CHEMICAL AND PHYSICAL PROPERTIES OF LIGNITE OVERBURDEN AS RELATED TO ENVIRONMENTS OF DEPOSITION[1]

by

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ABSTRACT

Texas lignite overburden is extremely variable particularly in particle size distribution. This is partly due to the diverse environments in which these sediments accumulated. This study was conducted to determine if any of the properties most critical to successful revegetation of the stripmined areas are related to the environments of deposition.

Lignite overburden strata in six cores obtained from representative locations along the outcrop of the lignite bearing sediments were grouped (based on geological structures) according to their environments of deposition. Selected physical and chemical properties of these subgroups were determined.

Although variability associated with all properties within each depositional environment was large, it was possible to recognize the following types of depositional environments based on the sand content: (1) bed load channel; (2) mixed load channel; (3) crevasse channel, crevasse splay, overbank and levee; (4) marsh and bay center. Several important parameters of the overburden (potential acidity, cation exchange capacity, available water and heavy metal elements), are related to the energy of the environment in which these sediments accumulated and whether or not these sediments have been affected by surface weathering processes.

INTRODUCTION

Near surface lignite in Texas occurs in a belt which extends from the northeast to the southwest region of the state. Extensive areas of land within this region will be disturbed as a result of surface mining for lignite. The major objective of this research was to determine the geologic environments of deposition in the overburden at selected sites along the outcrop of the Wilcox geologic group and determine if these environments are related to the chemical and physical properties of the materials. Depositional environments could provide a manageable unit for assessing the quality of overburden, especially if they could be separated based on potential for crop growth.

Previous research has shown that leveled spoil in Texas can be very productive with proper fertilization and management (1, 2, 3). However, zones of acid-forming pyritic minerals are occasionally found associated with these materials. Oxidation of exposed sulfides and subsequent lowering of the pH presents revegetation problems due to iron, aluminum and manganese toxicity (3).

The commercial quality lignites in Texas were formed in deltaic environments and their river sources systems (4). The lignite and overburden from northeast Texas is more fluvial in origin. These materials are characterized by multistacked, upward fining sequences with lignite forming in the old river channels and isolated floodplains (5). Lignite and overburden from central Texas tends to be deltaic in origin (4).

Common deltaic facies include alternating sand, silty clay and lignite units. Similar depositional environments occur in the Tongue River Formation of the Fort Union group (upper Paleocene) in North Dakota. Especially common in the Tongue River Formation are cycles of grey clays overlain by lignite (Floodbasin overlain by swamp environments) overlain by silts and sands.

A major deficiency at present is the lack of knowledge concerning the general properties of the overburden materials across the entire lignite bearing region. Six cores from present or future mine sites along the outcrop of the Wilcox Group in central and northeast Texas were analyzed and the data are discussed in this paper. The cores were selected as being representative of their region and of the particular mine site.

MATERIALS AND METHODS

The six cores were obtained from the following counties: Milam (Mi-5), Robertson (Ro-1, Ro-2), Freestone (Fr-5), Cherokee (Ch-1) and Harrison (Ha-6) (Fig. 1). The cores were characterized based on their lithological characteristics: composition, texture and sedimentary structure. These characteristics were used to delineate the various environments of deposition.

The upper 8-18 m of each core had been weathered by oxidation and leaching processes (Table 1). Weathering had significantly changed the chemical and, to a lesser degree, the physical properties of these materials. To isolate this effect, each environment of deposition was determined to be in an oxidized (near surface) environment with tan or brown colors or in a reduced (underlaying) environment with characteristically grey colors.

Samples were taken within each environment of deposition by removing a proportional sized subsample of material from the entire length of the deliniated zone. The subsamples represented major trends within the environment. Each sample was analyzed for its chemical and physical characteristics.

Particle size distribution was performed by the pipette method (6). Moisture retention at 1/3 bar (field capacity) and 15 bars (wilting point) was determined as described by Peters (7). Electrical conductivity and pH were determined in a 1:1 soil to water paste. The acid neutralizing potential was determined according to the procedure described by Sobek et al (8). Cation exchange capacity (CEC) was determined by the method of Chapman (9). However, sodium was determined by atomic emission spectrophotometry. The percentage of total sulfur in the whole soil (< 2.0 mm) was determined using a LECO sulfur analyzer. Overburden samples were digested as outlined by Bajo (10) and total heavy metal concentrations determined in the digest by atomic absorption.

RESULTS AND DISCUSSION

Depositional Environments

Lignite in east Texas was deposited in a frequently changing, mostly deltaic environment (11, 5, 4). The changes in depositional environments produced tremendous textural variations in these materials. Sediments characteristic of the following environments of deposition were observed in the cores: bed and mixed load channels, bay fill, bay center, levee, floodbasin, marsh and overbank. An attempt will be made throughout this discussion to compare and contrast the properties of the sediments deposited in the various environments of deposition. A portion of the geologic time scale with the formations and groups relevant to lignite deposits in Texas is shown in Fig. 2.

The upper overburden materials in cores Ch-1 and Fr-5 were bed load channel sands of the Carrizo Formation with some floodbasin and mixed load channel deposits. The materials underlying the Carrizo sands in both of these cores and the whole of core Mi-5 were characteristic of a marsh environment on an upper delta plain that was interrupted by mixed load stream channels and their associated overbank, levee, floodbasin and crevasse splay sediments. These materials are characteristic of the lignite bearing Calvert Bluff Formation of the Wilcox Group (Fig. 2). Sediments of core Ha-6 were deposited in a low energy fluvial environment, possibly located between major fluvial axes. The sediments in this core are also representative of floodbasin, splay, mixed load channel, marsh and levee environments. Cores Ro-1 and Ro-2 were quite different for their close proximity (approximately 3.25 miles apart). Thick crevasse splay deposits were observed in the upper portion of core Ro-1. These were underlain by a series of mixed load channel deposits down to the lignite seam. Core Ro-2 contained materials thought to be from the Simsboro and Hooper Formations (Fig. 2). The upper deposits were thick levee- floodbasin-splay complexes associated with the Simsboro Formation while the lower materials were made up of bay fill and mixed load channel sediments identified as part of the Hooper Formation.

Textural Relationships

The sand content of overburden materials can be related to the energy of the environment in which they were deposited (Fig. 3). According to Fig. 3, the bed load and mixed load channel sediments of the Carrizo Formation deposited in the high energy environments are quite distinct from the low energy bay center deposits of the Calvert Bluff Formation. However, materials deposited by the crevasse channel and splay, overbank, and levee environments were not statistically different based on sand content (Fig. 3 and Table 2). Percent clay and chemical parameters dependent on the amount of clay (e.g. CEC) showed similar trends, i.e. increased in value with decreasing energy.

There were no significant differences in the particle size distribution between samples of the same depositional environment in the oxidized and reduced zones. The variation in texture of each type of environment both within and between cores was large. For example, in core Ha-6 there were seven separate occurrences of a crevasse splay environment. The sand content ranged from 10-34%

while the clay content ranged from 21-33%. There were five additional occurences of a crevasse splay environment in other cores. The sand in these ranged from 8-69% while the clay ranged from 12-37%.

Although each environment was identified by characteristic structures and textural trends, individual depositional environments of the same type usually had considerable variation in both the mean and range of these parameters. For example, fluvial deposits tend to fine upward as the river changes course and the coarse materials deposited by rapidly moving water are overlain by finer sediments deposited by slower water near the banks. Factors such as erosion after deposition, periods of non-deposition, different sediment flow velocities, and different sized particles in the sediment supply are significant in determining properties of the environment that is finally preserved.

Moisture Relationships

The water holding capacity (maximum amount of water that a material will hold against gravitational forces) and the portion of that water which is available to the plants are important parameters which may influence revegetation and the movement of water through leveled mine spoils. Sands have a relatively low water holding capacity but most of that water is available to plants. Clays, on the other hand, have higher water holding capacities but more of this water is tightly retained by the clay thereby limiting its availability to plants. The available water held by the overburden strata was found to be closely related to the amount of silt and clay. Although there is considerable scatter in the data, the available water increased with increasing quantities of silt + clay in the overburden strata (Fig. 4).

The bed load channel deposits of the reduced zone have significantly less available water (3% average) than all other environments (Table 3). Flood basin, bay center, and overbank deposits from the reduced zone had significantly greater (α = 0.05) available water than the bed load channel, soil, mixed load channel, and the oxidized flood basin materials. Although not significantly different, materials from the oxidized zone generally retained less available water than similar materials in the reduced zone (Table 3). This may be due to differences in particle size distribution or an increase in kaolinitic over montmorillonitic type clays in the oxidized materials.

Chemical Properties

Cation Exchange Capacity

The cation exchange capacity (CEC) provides an estimate of the ability of the overburden material to retain cations, many of which are essential for plant growth. Clay minerals and organic matter are the negatively charged components which contribute to cation retention in soils and overburden materials. The overburden materials in these cores generally contain low amounts of active organic matter and cation retention is primarily due to the clay minerals. The coarse sediments of the bed load channel environment with minimal contents of clay, had the lowest CEC values (1.5 meq/100g, Table 4.). The finest materials (clays and silty clays) deposited in the marsh and bay center environments had the highest CEC values (>19 meq/100g). The other environments of deposition were characterized by intermediate CEC values which ranged from 9.1 to

19.7. In general, sediments in the oxidized zone had lower CEC values than similar materials in the reduced zone.

Overburden pH

Total sulfur contents ranged from less than 0.01% to 1.29% in the overburden materials. Reduced sediments characteristic of the overbank and flood basin environments contained significantly more total S than all of the other sediments (Table 5). The pH of these materials was determined after repeated wet and air dry cycles over a 9 month period. This process naturally oxidized the more active iron sulfides and achieved a pH value that was relatively constant in each sample. Fresh materials from the reduced zone contained large amounts of sulfides. The pH of these materials fell to as low as 2.8 as the sulfides oxidized (Table 6).

Much of the overburden material equilibrated at pH values between 6 and 7 (Fig. 5). However, there were also materials that were initially acid or had a potential to become acidic. A decrease in pH towards the surface was observed in all the cores. This decrease in pH was attributed to increased leaching of basic cations (Ca, Mg, Na, K). The overburden sediments in the upper (oxidized) portions of cores Fr-5 and Ch-1 have been particularly affected by leaching due to the coarse texture of the materials. In addition, surface soils (especially in northeast Texas) have naturally low pH values commonly in the range of 4-5.

In general, materials from the oxidized zone initially had lower pH and total sulfur values than similar materials from the reduced zone. The greatest amounts of total sulfur were often found immediately above and below the lignite seams. This is consistent with the previous investigations by Arora et al., (13). The sediments with the lowest S contents and high pH tended to occur in the thick zones between the lignitic beds. Sulfide minerals were occasionally observed in non-lignite zones in association with abrupt textural changes. Whether these sulfides formed during deposition or accumulated after the sediments were deposited was not apparent.

Heavy Metal Distribution

Total amounts of selected heavy metals were observed to follow a similar trend to that illustrated by core Ch-1 (Fig. 6). In all cores except Ro-1, Cu, Ni, Zn, and Mn contents were very low throughout the oxidized zones as well as the Carrizo sands. In cores Ch-1 and Fr-5, Fe was higher in the surface but decreased with depth. In core Fr-5 the iron content decreased from 2.14% at the surface to 0.06% at the base of the Carrizo sands. There is an abrupt increase in the contents of all of these cations from the oxidized to the reduced zone. In core Ch-1, there is a large increase in the content of Mn near the 64.5 m depth. Siderite ($FeCO_3$) was also found at that depth. Siderite is often associated with large amounts of Mn (14). The distribution of the heavy metals in the overburden appears to have been affected by weathering processes.

It was not possible to differentiate materials deposited in crevasse channel and splay, overbank, levee and bay center environments based on heavy metal concentrations. This conclusion is not unexpected since all of these sediments came from essentially the same source area and, in general, have been affected by the same external influences of transport and leaching.

CONCLUSIONS

The lignite overburden in Texas is quite different from the consolidated hard rock materials common in the eastern coal region (15), the unconsolidated glacial material including thick layers of topsoil and relatively fine-grained rock of the mid-west (16), the relatively hard rock overburden of the Rocky Mountain coal region, and the relatively soft rock of the northern Great Plains (17). Thin layers of topsoil are commonly associated with coal deposits of the east, rocky mountain and the northern great plains.

Extreme variation in particle size distribution is a characteristic of Texas lignite overburden materials. Attempts to correlate physical and chemical properties of these sediments with environments of deposition were only partly successful. The high energy bed and mixed load channel sediments contain more sand than levee or splay environments. Very low energy marsh and bay center deposits contain the least amounts of sand. The clay contents and CEC values generally increase with decreasing energy. The cation exchange capacity is least for the bed load channel sands. Electrical conductivity values are generally low in these sediments. However, electrical conductivity values did increase near the limit of the wetting front in the oxidized zone and near sulfidic lignite seams. A majority of the overburden was high in pH and low in total sulfur. Low pH values (after incubation) were associated with sulfidic zones. Overburden directly above and below the lignite usually contained significant sulfides as did occasional occurrences not associated with a lignite seam. There were differences between apparently similar overburden in the oxidized versus that in the reduced zones. Near surface materials generally had lower CEC, water holding capacity, and EC values. The pH of the near surface materials was often low due to natural weathering. The amount of total sulfur in the surface materials was very low. The depth of the oxidized zone was dependent on the texture and the degree of stratification in the near surface depositional environments.

The overall quality of these overburden materials is quite good. Experience has shown that excellent crop production can be achieved on the leveled overburden. Properties that could affect plant growth were a function of proximity to lignite and post depositional changes. Variations between sediments of the same depositional environment were so large in most cores that definitions of the environments, based on physical and chemical data was not possible.

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Table 1. Depth of the oxidized or weathered zone in each core.

Core	Depth of Oxidation
	—m—
Mi5	8.2
Fr5	14.3
Ch1	16.0
Ha6	8.4
Ro1	11.0
Ro2	17.9

Table 2. The relationship between the average sand content and environment of deposition.

Deposition	Mean (%)	Grouping				
Bed load channel (R)†	94.5	A*				
Bed load channel (O)	65.1	A	B			
Mixed load channel (R)	54.2		B			
Mixed load channel (O)	49.9	C	B			
Flood basin (O)	37.8	C	B	D		
Soil (O)	36.7	C	B	D		
Crevasse splay (O)	26.2	C	B	D	E	
Bay fill (R)	25.8	C		D	E	
Crevasse channel (R)	22.5	C		D	E	
Crevasse splay (R)	21.7			D	E	
Levee (R)	20.7			D	E	
Overbank (R)	18.5			D	E	
Bay fill (O)	9.7			D	E	
Flood basin (O)	6.1			D	E	
Marsh (R)	3.3			D	E	
Bay center (R)	3.0				E	

† Designates whether the depositional environment was located in the reduced (R) or oxidized (O) zone.

* Any mean followed by the same letter is not significantly different at the 95% confidence level.

Table 3. The relationship between the average plant available water and environment of deposition.

Deposition	Mean (%)	Grouping
Flood basin (R)[†]	19.8	A[*]
Bay center (R)	19.3	A
Overbank (R)	17.2	A
Crevasse channel (R)	16.6	A B
Crevasse splay (R)	16.2	A B
Bay fill (O)	16.0	A B
Marsh (R)	16.0	A B
Bay fill (R)	15.9	A B
Levee (R)	15.7	A B
Crevasse splay (O)	14.1	A B
Mixed load channel (R)	11.9	B
Flood basin (O)	11.6	B
Mixed load channel (O)	10.7	B
Soil (O)	10.7	B
Bed load channel (O)	10.4	B
Bed load channel (R)	3.0	C

† Designates whether the depositional environment was located in the reduced (R) or oxidized (O) Zone.

* Any mean followed by the same letter is not significantly different at the 95% confidence level.

Table 4. The relationship between the average cation exchange capacity and environments of deposition.

Deposition	Cation Exchange Capacity (meq/100g)	Grouping
Bay center (R)†	21.5	A*
Bed Load Channel (O)	19.7	A B
Overbank (R)	19.5	A B
Bay fill (R)	16.4	A B
Flood Basin (R)	16.0	A B
Bay Fill (O)	16.0	A B
Marsh (R)	15.7	A B
Crevasse channel (R)	15.3	A B
Crevasse splay (R)	14.5	B
Levee (R)	14.0	B
Crevasse splay (O)	12.6	B
Mixed Load channel (O)	11.2	B
Mixed Load channel (R)	10.4	B
Soil (O)	9.7	B C
Flood basin (O)	9.1	B C
Bed load channel (R)	1.5	C

† Designates whether the depositional environment was located in the reduced (R) or oxidized (O) Zone.

* Any mean followed by the same letter is not significantly different at the 95% confidence level.

Table 5. The relationship between the average total sulfur and environments of deposition.

Deposition	Mean (%)	Grouping
Overbank (R)†	1.29	A*
Flood Basin (R)	1.16	A
Crevasse splay (O)	0.39	B
Bay Fill (O)	0.25	B
Bay Center (R)	0.24	B
Mixed load channel (R)	0.19	B
Levee (R)	0.15	B
Crevasse splay (R)	0.11	B
Bed load channel (R)	0.03	B
Flood Basin (O)	0.02	B
Mixed load channel (O)	0.01	B
Soil (O)	<0.01	B
Marsh (O)	<0.01	B

† Designates whether the depositional environment was located in the reduced (R) or oxidized (O) zone.

* Any mean followed by the same letter is not significantly different at the 95% confidence level.

Table 6. Average pH of the sediments characteristic of the various environments of deposition.

Deposition	Mean (%)	Grouping
Marsh (R)†	7.5	A*
Crevasse channel (R)	6.5	A
Crevasse splay (R)	6.4	A
Bay Center (R)	6.4	A
Mixed load channel (R)	5.6	A
Bed load channel (O)	5.5	A B
Bay Fill (R)	5.5	A B
Levee (R	5.4	A B
Bed load channel (R)	4.8	A B
Soil (O)	4.6	A B
Crevasse splay (O)	4.5	A B
Bay fill (O)	4.4	A B
Mixed load channel (O)	4.1	A B
Overbank (R)	3.7	B
Flood Basin (O)	3.5	B
Flood basin (R)	2.8	B

† Designates whether the depositional environment was located in the reduced (R) or oxidized (O) zone.

* Any mean followed by the same letter is not significantly different at the 95% confidence level.

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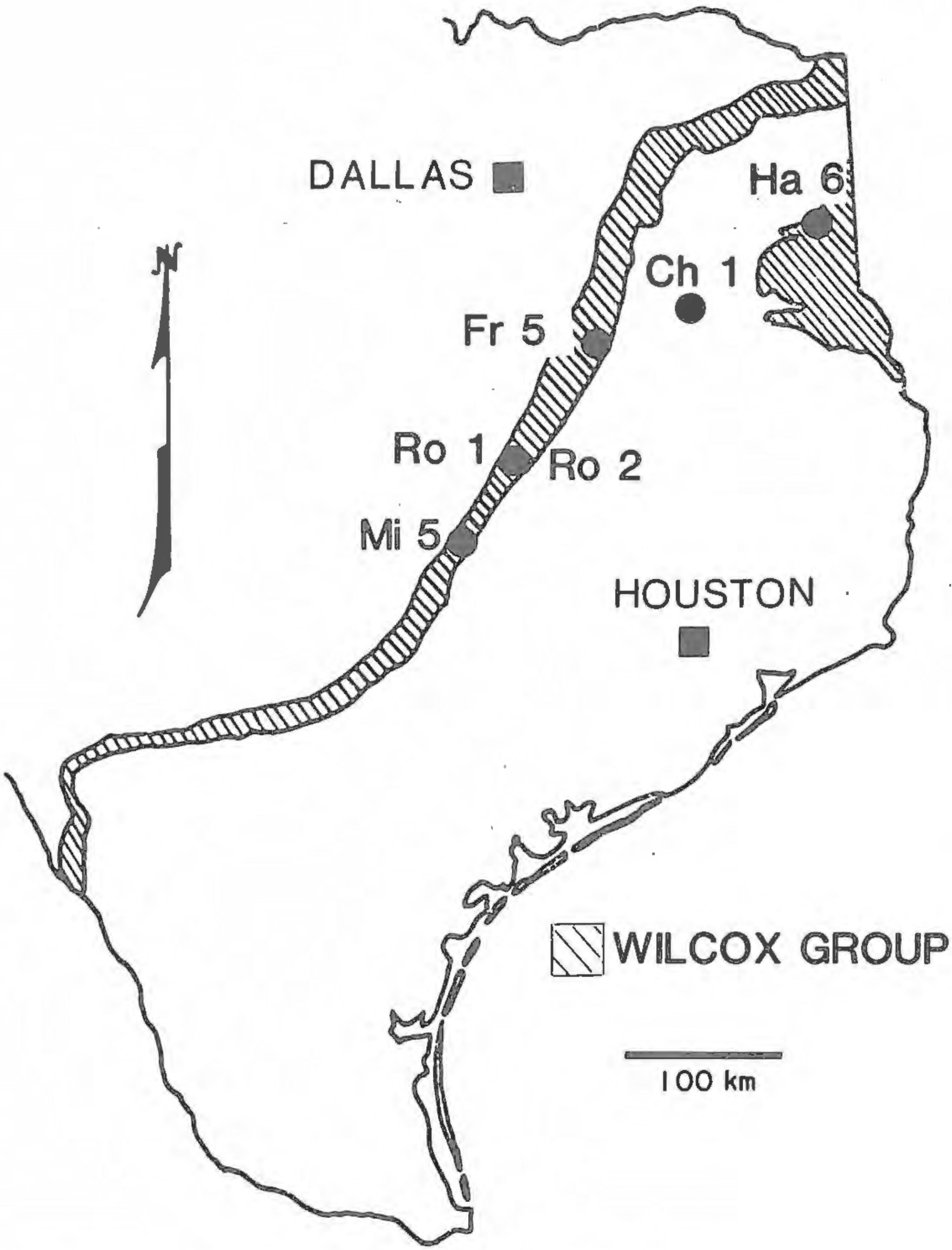

Figure 1. The Wilcox Group outcrop in Texas and location and overburden cores used in this study.

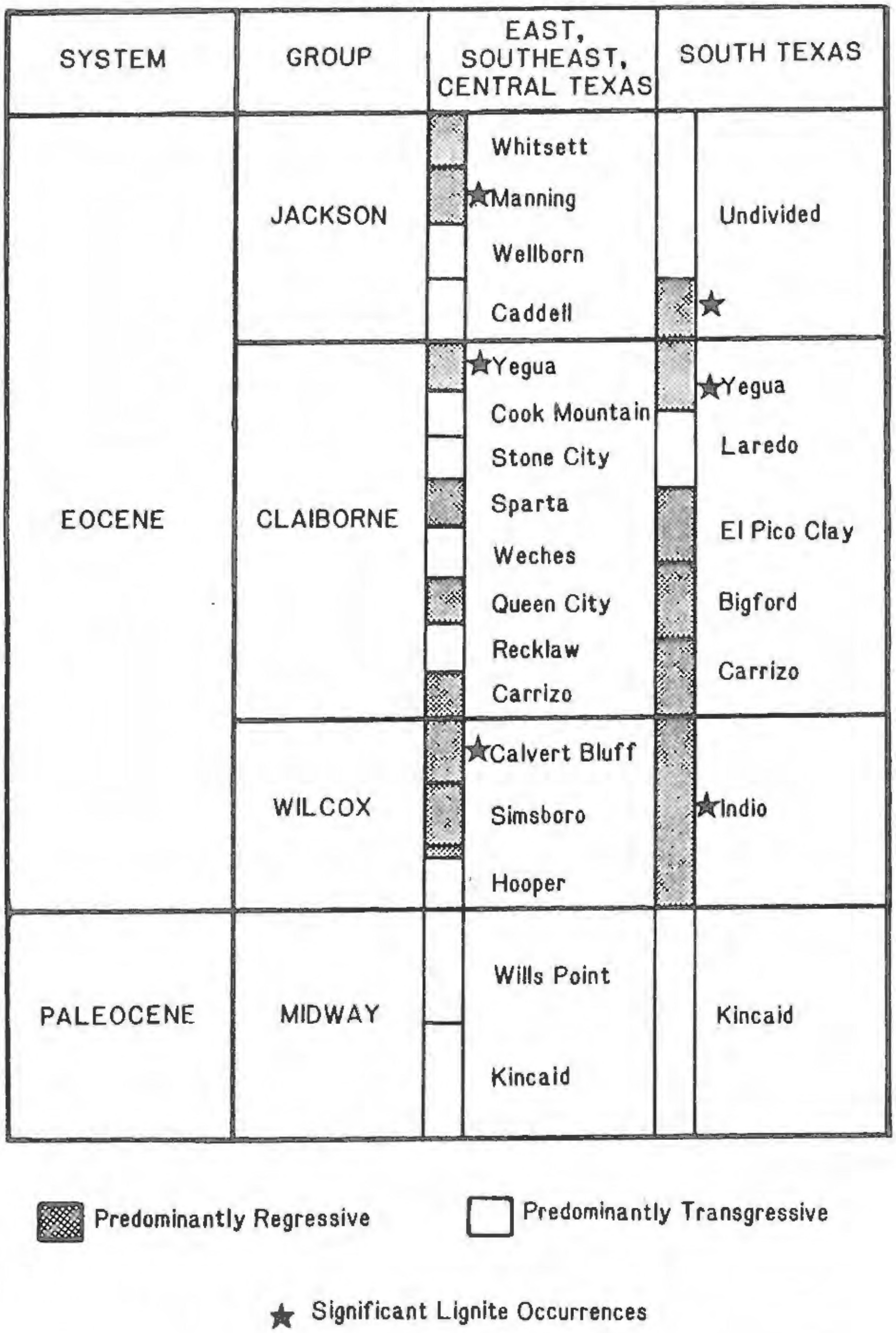

Figure 2. Geological relationships and lignite bearing formations in Texas.

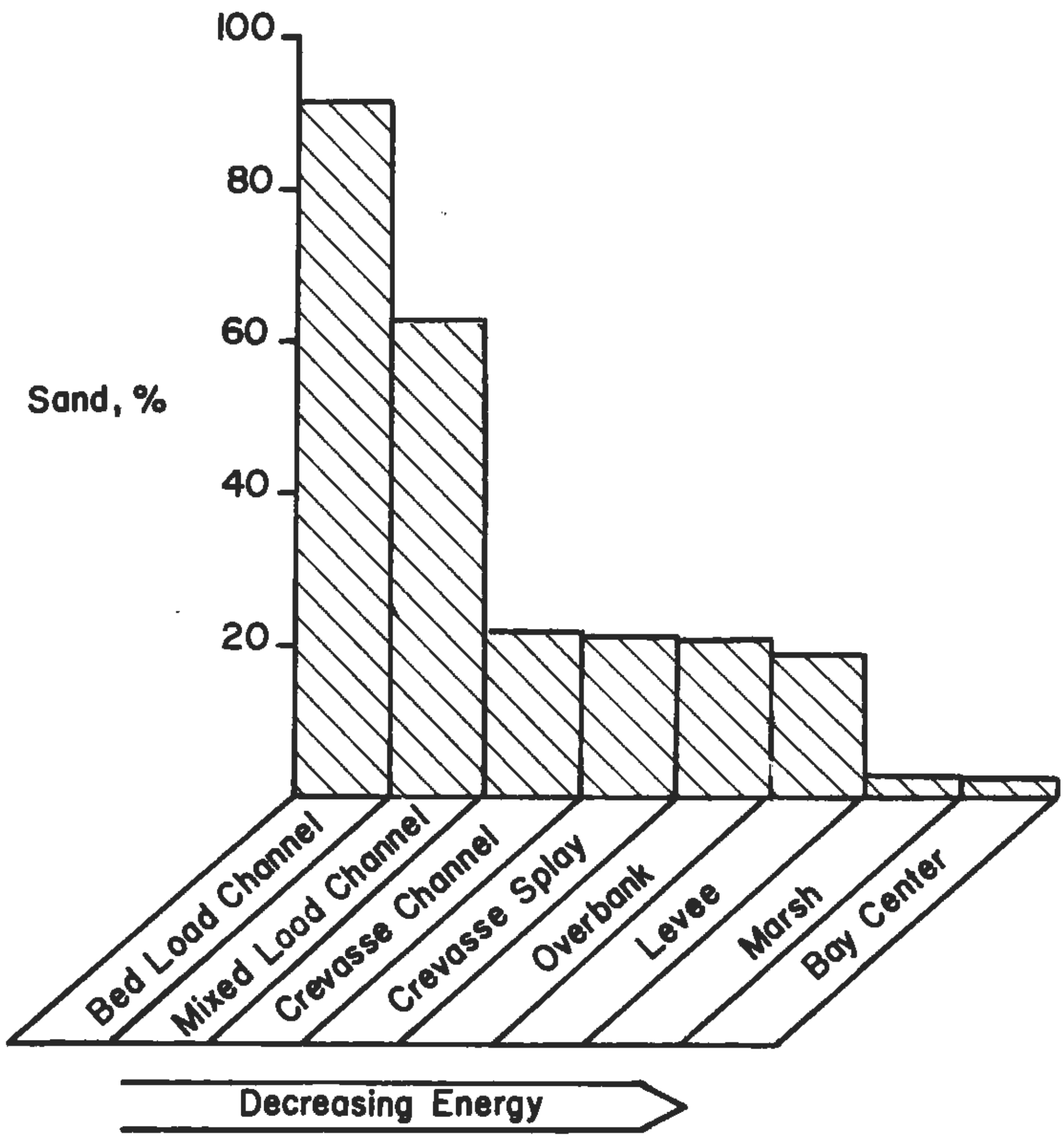

Figure 3. Characterization of the depositional environments of East Texas overburden based on sand content.

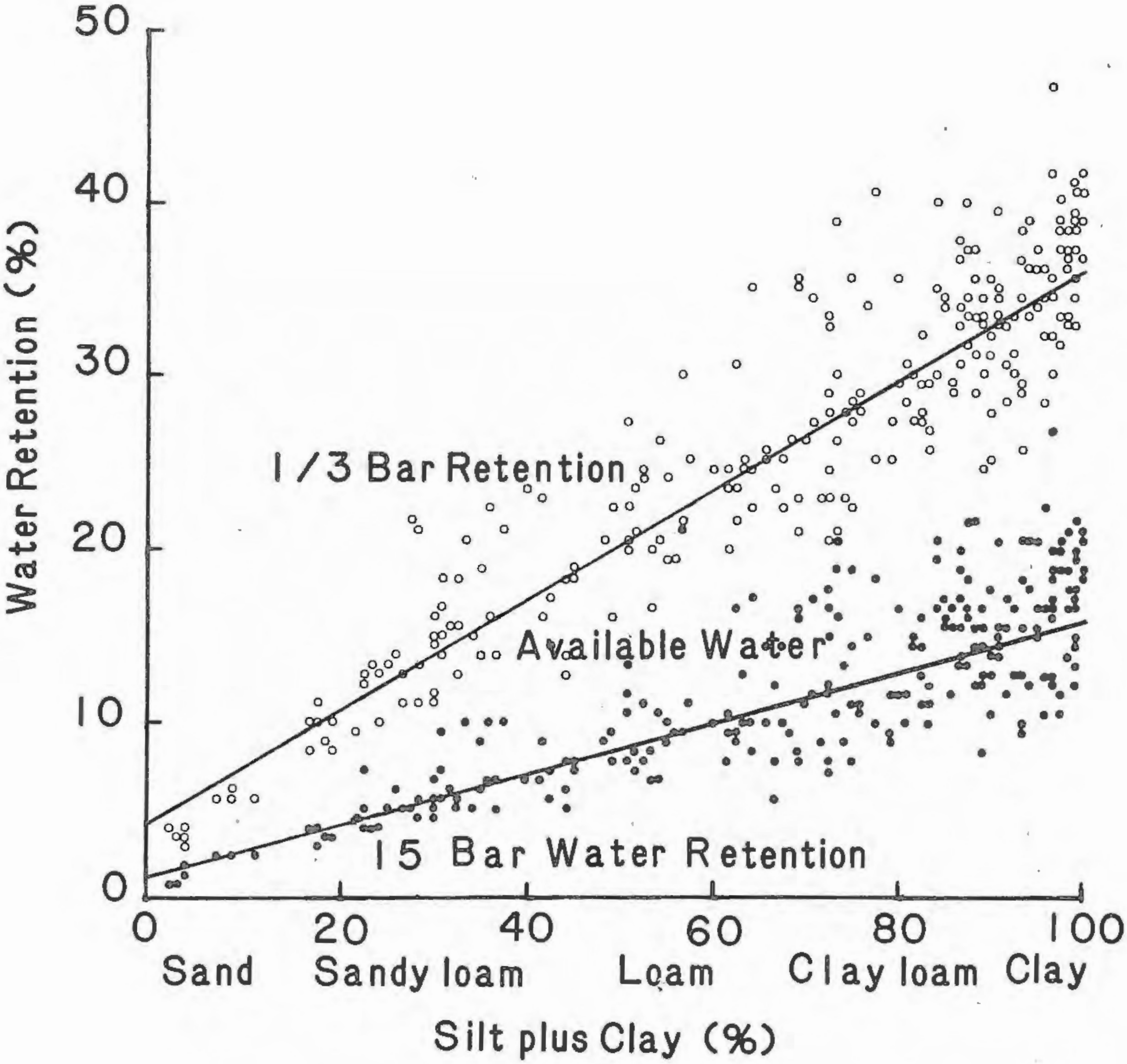

Figure 4. The relationship between silt plus clay content and the plant available water for all the samples investigated.

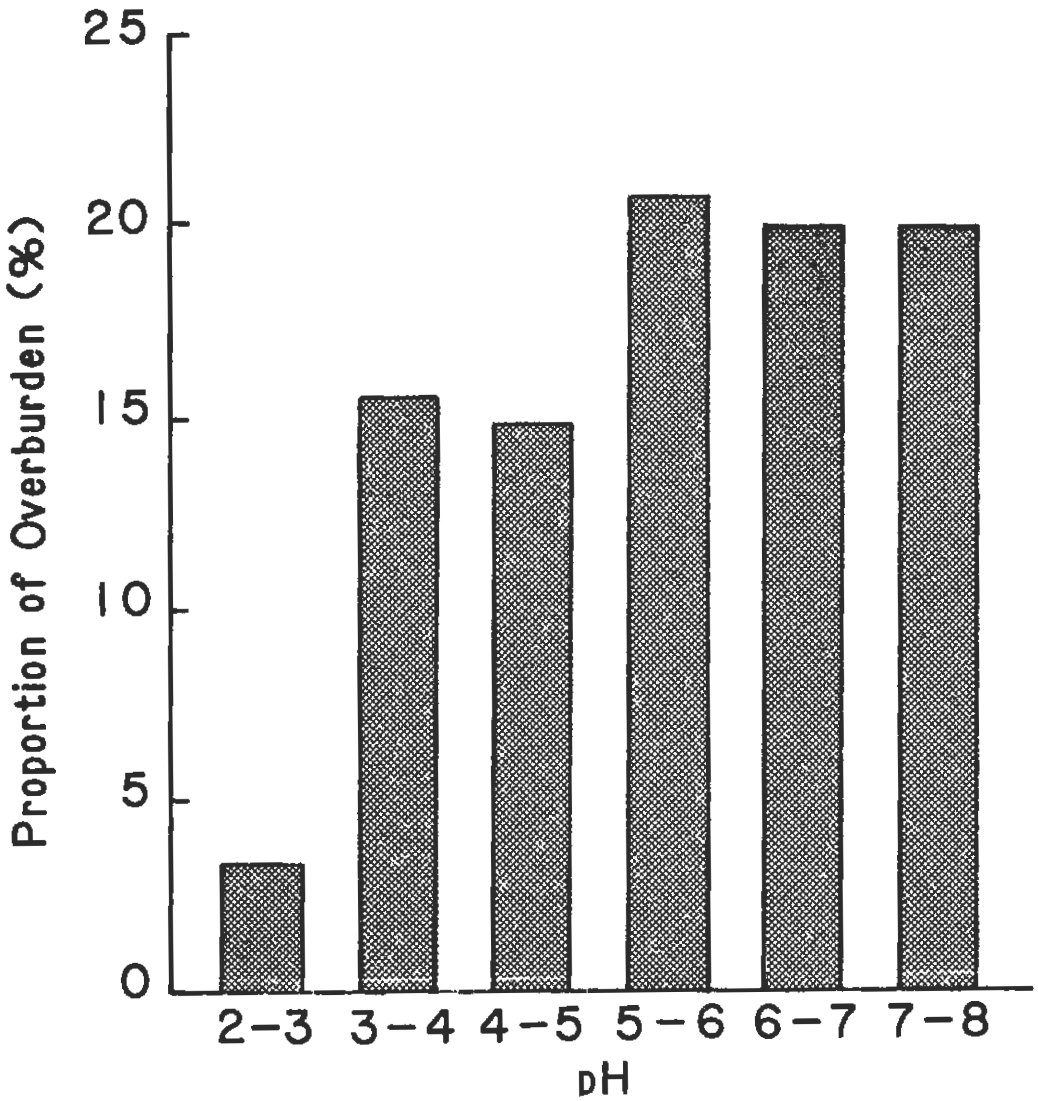

Figure 5. The final overburden pH values after nine months of incubation.

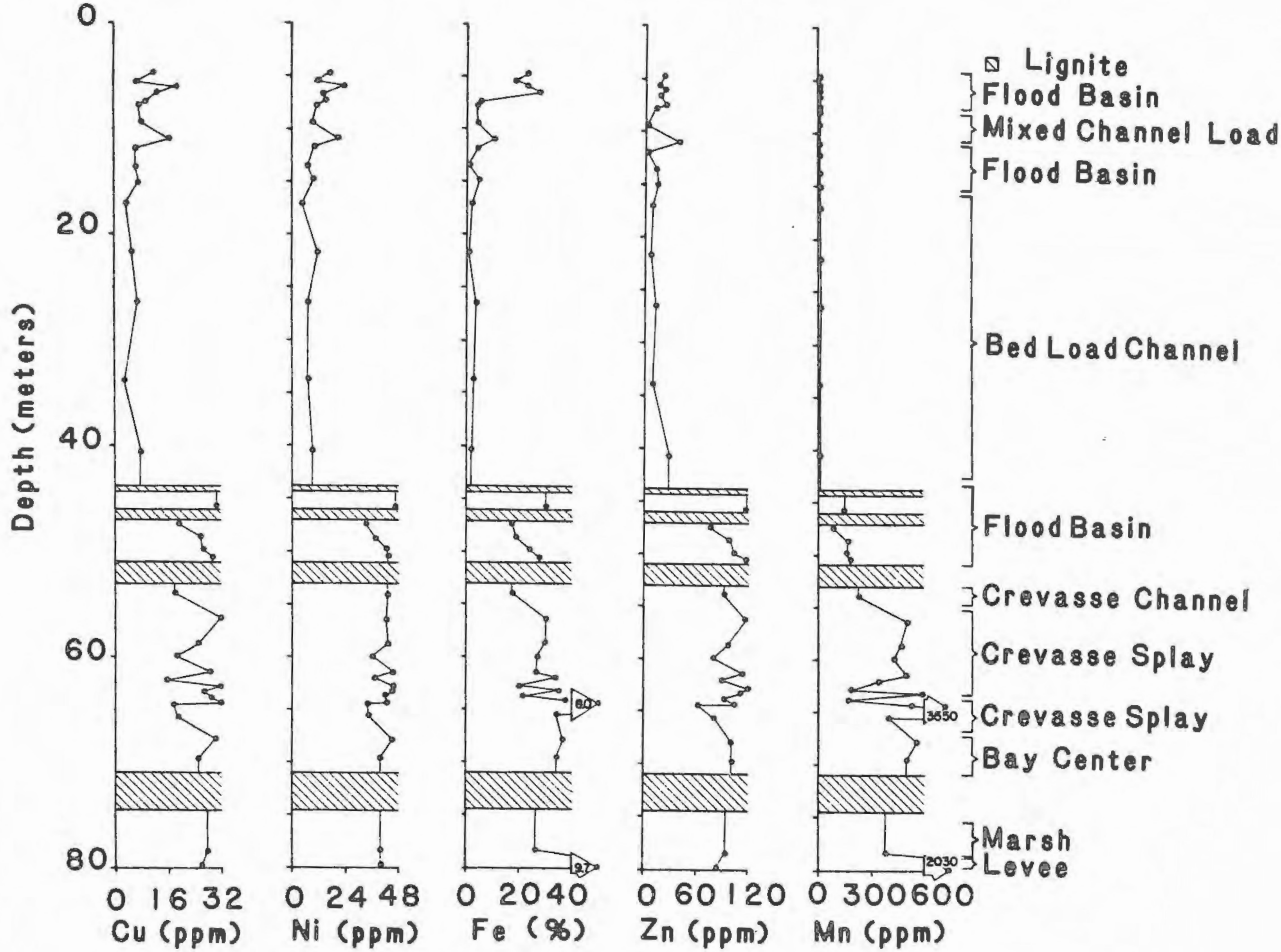

Figure 6. Distribution of selected heavy metals in core Ch-1.