OKLAHOMA STATE UNIVERSITY

"GEOTECHNICAL ENGINEERING CHARACTERISTICS OF HAZARDOUS WASTE LADEN SOILS"

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Phase 1 Final Report

Submitted to the

Ground Water Center
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on behalf of

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GEOTECHNICAL

ENGINEERING CHARACTERISTICS OF HAZARDOUS WASTE LADEN SOILS

INTRODUCTION

The objectives of this research was to determine the effects on, and the role of the soil in the transport of hazardous wastes in and around landfills. Certain aspects of the research represented technology transfer; whereas, other aspects of the research focused on defining the physical characteristics of type soils and the effects of hazardous wastes on their permeability, strength and plasticity.

The immediate goals (Phase I) included:

Task A - Assessment of the present state of the art with respect to the effects of hazardous waste material on the engineering behavior of soil.

Task B - The geotechnical engineering laboratory characterization of selected clay minerals which have been subjected to hazardous waste chemicals.

The long range goal (Phase II) is to apply the knowledge gained through the research effort to study soil behavior at specific hazardous waste disposal sites, either in operation or in the process of applying for permit, within the state of Okalhoma.

Task A was initiated on October 1, 1980. A literature search of the Oklahoma State University library was made using the disposal of hazardous wastes as a general topic. This was accomplished by reviewing current editions (1969-1980) of 1) The Index of Applied Science and Technology, 2) EPA Abstracts, 3) the card catalog, and 4) a literature review published yearly by the Journal of Water Pollution Control Federation. Some of the main topics included industrial waste disposal, solid waste disposal, sanitary landfill leachate, and soil pollution articles selected for inclusion in the literature review contained information on the interaction of hazardous wastes with soils, groundwater quality near a landfill, mechanism of transport of a waste within a soil, and effects of the waste on soil properties.

From the list of articles obtained, a bibliography was made that would be beneficial to the project. The articles were alphabetized by author. Each article was indexed on a 3" x 5" card and after locating it in the library, the abstract for each article was copied on 3" x 5" cards, in order to begin a permanent bibliography. The library search was expanded to include topics concerning hazardous waste landfill soil liners following the ASTM sponsored "Testing of Hazardous Solid Wastes" symposium in Fort Lauderdale, Florida, attended by the principal investigator in January, 1981. To date, 382 references have been catalogued. These are attached to the end of this report.

ENGINEERING RELEVANCE OF THE RESEARCH

The aim of environmentally acceptable landfill design is the prevention of formation of toxic leachates and/or the separation of formed leachates from the general environment. The Environmental Protection Agency suggests that landfill liners constructed from properly chosen and placed clays which have water permeabilities of 10^{-7} centimeters per second or less be utilized in the construction of hazardous waste landfills so as to effectively isolate the landfill contents and leachates from groundwater supplies. The 10^{-8} centimeter per second water permeability required for permit by the Department of Health within the state of Oklahoma is unusually strict and demands a thorough analysis and understanding of the on-site soil materials, and the effects that hazardous waste leachate will have upon them.

The alteration of the physical, chemical, and engineering and thus environmental properties of clay and clay liners is a problem which is not clearly understood, and which received little attention in the past. The failure of such a liner, or the deformation, lateral movement or differential settlement of the underlying or surrounding undisturbed material (soil), could lead to an environmentally unfortunate incident, whereby stored wastes and leachates might be released unchecked (and perhaps undetected) into subsurface and surface waters, thus contaminating public drinking water supplies. A similar problem may arise in waste lagoons contained by clay levees (embankments) whereby alteration of the structural properties of the clay may lead to wall-strength losses, related slope instability, and rapid escape of the contained wastes into the environment.

Research has shown that the engineering properties and performance of a clay material, in particular its permeability or transmissibility, are a direct function of the mineralogy of the clay, its structure (fabric) and the chemical properties of the permeating fluid, to name a few. Certain permeants, such as organics, have been shown to cause a significant increase in a clay's permeability leading to the rapid transmission of the pollutant through the clay and into the general environment. Other pollutants, such as heavy metals, have been shown to be held fixed by the clay material to one degree or another and, thus, the clay is said to safely attenuate these pollutants.

Two studies by the U.S. Army Corps of Engineers Waterways Experiment Station, of the soils beneath several landfills, led to the conclusion that although evidence of chemical changes in the soil existed, there was no evidence of any physical changes. These were unlined landfills and considerable questions may be raised concerning the soil sampling procedure which led to their conclusions.

More recent work has documented some of the influences of various hazardous waste components on the behavior of soils. Organic acids (e.g., phenolic and aliphatic acids) are very active with, and mobile in clays. Clays are also soluble in organic acids which can cause an increase in permeability. Strongly alkaline substances can have a similar effect. Clays will adsorb onto their surfaces strongly cationic substances, such as organic bases (e.g., aromatic amines and alkyl amines). Such adsorption will cause volume changes in the clay, as well as dissolving certain constituents out of the clay mineral.

Neutral-nonpolar organics (e.g., aliphatic and aromatic hydrocarbons) will move rapidly through a clay, eroding the pores as they pass through and causing an increase in permeability and shrinkage. Neutral-polar organics (e.g., alcohols, aldehydes, glycols, alkyl halides and keytones) will also influence a clay's permeability as well as the surface tension of the pore fluid. This will effect the shrink-swell properties of the clay. For example, montmorillonite may swell under the influence of these fluids, loose its integrity and shrink later when water replaces these organic fluids. If shrinkage occurs under the influence of organic cations, reversal of this process (i.e., swelling) may not occur.

The results of the Task A literature search indicated that almost any soil is capable of undergoing detrimental changes in its physical properties as a result of the addition of leachates generated from waste disposal systems. It is equally obvious that the need for additional research is quite evident if future hazardous waste disposal sites are to be safely designed.

DETAILS OF THE EXPERIMENTAL PROGRAM

Task B was initiated in January, 1981. The clay materials used in the study were kaolinite, smectite (bentonite), and Permian red clay. These were selected for the following reasons: (a) they were readily available in our soil engineering laboratory; (b) they are commonly used in clay liners, especially smectite. Permian red clay is high in smectite and is common within Oklahoma; and (c) they are generally reactive with leachate materials.

The samples were treated separately for one week at different pH concentrations within the acid range and subjected to a series of standard geotechnical engineering laboratory tests. These included consistency limit, shear strength and permeability tests.

Consistency Limit Test Results

The Atterberg consistency limits give an indication of the behavior of a soil upon changes in water content and delineates that water content range over which the soil will behave as a plastic. The limit tests were performed according to ASTM 423-66 (liquid limit) and ASTM D424-59 (plastic limit) standard tests. The soils were then classified according to the Unified Classification System. The results of these tests are given in Tables 1, 2, and 3. Each of these summary tables is followed by a plasticity chart which compiles the data and shows the position of each sample with respect to the A-line.

It is noted from the data that the acid treatment decreased the plasticity of each of the type soils tested. In most cases, the higher the acid concentration, the lower the plasticity. The Permian red clay, the only natural soil used in the test, gave the most scattered data. The USEPA considers soils which belong to the CL or CH groups to be the most suitable for clay liner material, and that probably the most favorable soils are those with a

Table 1

Atterberg Limit Tests - Kaolinite

Acid Concentration	Liquid Limit	Plastic Limit	Plasticity Index
pH = 7 control	74.5	36.9	37.6
"	74.5	37.3	37.2
"	72.8	35.8	37.0
"	73.2	35.4	37.8
"	73.2	32.7	40.5
"	72.1	34.4	37.7
"	72.8	36.1	36.7
"	72.0	34.0	38.0
"	71.9	36.1	35.8
"	70.8	35.8	35.0
1M	65.6	34.7	30.9
"	66.3	35.0	31.3
"	64.9	33.9	31.0
"	65.0	33.0	32.0
"	63.7	30.6	33.1
"	64.8	32.7	32.1
3M	61.4	29.1	32.3
"	62.4	28.3	34.1
"	63.0	28.8	34.2
"	62.3	27.6	34.7
"	61.7	29.3	32.4
"	60.9	27.9	33.0
6M	53.2	25.9	27.3
"	54.7	23.2	31.5
"	55.0	24.8	30.2
"	54.6	26.4	28.2
"	53.8	25.7	28.1
"	56.7	24.9	31.8
18M	57.8	26.2	31.6
"	53.7	23.7	30.0
"	52.3	25.6	26.7
"	56.2	24.4	31.8
"	55.3	26.3	29.0
"	56.4	25.2	31.2

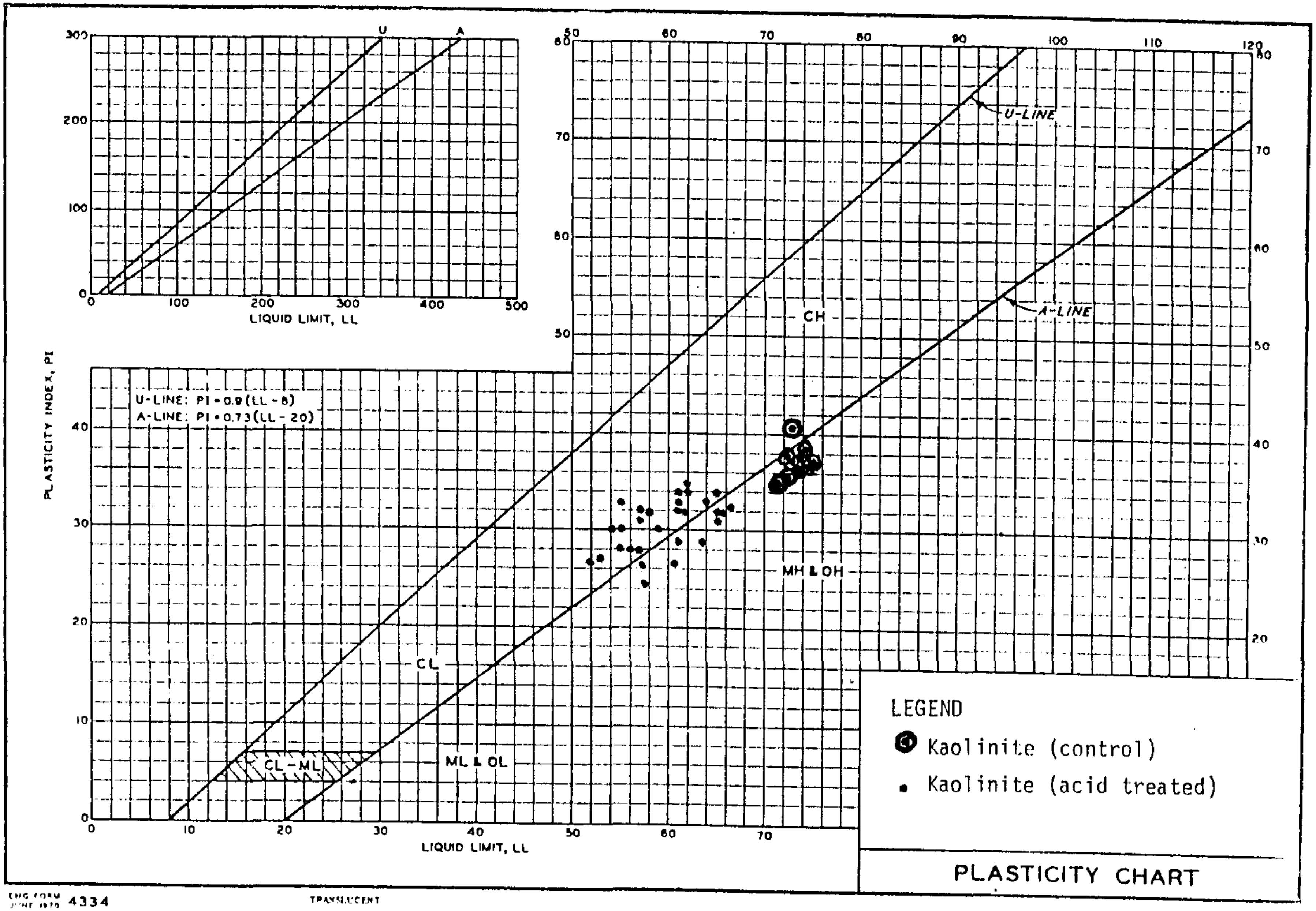

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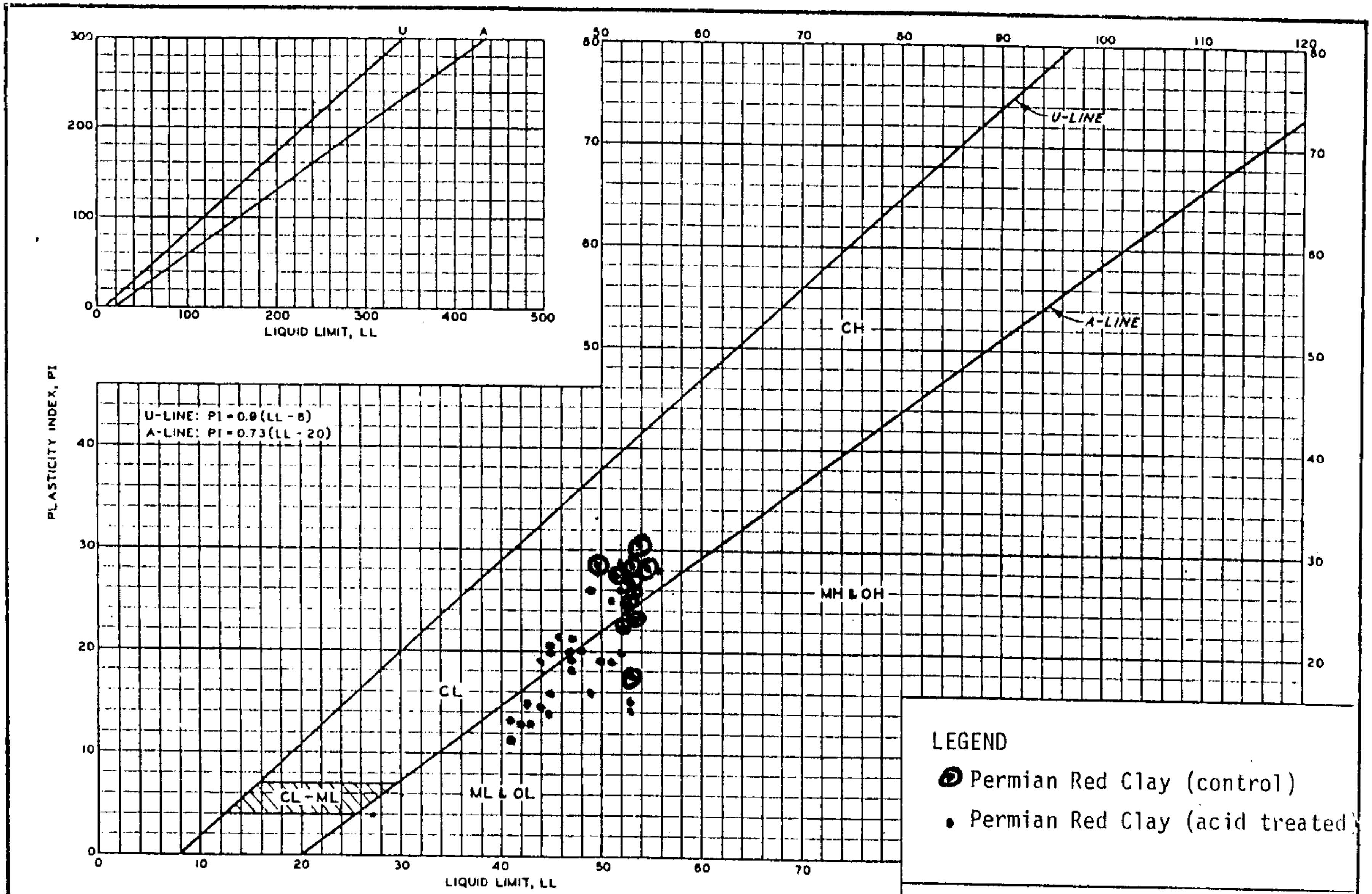
Table 2

Atterberg Limit Tests - Permian Red Clay

Acid Concentration	Liquid Limit	Plastic Limit	Plasticity Index
pH = 7 control	52.7	35.1	17.6
"	53.4	31.7	21.7
"	52.4	30.7	21.7
"	53.0	27.0	26.0
"	53.5	28.0	25.5
"	51.7	23.5	28.2
"	49.8	20.8	29.0
"	53.8	23.0	30.8
"	52.5	26.4	26.1
"	52.5	24.8	27.7
1M	55.7	27.5	28.2
"	52.4	24.2	28.2
"	51.9	23.9	28.0
"	53.6	25.0	28.6
"	52.1	26.1	26.0
"	50.9	25.5	25.4
3M	53.3	38.4	14.9
"	52.6	28.9	23.7
"	51.7	31.3	20.4
"	50.9	32.3	18.6
"	48.6	23.1	25.5
"	49.8	30.8	19.0
6M	47.1	28.5	18.6
"	47.3	27.6	19.7
"	48.4	28.2	20.2
"	45.2	25.4	19.8
"	44.6	23.8	20.8
"	46.9	25.6	21.3
18M	40.2	29.1	11.1
"	43.3	29.1	14.2
"	42.6	29.3	13.3
"	44.0	28.8	15.2
"	41.8	28.7	13.1
"	40.5	27.6	12.9



PLASTICITY CHART

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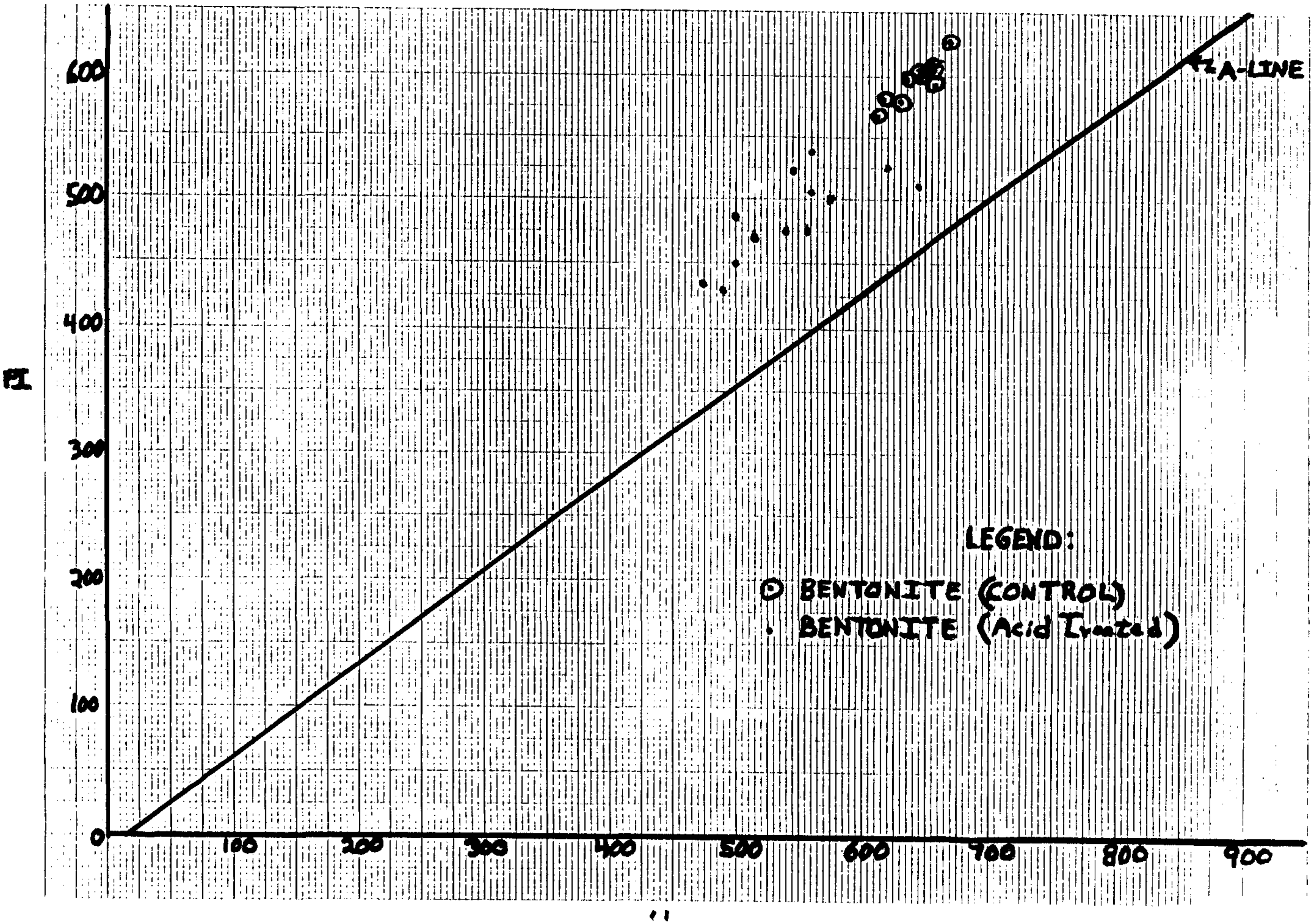
Table 3

Atterberg Limit Tests - Bentonite

Acid Concentration	Liquid Limit	Plastic Limit	Plasticity Index
pH = 7 control	612	46	566
"	635	63	572
"	657	65	592
"	630	51	580
"	646	45	599
"	625	44	581
"	645	44	601
"	654	51	603
"	654	47	607
"	672	42	630
1M	648	135	513
"	618	93	525
"	575	75	500
3M	565	35	530
"	555	50	505
"	556	81	475
6M	517	47	470
"	500	20	480
"	530	55	475
18M	475	43	432
"	490	58	432
"	500	50	450


PI
0
100
200
300
400
500
600
700
800
900
A-LINE
LEGEND:
BENTONITE (CONTROL)
BENTONITE (Acid Treated)

liquid limit between 35 and 60, placed above the A-line in the PI versus LL chart of the Unified Soil Classification. Most of the control Permian red clay tests gave favorable results according to this criterion. However, in the majority of cases, acidifying this soil resulted in a less desirable clay liner material.

Permeability Test Results

Constant head permeability tests were performed according to ASTM D2434-68. Because of the time required to perform a permeability test (about one week/test), only the Permian red clay was tested. The results are given in Table 4. It is noted that there is about a one order of magnitude increase in the permeability of the acid treated samples, from 10^{-9}cm/sec to 10^{-8}cm/sec. There is not a significant difference between the different acid concentration results.

The increase in permeability upon acidization is documented in the literature. Hurst (1970) found that the permeability of geologic formations could be increased by pumping in acetic or formic acid. Johansen et al. (1951) reported flow increases for water wells following their treatment with a solution containing citric acid. Grubbs et al. (1972) found acid waste as the probable casual agent in the permeability increase of carbonate-containing minerals. X-ray diffraction studies of the four clay minerals injected with acid waste showed them to be dissolved or completely altered. Diffraction peaks showed the most variability with montmorillonite clays.

The mechanism responsible for this physical property change is reported to be the dissolution of clay. Dissolution of a clay liner can be brought about by an infiltrating chemical that dissolves the exposed surfaces of a pore or channel. Either organic or inorganic acids or bases may solubilize portions of the clay structure. Acids have been reported to solubilize aluminum, iron, alkali metals and alkaline earths while bases will dissolve silica (Grim, 1953).

Table 4

Permeability Test - Permian Red Clay

Acid Treated Sample	k(cm/sec)
Control	6.4×10^{-9}
"	5.5×10^{-9}
"	2.1×10^{-9}
"	2.0×10^{-9}
1M	3.0×10^{-8}
"	5.2×10^{-8}
"	3.1×10^{-8}
3M	3.0×10^{-8}
"	2.2×10^{-8}
"	2.8×10^{-8}
6M	2.0×10^{-8}
"	1.3×10^{-8}
"	1.0×10^{-8}

Since clay minerals contain both silica and sluminum in large quantities, they are susceptible to partial dissolution by either acids or bases.

Pask et al. (1945) boiled several clay minerals in acid and found the percent solubilization of alumina was 3% from kaolinite, 11% from illite, and greater than 33% from montmorillonite. Grim (1968) found the solubility of clays in acid "varies with the nature of the acid, the acid concentration, the acid-to-clay ratio; the temperature and the duration of treatment." He also found that the action of an acid on clay was enhanced when the acid had an anion about the same size and geometry as a clay component. This would permit even weak acids, e.g., organic acids, to dissolve clays under some conditions.

An additional permeability test was performed in order to determine the soil moisture content-bulk density relationship. The results of this test, coupled with compaction data, indicate the permeability changes which occur during the construction of a clay liner. It reveals the ranges of soil moisture content during compaction and soil densities where soil permeability drops below the required design permeability.

The tests were performed on samples containing $\pm$3% water content differences from the compacted optimum moisture content. This information gives valuable information concerning the feasibility of utilizing this material as a clay liner. The results are given in Figures 1 and 2. Figure 2 gives the moisture-density curve and Figure 1 shows the accompanying permeability relationship. The permeability at the OMC could not be determined and was considered to be impermeable. Considerable effort was expended to obtain a flow thru the test sample. However, the threshold gradient was not reached. The sample was exposed to incremental increases in pressure over a period of 14 days until the pressure of 90 psi (209 feet of head) caused water to be leaked from around the gaskets in the permeability apparatus, at which point the test was terminated.

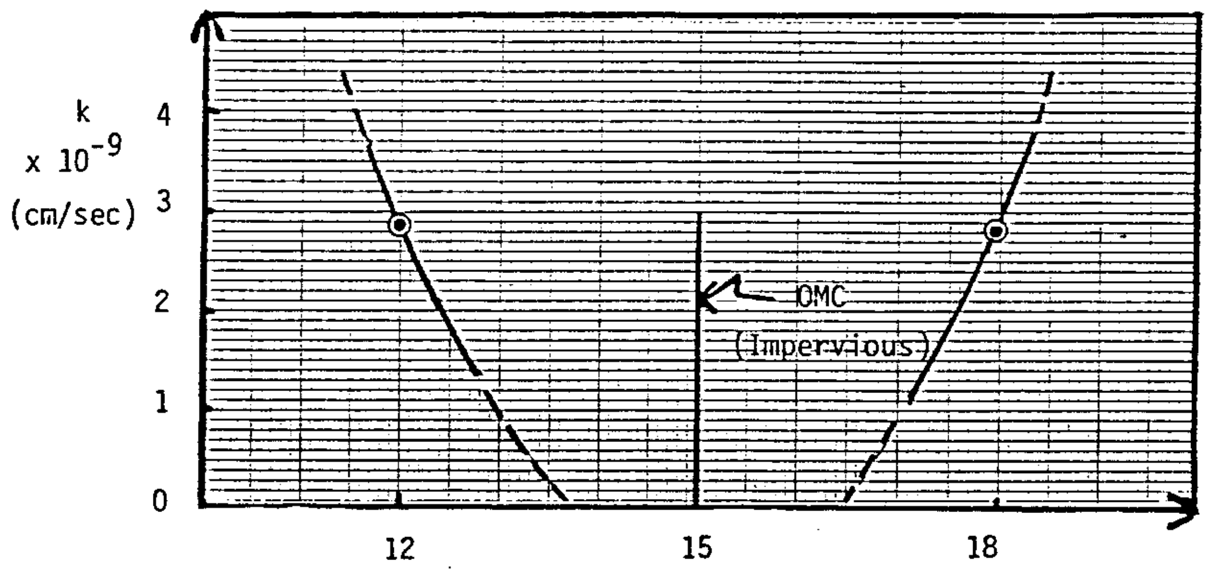


Figure 1 Soil Moisture Content (%)

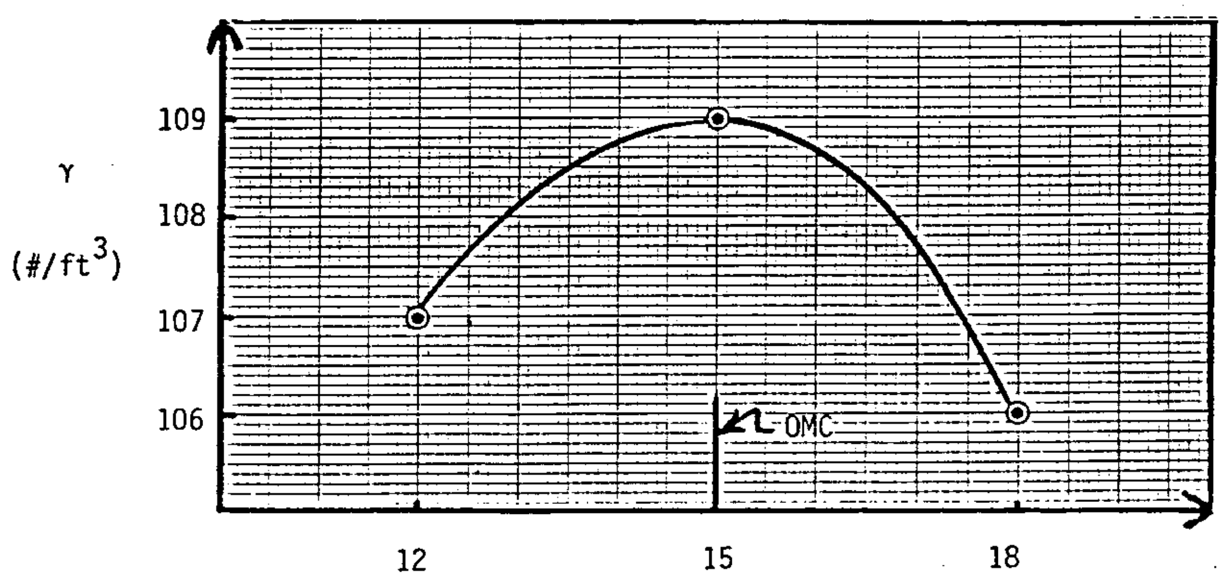


Figure 2 Soil Moisture Content (%)

Shear Strength Test Results

The shear strength of the soil was determined experimentally by the direct shear test. The purpose of this test was to obtain the soils ultimate shearing strength, τ, its cohesion, c, and its angle of internal friction, ϕ. These parameters were obtained by letting the Permian red clay soil specimen fail in shear in a controlled stress test.

The results of the tests were plotted on a shear stress vs. sample displacement graph. The highest shear strength test value was chosen to be the ultimate shear strength for the soil in any given test and these were then used in drawing a Mohr diagram for both the remolded case and the undisturbed case where applicable. From this diagram the angle of internal friction, ϕ, and the cohesion, c, for the soil was determined. The summary of the results is given in Table 5 and a typical test result is given in Figure 3.

No significant differences are noted in the strength parameter data. The variations are due primarily to differences in moisture content of the soil specimen being tested.

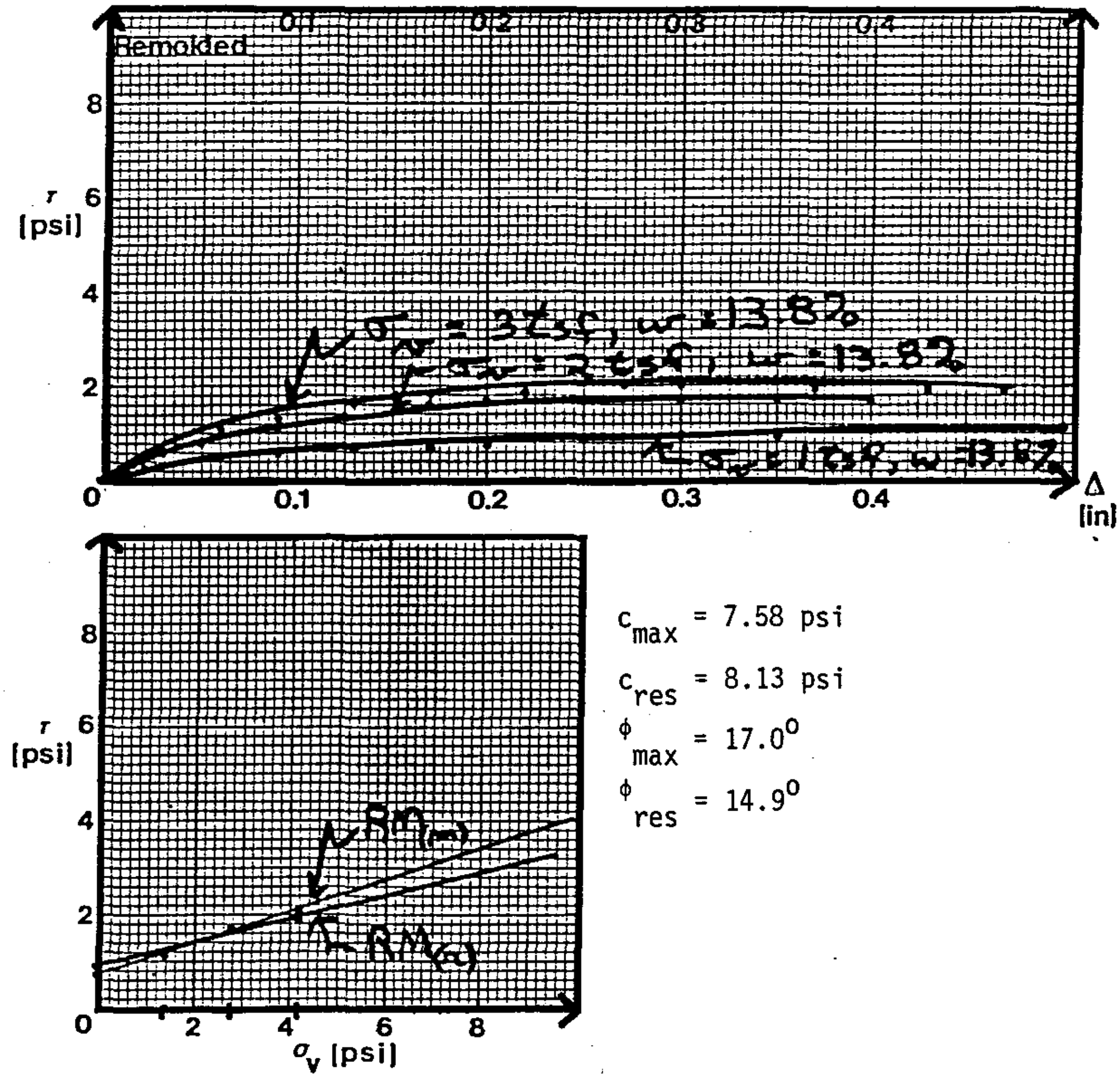
DISCUSSION

The research to date (Phase I) has involved the reaction of reagent grade chemicals with individual clay minerals and the subsequent effect on the clay engineering properties. Changes in engineering properties of clay minerals upon subjection to hazardous waste chemicals is predicted in the literature, and is being verified in the initial stage of this current research. However, due to the heterogeneity of natural soils, it is difficult to directly correlate control type experiments to the actual field situation.

Table 5

Direct Shear Test Results - Permian Red Clay

Acid Treated Sample	τ_{max}(psi)	c(psi)	ϕ(degrees)
Control	2.1	7.2	15.0
"	1.9	7.0	14.9
"	2.0	7.1	15.0
1M	1.8	6.7	14.5
"	1.9	7.0	15.0
"	1.7	6.5	13.8
3M	2.0	7.1	10.3
"	2.2	5.3	16.2
"	1.6	4.1	12.0
6M	1.7	5.2	8.6
"	2.3	6.2	14.5
"	1.8	5.2	11.0



c_{max} = 7.58 psi

c_{res} = 8.13 psi

ϕ_{max} = 17.0°

ϕ_{res} = 14.9°

Figure 3 - A Direct Shear Test Data Set

CONTINUATION RESEARCH

It is proposed that the continuation project (Phase II) be one which studies the effects of leachate on compacted clay liner materials in 1) a hazardous waste disposal site currently in operation in Major County in Northwestern Oklahoma and 2) a proposed hazardous waste disposal site near McAlester in Pittsburg County in Southeastern Oklahoma. The research would involve the site specific leachates and clay liner materials being used. With the principal investigators current involvement in hazardous waste disposal siting within Oklahoma, access to the sites and cooperation concerning the obtaining of the appropriate leachates and soil liner materials will not be a problem. The soils being considered for clay liner material at the proposed Scipio Creek site near McAlester have already been obtained for testing. Soils being used for the clay liner at the Major Co. site need to be obtained. Contacts have been made to obtain leachates unique to each of these two sites.

A Technical Continuation Research Proposal was submitted to the Ground Water Center, Oklahoma State University in April, 1981. No word has been received to date concerning whether continued research is warranted.

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