiscal year. TMPA is governed by a Board of Directors made up of two representatives from each Member City. This Board provides direction on the planning, financing, acquisition, construction, ownership, operation, and maintenance of facilities to be used for the generation, transmission, and sale of electric energy to the Member Cities. Additional information on TMPA may be found at its website: <www.texasmpa.org>

TMPA owns and operates the Gibbons Creek Steam Electric Station, a 470-megawatt coal-fired power plant, located near Carlos, in Grimes County. The power plant operates as a base-load unit (year-round with only an annual outage of three to five weeks for maintenance) with annual generation of approximately 3.6 million MWh (megawatt-hours). Construction of the plant began with the official ground-breaking on July 11, 1977 and commercial operations began on October 1, 1983. The plant was initially fueled with lignite, a low-grade type of coal (average heat content of about 4,500 Btu/lb, as-mined), supplied from the adjacent Gibbons Creek Lignite Mine (also owned by TMPA). In February 1996, the plant switched to low-sulfur sub-bituminous coal (heat content of about 8,400 Btu/lb) from the Powder River Basin, Wyoming, which is brought in by train under a contract with the Burlington-Northern-Santa Fe railroad company. TMPA has various supply contracts with different mines in the Powder River Basin coalfield.

The fuel switch was beneficial in a number of ways. The new fuel has a low sulfur content, which reduced the plant's sulfur dioxide emissions. The new fuel also has a low ash content, which reduced the erosion of boiler tubes. The new ash also had better engineering properties than the lignite ash and is sold as an additive to cement. This has provided TMPA with a source of revenue and has strongly reduced the need for landfilling. Other benefits included a significant reduction in fuel throughput (from 3.6 million tons of lignite to 2.1 million tons of sub-bituminous coal) because of the higher heat content of the latter. As a result, much of the power plant equipment is over-sized. For example, the over-sized boiler provides greater flexibility in controlling combustion processes allowing a reduction in nitrogen oxide (NOx) emissions and the over-sized electrostatic precipitator allows more efficient removal of particulate materials from the flue gases.

1.3 History of Gibbons Creek Lignite Mine

Operations at the Gibbons Creek Lignite Mine began in parallel with operations at the power plant. TMPA maintained ownership of the mine but hired Navasota Mining Company, a wholly-owned subsidiary of Morrison-Knudsen Company, as a contract miner. On August 18, 1980, TMPA received Permit No. 26, which allowed construction of a dragline and the mine facilities. By November 1980, assembly of Dragline Lot #29 was well under way. On September 8, 1981, the RCT issued mining Permit No. 6, which allowed mining operations to begin. By June 1982, the dragline had walked over to the B2 Mine Block and had made its first cut, the so-called "boxcut." Actual mining of the lignite uncovered by the dragline started on September 1, 1982.

The mine was planned to supply 80 million tons of lignite over a 30-year period. However, as stated, it was closed early in favor of the better quality coal from Wyoming. Since 1996, the Gibbons Creek Lignite Mine has been in the process of reclamation, long-term monitoring, and bond release. The permitted area as currently proposed totals approximately 14,600 acres (10,700 acres in Permit 26D and 3,900 acres in Permit 38D). However, not all of the permitted acreage was disturbed by mining; there are substantial undisturbed buffer areas around the mine blocks. Just over 8,800 acres were disturbed by mining and were therefore covered by a mine reclamation bond. This bond may be released by the main regulatory authority, the Railroad Commission of Texas, upon a satisfactory demonstration that reclamation performance standards have been attained. The current status of bond release is summarized in Table 1.1.

Table 1.1 – Status of bond release at Gibbons Creek Lignite Mine

	No bond release (acres)	Phase I bond release (acres)	Phase I and II bond release (acres)	Phase I, II, and III (full) bond release (acres)	Original bonded area (acres)
Permit 26D					
Mined land	107.1	1.1	3,981.4	55.3	4,144.9
Disturbed land	913.7	2.5	1,317.3	113.5	2,347.0
Ancillary	31.2	0.0	31.2	0.0	62.4
Subtotal	**1,052.0**	**3.6**	**5,329.9**	**168.8**	**6,554.3**
Permit 38D					
Mined land	699.0	963.5*	0.0	0.0	1,662.5
Disturbed land	588.9	5.6*	0.0	0.0	594.5
Ancillary	0.0	0.0	0.0	0.0	0.0
Subtotal	**1,287.9**	**969.1***	**0.0**	**0.0**	**2,257.0**
Total (acres)	**2,339.9**	**972.7**	**5,329.9**	**168.8**	**8,811.3**
Total (percent)	**26.6%**	**11.0%**	**60.5%**	**1.9%**	**100.0%**

*Note: Recommended for Phase I bond release by RCT Staff, letter dated February 16, 2010

As is evident, almost three-quarters of the mine has received some phase of bond release. The remaining quarter is mostly composed of sedimentation ponds and associated ditches, which will be eligible for bond release once the mine blocks that they control run-off from have received full (Phase I, II, and III, bond release).

1.4 Location of Gibbons Creek Lignite Mine

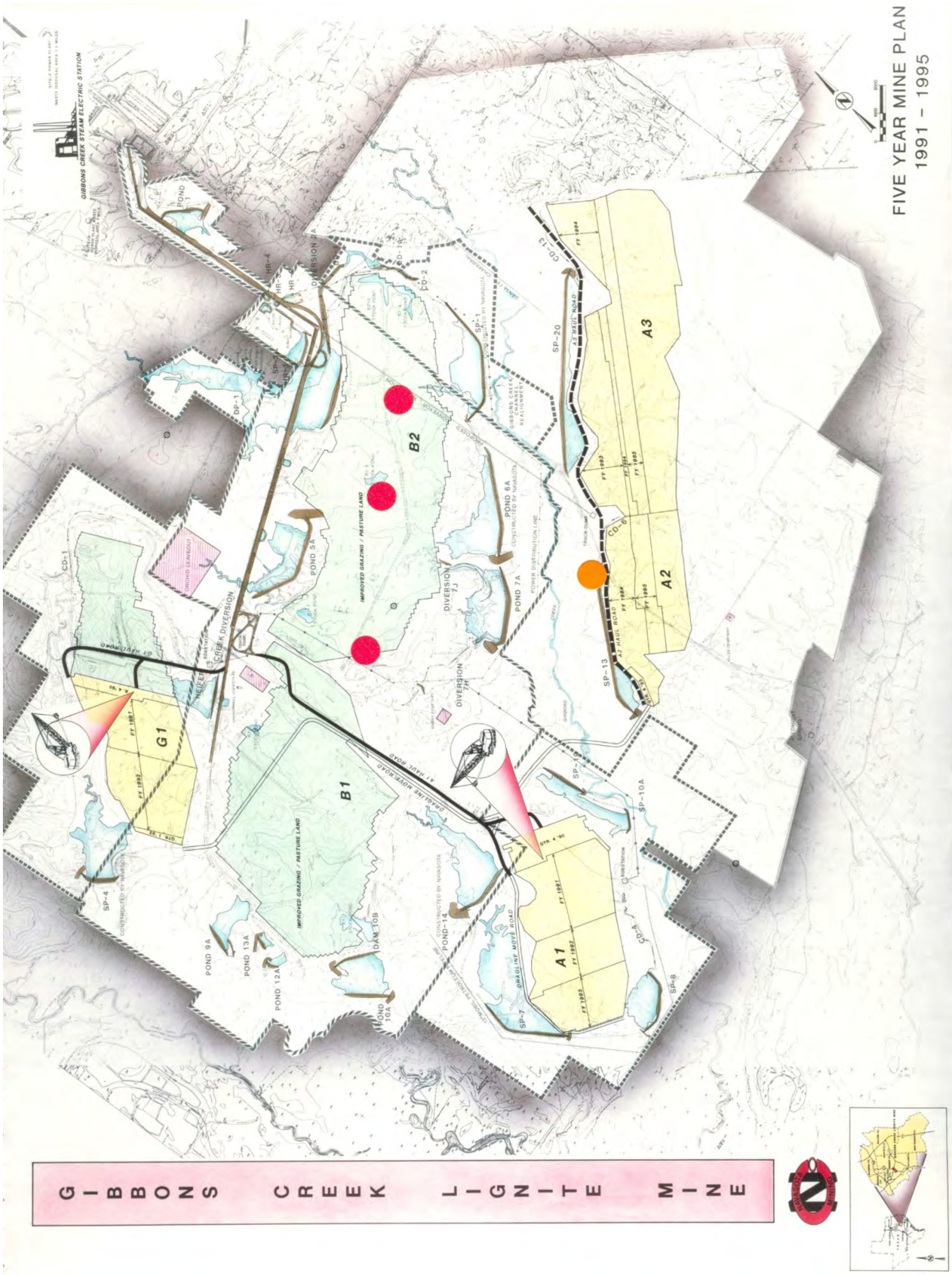
The location of the Gibbons Creek Lignite Mine is shown in the Frontispiece and in Figure 1.1. It is located in Grimes County in east-central Texas, about 70 miles north-west of the city of Houston, and 16 miles east of the cities of Bryan-College Station just off State Highway 30, near the community of Carlos.

The mine is bounded to the north by State Highway 30, to the east by Farm-to-Market Road (FM) 244, to the south by FM 3090, and to the west by the Navasota River. It is traversed by Gibbons Creek from which it derives its name. The mine is permitted with the RCT under Permit 26D and Permit 38D. Permit 26D lies to the north of Gibbons Creek and Permit 38D to the south. Of the total permitted 14,600 acres, TMPA owns about 10,500 acres and leases the rest from local landowners.

The main points of interest on Figure 1.1 include the following:

- TMPA's power plant, the Gibbons Creek Steam Electric Station, located approximately 1.5 miles north of the mine and connected to it by the main North-South Haul Road.
- The mine blocks from which the lignite was mined. These are designated as Mine Blocks G1, B1, B2, A1, A2, and A3 depending on which lignite seam was being mined (see Section 2.2). As an indication of scale, Mine Block G1 encompasses approximately 1,000 acres.
- The water control structures. These include diversion ponds and diversion ditches used to convey undisturbed stormwater runoff around the mine blocks for direct discharge into Gibbons Creek. Undisturbed runoff, in this context, applies to rainfall runoff that did not come into contact with land disturbed by mining activities. In contrast, disturbed runoff applies to rainfall runoff that did come into contact with land disturbed by mining activities and could therefore be contaminated by sediment. This disturbed runoff was routed through control ditches to sedimentation ponds in which it could be held for the sediment to settle out. The water was discharged into Gibbons Creek or the Navasota River only after it had reached wastewater discharge standards.
- Transportation facilities including lignite conveyor belts, haul roads, and access roads.

Figure 1.1 – Plan of Gibbons Creek Lignite Mine



Source: Navasota Mining Company (1990). Minesoil pit locations of field workshop are shown with red dots and Acid Seep 1 with an orange dot.

1.5 Post-mining land uses at Gibbons Creek Lignite Mine

The post-mining land uses proposed for the reclaimed area of the Gibbons Creek Mine are summarized in Table 1.2. It should be noted that almost half of the area of the two mine permits was left undisturbed. This area consists of the buffer zone between the mine and adjacent areas. Of the area that was disturbed by mining, approximately 6,800 acres have been developed into pasture and approximately 1,100 acres are now permanent ponds and lakes. The remaining acreages represent appurtenant structures for the impoundments, such as embankments and spillways (300 acres) and industrial/commercial facilities, such as the mine shop facilities, roads, gas well pads (300 acres).

Table 1.2 – Post-mining land uses at Gibbons Creek Lignite Mine

Permit	Pasture (acres)	Developed water (water surface) (acres)	Developed water (appurtenant structures) (acres)	Industrial/ Commercial (acres)	Residential (acres)	Undisturbed (acres)	Permit area (total) (acres)
26D	5,140.2	856.7	182.9	224.8	0.9	4,312.8	**10,718.3**
38D	1,629.6	280.3	150.3	75.0	0.0	1,764.5	**3,899.7**
Total	**6,769.8**	**1,137.0**	**333.2**	**299.8**	**0.9**	**6,077.3**	**14,618.0**

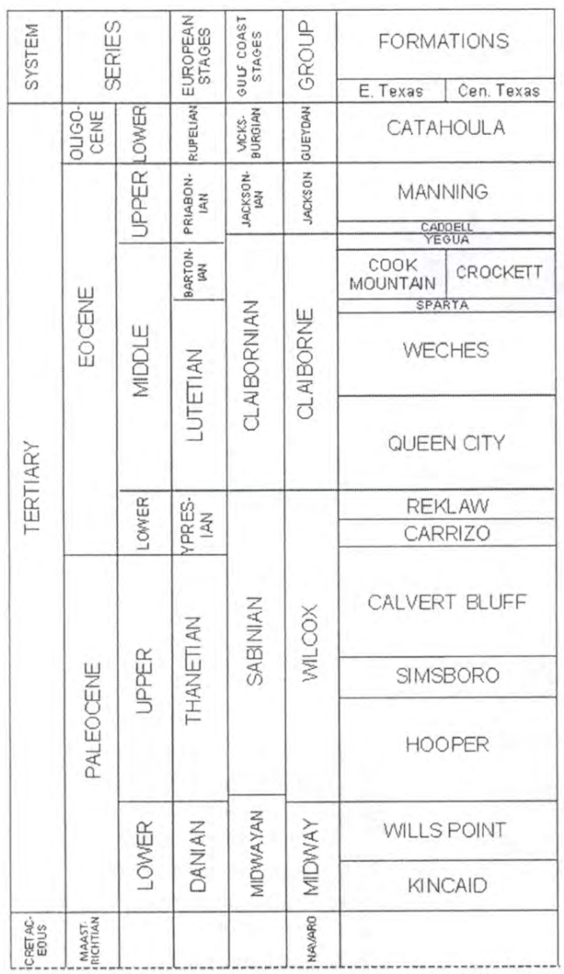
Note: Acreages as proposed in Sections .147 of the Permit 26D Renewal/Revision Application, Supplement 3, January 2010, and the Permit 38D Renewal/Revision Application, Supplement 2, November 2009. These do not include some of the acreages in Table 1.1, which have been completely released from bond and disposed of (e.g., Mine Shop Facilities).

2. PRE-MINE GEOLOGY

2.1 Geological setting

Stratigraphically, the Gibbons Creek Lignite Mine belongs to the Manning Formation of the Tertiary late Eocene (Figure 2.1). The Manning Formation (also commonly known as the "Jackson-Yegua") was deposited over the period 36.2 million years ago (Ma) to 33.7 Ma (Elsik and Yancey, 2000). Only two other Texas coal mines have been located in this formation – the active San Miguel Lignite Mine, south of San Antonio, and the Cummins Creek Mine, near La Grange, which never did become active. Most of the other coal mines in Texas are located in the Calvert Bluff Formation of the late Paleocene/early Eocene Wilcox Group (58 Ma to 52 Ma) (Hutto et al., 2009).

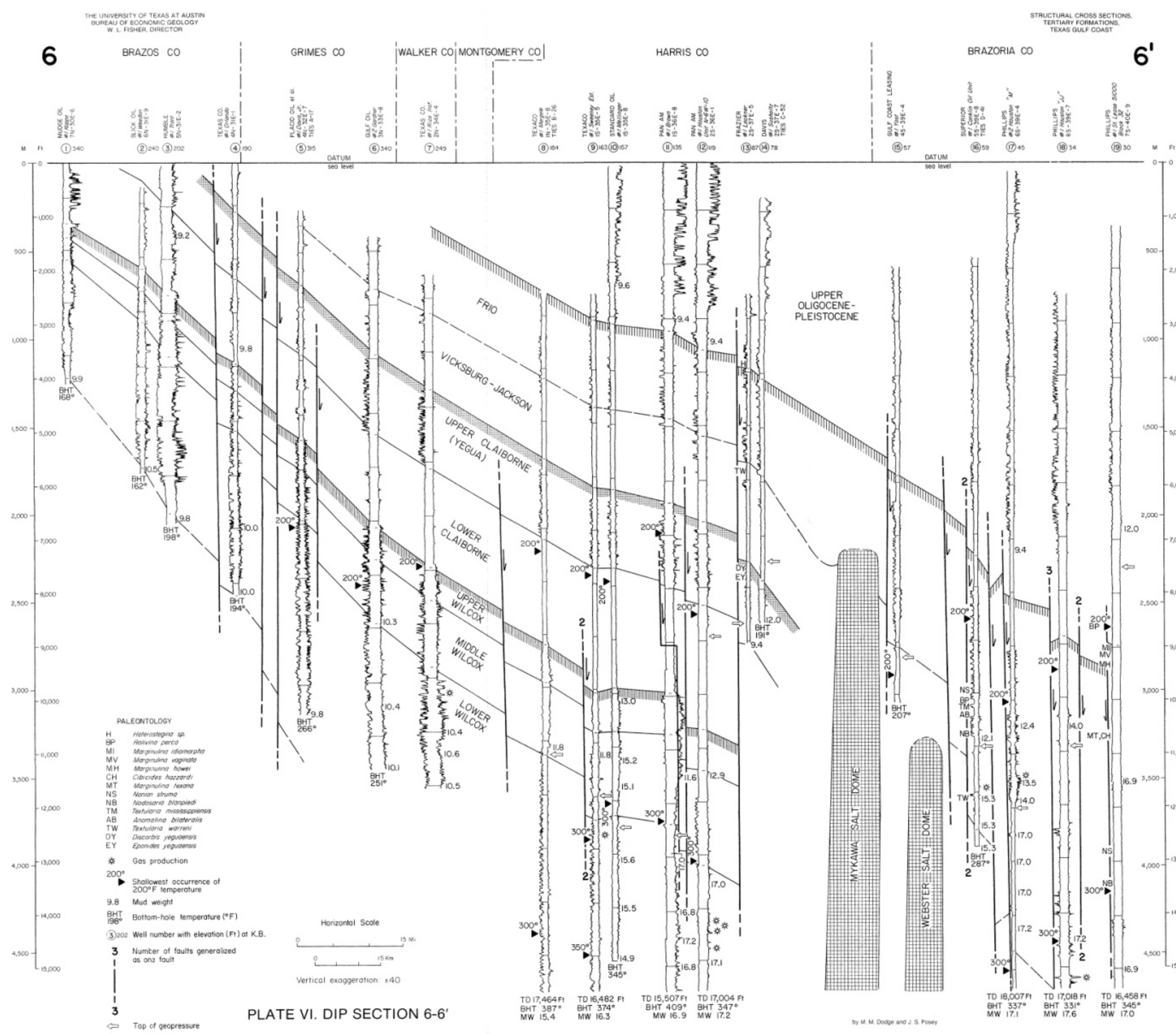
Figure 2.1 – Stratigraphic setting of Manning Formation



Source: O'Keefe et al. (2005).

The regional geology Wilcox is illustrated by the dip section (Figure 2.2). This section extends from Brazos County in the northwest to Brazoria County in the southeast over a distance of 150 miles. It shows the Manning Formation as part of the Vicksburg-Jackson unit outcropping in Grimes County and the Calvert Bluff Formation as part of the Middle/Upper Wilcox. It should be noted that the Calvert Bluff lignite underlies Gibbons Creek mine at a depth of over 5,000 ft. Other features of interest are the tremendous thicknesses of sediments and the thickening of individual units in a down-dip direction. Also of interest is the series of faults with downthrows to the southeast. Finally, it should be noted that gas production is mostly associated with the salt domes that penetrate the wedge of clastic sediments to the southeast in Harris and Brazoria Counties. There is some oil and gas production in Grimes County but it is mostly from formations deeper than those shown in the section.

Figure 2.2 – Regional geology – dip section



Source: Dodge and Posey (1981).

The surface expression or outcrops of these formations is shown in the geological map of Gibbons Creek Lignite Mine and the surrounding area (Figure 2.3). The oldest formation is the Middle Eocene Yegua Formation which underlies the cities of Bryan and College Station. This is followed by narrow outcrops of the Upper Eocene Caddell and Wellborn Formations.

The Wellborn Formation underlies the lignite-bearing Manning Formation and is described (Bureau of Economic Geology, 1981, and 1992) as a fine to very fine, glauconitic, quartz sand interbedded with brown, lignitic clay and lignite, with abundant fossil wood and imprints of marine megafossils. This is the formation in which the Gibbons Creek power plant is located as well as the new Brazos Valley Solid Waste Management Agency municipal landfill.

The Manning Formation, in which the Gibbons Creek Lignite Mine is located (green boundary on Figure 2.3), is generally described as fine- to medium-grained, lignitic, quartz sand, interbedded with sandy, lignitic clay, and lignite, with abundant fossil wood. The distinguishing feature of the Manning Formation is that it contains well-developed lignite seams. As discussed in the next section, there is considerable variation in lithologies even within the Manning Formation with a preponderance of finer sediments in the lower units (G- and B-series of Mine Blocks) and higher-energy sands in the upper units (A- and P-series of Mine Blocks).

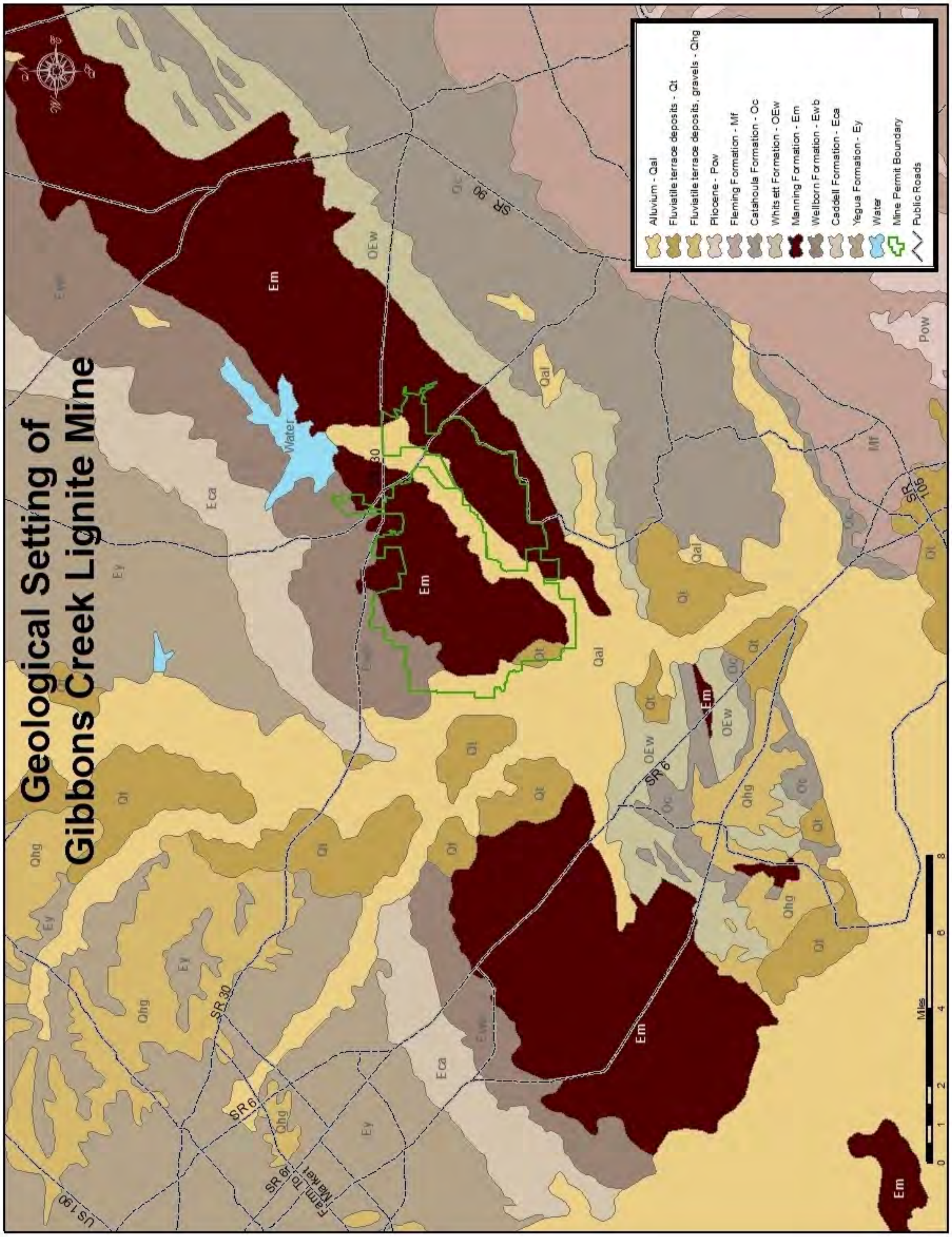
Immediately overlying the Manning Formation, is the Whitsett Formation, which is described as fine- to medium-grained, tuffaceous, lignitic, argillaceous quartz sand, locally silica-cemented, containing abundant fossil wood. The geological sequence on the map is followed by the Oligocene Catahoula Formation, the Miocene Fleming Formation and the Pliocene.

Quaternary alluvium and terrace deposits are very extensive filling the Brazos River, Navasota River, and Gibbons Creek valleys. The Gibbons Creek essentially divides the Gibbons Creek Lignite Mine into two portions with the Permit 26D area occupying the area to the north of Gibbons Creek and the Permit 38D area occupying the area to the south.

2.2 The lignite reserve

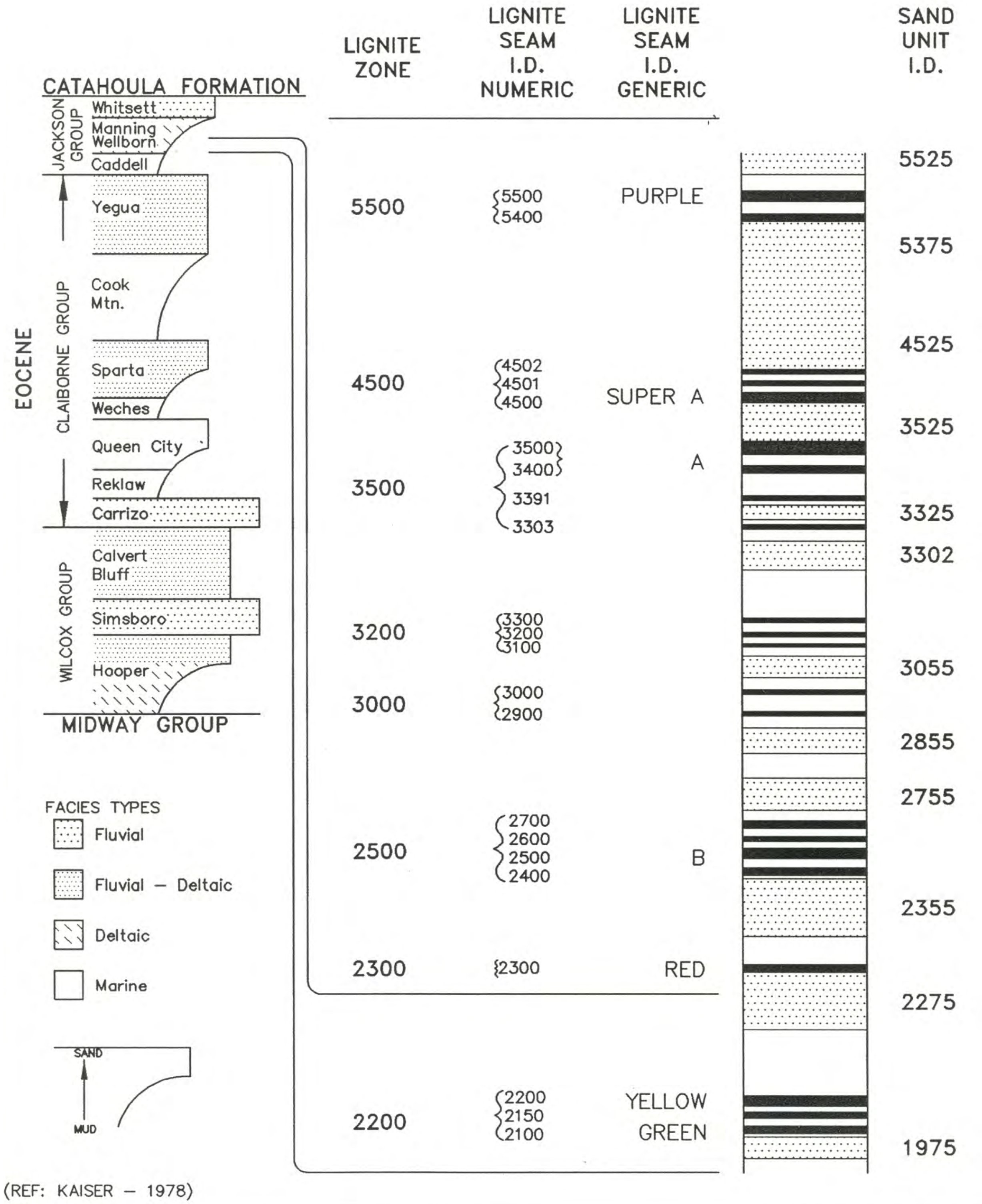
At Gibbons Creek mine, the Manning Formation has a total thickness of approximately 800 feet and contains a number of lignite zones, interbedded with moderately consolidated mud units and generally unconsolidated sand units (Figure 2.4). In the early coal exploration phase, the lignite seams were color-coded (e.g., “purple” and “green” seams), which gave rise to the nomenclature for the corresponding mine blocks (e.g., the P- and G- series of mine blocks). However, more detailed drilling and stratigraphic correlation of lignites and sand units led to the use of numeric codings that are stratigraphically ordered (i.e., in sequence of deposition). Thus, the first (oldest) significant lignite zone is the 2200 and the last (youngest) is the 5500.

Figure 2.3 – Geological map of Gibbons Creek Lignite Mine and surrounding area



Map developed by Lindy Liles based on information from U.S. Geological Survey.

Figure 2.4 – Stratigraphic column for Gibbons Creek Lignite Mine



Source: Navasota Mining Company (1994)

Only five of the lignite seams at the Gibbons Creek mine were selected as economically recoverable by surface mining methods using draglines. The properties of the seams are summarized in Table 2.1. It should be noted that the 5500 seam (in the P- blocks), included in the original mine plan, was not mined at all owing to the early closure of the mine.

Table 2.1 – Properties (as mined) of lignite seams at Gibbons Creek Lignite Mine

Lignite seam*	Lignite seam**	Mine Blocks*	Thickness of seam	Heat content (BTU/lb)	Ash content	Sulfur content	Moisture content
5500 (youngest)	P (purple)	P1-P7 Blocks (not mined)	7.0 ft	5,000	13%	1.6%	45%
4500	Super A	A1-A6 Blocks (A1 mined 1990-1992) (A2 mined 1992-1996) (A3 mined 1992-1996) (A4-A6 not mined)	3.3 ft	4,300	19%	1.6%	42%
3500	A	Same as 4500 seam	6.0 ft	4,600	17%	1.6%	42%
2500	B	B1-B3 Blocks (B1 mined 1982-1990) (B2 mined 1982-1989) (B3 not mined)	5.2 ft	4,400	26%	1.1%	37%
2200 (oldest)	G (green)	G1 Block (G1 mined 1988-1994)	5.4 ft	4,500	26%	1.3%	37%

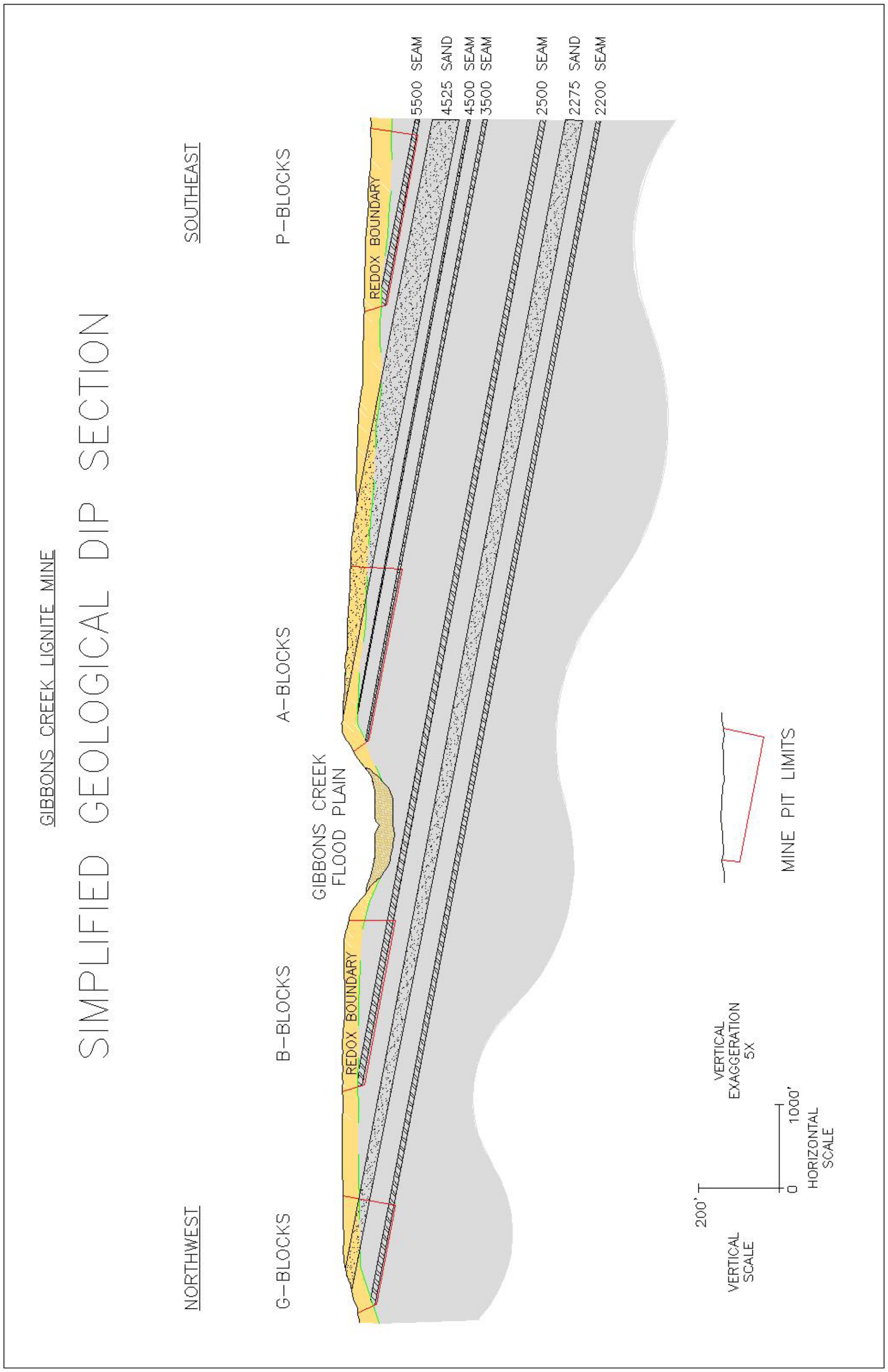
*Numeric codings assigned by Morrison Knudsen during mine design phase.
**Color/generic codings assigned by Weir Consultants in earlier exploration phase.
Source: compiled from various Navasota Mining Company mine plans.

The regional dip is approximately 2° to the southeast (although locally the dip is more variable due to uneven settling and faulting). Thus the lignite seams dip at a rate of about 20 feet vertically over a distance of 1,000 feet horizontally. Given that the draglines used for stripping the overburden could not dig deeper than about 120 feet, the length of the pits if oriented perfectly down-dip could not exceed about 6,000 feet. Given also that the lignite seams were often oxidized at the outcrop to a depth of about 30 feet, the up-dip pit limits were dictated by the subcrop and the mineable length of lignite in a down-dip orientation was therefore shortened by an additional 1,500 feet to not much more than 4,500 feet. Thus, not much of the lignite could in fact be recovered and a considerable amount remains in the ground unmined (Figure 2.5).

Other limitations on the recovery limits of the lignite seams (resulting in the distribution of the mine blocks seen in Figure 1.1) were dictated by the following.

- Economic stripping ratio (a ratio of 11 cubic yards of overburden removal for 1 ton of lignite was generally considered to be the economic limit)
- Major drainages (such as the Navasota River to the west and Gibbons Creek itself)
- Civil features such as major public roads (State Highway 30 and Farm-to-Market Road 244). Minor public roads, such as County Roads 171, 190, and 192 were mined through and then replaced

Figure 2.5 – Simplified geological dip section of Gibbons Creek Lignite Mine

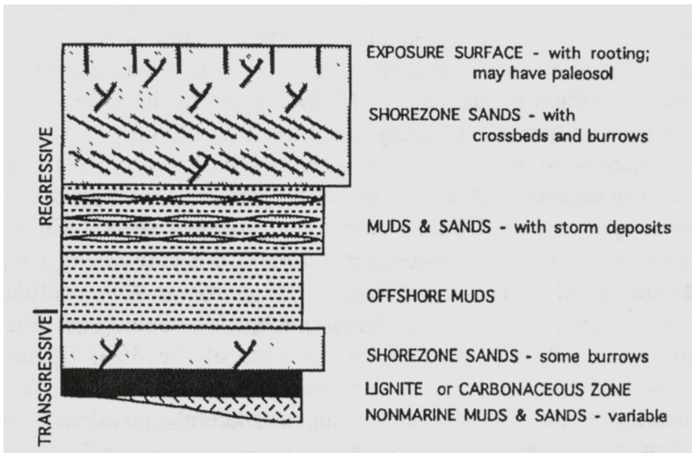


Drawn by: Rachel Brandt

2.3 Geological environment of deposition

The model for the formation of each lignite seam and its associated sediments in the Manning Formation is that of the cyclothem in which the sea transgressed over land and then regressed (Yancey, 1997). The type of sediments deposited reflects the energy of the depositional environment (Figure 2.6).

Figure 2.6 – Typical cyclothem for Gibbons Creek lignites



Source: Yancey (1997)

The cyclothem typically begins with thick deposits of vegetation in coastal swamps. This vegetation eventually becomes converted to lignite if it is thick enough or to a carbonaceous zone if it is not. The energy of the depositional environment is very low – very still standing water. The energy is so low, in fact, that volcanic ash falls are preserved as partings (Figure 2.7). In higher energy environments such ash falls would be reworked by water-sorting processes and mixed in with other sediments. (Volcanic ash deposits are useful for radiometric dating purposes – a volcanic ash deposit at the base of the 3500 lignite at Gibbons Creek mine has been dated to 34.5 Ma [Yancey, 1997]).

The next step in the cyclothem is the deposition of shorezone sands. These represent the beginning of a marine transgression in which the high energy wave-affected environment results in the deposition of beach sands and shallow-water sands. These deposits often show signs of burrowing and other bioturbation (Figure 2.8). They may also show evidence of shell-banks (Figure 2.9).

As the sea transgresses farther over the land, the water becomes deeper and the high-energy sands give way to lower-energy offshore muds. These represent conditions in which fine silt and clay can settle without being disturbed by wave action. They are therefore deep water sediments, which tend to form massive and undifferentiated clays and, where lithified, mudstones or shales (Figure 2.10).

Figure 2.7 – Volcanic ash fall preserved in lignite rider seam

Note: Volcanic ash layer (pink) in center of 2700 lignite rider seam in B2 Mine Block. Rider seam at 14.1-15.0 ft above top of 2500 lignite, Overburden profile B2-1. Photograph: J. Horbaczewski (Film 3, 13A)

Figure 2.8 – Casts of bioturbation in sandstone from A2 Mine Block

Note coin (nickel) supported on cast of worm burrow. Photograph: J. Horbaczewski.

Figure 2.9 – Shell bank in marine shorezone sands

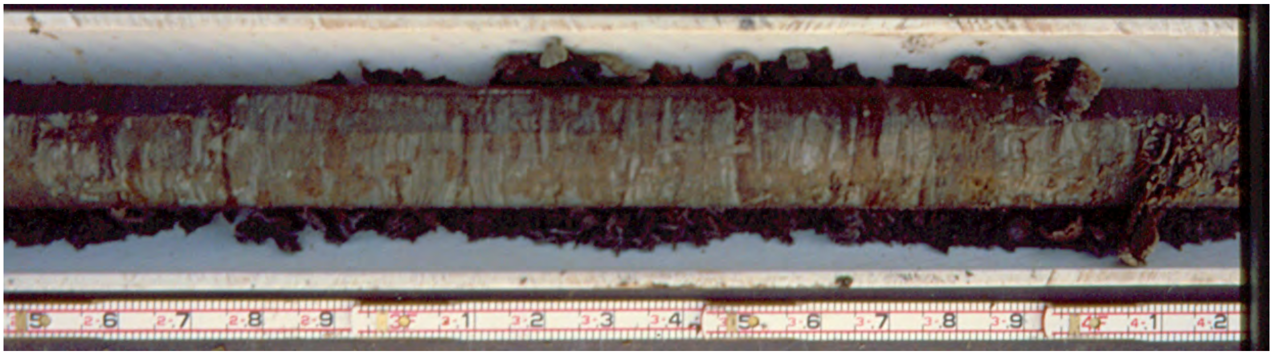
Photograph: Rachel Brandt

Figure 2.10 – Massive undifferentiated mudstone with pyrite nodules

Note brassy color of pyrite nodules vertically above 4 in mark on ruler. Nodules at 20.5 ft above top of 2500 lignite, Overburden profile B2-2. Photograph: J. Horbaczewski.

With time, the sea begins to regress and the water becomes shallower again. The deep-water low-energy muds and clays are succeeded by shallower-water conditions again. The water is still deep enough for the gradual settling of very fine materials but is also close enough to the coast to receive the occasional coarser sandy sediments from storms. These sediments consist of muds that are intercalated with lenses of sandier material (Figure 2.11).

Figure 2.11 – Mudstone with intercalated sandy storm deposits



Overburden core: G1 Mine Block. Photograph: J. Horbaczewski.

Finally, the continued retreat of the sea results in the water becoming shallow enough again to form high-energy, wave-sorted, sands. These are characterized by strong cross-bedding and animal burrows. The final stage occurs when the retreat of the sea is complete and the area emerges (exposure surface) and becomes vegetated again. At this time, the uppermost sediments may show signs of ancient soils (paleosols) and even traces of in-situ roots (Figure 2.12). There is evidence that cementation of sands into sandstones may also occur at these times of subaerial exposure. The cement in some cases has been identified as opaline silica.

Figure 2.12 – Paleosol with in-situ pyritized roots (stereopair)

B2 Mine Block – Overburden profile B2-2. Note dark color of paleo-topsoil horizon above root traces.
Stereo photographs: J. Horbaczewski.

Evidence supporting the mostly marine origin of the Manning Formation sediments comes from the following (Yancey, 1997).

- Characteristic marine trace fossil assemblages
- Common occurrence of sedimentary structures similar to modern tidal deposits
- Siliceous microfossils (diatoms, radiolarian, silicoflagellates, spicules)
- Organic microfossils (palynomorphs, such as pollen, spores, dinoflagellate cysts)
- Marine shell casts/fossils (original calcareous material leached away)
- Pyrite (derived from the reduction of sulfate present in seawater)

Pollen assemblages are particularly sensitive indicators. Through vegetation changes, they reveal the ecological changes as the sea transgressed over the land (O'Keefe et al., 2005):

- Palm communities
- Fern marshes
- Closed-canopy swamps
- Open-canopy swamps
- Open-canopy wetlands
- Marine assemblages

The pollen evidence also provides indications of the climate at the time of deposition of the Manning Formation. Tree species such as *Engelhardia* (*Momipites* sp.), *Pinus* sp. and *Picea* sp. suggest that the climate was variable warm-cool.

More evidence on the cooling trend from the late middle Eocene to the early Oligocene is provided by Elsik and Yancey (2000) based on palynomorph assemblages (palynomorphs are organic microfossils up to 0.5 mm in size). Since they are so small, these fossils provide statistically significant samples in sedimentary rocks for characterization of assemblages. Plots of the occurrence of these palynomorphs indicate that over the period 42 Ma – 33 Ma tropical and subtropical indicators disappear from the Gulf Coast area and cooler elements appear.

Indications of cooling in late Eocene times are also provided by carbon isotope analyses of deep-sea cores. These suggest that carbon dioxide concentrations were in the range of 1,000-1,500 parts per million by volume in the middle to late Eocene and had declined to modern levels by the late Oligocene (Pagani et al., 2005). (For reference, the current concentration of carbon dioxide is 385 parts per million by volume).

<u>Formation of pyrite</u>

A marine environment of deposition favored the formation of pyrite. As noted by Goldhaber and Kaplan (1982), anoxic conditions often occur near the surface of marine sediments due to rapid oxygen consumption by aerobic respiration. Further chemical reduction is caused by bacteria which need to lose electrons for their respiration to proceed. These bacteria therefore need electron acceptors. Theoretical considerations, supported in general by applied research in the kaolin industry, suggests that the metabolization of organic matter by bacterially-mediated reduction processes generally occurs in the following sequence (Kogel et al., 2002, p. 58).

1. Aerobic processes
2. Nitrate reduction processes
3. Mn^{4+} reduction processes
4. Fe^{3+} reduction processes
5. Sulfate-reduction processes
6. Methane generation processes

It should be noted that concentrations of iron and sulfate are relatively high in seawater, while the solubility product of iron sulfides is extremely low. Thus, as soon as ferrous ions in solution come into proximity with sulfide ions, iron sulfide is immediately precipitated. The various mineral pathways in this reaction are complex and not well defined, but eventually they result in the formation of pyrite, as summarized by the following reactions (Kogel at al., 2002, p. 55).

$$2CH_2O \text{ (organic matter)} + (SO_4)^{2-} \rightarrow H_2S + 2(HCO_3)^{-}$$

$$Fe^{2+} + H_2S \rightarrow FeS + 2H^{+}$$

$$FeS + S \rightarrow \text{(via mineral transformation)} \rightarrow FeS_2$$

The bacterially-mediated pyrite often assumes the form of framboidal pyrite (Goldhaber and Kaplan, 1982). The common occurrence of framboidal pyrite in Texas lignite formations has been well documented (e.g., Dixon et al., 1982).

3. MINING AND RECLAMATION OPERATIONS

3.1 Mining operations

In essence, the method of coal recovery consisted of stripping the rocks overlying the lignite seams (termed the overburden) with a dragline, picking up the coal seam with a specialized piece of equipment (an Easi-Miner), hauling the coal with 120-ton "belly-dump" trucks (later 150-ton belly-dump trucks) to the truck-dump, and conveying the coal with an overland conveyor from the truck-dump to Gibbons Creek Steam Electric Station.

The overburden stripping was achieved with a Bucyrus-Erie 1570-class dragline (total weight 3,900 tons) with a 320-ft boom, giving an operating radius of 295 feet (and an effective reach of 242 ft), equipped with a 75-cubic-yard bucket (Figure 3.1). Performance history indicated that a production rate of 21.2 million cubic yards per dragline per year was achievable. The mine operated with two draglines each in its own mine block.

Figure 3.1 – Aerial view of dragline in B2 Mine Block, c. 1984

Note relative size of pick-up truck in foreground. Photograph: Aero Views.

The dragline generally operated in straight pits oriented either parallel to the geological dip or to the geological strike of the deposit. In this aerial view of the B2 Mine Block (Figure 3.2), the dragline is seen advancing down-dip, southward (towards the camera), in chevron pits. The dragline can be seen removing the overburden (on the tight) and thereby exposing the black lignite seam (to the north) and casting the overburden to the left into the mined-out pit (less dark because the coal has been removed) in the foreground. The location of the entire mined-out pit may be traced by the spoil ridge that the dragline is creating.

Figure 3.2 – Aerial view of mining operation in B2 Mine Block, c. 1984

Photograph: Aero Views.

In the 1980s, the draglines operated from the highwall side and the pits were 120 feet wide at the bottom. Later, in the early 1990s, the draglines began to operate from the spoil side and it became possible to widen the pits to 160 feet. In the photograph mobile equipment may be seen leveling the spoil peaks. The mine operated two Caterpillar D-11 dozers for the regrading of the spoil, and later increased that number to four. The pits had a maximum depth of 140 feet representing the economic recovery limit dictated by the stripping ratio (the ratio of the number of cubic yards of overburden moved to recover one ton of coal).

After exposure of the seam, the lignite was mined using an Easi-Miner (made by Huron Manufacturing Corporation), which essentially consists of a revolving drum armed with steel teeth which can be adjusted for depth of cut up to a maximum of 28 inches. The drum fed the lignite onto a conveyor belt inside the Easi-Miner, which then loaded it out into the 150-ton bottom-dump haul trucks.

The trucks were used to haul the coal out of the pit and to dump it into the hopper at the truck-dump. From the hopper, the coal was fed onto the 4.2 mile overland conveyor for delivery directly to the power plant.

3.2 Reclamation operations

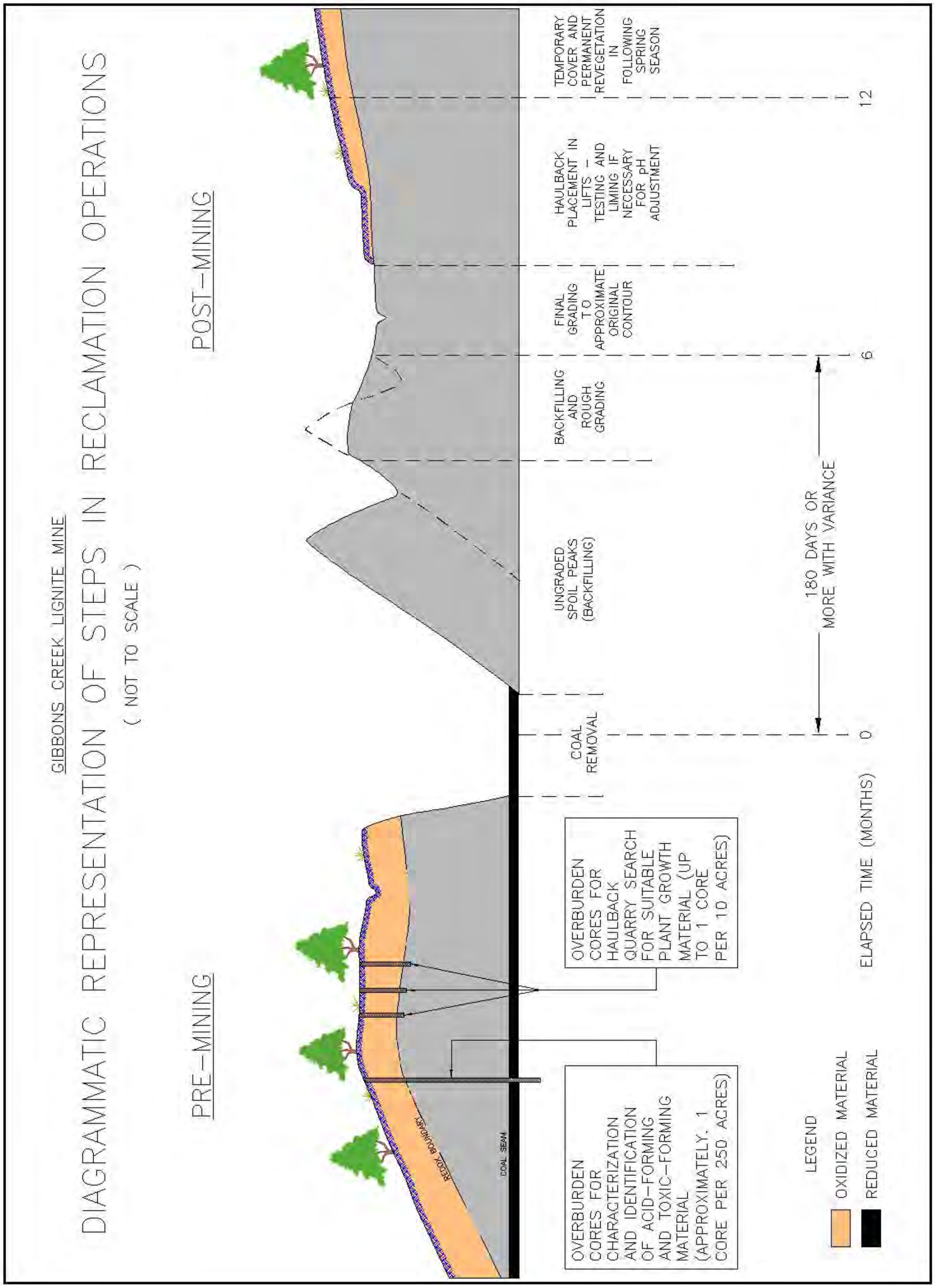
Since the mining operation advances at the rate of about 400 acres per year, reclamation had to proceed at the same pace if it was not to lag behind. Initially, reclamation consisted of leveling the spoil ridges that had been formed by the dragline and planting permanent vegetation. By December 1989, however, reclamation had become much more complex, consisting of eight steps, as outlined below (Figure 3.3).

Step 1 - The reclamation process began in the pre-mining stage with a drilling program to characterize the overburden chemistry all the way to the lignite sema to be mined. The purpose was to identify potentially acid-forming and toxic-forming materials so that these could be handled appropriately during mining to avoid incorporation in the post-mining soils. Locating the redox boundary was especially important because oxidized materials above the boundary were generally found to be free of pyritic materials whereas reduced materials below the redox boundary had the potential to contain such materials. Information from the overburden cores was correlated with other available drilling data from coal exploration, groundwater wells, and geotechnical borings. The set of overburden cores was drilled at a density of approximately one per 250 acres.

Step 2 - Based on this information, a more concentrated drilling program would be conducted, this time just to the redox boundary (usually about 30 feet deep), to identify potential “quarry” sites of suitable plant growth material. The most important criteria were pH and texture. At this stage, the drilling was generally at densities of one core per 10 acres or less (e.g., in G1 Block, they were drilled on 500-foot centers, equivalent to one core per 5.75 acres).

Step 3 - This consisted of the salvaging of selected overburden material from the designated “quarries” ahead of the active mine pit for direct respreading on regraded areas behind the active mine pit. Alternatively, when there was a surplus of such material for direct replacement, it would be stockpiled for

Figure 3.3 – Steps in reclamation process



Drawn by: Rachel Brandt

later use. This “haulback” material would be moved from the highwall side to the spoil side either by the dragline itself or, more often, by mobile equipment, such as Caterpillar 992 front-end loaders and Caterpillar 777 end-dump trucks.

Step 4 - This consisted of backfilling the mined-out dragline pits with spoil material from the new pit being excavated by the dragline. The dragline cast the spoil in the form of a ridge filling the previous pit.

Step 5 - This step consisted of rough grading in which the spoil ridges or “peaks” were pushed by dozers into the spoil “valleys.” This is known as backfilling and rough grading and is required by the mining regulations to be completed within 180 days of coal removal.

Step 6 - This consisted of final grading to restore the land surface to “approximate original contour” as required by the regulations. This includes the relocation of drainages, drainage divides, stock ponds, and wetland/depressional areas.

Step 7 - This consisted of the reconstruction of a suitable minesoil on the final graded spoil surface. This process is described in more detail in Section 4.5 (Reconstruction of minesoils).

Step 8 - The final step in the reclamation process consisted of permanently revegetating the newly-created minesoil. Permanent grasses were planted in the spring planting season. At other times of the year, temporary grasses were planted to provide interim cover for erosion control. Trees and shrubs were planted in selected areas (generally along drainages, near wetlands, and around ponds) for wildlife habitat and shade for livestock.

4. MINESOIL RECONSTRUCTION

4.1 History of minesoil reconstruction standards

The history of minesoil reconstruction standards applicable to the Gibbons Creek Lignite Mine is has evolved significantly over the history of the mine (TMPA, 1989b). At the time of issuance of the initial Permit No. 6 on June 22, 1981, the regulations required the following.

- Soil testing to determine proper fertilizer levels to support the approved post-mining land use
- Establishment of soil testing plans to determine the success of topsoil handling plans and reclamation procedures related to revegetation
- No acid- or toxic-forming materials to be present in the top four feet of reclaimed spoil

However, the regulations did not specify the methodologies for soil testing and did not define acid- or toxic-forming materials.

By April 1, 1982, the first of the two draglines had been assembled and Navasota Mining Company (a wholly-owned subsidiary of Morrison Knudsen Company), the mining contractor for TMPA, began its mining and reclamation operations. In accordance with the permit, reclamation consisted of leveling the spoil cast by the draglines (also referred to as mixed overburden). There was no topsoil salvage at the time. Over the next few years, the interpretation of the regulations began to evolve as more field information started becoming available.

On June 20, 1984, the RCT requested that native topsoil be salvaged, which TMPA began to implement in September 1984, and by January 1985 topsoil was being replaced on regraded spoil areas (by this time approximately 700 acres had already been reclaimed). On July 3, 1984, the RCT also requested an overburden characterization program for the identification of acid-forming materials. A highwall sampling program was completed in the fall of 1984 and a report submitted to the RCT on March 28, 1985.

On January 21, 1985, RCT Staff began unofficially distributing a document entitled *Overburden Parameters and Procedures*. These procedures were requested for use on TMPA's overburden samples after it was determined that there were many inconsistencies in the initial set of laboratory analyses. Final re-analyzed highwall data using the new procedures were submitted to the RCT in October 1985.

On October 4, 1985, RCT Staff (Paul Askenasy and Paul Powell) prepared an internal document entitled *Topsoil Substitute Suitability Criteria/Material Suitable for Placement in the Top Four Feet of Leveled Minesoil/Overburden Parameters and Procedures*. This was informally distributed to industry over the following weeks.

By 1986 the need for an integrated approach to minesoil reconstruction began to become apparent. In 1987, TMPA in consultation with RCT Staff, embarked on a three-part geochemical investigation, the results of which eventually became incorporated in TMPA's mining permits.

- Native soil characterization to obtain quantitative baseline information on pre-mine soils
- Spoil characterization to identify current and potential future problem areas for the application of remedial and preventative measures
- Overburden characterization to identify suitable plant growth material for placement in the top four feet of future minesoils

These are discussed in more detail below.

4.2 Native soil characterization

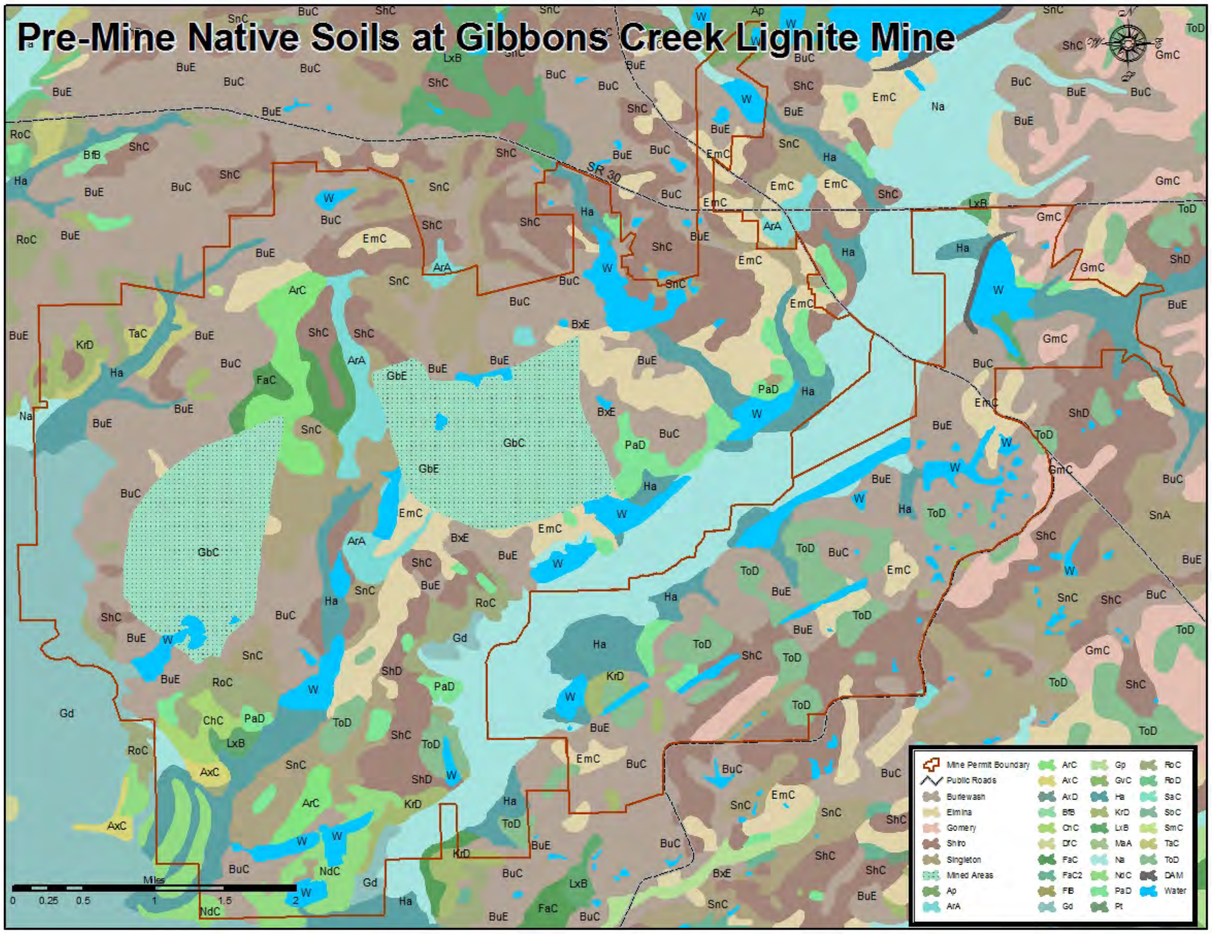
The native soils of the area were investigated and sampled in the summer of 1987 and a final report entitled *Native Soil Characterization Study* was submitted to the RCT on September 19, 1988. A statistical supplement entitled *Native soil baseline data: one foot weighted averages* was submitted on July 14, 1989. The native soil study benefitted from the assistance of the county soil survey that was in progress at the time under the leadership of James Greenwade. This was published several years later as the *Soil Survey of Grimes County, Texas* (U.S. Department of Agriculture, 1996). The portion of the survey covering the mine permit area is shown in Figure 4.1. It should be noted that by the time the county soil survey started, mining had already begun and thus some of the areas, corresponding to the B1 and B2 Mine Blocks are represented by a new minesoil – the Gibbonscreek Series (mapping units GbC and GbE).

The main findings from the native soil study were that:

- The native soils of the upland areas that were mined consisted predominantly of alfisols or ultisols, more commonly known as "claypan" soils. These typically have a few inches of fine sandy loam topsoil overlying an extremely acidic (pH < 4.5), clayey and impermeable subsoil (e.g., Burlewash soil [Figure 4.2] and Shiro soil [Figure 4.3]).
- Often there were hard geological strata ("paralithic" contact) at less than four feet underlying the clayey subsoil.
- The area is located in a "thermic" soil temperature regime (mean annual soil temperature between 15° C and 22° C) and an "ustic" soil moisture regime (soil dry for 90 cumulative days in most years), as defined by soil taxonomy (U.S. Department of Agriculture, 2010).
- The native soils overlying the more clayey geological formations of the G1 and B1 and B2 Mine Blocks primarily belonged to the Burlewash series (mapping units BuC, BuE, and BxE), Shiro (mapping unit ShC), and Singleton series (mapping units SnA, SnC); the native soils overlying the more sandy geological formations of the A1, A2 and A3

Mine Blocks primarily belonged to the Elmina (mapping unit EmC), Gomery (mapping unit GmC), and Shiro series (Figure 4.1).

Figure 4.1 – Soil survey of Gibbons Creek Lignite Mine



Map prepared by Lindy Liles based on data from Natural Resource Conservation Service of the U.S. Department of Agriculture. Original mapping published in U.S. Department of Agriculture (1996).

The presence of the claypan in these soils is revealed by the "-alf" and "-ult" suffixes of the soil taxonomic classifications (U.S. Department of Agriculture, 1996):

Burlewash – Fine, montmorillonitic, thermic Ultic Paleustalf
Elmina – Clayey, montmorillonitic, thermic Aquic Arenic Hapludalf
Gomery – Loamy, siliceous, thermic, Arenic Hapludult
Shiro – Fine, mixed, thermic, Aquic Paleustalf
Singleton – Fine, montmorillonitic, thermic, Aquic Paleustalf

The highly leached and therefore acidic nature of these claypan soils is indicated by the "-ult" and "ultic" designations. These soils often exhibit pH < 4.0 especially in the upper parts of the claypan. The low pH and the low permeability of these claypans both serve to restrict root development and cause the soils to be droughty.

Figure 4.2 – Burlewash soil profile

Note: Tape marked in tenths of a foot.
Photograph: Soil Conservation Service.

Figure 4.3 – Shiro soil profile

Photograph: J. Horbaczewski, February 20, 1985.

Both of these soils show exhibit a sandy loam topsoil overlying a claypan. The topsoil in the Burlewash soil is only a few inches thick, whereas it is just over a foot and a half in the Shiro soil. The "Aquic" nature of the Shiro soil is evident in the mottling and the perched water table sitting on top of the claypan. The bottom of the topsoil was saturated and can be seen to be sloughing off just above the claypan, shortly after the profile had been prepared for photographing.

4.3 Overburden characterization

The overburden characterization program consisted of the drilling of overburden cores in the summer of 1987 in the proposed G1 Mine Block (in which mining started a year later in July 1988) and A1 Mine Block (in which mining started in May 1990). In addition, overburden samples were described and collected directly from the highwall of the active pit in the B1 Mine Block using a “cherry-picker.”

A key factor in the reconstruction of minesoils at the Gibbons Creek mine was the recognition of the significance of the reduction-oxidation (redox) boundary. This boundary has been observed in all the mine pits (e.g., Figure 4.4) and in the thousands of geological exploration holes that have been drilled in the area. It is typically a single boundary separating oxidized overburden near the surface (characterized by tan, red and brown coloring) from reduced overburden at depth (characterized by dark gray, green, and blue coloring).

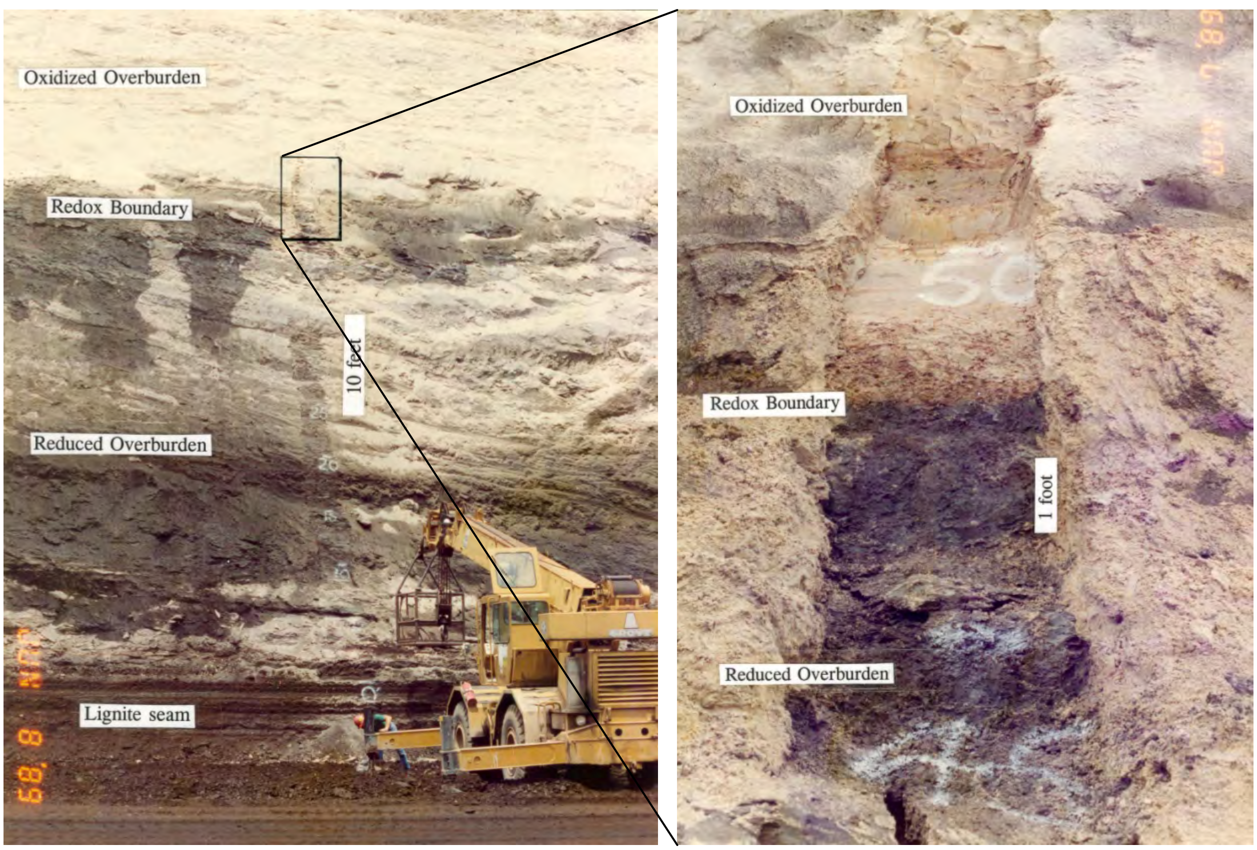
Figure 4.4 – Redox boundary in A3 Mine Block, November 11, 1992

Photograph: J. Horbaczewski

As seen in Figure 4.4, the oxidized zone appears to parallel the stratigraphic units but, when traced over the full length of the pit and longer geological sections, it becomes evident that the redox boundary parallels the surface topography. Close examination shows that it transgresses strata and displacement faults, as shown diagrammatically in the dip section (Figure 2.5). Generally speaking, the redox boundary occurs at a depth of about 27 feet from the surface, but it has been observed to vary from as little as 15 feet to as much as 50 feet or more.

One feature of the redox boundary is that when the profile has been cleaned up, it is often surprisingly sharp (Figures 4.5), usually of the order of a millimeter or two.

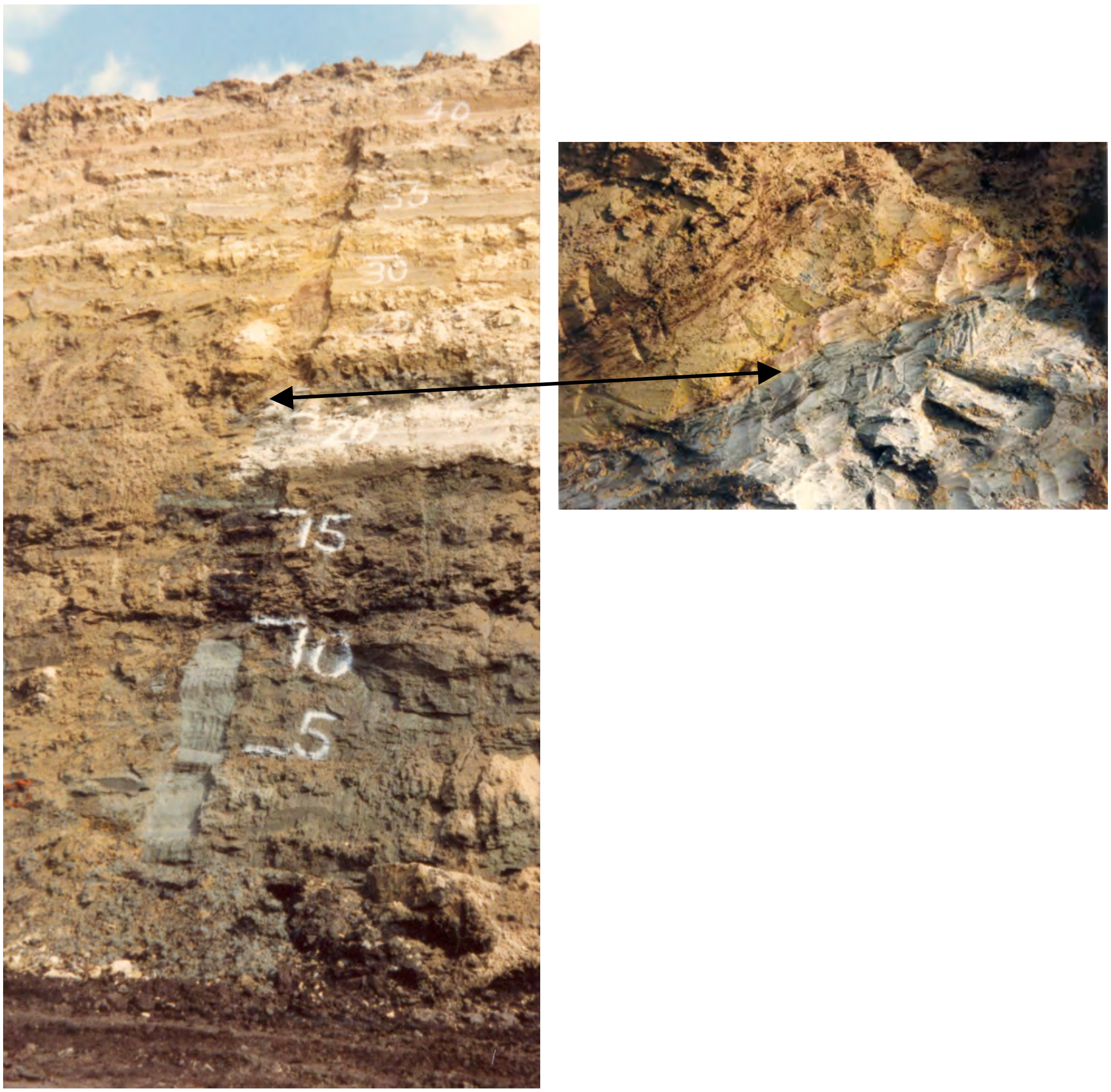
Figure 4.5 – Overburden profile and redox boundary in G1 Mine Block, June 7, 1989



Note: Mine Block G1, Overburden profile G1-5. Numbers painted on the highwall indicate height in feet above the top of the 2200 lignite seam (shown as 0'). Photographs: J. Horbaczewski.

The sharpness of the redox boundary is even better displayed in Overburden Profile B2-1 (Figure 4.6). Localized settling has caused the boundary to be inclined but other profiles demonstrated that it followed the surface topography along the length of the pit.

Figure 4.6 – Overburden profile and redox boundary in B2 Mine Block, December 6, 1988



Note: Mine Block B2, overburden profile B2-1. Numbers by marks indicate height in feet above the top of the 2500 lignite seam; redox boundary is just above the 20 ft mark. Note sharpness of redox boundary. Photographs: J. Horbaczewski.

4.4 Spoil characterization

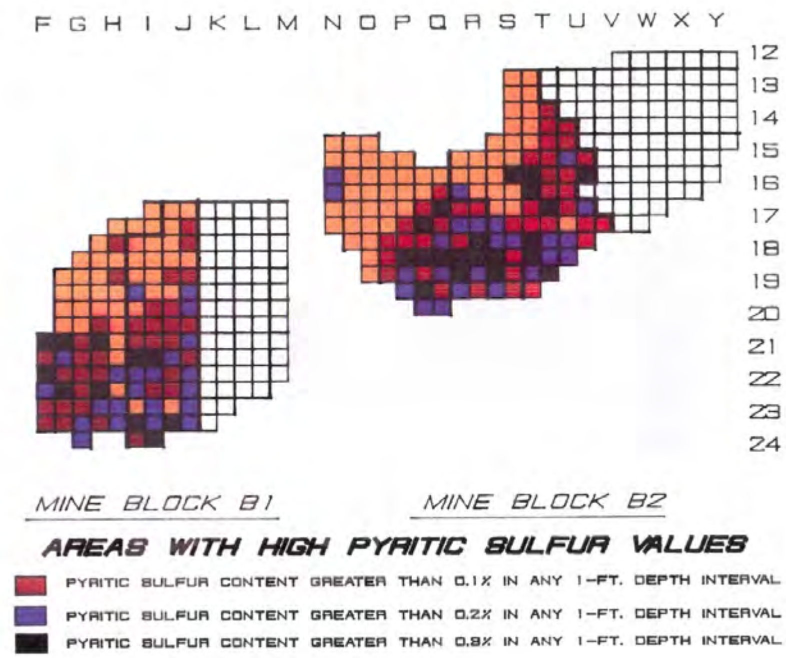
The original permit did not specify how reclaimed spoil areas were to be tested for minesoil properties. Initially, a 1,000 ft grid system (resulting in grid squares of 23 acres) was developed as a compromise between the RCT and TMPA and was used for the first four years (1983-1986). However, because of the inconsistent spoil chemistry results that were being obtained, TMPA decided in 1987 to sample at a higher intensity. In this period, the RCT's Soils and overburden Technical Committee was considering a scenario of annual sampling on a 500 ft grid system (5.75 acre squares). Therefore, in the fall of 1987, TMPA established a permanent grid on this basis with markers at the grid corners on the entire area that had been reclaimed to date (approximately 1,420 acres). The minesoils in these grids were sampled using the new methodology:

- A minimum of four cores were recovered to a depth of four feet in each 5.75-acre grid
- Each core was split up into the following depth increments
    - For non-topsoiled areas: one-foot depth increments
    - For topsoiled areas: topsoil increment, base of topsoil to 2 feet increment, and one-foot depth increments below that
- The sub-samples from each core in a particular grid were physically composited with the corresponding depth increments from the other cores
- The resulting composite samples of the four depth increments in each grid were delivered to the laboratory (Inter-Mountain Laboratories, Inc., of College Station) for analysis

The final submittal of the resulting laboratory data was made to the RCT on July 22, 1988. The database contained data for four depth increments in 241 5.75-acre grids with 21 different analyses per sample, for a total of 20,244 data values (not including duplicate analyses run for QA/QC purposes and a suite of fertility parameters for the topsoil/topsoil substitute layer). This huge database, with rigorous QA/QC and adequate spatial resolution, finally provided reliable information for further investigation and meaningful interpretation.

One of the more interesting findings was that there was a spatial pattern to the distribution of pyritic sulfur contents (Figure 4.7). In particular, there was evidence of a progressive increase in pyritic sulfur content in a down-dip direction, i.e., towards the southeast. This pattern was interpreted as the result of a decreasing down-dip dilution effect of pyrite-bearing material from the reduced zone by pyrite-free material from the oxidized zone, as illustrated diagrammatically in Figure 4.8 (Blanke and Horbaczewski, 1990). This effect assumes that there has been random mixing of the spoil. Although the mixing may not be perfectly random, the spoil appears to be sufficiently mixed after being dumped by the dragline bucket during side-casting and after being leveled by bulldozers and other mobile equipment.

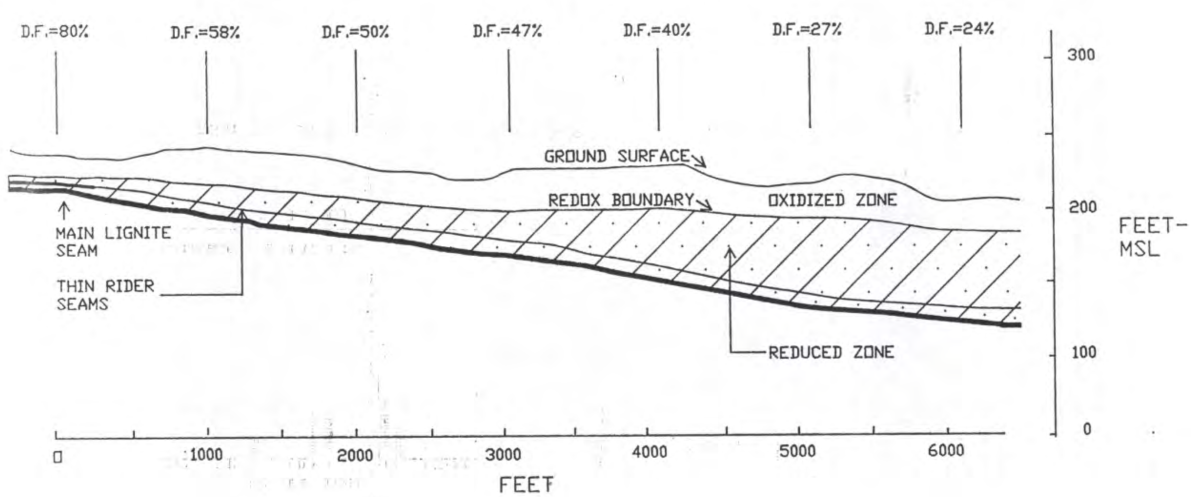
Figure 4.7 – Pyritic sulfur in reclaimed 5.75-acre grids in B1 and B2 Mine Blocks, 1987



Source: Blanke and Horbaczewski, 1990

The dilution factor shown in Figure 4.8 represents the ratio of oxidized material to reduced materials at a given point in the dip section.

Figure 4.8 – Dilution factor for reduced overburden, diagrammatic dip section



Source: Blanke and Horbaczewski, 1990

4.5 History of minesoil reconstruction

As previously discussed, the reconstruction of minesoils at Gibbons Creek Lignite Mine evolved over several years. The main stages were, as follows (Horbaczewski, 2001):

1982-1985 Mixed overburden or spoil dumped by the dragline and leveled by mobile equipment. The resulting soils tended to reflect the local geology and to be very varied, e.g., sandy soils in the B1 Mine Block and more clayey soils in the B2 Mine Block.

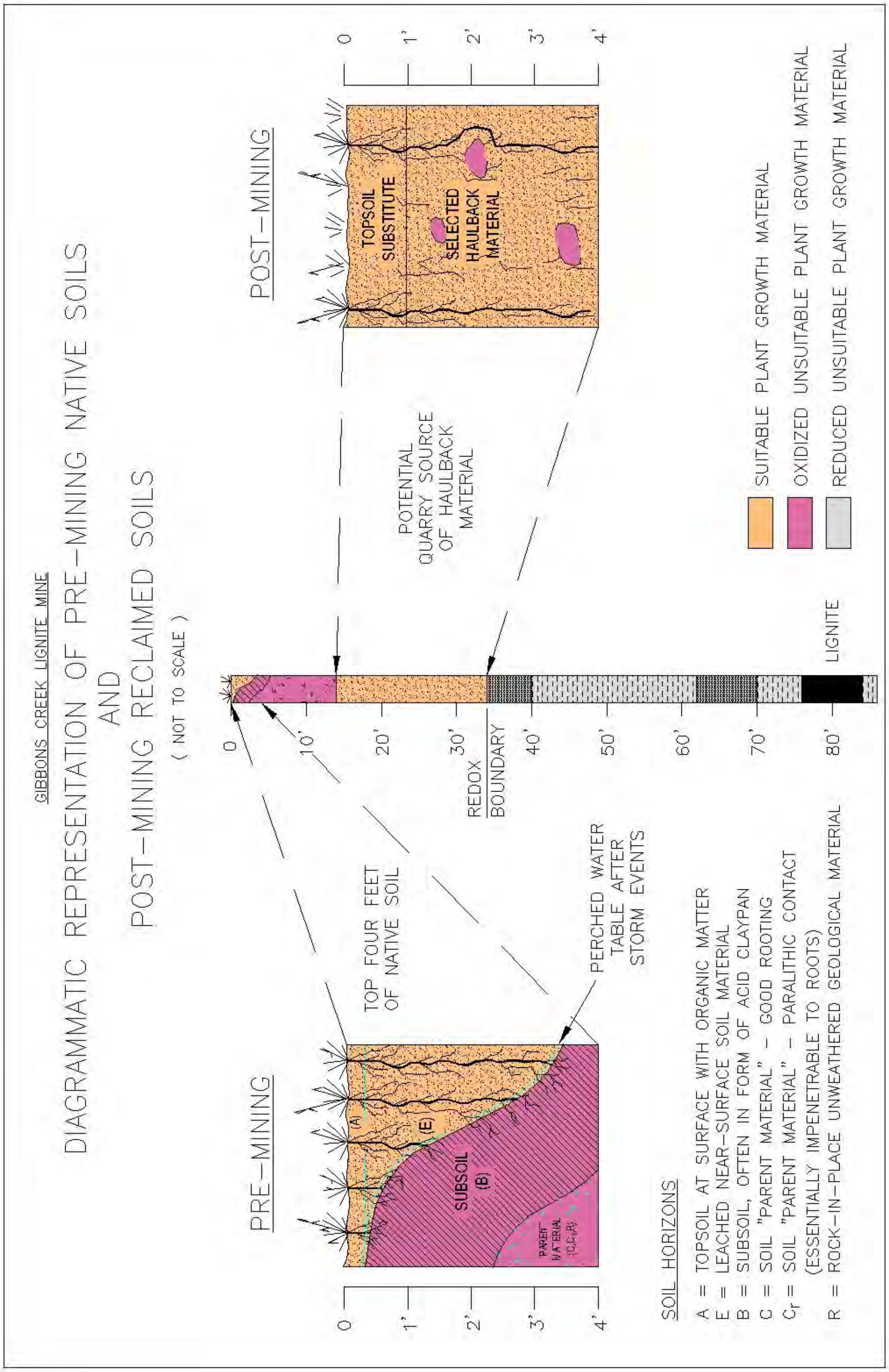
1985-1988 Mixed overburden with native soil replaced on the surface to a depth of at least 6 inches.

1988-1989 Selective handling of overburden by the draglines to bury potentially pyritic reduced overburden and selectively place non-pyritic overburden near the surface. This approach worked for overburden depths up to 60-65 feet but beyond that the draglines had insufficient reach (even with an operating radius of 295 feet) and could not practice selective handling. Replacement of native topsoil at the surface.

1989-1992 Haulback of oxidized material with a mobile fleet and replacement of native topsoil at the surface.

1992-1996 In the A2 and A3 Mine Blocks haulback of oxidized material with a mobile fleet to create the entire minesoil including a topsoil substitute at the surface.

Figure 4.9 – Comparison of pre-mining native soils to post-mining reconstructed minesoils



Drawn by: Rachel Brandt

4.6 Deep liming program

Over the period May 1989 – May 1992, TMPA and its mining contractor, Navasota Mining Company, carried out a deep liming program (TMPA, 1992a). The purpose of the deep liming was to remediate low pH values encountered in some of the grids that had been reclaimed before 1989 with mixed overburden. In the course of this program, a total of 58 5.75 acre grids were treated with lime to the following depths:

- 3 grids to 1 foot, using a 36-inch Rome disc
- 23 grids to 2 feet, using an Easi-Miner
- 32 grids to 4 feet, using a Cleveland Trencher (see Figure 4.10)

In total, approximately 310 acres were treated (some grids were on the edges of the mine blocks and were not a full 5.75 acres). The total volume of spoil treated, allowing for the different depths of treatment, was 1.5 million cubic yards. The total amount of lime used was 9,400 tons.

Figure 4.10 – Cleveland Trencher mixing lime from the surface to a depth of four feet

Photograph: J. Horbaczewski, April 3, 1990.

5. MINESOIL PIT – GRID U15NW

5.1 History of reclamation

Grid U15NW is a grid of 5.75 acres (500 ft x 500 ft) with its northwest corner at 3,332,500 E and 356,000 N (Texas Central State Plane coordinates, North American Datum 1927). This area was mined in 1986, regraded in 1987, topsoiled in 1987, and permanently revegetated in 1987 (Texas Municipal Power Agency, 1992b, Section .145). The minesoil consists of mixed spoil as deposited by the dragline and leveled by bulldozers and scrapers, with at least six inches of native topsoil replaced on the surface.

Grid U15NW is part of Extended Responsibility Period (ERP) Area B2-1, which was accepted into the ERP by the RCT on May 22, 1991. Grass species identified by the RCT in the course of the ERP inspection included kleingrass, coastal bermudagrass, common bermudagrass, sideoats grama, Indiangrass, Alamo Switchgrass, Old World bluestems, green sprangletop, white sweetclover, yellow sweetclover, and arrowleaf clover. This grid is part of a larger area that was released from Phase I and Phase II mine reclamation bonding by RCT Order dated June 2, 1998.

5.2 Minesoil description and properties

On February 25, 2010, a pit was opened in Grid U15NW (at 3,332,667 E; 355,810 N, Texas Central State Plane coordinates, North American Datum 1927), and the minesoil profile was described and sampled by Nellie Frisbee (Figure 5.1). The profile essentially consists of two horizons, a surface "A" horizon of native topsoil that had been replaced at this location to a depth of 11 inches (upper white flag) overlying a "C" horizon of mixed overburden. The topsoil is distinguishable in the field by its lower clay content that is also borne out by laboratory analyses (Table 5.2).

The analyses show that originally (1988) the pyritic sulfur content was over 0.1% and almost 0.2%. A decade later (1997), the pyritic sulfur content had declined significantly and the sulfate sulfur content had increased. By 2010, the pyritic sulfur content was even lower and sulfate sulfur was only present in appreciable amount in the deepest (3-4 ft) depth interval. This suggests that the pyrite had undergone oxidation becoming converted to sulfate and that much of the sulfate had been leached from the soil. The decline in pH supports this interpretation. It should be noted that the decline in pH appears to be temporary since the upper two feet are close to pH 7.0 and it is expected that the lower two feet will also rise in pH as bases become redistributed in the profile. The BT (base of topsoil) to 2 ft interval has an acid base account of +30 tons/1000 tons and is therefore expected to be a good source of bases.

Figure 5.1 – Profile of minesoil in Grid U15NW, February 25, 2010

Photograph (No. 180): Nellie Frisbee

Average Depth	Horizon	Description of minesoil in Grid U15NW
0-12”	A	Brown (10YR 5/3) loamy sand; weak, granular, fine; common, fine and very fine roots; neutral (pH 6.9); abrupt, wavy boundary.
12”-60”+	C	Intermingled light olive brown (2.5Y 5/3) with olive yellow (2.5Y6/6) (approximately 70% with 30%) clay loam; few, coarse to very coarse, cylindrical masses of weathered pyrite gray (10YR 5/1) center has metallic flakes still visible with a yellow (2.5Y 8/8) rind; few fine to medium lignite fragments; few coarse shaley clay fragments pale yellow (2.5Y 8/3) rounded and firm; common medium to cobble-sized shaley clay fragments very pale brown (10YR 8/2) with reddish yellow (7.5YR 7/8) on top surface rounded with blocky internal fracture; common coarse shaley clay fragments light yellowish brown (2.5Y 6/3) rounded firm; few very fine roots; strongly acid (pH 5.1).

Profile description: Nellie Frisbee

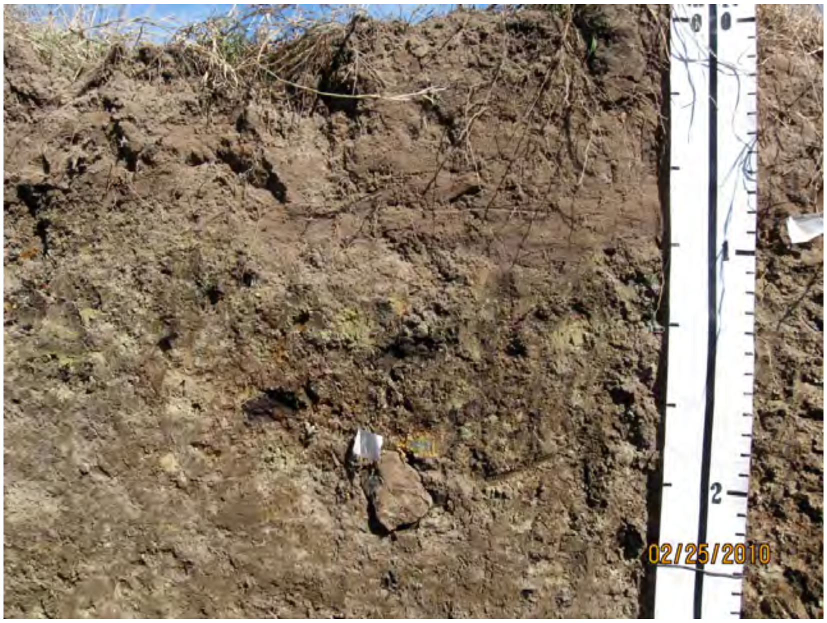
Table 5.1 – Grid U15NW – Comparison of soil analytical properties over time

	1988[1]	**1997**[2]	**2010**[3]
Type of sample	Physical composite from approx. 4 sites in grid.	Physical composite from 6 sites in grid (January 6, 1997)	Samples from 1 site in grid (February 25, 2010)
Total sulfur content (%)			
0-base topsoil (BT)	0.03	0.00	<0.01
BT-2 ft depth interval	0.32	0.04	0.07
2-3 ft depth interval	0.24	0.28	0.05
3-4 ft depth interval	0.20	0.21	0.19
Pyritic sulfur content (%)			
0-base topsoil (BT)	0.03	0.00	<0.01
BT-2 ft depth interval	0.19	0.03	0.03
2-3 ft depth interval	0.15	0.08	0.01
3-4 ft depth interval	0.11	0.05	0.03
Sulfate sulfur content (%)			
0-base topsoil (BT)	0.01	0.00	<0.01
BT-2 ft depth interval	0.04	0.01	<0.01
2-3 ft depth interval	0.01	0.14	0.01
3-4 ft depth interval	0.02	0.11	0.13
pH (s.u.)			
0-base topsoil (BT)	7.1	7.6	6.9
BT-2 ft depth interval	7.6	7.0	6.8
2-3 ft depth interval	7.8	5.8	4.7
3-4 ft depth interval	7.3	6.4	4.7
Acid Base Accounting (t/kt)			
0-base topsoil (BT)	1	8	1
BT-2 ft depth interval	6	3	30
2-3 ft depth interval	2	0	0
3-4 ft depth interval	3	2	1
Organic matter (%)			
0-base topsoil (BT)	--	--	0.6
BT-2 ft depth interval	--	--	2.0
2-3 ft depth interval	--	--	1.9
3-4 ft depth interval	--	--	1.7
Clay content (%)			
0-base topsoil (BT)	8	8	7
BT-2 ft depth interval	28	26	34
2-3 ft depth interval	29	36	31
3-4 ft depth interval	30	38	33
E.C. (mmhos/cm)			
0-base topsoil (BT)	--	--	0
BT-2 ft depth interval	--	--	1
2-3 ft depth interval	--	--	1
3-4 ft depth interval	--	--	3

[1] Inter-Mountain Laboratories, Inc., report dated May 6, 1988.
[2] Inter-Mountain Laboratories, Inc., report dated March 17, 1997.
[3] Energy Laboratories, Inc., report dated March 10, 2010.

While most of the pyrite has been weathered out, there are still a few pyrite nodules present, such as the one at a depth of just under 2 ft (white flag to the left of the tape) (Figures 5.2 and 5.3). This nodule has a rim of jarosite, ($KFe_3(SO_4)_2(OH)_6$, a common weathering product of pyrite (Nordstrom, 1982).

Figure 5.2 – Pyrite nodule at 2 ft depth in Grid U15NW, February 25, 2010



Photograph (No. 101): Nellie Frisbee

Figure 5.3 – Detail of pyrite nodule at 2ft depth in Grid U15NW, February 25, 2010

Photograph (No. 186): Nellie Frisbee

There is another pyrite nodule at a depth of 3.5 ft (Figure 5.4). This one appears to show the hydrolysis product of jarosite, the rust-colored ferric oxyhydroxide known as goethite (α-FeOOH) (Soil Working Group, 1998, p. 5). The central part of the nodule reveals a residual core of pyrite.

Figure 5.4 – Detail of pyrite nodule from 3.5 ft depth in Grid U15NW, February 25, 2010

Photograph: Rachel Brandt

6. MINESOIL PIT – GRID X14SE

6.1 History of reclamation

Grid X14SE is a grid of 5.75 acres (500 ft x 500 ft) with its northwest corner at 3,336,000 E and 356,500 N (Texas Central State Plane coordinates, North American Datum 1927). This area was mined in 1988, regraded in 1988, topsoiled in 1989, and permanently revegetated in 1989 (Texas Municipal Power Agency, 1992b, Section .145). As of April 2010, the reconstructed minesoil is therefore 21 years old. The minesoil consists of mixed spoil as deposited by the dragline and leveled by bulldozers and scrapers, with six inches of native topsoil replaced on the surface.

Grid X14SE is part of Extended Responsibility Period (ERP) Area B2-2, which was accepted into the ERP by the RCT on November 3, 1994. Grass species identified in the course of the 1999 growing season included bahiagrass, bermudagrass, Alamo Switchgrass, kleingrass, indiangrass, and other grasses (Marston Environmental Inc., 2000). This grid is part of a larger area that was released from Phase I and Phase II mine reclamation bonding by RCT Order dated December 7, 1999.

6.2 Minesoil description and properties

On February 22, 2010, a pit was opened in Grid X14SE (at 3,336,329 E and 356,170 N, Texas Central State Plane coordinates, North American Datum 1927) and the minesoil profile was described and sampled by Nellie Frisbee (Figure 6.1). The profile essentially consists of two horizons, a surface "A" horizon of native topsoil that had been replaced at this location to a depth of 9 inches (upper white flag to right of tape) overlying a "C" horizon of mixed overburden. The topsoil is distinguishable in the field by its lower clay content that is also borne out by laboratory analyses (Table 6.2). The "C" horizon was subdivided into three sub-horizons: the "C1" characterized by a strong coloration due to jarosite to a depth of 27.5 in (middle white flag to right of tape), the "C2" that is less strongly colored by jarosite to a depth of 53 in (lower white flag to right of tape), and the "C3" showing relatively little evidence of oxidation processes at a depth greater than 53 in.

The analyses show that originally (1989) the pyritic sulfur content was over 0.1%. By 1998, the pyritic sulfur content had declined significantly. By 2010, there was virtually no pyritic sulfur present in the top two feet and concentrations were very low even in the deeper intervals to four feet. On the other hand, sulfate sulfur had increased particularly in the two lower (2-3 ft, and 3-4 ft) depth intervals. As with Grid U15NW, this suggests that the pyrite in Grid X14SE had undergone oxidation becoming converted to sulfate, although in this case the sulfate had not yet been leached from the soil, as reflected also in the electrical conductivity (E.C.) values. The decline in pH supports this interpretation. The decline in pH is expected to be temporary as bases, such as calcium, are leached from the surface into the lower depth intervals.

Figure 6.1 – Profile of minesoil in Grid X14SE, February 22, 2010

Photograph (No. 173): Nellie Frisbee

Average Depth	Horizon	Description of minesoil in Grid X14SE
0-9”	A	Brown (10YR 5/3) sandy loam; weak, granular, coarse; many fine and very fine roots; neutral (pH 6.9); irregular, gradual boundary.
9”-27.5”	C1	Intermingled brown (10YR 5/3) and light yellowish brown (2.5Y 6/4) clay loam; massive; common, coarse, rounded masses of jarosite yellow (2.5Y 8/6) with yellow brown (10YR 5/6) rinds; common, coarse lignite fragments rounded to irregular with blocky fracture and fine roots within fractures; few, coarse shaley clay fragments dark grayish brown (2.5Y 4/2) rounded, with a blocky and conchoidal internal fracture and occasional reddish yellow (7.5YR6/8) on fracture faces; extremely acid (pH 3.7); diffuse, broken boundary.
27.5”-53.0”	C2	Light olive brown (2.5Y 5/3) clay loam with lenses of light brownish gray (2.5Y 6/2) loamy sand; massive; few, coarse, cylindrical and irregular masses of weathered pyrite dark gray (2.5Y 4/1) center with a yellow (2.5Y 7/6) rind; few, coarse and cobble-sized lignite fragments, irregular; common, coarse rock fragments very dark gray (10YR 3/1) and pale olive (5Y 6/3) core with yellowish red (5YR 4/6) rind, rounded; few, very fine roots; minor seepage occurs from open pit face within this interval; extremely acid (pH 3.9); diffuse broken boundary.
53”-60”+	C3	Light olive brown (2.5Y 5/3) clay and loamy sand lenses (70% and 30%); massive; few, cobble to stone-sized rock fragments, fresh faces are greenish gray (Gley 2 5/10G) with an olive (5Y 5/3) rind, the core turns gray (5Y 6/1) within hours of exposure, irregular; few very fine roots; moderately acid (pH 5.7).

Profile description: Nellie Frisbee

Table 6.1 – Grid X14SE – Comparison of soil analytical properties over time

	1989[1]	1998[2]	2010[3]
Type of sample	Physical composite from approx. 4 sites in grid.	Physical composite from 6 sites in grid.	Samples from 1 site in grid.
Total sulfur content (%)			
0-base topsoil (BT)	--	--	<0.01
BT-2 ft depth interval	--	0.06	0.07
2-3 ft depth interval	--	0.04	0.31
3-4 ft depth interval	--	0.06	0.27
Pyritic sulfur content (%)			
0-base topsoil (BT)	0.00	--	<0.01
BT-2 ft depth interval	0.16	0.03	<0.01
2-3 ft depth interval	0.13	0.01	0.03
3-4 ft depth interval	0.13	0.04	0.01
Sulfate sulfur content (%)			
0-base topsoil (BT)	--	--	<0.01
BT-2 ft depth interval	--	0.02	0.05
2-3 ft depth interval	--	0.01	0.22
3-4 ft depth interval	--	0.02	0.19
pH (s.u.)			
0-base topsoil (BT)	6.5	4.9	6.9
BT-2 ft depth interval	6.8	7.3	3.8
2-3 ft depth interval	6.3	8.1	4.0
3-4 ft depth interval	6.1	7.6	4.0
Acid Base Accounting (t/kt)			
0-base topsoil (BT)	4	--	1
BT-2 ft depth interval	2	9	-1
2-3 ft depth interval	2	11	-2
3-4 ft depth interval	2	7	-1
Organic matter (%)			
0-base topsoil (BT)	--	--	0.7
BT-2 ft depth interval	--	--	1.3
2-3 ft depth interval	--	--	1.9
3-4 ft depth interval	--	--	2.7
Clay content (%)			
0-base topsoil (BT)	8	--	10
BT-2 ft depth interval	35	36	33
2-3 ft depth interval	26	36	34
3-4 ft depth interval	25	36	35
E.C. (mmhos/cm)			
0-base topsoil (BT)	0	--	0
BT-2 ft depth interval	2	--	2
2-3 ft depth interval	2	--	3
3-4 ft depth interval	3	--	3

[1] Samples taken April 6, 1989 (topsoil January 19, 1990) – data from TMPA, 1992, Application for Area B2-2 into Extended Responsibility Period.

[2] Soil Analytical Services, Inc., report dated July 9, 1998.

[3] Energy Laboratories, Inc., report dated March 8, 2010.

This profile shows a number of pyrite nodules in various stages of oxidation. The one at a depth of 1 ft (next to the white flag on the upper right-hand side of Figure 6.1) reveals complete oxidation in close-up (Figure 6.2). It should be noted that root distribution does not appear to have been affected by this nodule.

Figure 6.2 – Oxidized pyrite nodule at 1 ft depth in Grid X14SE, February 22, 2010

Photograph (No. 163): Nellie Frisbee

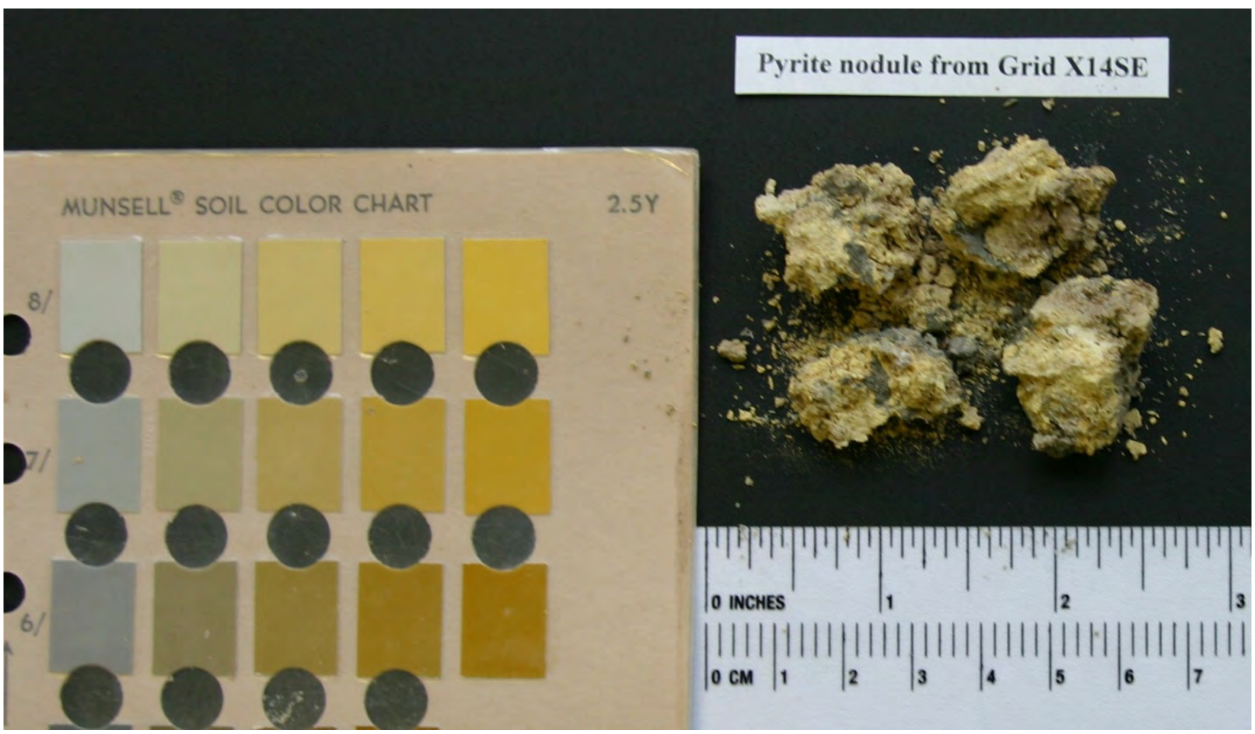
Another pyrite nodule at a depth of 2.5 ft (next to the white flag on the lower center-right side of Figure 6.1) reveals partial oxidation of pyrite to jarosite (Figure 6.3). The characteristic 2.5Y Munsell hue of the jarosite is evident in the close-up of this nodule (Figure 6.4).

Finally, a nodule found at a depth of 4 ft in this pit shows the radial disintegration (Figure 6.5) leading to rapid decomposition that had been observed in other investigations at Gibbons Creek mine (Horbaczewski, 2007b).

Figure 6.3 – Partly oxidized pyrite nodule at 2.5 ft depth in Grid X14SE, February 22, 2010

Photograph (No. 165): Nellie Frisbee

Figure 6.4 – Partly oxidized pyrite nodule at 2.5 ft depth in Grid X14SE, February 22, 2010



Photograph (No. 7057): Rachel Brandt

Figure 6.5 – Partly oxidized pyrite nodule at 4 ft depth in Grid X14SE, February 22, 2010

Photograph (No. 61): Murphy Hawkins

7. MINESOIL PIT – GRID P19SE

7.1 History of reclamation

Grid P19SE is a grid of 5.75 acres (500 ft x 500 ft) with its northwest corner at 3,328,000 E and 351,500 N (Texas Central State Plane coordinates, North American Datum 1927). This area was mined in 1983, regraded in 1984 and permanently revegetated in 1984 (Texas Municipal Power Agency, 1992b, Section .145). The minesoil consists of mixed spoil as deposited by the dragline and leveled by bulldozers and scrapers. The grid was reclaimed before the replacement of native topsoil started in January 1985.

This grid was one of 32 grids selected by TMPA for liming to a depth of four feet in 1989 as part of a remediation program. Deep lime incorporation was completed by December 1991. The original material of the reconstructed minesoil as of April 2010 is therefore 26 years old although the reworked limed material is 19 years old.

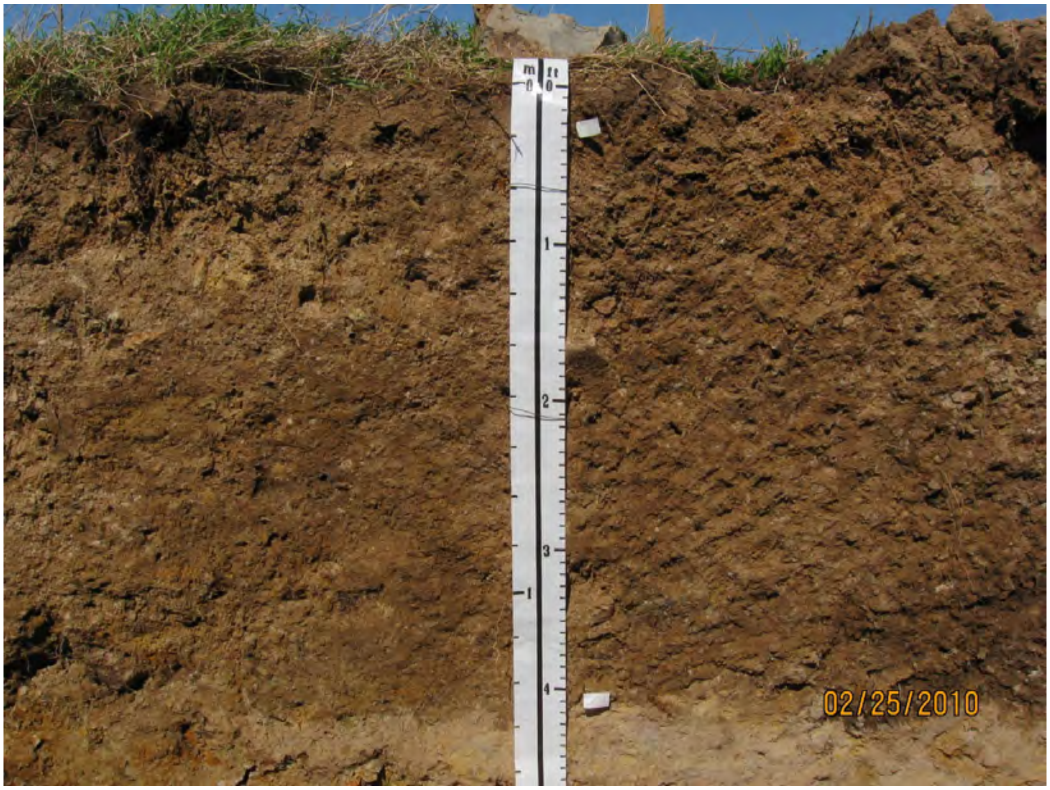
Grid P19SE is part of Extended Responsibility Period (ERP) Area B2-6, which was accepted into the ERP by the RCT on December 16, 1998. Grass species identified in vegetation studies conducted in the 2002 growing season included Coastal bermudagrass, kleingrass, Alamo Switchgrass, indiangrass, bahiagrass, sideoats grama, yellow bluestem, and other grasses (Marston Environmental Inc. 2003a). This grid is part of a larger area that was released from Phase I and Phase II mine reclamation bonding by RCT Order dated December 7, 1999.

7.2 Minesoil description and properties

On February 25, 2010, a pit was opened in Grid P19SE (at 3,328,444 E; 351,437 N, Texas Central State Plane coordinates, North American Datum 1927) and the minesoil profile was described and sampled by Nellie Frisbee (Figure 7.1). The profile essentially consists of two horizons: a surface “A” horizon composed of mixed overburden that has developed sufficient structure and organic matter to be considered topsoil to a depth of 2.5 inches (upper white flag) overlying a “C1” horizon of mixed overburden to a depth of 53.5 inches. A “C2” horizon was recognized below that. The lower white flag at 49 inches represents the depth of trenching at this site.

Compared to the minesoils in Grids U15NW (23 years old) and X14SE (21 years old), the minesoil in Grid P19SE at 26 years is only a few years older. However, it does not exhibit the jarosite streaking or pyrite nodules even though originally it had a comparable, if not higher, pyritic sulfur content. In fact, the predominant yellowish brown (10YR) hue of this profile suggests the presence of ferric oxyhydroxides. It would seem that this profile has already passed through the pyrite oxidation and jarosite hydrolysis stages. That this occurred relatively quickly is probably attributable to the trenching which fluffed up the soil and allowed greater mixing with air and water.

Figure 7.1 - Profile of minesoil in Grid P19SE, February 25, 2010



Photograph (No. 199): Nellie Frisbee

Average Depth	Horizon	Description of minesoil in Grid P19SE
0”-2.5”	A	Dark yellowish brown (10YR 3/6) clay loam; weak, granular, coarse to very coarse; common, fine, platelike crystals; many, very fine to very coarse roots; slightly acid (pH 6.5); irregular, gradual boundary.
2.5”-53.5”	C1	Intermingled dark yellowish brown (10YR 4/4) with yellow (2.5Y 7/6) (approximately 70% with 30%) clay loam; massive; many, medium, prominent, mottles white (5Y 8/1) occurring as spots with sharp boundaries; few, very fine lignite fragments; common, pebble to boulder-sized, shaley clay fragments light yellowish brown (2.5Y 6/4) with yellow (2.5Y8/8) and yellowish red (5YR 5/8) on surfaces and fracture planes, blocky internal fracture; few, medium rock fragments brown (10YR 4/3) with yellowish red (5YR 5/8) and yellow (2.5Y 8/8) on surfaces and fracture planes, blocky internal fracture, roots in fractures, rounded; few, fine platelike crystals on rock surfaces; few, fine roots; very strongly acid (pH 4.5); clear, wavy to broken boundary.
53.5”-60”+	C2	Intermingled light gray (2.5Y 7/2) with pale yellow (2.5Y 7/4) (approximately 70% with 30%) silt loam; few, cobble-sized rock fragments light yellowish brown (2.5Y 6/4) with some dark greenish gray (Gley 1 4/5GY) areas and strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/8) on the weathered surfaces and fracture planes, internal blocky fracture, rounded; few, coarse rock fragments black (10YR 2/1) and strong brown (7.5YR 5/8) with a reddish yellow (7.5YR 6/8) “halo” in the surrounding material, rounded; few, fine platelike crystals on rock surfaces and fracture planes; few, very fine roots; extremely acid (pH 3.9).

Profile description: Nellie Frisbee

Table 7.1 – Grid P19SE – Comparison of soil analytical properties over time

	1987[1]	Post-liming (1995)[2]	2010[3]
Type of sample	Physical composite from approx. 4 sites in grid.	Physical composite from 6 sites in grid.	Samples from 1 site in grid.
Total sulfur content (%)			
0-1 ft depth interval	0.34	0.43	0.07
0-2 ft depth interval	0.39	0.45	0.09
2-3 ft depth interval	0.51	0.40	0.09
3-4 ft depth interval	0.48	0.48	0.14
Pyritic sulfur content (%)			
0-1 ft depth interval	0.04	0.14	<0.01
0-2 ft depth interval	0.17	0.09	<0.01
2-3 ft depth interval	0.08	0.09	<0.01
3-4 ft depth interval	0.26	0.18	0.01
Sulfate sulfur content (%)			
0-1 ft depth interval	0.20	0.23	0.04
0-2 ft depth interval	0.13	0.29	0.06
2-3 ft depth interval	0.31	0.23	0.06
3-4 ft depth interval	0.11	0.22	0.10
pH (s.u.)			
0-1 ft depth interval	4.5	6.8	5.5
0-2 ft depth interval	4.8	6.7	4.4
2-3 ft depth interval	3.8	5.9	4.4
3-4 ft depth interval	6.0	6.4	4.3
Acid Base Accounting (t/kt)			
0-1 ft depth interval	-1	4	2
0-2 ft depth interval	-3	6	-1
2-3 ft depth interval	-7	1	-1
3-4 ft depth interval	-4	-1	-1
Organic matter (%)			
0-1 ft depth interval	--	--	2.0
0-2 ft depth interval	--	--	1.7
2-3 ft depth interval	--	--	1.7
3-4 ft depth interval	--	--	1.9
Clay content (%)			
0-1 ft depth interval	37	28	28
0-2 ft depth interval	33	26	27
2-3 ft depth interval	32	27	28
3-4 ft depth interval	36	27	29
E.C. (mmhos/cm)			
0-1 ft depth interval	3	4	1
0-2 ft depth interval	3	4	0
2-3 ft depth interval	4	3	1
3-4 ft depth interval	3	3	2

[1] Inter-Mountain Laboratories, Inc., report dated June 10, 1988.
[2] Inter-Mountain Laboratories, Inc., report dated March 24, 1995.
[3] Energy Laboratories, Inc., report dated March 10, 2010.

The analyses (Table 7.1) show that in 1987 the pyritic sulfur content was over 0.1% and even over 0.2% but that oxidation had already penetrated to a depth of 3 ft as evidenced by the low pH. It should be noted that even earlier, less reliable pre-1987 analyses performed on 23 acre grids in this area showed pyritic sulfur contents greater than 0.3%. By 1995, the pyritic sulfur content had begun to decline and the sulfate sulfur content to increase. By 2010, pyritic sulfur analyses indicate that pyrite has been eliminated from the profile (no pyrite nodules were seen in this pit) and even sulfate sulfur was showing evidence of leaching with the highest concentration in the deepest (3-4 ft) depth interval.

As in previous profiles, the decline in pH supports the theory that the pyrite has undergone oxidation, become converted to sulfate, and that much of the sulfate has been leached from the minesoil. As previously indicated, the decline in pH appears to be temporary since there is a positive acid base account in the upper foot indicating the presence of bases which are expected to become redistributed in the profile.

8. ACID SEEP 1

8.1 History of Seep 1

Seep 1, located in the Gibbons Creek floodplain (at elevation 200-201 ft above mean sea level, and 3,335,785 E and 348,258 N, Texas Central State Plane coordinates, North American Datum 1927), was first investigated and sampled by TMPA on September 5, 2002. Laboratory analyses confirmed the acid nature of the seep with a pH value of 2.9 standard units (s.u.), iron content of 50.2 milligrams per liter (mg/L) and aluminum content of 13.4 mg/L. The probability that the acidity was caused by oxidation of pyritic material was indicated by the moderately high sulfate content (1,100 mg/L).

Marston Environmental Inc. was retained by TMPA to investigate this seep and over the period November 2002 to February 2003, Craig Bejnar, geologist with Marston excavated trenches at the site, collected additional water samples and reviewed the pre-mining and post-mining geology in considerable detail. The pre-mining geology was reconstructed on the basis of 19 lignite exploration drill holes in the vicinity of the seep including 6 closely-spaced (fence) holes that had been drilled immediately south of the seep to define the subcrop of the lignite (Marston Environmental, Inc., 2003b).

8.2 History of mining and reclamation in the area

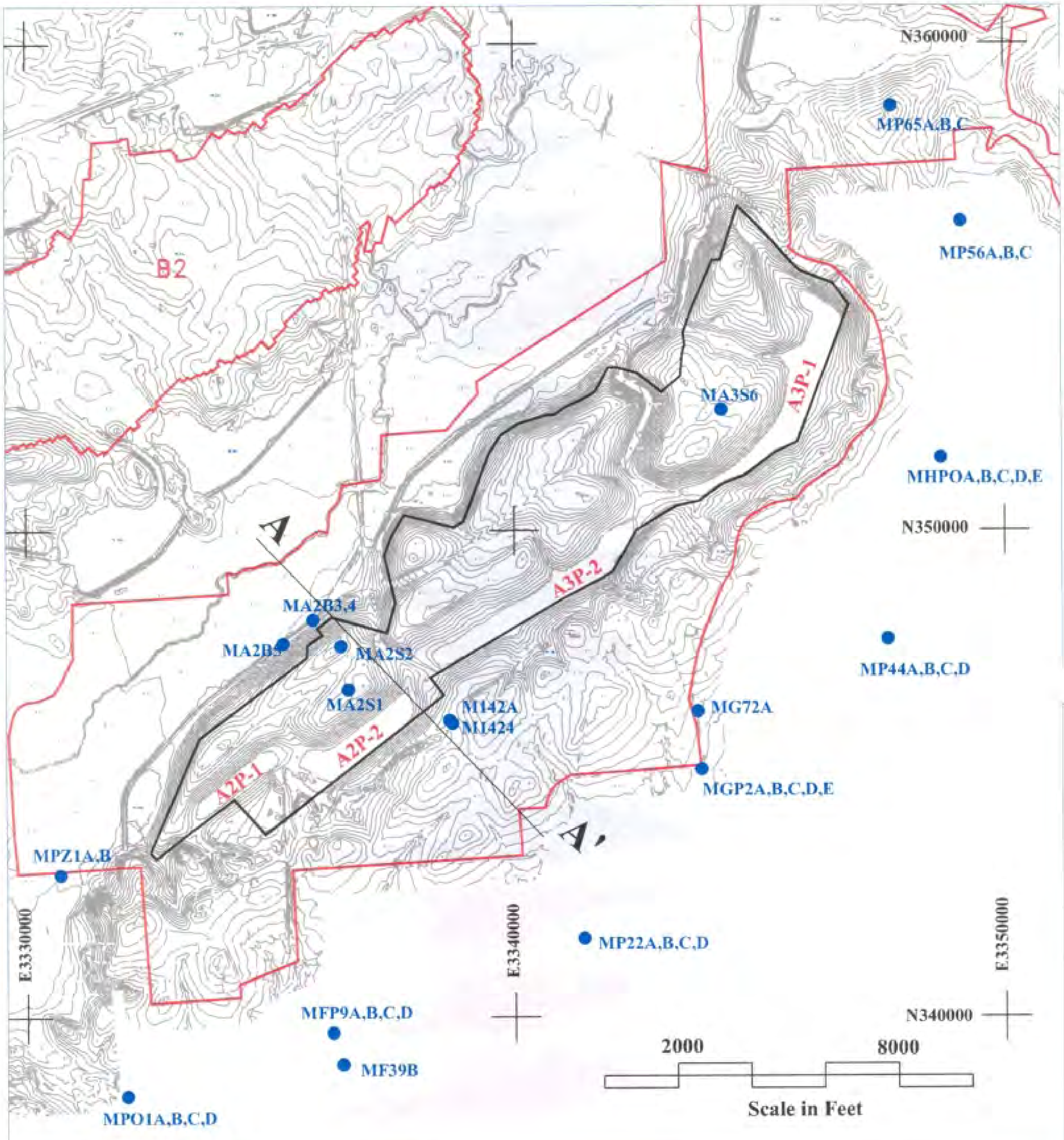
It should be noted that Seep 1 is located immediately to the north of the first strike pit excavated in the A2 Block in June 1992 (Figure 8.1). Mining then continued on strike-aligned dragline pits towards the southeast. The boxcut spoil slopes were regraded in 1993 and minesoil reconstruction was completed in 1993-1994. The minesoil consists of oxidized overburden deposited to a depth of four feet over the spoil. No native topsoil was replaced on the surface. The reclaimed area was planted to permanent vegetation (Coastal bermudagrass, *Cynodon dactylon*, var. Tifton 78) in 1994-1995. Since then, the area has not changed significantly although there was some reshaping of the slopes in 2002.

The groundwater regime of the A2 Block in the vicinity of Seep 1 appears to be influenced by End Lake A2P-2, which is about 2,500 ft to the southeast (Figure 8.2). This lake occupies the last dragline pit which had started filling with rainfall runoff at the time of mine closure in 1996. Construction of the end lake started in August 2000 and was completed towards the end of 2001. The pond was then allowed to fill with rainfall runoff and it spilled for the first time in February 2003 at the design elevation of 236 ft above mean sea level. It has remained at this elevation with only minor seasonal fluctuations of a foot or two. Since Seep 1 is at elevation 200-201 ft, there is a difference of approximately 35 ft in water elevation between the end lake and the seep.

Figure 8.1 – Location of Seep 1 in relation to A2 Mine Block

Arrow indicates future location of Seep 1. Photograph taken in April 1994 before development of seep. Source: unknown.

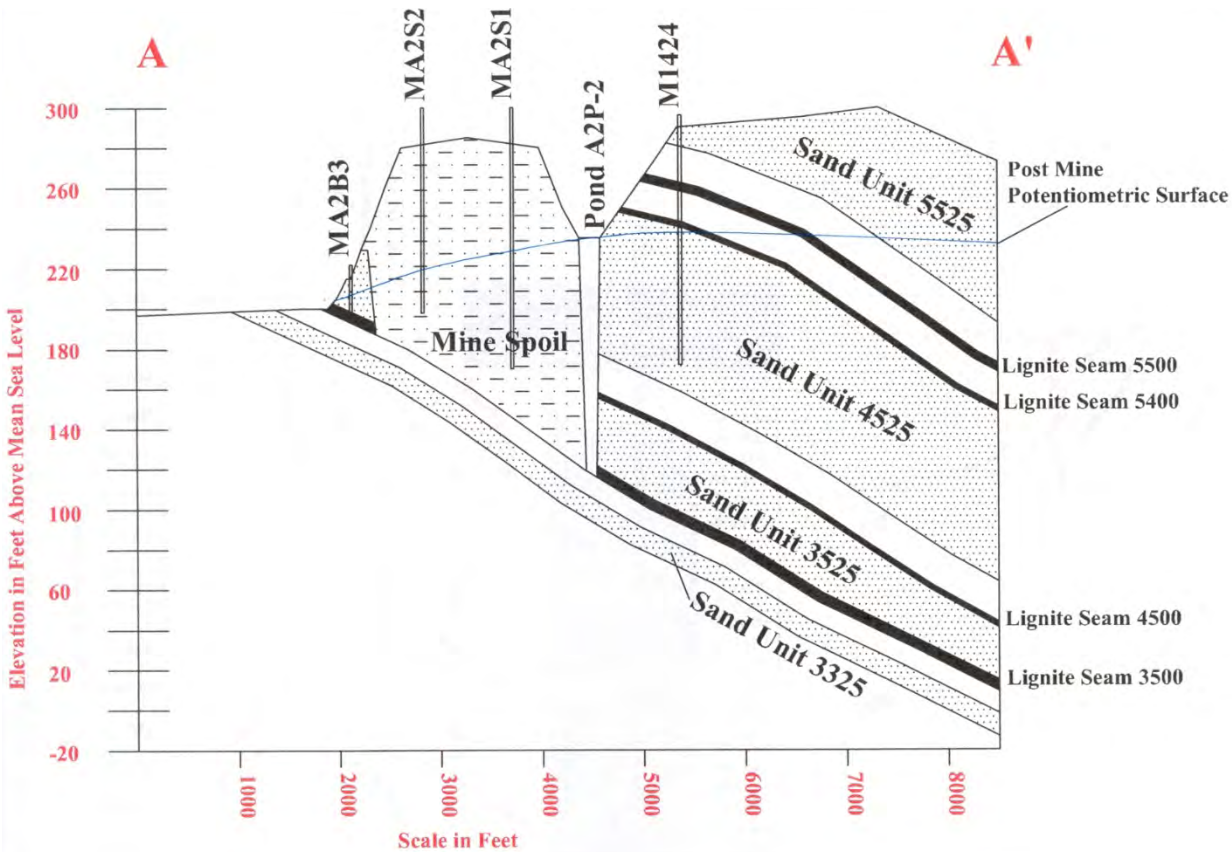
Figure 8.2 – Location of Seep 1 and monitoring wells in A2 Mine Block



Source: Marston Environmental Inc. (2009). Seep 1 is located on Section A-A' (see Figure 8.2) immediately to the northwest of Groundwater Monitoring Wells MA2B3, 4.

The form of the potentiometric surface between End Lake A2P-2 and Seep 1 has been derived from groundwater monitoring that started towards the end of 2003. The diagrammatic cross section (Figure 8.3) shows the potentiometric surface dropping from a level of 236 ft in the end lake through monitoring wells MA2S1, MA2S2, to MA2B3 and Seep 1 located just beyond the toe of the mine spoil. It should be noted that there is a residual wedge of unmined overburden at MA2B3 including a short section of the 3500 lignite seam.

Figure 8.3 – Potentiometric surface and monitoring well locations near Seep 1



Source: Marston Environmental Inc. (2009). Seep 1 is located immediately to the left (northwest) of Groundwater Monitoring Well MA2B3.

8.3 Formation of Seep 1

The changes in the potentiometric surface in the spoil in relation to the water level in End Lake A2P-2 and the formation of Seep 1 may be summarized graphically (Figure 8.4). Following the completion of construction of End Lake A2P-2 towards the end of 2001, the water level began to rise quickly from 221 ft in November 2001 to 230 ft in September 2002 when Seep 1 was discovered. Monitoring of groundwater levels in the spoil started in November 2003 and showed a continuous rise until the beginning of 2006 when levels in both MA2S1 and MA2S2 began to level off. The water quality in both these wells showed gradual declines in pH over this period suggesting oxidation of pyrite in the spoil.

Figure 8.4 – Water levels at Seep 1 and monitoring wells in relation to End Lake A2P-2

Source: Horbaczewski (2007a)
Drafting: Rachel Brandt

The low pH of the groundwater and reducing conditions maintained iron in solution until it came into contact with the air and was oxidized to ferric oxyhydroxides (Figure 8.5). Similar deposition of iron oxyhydroxides has been observed in natural drainages of the area that have been completely undisturbed by mining activities. One such area is Peach Creek.

Figure 8.5 – Crust of iron oxyhydroxides from Seep 1, February 25, 2010

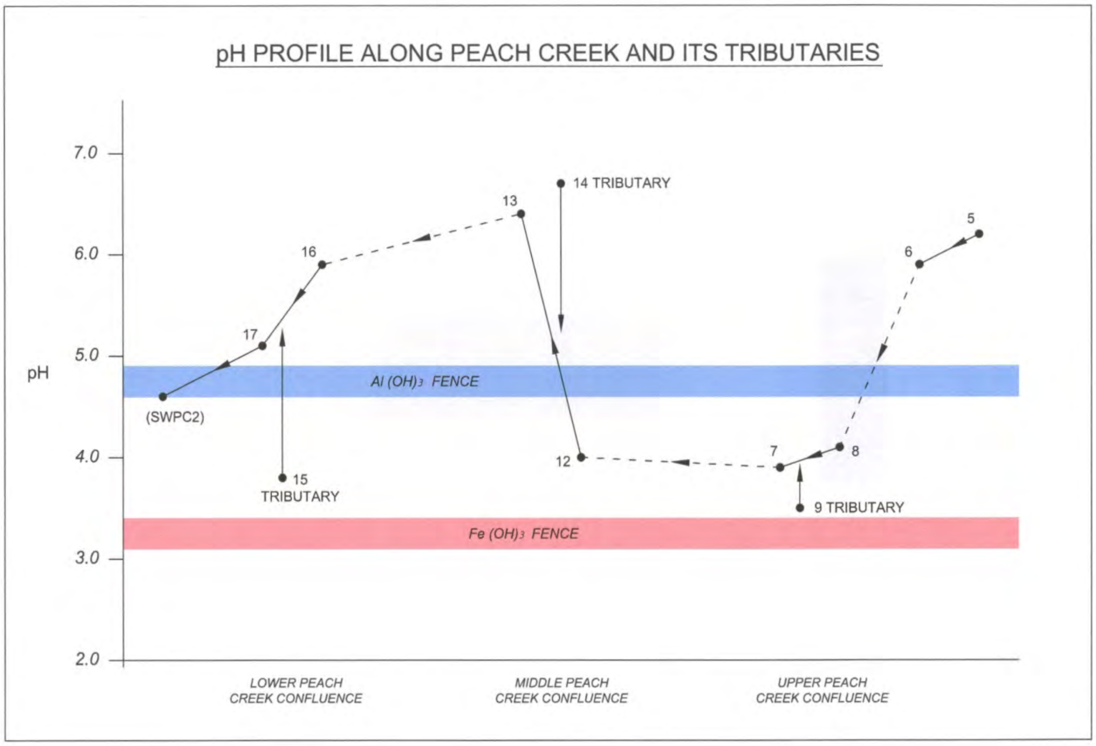
Photograph (No. 7078a): Rachel Brandt

8.4 Peach Creek case study

As stated previously (Section 4.3) the redox boundary (or more accurately, redox plane, since it has a lateral extent) parallels the surface topography and transgresses lithological units. This has a deeper significance: it indicates that the redox plane is a dynamic rather than static feature and that it continues to migrate downwards over geological time (Horbaczewski, 2007a). And since it occurs at a relatively constant depth, it also suggests that it is in equilibrium with the rate of erosion occurring at the surface. The geochemical implications are profound. As the redox boundary migrates downwards, fresh pyritic material that was previously protected from oxidation becomes exposed to oxidation processes as the boundary migrates over it. This in turn means that acidity from pyrite oxidation is constantly being produced naturally. Supporting evidence for this comes from a case study of Peach Creek (Horbaczewski, 2009), an undisturbed drainage upstream of the Gibbons Creek mine.

A systematic survey of the main channel and tributaries of Peach Creek showed very variable pH values in the water (Figure 8.6). At some locations the pH was less than 4.0 standard units (s.u.) and even as low as 2.1 s.u. One tributary (sampling site 9) was acidic enough to maintain ferric iron in solution until it mixed with less acidic water from sampling site 8 and precipitated iron oxyhydroxides immediately downstream at sampling site 7 (Figure 8.7).

Figure 8.6 – Peach Creek pH profile vs. precipitation ranges of iron and aluminum oxyhdroxides



Source: Horbaczewski (2009)

In conclusion, if the redox boundary is a dynamic feature that has been migrating downwards over geological time, should there not be evidence of former pyrite nodules in the oxidized zone and perhaps even in native soils? This is, in fact the case. Jarosite has been identified in several Texas native claypan soils, including the Aubrey and Birome soil series developed in the Woodbine Formation (Upper Cretaceous), the Lufkin soil series in the Yegua Formation (Eocene), and the Shalba series developed in the Catahoula Formation (Oligocene) (Carson et al., 1982). The authors attribute the jarosite and associated barite and gypsum to the weathering of pyrite which provided the source of sulfate ions and the acidity necessary for the formation of jarosite. The preservation of the jarosite is attributed to the very dense clayey subsoil.

Figure 8.7 – Peach Creek sampling site 7, precipitation of iron oxyhydroxides

Source: Horbaczewski (2009)

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