SEQUENCE STRATIGRAPHY AND ENGINEERING GEOLOGY OF LAWRENCE FORMATION (DOUGLAS GROUP) IN NORTHEASTERN KANSAS

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November 2007

KANSAS DEPARTMENT OF TRANSPORTATION

Division of Operations
Bureau of Materials and Research
| **1** Report No. | KS-06-3 |
| **2** Government Accession No. | |
| **3** Recipient Catalog No. | |
| **4** Title and Subtitle | Sequence Stratigraphy and Engineering Geology of Lawrence Formation (Douglas Group) in Northeastern Kansas |
| **5** Report Date | November 2007 |
| **6** Performing Organization Code | |
| **7** Author(s) | Allen W. Archer, Ph.D., and Christopher J. Hoglund |
| **8** Performing Organization Report No. | |
| **9** Performing Organization Name and Address | Kansas State University Department of Geology, 108 Thompson Hall Manhattan, Kansas 66506-3201 |
| **10** Work Unit No. (TRAIS) | |
| **11** Contract or Grant No. | C1518 |
| **12** Sponsoring Agency Name and Address | Kansas Department of Transportation Bureau of Materials and Research 700 SW Harrison Street Topeka, Kansas 66603-3754 |
| **13** Type of Report and Period Covered | Final Report January 2005 – August 2006 |
| **14** Sponsoring Agency Code | RE-0396-01 |
| **15** Supplementary Notes | For more information write to address in block 9. |
| **16** Abstract | Numerous cases of rock and slope instability in the Lawrence Formation (Virgilian Series, Douglas Group) have been encountered in construction, excavation, and highway projects in eastern Kansas (Archer, 1992). This formation consists of a thick interval of shales, mudstones, sands, and local marine limestone (Joeckel, 1994). Because of its heterolithic nature, the factors controlling rock/slope stability will vary throughout this formation. Furthermore, failures that occur following project completion are extremely costly. The principle objective of this report is to provide a detailed facies characterization of the Lawrence Formation that identifies the sedimentological and depositional properties and their corresponding durability’s. In order to identify potential areas that will be the most susceptible to failure, the following tests were conducted: Slake Durability, Jar Slake Index, Chittick (CaCO₃ content), water absorption, clay mineralogy (XRD), and petrographic thin sections. This research will provide a better representation of the spatial distribution of the variability and durability within and between this problematic formation. The results will be useful for both engineers and contractors that encounter the Lawrence Formation in assessing the risk of rock/slope instability for future project developments. This research will not only benefit future project/construction costs, but it will also assist in protecting the safety of people and the environment. |
| **17** Key Words | Geology, Shale, Limestone, and Stabilization. |
| **18** Distribution Statement | No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161 |
| **19** Security Classification (of this report) | Unclassified |
| **20** Security Classification (of this page) | Unclassified |
| **21** No. of pages | 126 |
| **22** Price | Form DOT F 1700.7 (8-72) |
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Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

November 2007

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ABSTRACT

Numerous cases of rock and slope instability in the Lawrence Formation (Virgilian Series, Douglas Group) have been encountered in construction, excavation, and highway projects in eastern Kansas (Archer, 1992). This formation consists of a thick interval of shales, mudstones, sands, and local marine limestone (Joeckel, 1994). Because of its heterolithic nature, the factors controlling rock/slope stability will vary throughout this formation. Furthermore, failures that occur following project completion are extremely costly.

The principle objective of this report is to provide a detailed facies characterization of the Lawrence Formation that identifies the sedimentological and depositional properties and their corresponding durability's. In order to identify potential areas that will be the most susceptible to failure, the following tests were conducted: Slake Durability, Jar Slake Index, Chittick (CaCO$_3$ content), water absorption, clay mineralogy (XRD), and petrographic thin sections.

This research will provide a better representation of the spatial distribution of the variability and durability within and between this problematic formation. The results will be useful for both engineers and contractors that encounter the Lawrence Formation in assessing the risk of rock/slope instability for future project developments. This research will not only benefit future project/construction costs, but it will also assist in protecting the safety of people and the environment.
INTRODUCTION

The variability within and among the Lawrence Formation makes it problematic to manage and leads to complex and expensive construction, excavation, and highway projects. In collaboration with the Kansas Department of Transportation (KDOT), the focus for this report is to create a detailed stratigraphic, depositional, and sedimentological description of the Lawrence Formation, relative to its mechanical/durability properties. This has been accomplished by analyzing six cores received from the Kansas Department of Transportation (KDOT). KDOT obtained these cores, for preliminary analysis, for the realignment of Highway 59 from Lawrence, KS, south to Ottawa, KS (KDOT Project Number 59-23 K 7888-01). Currently, this stretch of highway is one of the most dangerous in Kansas. It is a hilly, narrow, two lane highway that has a high traffic volume with many access points to side roads and residential areas. The new highway will be a four lane divided highway that will run parallel to the current Highway 59 and include limited access roads and on/off ramps. The area of interest for this realignment project is located in eastern Kansas (Douglas County) near the town of Pleasant Grove, approximately five miles south of Lawrence, KS (Fig. 1.1, 1.2). This research site was chosen because the projected highway realignment involves excavating into a hillside (Pleasant Grove Hill) and creating road-cuts that will expose approximately seventy-five feet (in height) of the problematic Lawrence Formation.
**Figure 1.1** Location of Study Area

*ArcView GIS 3.2; data from DASC

Douglas County, KS

Green Box indicates study area along Highway 59

www.yahoo.com/maps

**Figure 1.2:** Aerial View of Study Area

(Aerial photo from www.terraserver-usa.com and projected realignment courtesy of KDOT)
CHAPTER 1: BACKGROUND

Tetonic Setting

The deposition of the Lawrence Formation occurred during the Late Paleozoic Era (543-248 million years ago) in a period known as the Carboniferous (354 to 290 million years ago). During this time the supercontinent of Euramerica, also known as Laurussia, included North America, Greenland, and Europe. This supercontinent collided with Gondwanaland, which included South America, Africa, Antarctica, India, and Australia. The joining of these two supercontinents formed Pangea (Fig. 1.3, 1.4). The collision and suturing of both Laurussia (to the north) and Gondwanaland (to the south) induced the orogenies of the Appalachian (eastern North America), Ouachita (Oklahoma and Arkansas), Marathon, Ural (Russia), Variscan, Hercynian (United Kingdom), and the Ancestral Rockies (in west-central North America). Other tectonic structures that influenced Kansas, besides...
orogenies, were generated by mostly low amplitude vertical movements within the North American craton.

In areas surrounding eastern Kansas, uplift and subsidence were occurring simultaneously. While these uplifted regions provided sources of clastic sediments, they also generated areas of subsidence which promoted the development of depositional basins. Related to surrounding structural controls within the study region, the Lawrence Shale was deposited in the Forest City basin that extended from central Iowa, through southeastern Nebraska and northeastern Missouri, and into northeastern Kansas. The Forest City Basin is structurally bounded by a variety of geomorphic features. These structural features include (Fig. 1.5): the Canadian Shield and Wisconsin Arch to the north, the Sioux Arch to the northwest, uplifted regions of the failed Mid-Continent Rift (MCR) system from the north through the west (include the St. Croix Horst, Iowa Horst/Thurman-Redfield Structural Zone, and the Nemaha Ridge), the Bourbon Arch and Ouachita Mountains to the south, the Ozark Dome to the southeast, and the Mississippi River Arch to the east.
Sediment Sources and Structural Controls

The positive relief structures surrounding the Forest City basin generated major sources of siliciclastic sediments in northeastern Kansas. Through paleocurrent analyses (Feldman and Archer, 1995), the dominant source of siliciclastic sediments was from the northeast. North of Kansas there were large uplifts that exposed Precambrian basement granites known as the Canadian Shield, in Minnesota, and the Wisconsin Arch, in Wisconsin. Both granitic features provided a source of clastic sediment to surrounding basins.

The Sioux Arch/Ridge extends from southeastern Minnesota into central South Dakota and consists largely of quartzite. The quartzite was metamorphosed from sandstone and claystone that were deposited in a shallow sea approximately 1.7 billion years ago (Southwick, 1986).

The Mid-Continent Rift (MCR) system, also referred to as the Keweenawan Rift, is a 1.1 billion year old failed rift (Anderson and McKay, 1989). The MCR extends southwestward from eastern Lake Superior, across north-central to southwest Iowa, through eastern Kansas, and into central Oklahoma. The cessation of the MCR rifting phase initiated uplift along most of its axis. As the rift became filled with mafic volcanic rocks (basalts), this generated the mid-continent gravity anomaly (MGA). The uplifted region within the MCR consists of the Nemaha Ridge in north-central Kansas, the Iowa Horst in central Iowa, and the St. Croix Horst in Wisconsin (Runkel, 2002).

During the Carboniferous, southern Oklahoma was undergoing its greatest period of mountain building. These orogenic events resulted in the Ouachita, Arbuckle, and Wichita-Amarrillo mountains.
Figure 1.5: Tectonic Framework Surrounding Kansas during the Carboniferous.

(Tectonic framework modified and adapted from Jewett, M., 1951, and Runkel, 2002, Rutan, D., 1975, and Steeples, D., et. al., 1979; the carboniferous deposits were adapted from http://www.paleoportal.org/time_space/period_map.php?period_id=12; and Douglas Group was adapted from KGS Map M-23)
**Geologic Setting**

The Carboniferous is separated further into a Lower/Early Carboniferous and an Upper/Late Carboniferous. In North America these subdivisions are known as the Mississippian (354-353 million years ago) and the Pennsylvanian (323-290 million years ago) systems. Most of the Early Paleozoic and into the Early Carboniferous (Mississippian) was a period of expansive shallow epicontinental seas. Throughout this time period, much of the mid-continent United States resulted in predominately thick carbonate deposits. In North America, the Early Carboniferous (Mississippian) is differentiated from the Late Carboniferous (Pennsylvanian) by an unconformity resulting from the regression of the Kaskaskia epi-teric sea and the transgression of the Absaroka epi-teric sea. This created a transition from the Early Carboniferous marine environments, in eastern Kansas, to a geologic province consisting of alternating siliciclastic (shale and sandstones), coal, and carbonate (limestone) strata in the Late Carboniferous. These lithologic cycles of repetition, known as cyclothems, are a result of both glacioeustatic fluctuations, due to Gondwanaland ice sheets, and regional tectonic activity (Wanless and Weller, 1932). In 1932, cyclothems were originally applied by Wanless and Weller to the Illinois Basin (Weller, 1964). Moore (1935) continued extensive research in the Illinois Basin and later to the Mid-Continental where he used the concept of megacyclothems. A megacyclothem, according to Heckel (1977), are cyclic repetitions in depositional sequences which are defined as having the outside parts of the cycles consisting of siliciclastic and coal-bearing material while most marine material (limestones and black shales) are designated in the center of the cycles. He interpreted the megacyclothem as the now widely accepted cyclothem model.
for Kansas. The depositional environments of the Douglas Group interval, containing the Lawrence Formation, consisted of fluvial, estuarine, and marine facies (Archer and Feldman, 1995).
The coal-bearing layers, from which the Carboniferous is named, are attributed to the vast amounts of plant material provided by wetlands (e.g., swamps, marshes, and bogs) throughout mid-western and eastern North America, as well as other parts of the world. These stagnant and oxygen deficient wetlands accumulated plant debris with limited decomposition. Periodically, the plant material provided by wetlands were submerged by transgressive seas and buried by sand, clay, and other debris. Over thousands and millions of years, the buried organic material (peat) is altered by increased overburden pressure and temperature to form coal deposits. These coal seams/beds are important stratigraphic markers that are indicative of terrestrial environments. A paleogeographic reconstruction during the Paleozoic locates Kansas near the equator (Fig. 1.5) where tropical and humid conditions prevailed (Archer and Feldman, 1995). Figure 1.6 depicts what Kansas may have looked like during the Carboniferous, where the main biomes were swamps and/or tropical rainforests. Vegetation included a variety of ferns and large tree-like relatives of present-day *Lycopodium*. There were many amphibians, as well as insects, spiders, and other arthropods.

**Figure 1.6: Carboniferous Reconstruction**

http://hoopermuseum.earthsci.carleton.ca/carbocoal/LIFE3.HTM
**Stratigraphy**

The Lawrence Shale is an interval within the Douglas Group that lies in the Virgilian Series of the Upper Carboniferous period (Late Pennsylvanian System). It is important to discuss the stratigraphy of the overlying and underlying lithologies surrounding the Lawrence Formation (Fig. 1.7). This can provide insight into paleoenvironmental conditions and yield key stratigraphic markers used as depth indicators during drilling. The stratigraphy within my study area (Fig. 1.7) includes the Stanton Limestone (Lansing Group) in the Missourian Series and extends upward through the top of the Oread Limestone (Shawnee Group) in the Virgilian Series.

Looking at the stratigraphic column in Figure 1.7, there are noticeable similarities and differences within and between the formations. The Oread and Stanton Limestone Formations are similar in that they comprise of the typical Kansas cyclothem with black platy shale members (Eudora and Heebner) and thick, laterally extensive limestones (Heckel, 1977). However, the Douglas Group (Lawrence Shale and Stanton Formation) lack these thick, extensive limestones and black platy shales and primarily consist of siliciclastic facies with locally deep incised valley-filled sandstones. Prominent marker beds exist in the stratigraphic column and can be used to correlate and determine relative stratigraphic position. These marker beds consist of the following: the black fissile Heebner and Eudora Shale, the Upper/Lower Williamsburg Coal, the Ireland and Tonganoxie Sandstone (however in some cases the Ireland may extend into the Tonganoxie and may be hard to determine from one another), and the thick, laterally extensive limestones within the Oread and Stanton Limestone Formations.
Figure 1.7: Generalized Stratigraphy of the Douglas Group and Surrounding Lithologies

(Hagen and Hensiek, 1968)
As defined by O’Connor (1963), the Douglas Group is divided into two formations, the Lawrence Shale and Stranger Formation, which include rocks that were formerly assigned to the Pedee Group. The Lawrence Formation consists of a thick interval of shales, mudstones, sands, and local marine limestone (Joeckel, 1994). Zeller (1968), describes the formation as containing chiefly gray shale and sandstone, which weathers yellowish-gray, minor amounts of red shale, coal (Williamsbrug coal bed), gray limestone, and conglomerate. The Lawrence Formation, which ranges from 140 feet in northern Kansas to 250 feet in southern Kansas (Zeller, 1968), is subdivided into four members that extend from the base of the Haskell Limestone Member to the base of the Toronto Limestone Member (Fig. 1.7). The Haskell Limestone and Robbins Shale members were formerly included in the underlying Stranger Formation. Above the discontinuous Amazonia Limestone Member, an unnamed shale unit (10 to 60 feet thick) consists of gray, green, and red shale, and earthy limestone with minor amounts of siltstone and sandstone and contains the Williamsburg coal bed from Douglas County to Elk County (Zeller, 1968).

**Stratigraphic Descriptions and Sampling**

Stratigraphic descriptions and laboratory sampling, of the Lawrence Formation, was conducted by analyzing six cores that have were provided by the Kansas Department of Transportation (KDOT). All the cores were obtained using a truck mounted wireline core drilling rig on Pleasant Grove Hill (just east of Pleasant Grove, KS). Cores were hoisted to the surface, through drill rods, in five foot core tubes attached to a wireline. Cores were then taken out of the inner core tube and placed in sequential order in boxes for geological examination.
Detailed measurements, of the various lithologic facies encountered within the cores, were recorded (in feet) along with sedimentological descriptions. These descriptions included: rock type, color (Munsell, 1994), texture, bedding, fractures, and concretions. Using these detailed sedimentological core descriptions, the depositional environments can be determined for the different microfacies. High resolution digital pictures were taken of all the core boxes and materials sampled for testing. Detailed stratigraphic columns and fence diagrams were generated using gINT Professional, which is a software package used for geoenvironmental and/or geotechnical engineering reports. This software allows data to be entered into a relational database system that can generate borehole logs, well logs, fence diagrams, and geotechnical lab testing reports. This software package was used to store and manipulate the data gathered from the core descriptions and laboratory tests to generate graphical representations of the Lawrence Shale using borehole logs and fence diagrams.

Borehole and test pit information with sampling schemes are given in Table 1.1 and 1.2. Figure 1.8 provides an aerial view of Pleasant Grove Hill with borehole locations, while Figure 1.9 displays a profile of Pleasant Grove Hill with borehole information. For testing analysis, representative samples were taken directly from the cores based on lithologic changes within the Lawrence Shale. With these samples, the following tests were conducted to assist in determining durability: slake durability, jar slake, chittick (calcium carbonate content), X-ray diffraction (XRD), and petrographic thin sections.
### Table 1.1: Borehole Information and Sampling Identification

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Surface Elevation (ft)</th>
<th>Completion Depth (ft)</th>
<th>Boxes</th>
<th>Cores</th>
<th>Sample ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>506+36, 200'</td>
<td>Top of Pleasant Grove Hill - Deep Hole 1</td>
<td>1083.5</td>
<td>88.2</td>
<td>8</td>
<td>24</td>
<td>DH1</td>
</tr>
<tr>
<td>Rt CL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>506+36, 200'</td>
<td>Top of Pleasant Grove Hill - Deep Hole 2</td>
<td>1083.5</td>
<td>102.8</td>
<td>9</td>
<td>29</td>
<td>DH2</td>
</tr>
<tr>
<td>Rt CL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>512+00</td>
<td>Northwest corner of soybean field</td>
<td>1082.5</td>
<td>72.5</td>
<td>6</td>
<td>18</td>
<td>SF1</td>
</tr>
<tr>
<td>524+25, 25'</td>
<td>Back in timber on north face of Pleasant Grove Hill</td>
<td>1058</td>
<td>102.5</td>
<td>9</td>
<td>23</td>
<td>NFH1</td>
</tr>
<tr>
<td>Lt CL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>526+30, 7'</td>
<td>Middle of Pleasant Grove Hill (north face)</td>
<td>1024</td>
<td>62</td>
<td>5</td>
<td>14</td>
<td>MH1</td>
</tr>
<tr>
<td>Rt CL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>531+50+25'</td>
<td>Base of hill (north face)</td>
<td>940</td>
<td>36.5</td>
<td>3</td>
<td>7</td>
<td>BH1</td>
</tr>
</tbody>
</table>

### Table 1.2: KDOT Test Pits for Slake Durability Sampling

<table>
<thead>
<tr>
<th>Station</th>
<th>Sample ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>528+84 CL</td>
<td>P-1-3</td>
</tr>
<tr>
<td>530+06 CL</td>
<td>P-2-1</td>
</tr>
<tr>
<td>530+06 CL</td>
<td>P-2-3</td>
</tr>
<tr>
<td>530+06 CL</td>
<td>P-2-5</td>
</tr>
<tr>
<td>527+80, 20 ft Lt CL</td>
<td>P-3-2</td>
</tr>
<tr>
<td>527+80, 20 ft Lt CL</td>
<td>P-3-4</td>
</tr>
</tbody>
</table>
Figure 1.8: Contoured Aerial View of Study Area Showing Projected Realignment and Borehole Locations

Boreholes Identifications from south to north: DH1/DH2 (Sta. 506 + 36, 200' Rt CL)  
SF1 (Sta. 512 + 00)  
NFH1 (Sta. 524 + 26)  
MH1 (Sta. 528 + 30)  
BH1 (Sta. 531 +50)
**Figure 1.9:** Profile of Pleasant Grove Hill with Borehole Locations and Elevations

*Surface elevation (ft) is given in parentheses, while bottom-hole elevation (ft) is not given in parentheses.*
CHAPTER 2: MICROFACIES

Detailed measurements and sedimentological descriptions were recorded for all of the cores received from KDOT. The data were input into gINT Professional to generate graphical borehole logs (Appendix A) as well as identify the sample locations with corresponding durability test results (slake durability, jar slake, and percent calcium carbonate). The general stratigraphy of Pleasant Grove Hill is shown in Figure 2.1.

The tallest road-cut will be approximately seventy-four feet, in height, from Station’s 524+25 to 518+250. At most, sixty-six feet (~ 89 %) of the exposure will contain the Lawrence Shale at Station 524+25. Road-cuts containing only the Lawrence Shale will be located on the north face of Pleasant Grove Hill at Station’s 524+500’ (66’ road-cut) to 530 (no road-cut created).

Based on the sedimentological core descriptions within the Lawrence Shale, ten microfacies were defined using primary and secondary sedimentary structures. Based upon an identification of microfacies, an interpretation can be determined regarding its original depositional environment. The microfacies identified include: Churned Shale (bioturbated), Shale, Clayshale, Coal, Paleosol, Carbonate-rich Shale (nodules), Lenticular Shale, Silty/Sandy Shale, and Weathered Shale. A profile of Pleasant Grove Hill with the locations of the microfacies is shown in Figure 2.2. Table 2.1 provides approximate percentages of microfacies encountered during coring within Pleasant Grove Hill.
Figure 2.1: Stratigraphic Profile of Pleasant Grove Hill

STRATIGRAPHIC PROFILE OF PLEASANT GROVE HILL

- Plattsmouth Limestone
- Heebner Shale
- Leavenworth Limestone
- Snyderville Shale
- Toronto Limestone
- Lawrence Shale

* Borehole indicated by solid black vertical line
** Soil on top of Plattsmouth Ls.

Upper/Lower Williamsburg Coal (horizontal)
Figure 2.2: Detailed Stratigraphic Profile of Pleasant Grove Hill, with Microfacies
Table 2.1: Approximate Percentages of Lawrence Shale and Microfacies within Pleasant Grove Hill (based on coring).

<table>
<thead>
<tr>
<th>Station</th>
<th>506+36, 200' Rt (DH1)</th>
<th>506+36, 200' Rt (DH2)</th>
<th>512+00 (SF1)</th>
<th>524+25, 25' Lt (NFH1)</th>
<th>526+30; 7' Rt CL (MH1)</th>
<th>531+50, 25' Rt CL (BH1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawrence Shale cored</td>
<td>62%</td>
<td>67%</td>
<td>35%</td>
<td>92%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Churned Lenticular Shale</td>
<td>10%</td>
<td>8%</td>
<td>22%</td>
<td>15%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Churned Lenticular Shale</td>
<td>16%</td>
<td>11%</td>
<td>35%</td>
<td>17%</td>
<td>8%</td>
<td>39%</td>
</tr>
<tr>
<td>Coal</td>
<td>2%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Paleosol</td>
<td>11%</td>
<td>12%</td>
<td>17%</td>
<td>7%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Churned Shale</td>
<td>17%</td>
<td>16%</td>
<td>17%</td>
<td>1%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Carbonate-rich Shale</td>
<td>13%</td>
<td>7%</td>
<td>7%</td>
<td>2%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Claystone</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Lenticular Shale</td>
<td>25%</td>
<td>29%</td>
<td>--</td>
<td>21%</td>
<td>28%</td>
<td>--</td>
</tr>
<tr>
<td>Silty/Sandy Shale</td>
<td>5%</td>
<td>14%</td>
<td>--</td>
<td>35%</td>
<td>42%</td>
<td>--</td>
</tr>
<tr>
<td>Weathered Shale</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>22%</td>
<td>61%</td>
</tr>
<tr>
<td>SUM</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Microfacies #1: Churned Shale**

**Description:** Light Greenish Gray (5G 8/1) to Greenish Gray (5G 8/1) shale that was identified by disruption or reformation of the primary sedimentary bedding features. The churned shales were identified at three localites within the Lawrence Shale:

1) Beneath the Toronto Limestone, the churned shale was comprised of very fine sand to silty, isolated lenticels. The lenticels were irregularly shaped and deformed due...
to bioturbation. The more resistant, coarser lenticels protruded from the less resistant shale/mud creating a “ribbed” appearance on the surface of the core (Fig. 2.3a).

2) Underlying the carbonate-rich (nodular) shale microfacies, was a fossiliferous shale containing bivalves. The presence of the bivalves and disruptive bedding (“ribbed”) were indications of bioturbation (Fig. 2.3b).

3) Beneath the lower Williamsburg coal a churned shale was identified with disrupted bedding, wisps on the outside of the core, and plant fossils. The wisps are good indication of root penetration, and correlates well with the presence of plant fossils. Underlying a coal seam, this churned shale may represent a weakly developed paleosol.
Figure 2.3: Churned Shale
a) Very thin, isolated silty to sandy lenticels/ripples. The more resistant silty/sandy ripples protrude out from the weaker (less resistant) shale generating a ribbed appearance on the surface of the core. The ripple morphology is not well defined due to alteration by bioturbation.
b) Shale displaying ribbed appearance on the surface of the core due to bioturbation. Bivalves within the bedding plane are associated with this shale.
Scale in both core photos is 1/10'.

a) Churned Shale; Lenticular/Streaked Bedding

b) Churned Shale; Bivalves
Figure 2.4: Churned Shale microfacies
a) silty streaked to lenticular shale with disturbed bedding caused by abundant bioturbation.
b) rotated 45°, the clay orientation is identified by the high birefringence. Disrupted silty lenticel and bedding due to bioturbation.
Frame length in both photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized; 5x total magnification

(b) cross-polarized; 5x total magnification; rotated 45°
Figure 2.5: Churned Shale microfacies
a) silty shale with burrow filled with coarser silt (spreites).
b) lenticular shale with disturbed bedding generated by bioturbation; root (right) and disrupted silty lense in upper left.
Frame length in both photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized; 5x total magnification

(b) cross-polarized; 5x total magnification
**Interpretation:** The term “churned” is referring to the agitation or deformation of the primary bedding structure, due to bioturbation. The churned shales are located in three regions within the Lawrence Shale. Directly beneath the Toronto Limestone lies a light greenish gray churned lenticular shale. Because of its proximity to limestone, it suggests transgressive sequence where marine bioturbation has disrupted the silty/sandy lenticles within the shale. Another sequence of this microfacies is located beneath the carbonate-rich shale, where the shale has been churned by bivalves. The final churned shale microfacies was located in proximity to coal seams, with root wisps/traces, which indicate terrestrial influence.

**Microfacies #2: Shale**

**Description:** Light Gray (N7) to Medium Dark Gray (N4) lithified clay/mud that breaks (platy to slabby) parallel to horizontal bedding plane. A majority of the shales were clay-rich (Fig. 2.6a), displaying irregular partings along bedding plane due to the presence of expandable clays (shrink/swell).
Figure 2.6: Shale Core Photographs.

a) Light gray clay-rich shale with abundant fractures that are irregular (shrink/swell) and parallel to the horizontal bedding plane.

b) Medium gray shale that lacks the irregular fractures (shrink/swell clay) as in (a), with flat, parallel fractures along horizontal bedding plane. Scale is 1/10" in core photos.

a) Clay-rich Shale  

b) Shale
Interpretation: Low energy, open marine environment below wave base allowing fall out from suspension.

Microfacies #3: Clayshale

Description: Light Gray (N7) to Light Olive Gray (5Y 6/1) fat/slick clay with very thin laminations. Predominately occurs in isolated, small beds, no thicker than 0.5 feet. Typically creates sharp contacts with the underlying and overlying materials. Clayshale is very weak/soft clay-rich material with abundant fractures (irregular). Because of its high plasticity, the material is compressed and deformed easily (expandable clays).
Figure 2.7: Displays the abundance of irregular fractures throughout the friable clayshale.

Fig. 3.10: Due to the high plasticity of the material, finger prints were preserved on the surface of the core during core retrieval.

Fig. 3.11: Light gray clayshale showing the thinly laminated structure within the core. Scale in all core photos is 1/10".

A: Clayshale  
B: Clayshale  
C: Clayshale
Figure 2.8: Clayshale Photomicrographs
a) contains abundant clay.
b) rotated 45°, the high birefringence of the oriented clays displays the bistrial b-fabric (micromass) where two intersecting sets of oriented clays can be seen.
Frame length in both photomicrographs is 1330 μm (1.33 mm).

(a) crossed polarized; 25x total magnification

(b) crossed polarized; 25x total magnification; rotated 45°
**Interpretation**: The extremely high clay content suggests a very low energy environment of deposition. The isolated pod-like and irregular lateral distribution of this facies indicates that the paleoenvironmental conditions were highly variable laterally. Similar shales occur in the roof rocks of coal mines in Indiana and Illinois (A. Archer, pers. comm., 2006). The various features of these shales could be interpreted as having formed within areas of ponded water, such as lagoons or abandoned tidal creeks and channels. Such features are common in areas of laterally extensive tidal flats which develop only poor drainage conditions.

**Microfacies #4: Coal**

**Description**: Two coal seams exist within the Lawrence Shale, the Upper and Lower Williamsburg Coal. The Lower Williamsburg Coal, located at ~1010’, is more laterally extensive than the Upper Williamsburg Coal, located at ~1038’ (Fig. 2.2). The coal beds are thin (0.1’-0.4’ thick) and mostly consist of Dark Gray (N3) to Black (N1), brittle, bituminous coal. Gradations exist where the coal becomes very thinly interlaminated with shale or becomes carbonaceous shale.

**Interpretation**: The coal beds are attributed to highly reducing environments where vast amounts of plant material existed with little biodegradation. Environments include waterlogged regions or wetlands (e.g. swamps, marshes, and bogs) that were quickly submerged by transgressive oceans, burying the organic matter with sediments before it could be decomposed.

**Microfacies #5: Paleosol**

**Description**: The paleosols are located at an elevation of 1038’ to 1030’. The color ranges from Light Gray (N7) to Medium Dark Gray (N4), and Greenish Gray (5G 6/1).
Occasional there are shades of Pale Red (10R 6/2) to Grayish Red (5R 4/2), and
Grayish Red Purple (5RP 4/2). Paleosols are identified by post-depositional
sedimentary structures and fossils. Post-depositional structures include mostly platy
mudstone “clods”, with few columnar mudstone “clods”. Other post-depositional
sedimentary features include the presence of shrink/swell cracks (slickensides),
carbonate nodules, and root traces.

Figure 2.9: Paleosol Core Photographs
a) Purplish-gray, fine platy, paleosol with an angled shear plane (A) containing slickensides. Bottom of
core becomes finely mottled with yellow drab-haloed root traces (B).
b) Close-up of yellow drab-haloed root traces within grayish red purple paleosol.
c) Gray clay-rich paleosol with desiccation cracks (shrink/swell). Bottom of core displays its columnar ped
structure.
1/10’ scale in all core photos.
   a) Paleosol
   b) Paleosol
   c) Paleosol
**Figure 2.10: Paleosol Core Photographs**
a) Light greenish gray paleosol containing a recrystalized, pale brown, calcite root cast (A).
b) Indurated churned shale to weak paleosol with irregularly distributed wisps on the side of the core. These wisps represent root traces causing minor disorientation of the bedding. Shear planes (with slickensides) on the top and bottom of the core.
c) Paleosol with red clay coated slickenside (angled shear plane).
All scales in core photos are 1/10’.
Figure 2.11: Paleosol Microfacies
a) dendritic root channel with abundant rootlets branching into clay/silt matrix. Root traces lined with a red clay coating (ferri-argillan).
b) root channel with fine branching rootlets with ferri-argillans.
c) abundant root traces, within clay/silt matrix, with ferri-argillans.
Frame length in all photomicrographs is 6650µ (6.65 mm).
Figure 2.12: Paleosol microfacies
a) dark, iron oxidized root trace (center) with illuviated clay (high birefringence) throughout the clay/silty matrix.
b) abundant root traces within clay/silt matrix with chert sand grains. Finer root traces lined with ferriargillans (red).
Frame length in all photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized; 5x total magnification

(b) plane-polarized; 5x total magnification
**Interpretation:** Paleosols are relicts of ancient soils that represent the conditions present during soil formation. Paleosols can be distinguished by the presence of ped structure, root traces, and fossils. Any one of these characteristics, for this study, is interpreted as a paleosol forming from weathering and pedogenic (soil-forming) processes during subaerial exposure.

Few paleosols for this project exhibit red to purplish red color indicating oxidizing environments. The gray to greenish gray color dominating the paleosols within the Lawrence Shale indicates environments with reducing conditions, such as waterlogged regions (swamp, marshes, or bogs). Jockel (1994) suggests the paleosols show a strong resemblance to modern Vertisols.

**Microfacies #6: Carbonate-Rich Shale; Nodules**

**Description:** The shales containing these hard/dense carbonate nodules are usually Light Greenish Gray (5G 8/1) to Greenish Gray (5G 6/1). There are two noticeable types of carbonate-rich shales: 1. contains hard limey nodules with sharp contacts between the shale/carbonate interface (Fig. 2.13 a,b), and 2. carbonate nodules consisting of a diffuse (or gradational) contact within the shale (Fig. 2.13 c). The shales in which the carbonates are contained are also calcareous.
Figure 2.13) Carbonate-rich Core Photographs.  a,b) Carbonate-rich shale consisting of hard/dense carbonate nodules (C).  c) Pebble-like carbonate nodules within the shale.  Scale in all core photos is 1/10'.

a) Carbonate-rich Shale  

b) Carbonate-rich Shale  

c) Carbonate-rich Shale
Figure 2.14: Carbonate-Rich Shale microfacies
a) micrite calcite skeletal shell fragments.
b) micrite nodule, with shell fragments, surrounded by micritic matrix; notice how fractures occur at matrix and nodule interface.
Frame length in all photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized; 5x total magnification

(b) cross-polarized; 5x total magnification
Figure 2.15: Carbonate-rich Shale microfacies
a) Fine micritic matrix with clay lined root trace (left); fractured micrite nodule, due rooting; calcite-spar filled vughes.
b) Linear voids within micrite nodule due to root penetration. Linear voids lined/filled with both clay and calcite. Larger vughes filled with calcite.
Frame length in all photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized; 5x total magnification

(b) plane-polarized; 5x total magnification
**Interpretation:** The nodular carbonate concretions within the Lawrence Shale are believed to have at least two origins, both marine and pedogenic. Joekel (1994) suggested that the carbonate, underlying the paleosols, is entirely related to pedogenic processes (caliche-like nodules). However, further work by Feldman and Archer (1995) identified shell fossils within some of these carbonate nodules, which indicates original deposition of marine limestone. The limestone is suggested as being the discontinuous Amazonian Limestone that was subaerially exposed due to a fall in sea level. This resulted in paleosol development on top of the Amazonian Limestone, which incorporated pedogenic carbonate and limestone fracturing within the facies.

**Microfacies #7: Lenticular Shale**

**Description:** Lenticular shales consist of parallel laminated, White (N9) to Light Gray (N8) very fine sandstone to siltstone lenses/ripples that are incorporated in a Medium Dark Gray (N4) to Light Gray (N7) mud (Fig. 2.16). In a few areas the clay is Light Greenish Gray (5G 8/1). The fine grained sandstone/siltstone lenticels form sharp, flat to irregular contacts with the surrounding shale. Based on the morphology of the lenticels, lenticular bedding is separated into two categories; either isolated (starved) lenses or connected lenses. According to Reineck and Singh (1980), the criteria for classification depend on whether 75% of the sandstone lenses are continuous or isolated in the horizontal and vertical direction. Further subdivision can be determined by whether the lenticels are thick (length/height ratio <20) or flat (length/height ratio >20). Both lenticular categories exist within the Lawrence Shale, however, most contain flat, discontinuous lenticels. Foreset laminae of current/wave
ripples are preserved within some of the thicker lenticels. Secondary bedding features are exhibited in the forms of load structures and disturbed bedding (mud flow/slump).

**Figure 2.16: Lenticular Shale Core Photograph**

*a*) Lenticular Shale displaying very thin, isolated sandstone lenticels/ripples. Sand lenticels become more continuous toward the top of the core (A) with siderite cementation. Becoming for sandy at top with flaser bedding (B).

*b*) Lenticular Shale displaying more continuous sandstone lenticels (C). Bedding slightly disturbed (loading or bioturbation). Notice in both figures how the shale fractures along the sandstone/mud interface.

Scale in both core photos is 1/10′.
Figure 2.17: Deformed Lenticular Shale; Soft Sediment Deformation
a) Lenticular shale displaying convolute bedding; related to sandy mudflow or slumping activity.
b) Lenticular Shale displaying vertical bedding; consisting of very fine sand to silt, wavy/crenulated laminations. Sandstone lenticels (C). Bedding slightly disturbed (loading or bioturbation).

Scale in both core photos is 1/10".

a) Lenticular Shale; Deformed

b) Lenticular Shale; Deformed
**Figure 2.18:** Lenticular microfacies
a) Alternating dark, organic rich clay laminae with coarser grained lenticels (isolated and connected). Frame length is 6650 μm
b) Lenticels primarily consist of very fine sand to silt sized, sub-angular to sub-rounded quartz grains. Grains are well sorted and display equigranular sutured/mosaic-like internal fabric. There is a sharp, prominent contact between the organic-rich clay and sand/silt interface. Notice the parallel orientation (perpendicular to overburdened stresses) of the organic matter. The frame length is 1330 μm (6.65 mm).

(a) plane-polarized light; 5x total magnification

(b) cross-polarized light; 25x total magnification
Figure 2.19: Lenticular Shale Microphotographs
a) Vertical bedding of lenticular shale due to mud flow/slumping activity. Quartz-rich, very fine sand to silt lenticels consist of a sharp undulating boundary with the surrounding dark, organic rich clay. Frame height is 6650 μm (6.65 mm).
b) More vertical lenticular bedding with undulating morphology. Few lenticels displaying crenulated/crinkled laminae. Frame length is 6650 μm (6.65 mm).
Interpretation: The incomplete or starved ripples are generated by an insufficient supply of sand with conditions favoring the deposition and preservation of mud. The formation of these lenticular shales depends upon alternating periods of both high energy (turbulent water) and low energy (slack water) depositional events. The sand ripples are deposited on a muddy substratum, during limited intervals of current or wave action, and preserved by mud deposition from slack water suspension fallout.

The main environments of this occurrence are subtidal zones (Reineck 1963 a; Reineck et al. 1968), intertidal zones (Hantzschel 1936 a; van Straaten 1954 a), and mid tidal flats (deVries Klein, 1977). Similar bedding was reported in Carboniferous rocks deposited in Indiana by Kvale and Archer (1990) and subsequently in Kansas by Archer (1994).

Microfacies #8: Sandy/Silty Shale

Description: The silty/sandy shale facies consists of a Light Gray (N7) to Medium Light Gray (N6) heterogeneous mixture of sand, silt and clay with massive bedding. There are abundant amounts of mica and black organic debris/particles. Associated with some of these rocks are slightly connected to isolated ball-and-pillow structures (or “sunken/starved” ripples) consisting of very fine sandstone. The pillows themselves may be structureless or display curved or deformed laminations (Fig. 2.20 a). These very fine sandstone pillows form a sharp, contoured contact with the surrounding mud matrix. Other bedding features include soft sediment deformation (Fig. 2.20 b) This microfacies provides more resistant cores with very few fractures. This microfacies is often found interbedded with lenticular shale.
Figure 2.20: Sandy/Silty Shale Core Photographs
a) Massive gray, sandy shale/siltstone with an isolated sandstone load structure (A) in the middle of the core.
b) Massive, light gray, silty/sandy shale with fine sandstone ball-and-pillow structure (B) and contorted soft sediment deformation (C). Notice how resistant the cores are in both figures, with very few fractures.
c) Abundant sand, mica, and macroscopic organics within sandy/silty shale.
Scale in all core photos is 1/10".
Figure 2.21: Silty/Sandy Shale Photomicrographs
a) heterogeneous mixture of clay, silt and very fine sand; dominate minerals are quartz and muscovite mica; abundant black organic debris/particles
b) well sorted, very fine sand "sunken" pillow preserved within very fine sand, silt, and clay matrix with abundant black organic debris.
Frame length in both photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized light; 5x total magnification

(b) cross-polarized light; 5x total magnification
**Figure 2.22: Silty/Sandy Shale Photomicrographs**

a) large “sunken” pillow consisting of predominately well sorted and sutured quartz grains (very fine sand to silt); thick, dark, organic-rich clay film (left) accumulated around pillow as it sank through the silty/sandy clay matrix.

b) soft sediment deformation within silty/sandy clay matrix related to mudflow or slumping prior to deposition.

Frame length in both photomicrographs is 6650 μm (6.65 mm).

(a) cross-polarized light; 5x total magnification

(b) cross-polarized light; 5x total magnification
**Interpretation:** The ball-and-pillow structure is generated by a disturbance within the deposit (e.g. applied shock, loading or slumping activity) that results in the overlying sandy layers to be broken into “pillows”. These sandy pillows then sink into the underlying mud. In some cases, rather than being broken into pillows, a larger portion of the sandy layer is vertically displaced causing contorted/convolute bedding to develop (Fig. 2.20 b).

Along with the ball-and-pillow and contorted structures, the heterogeneous composition of very fine sand, silt, and clay, implies rapid sedimentation. The presence of abundant very fine sand and macroscopic organic debris indicates the deposition is proximal to continental or marginal marine environments (near-shore, fluvial-deltaic to estuarine).

**Microfacies #9: Weathered Shale**

**Description:** The shale consists of oxidized Grayish Orange (10YR 7/4) to Pale Yellowish Orange (10YR 8/6) sandy/silty shale. Besides the color, the most distinguishing feature of this microfacies was the abundant fractures and presence of modern roots. A significant portion of the fractures were vertical, with black manganese or red iron oxidation on the fracture surfaces. The weathered silty/sandy shale is found along the backslope, or toe, of Pleasant Grove Hill. The weathered portion thickens (~30’) toward the toe and base of the hill where it grades into Light Gray (N7) to Medium Gray (N5) sandy/silty shale microfacies.
Figure 2.23: Weathered Sandy/Silty Shale Core Photographs

a) Weathered and fractured shale.
b) Orangish-Gray weathered shale with shear plane (A) in the middle of the core.
c) Weathered shale exhibiting prominent vertical fractures.
d) Modern root development within weathered shale; notice the drabe halos (light green) forming around the rootlets.

1/10’ scale on all core photos.
Figure 2.24: Weathered Sandy/Silty Shale Photomicrograph
Highly oxidized and iron rich silty/sandy shale with numerous voids and fractures. Frame height in photomicrograph is 6650 μm (6.65 mm).

Cross-polarized; 5x total magnification
**Figure 2.25:** Weathered Shale Photomicrograph
Highly oxidized and iron rich silty shale with numerous voids and fractures. Frame length in photomicrograph is 1330 μm (1.33 mm).

*Cross-polarized; 25x total magnification*

**Interpretation:** The relic lithofacies, superimposed by weathering and pedogenic alteration, is the same silty/sandy shale found at depth within Pleasant Grove Hill. Weathering and pedogenic process within the Lawrence Shale are influenced by the overlying material and the slope of the hill. The top of the hill is heavily vegetated and capped by approximately forty feet of overlying material, including three laterally extensive limestones (Plattsmouth Ls., Leavenworth Ls, and Toronto Ls.). This overlying material prevents percolating water and root penetration from reaching the Lawrence Shale. However, on the slopes and base of the hill, where the Lawrence
Shale is exposed in close proximity to the surface, the weathering and pedogenic effects can be seen. The highest degree and extent of weathering and pedogenisis is located near the base or toe of Pleasant Grove hill. Surface runoff, generated from the steeper slopes of the hill, accumulates and percolates into the ground due to the low relief at the base of the hill. This results in more water infiltration/percolation and vegetative growth. The depth, or extent, of weathering diminishes on the slopes of the hill. This is primarily due to both higher surface runoff on slopes and reduced vegetation cover on slopes.
CHAPTER 3: TEST RESULTS

*Slake Durability*

The slake durability procedure proved to be the most useful in terms of determining the materials durability within the Lawrence Formation. A total of sixty-five test were conducted on samples taken from cores received by KDOT at the six borehole locations. Using slake durability classification schemes proposed by Deo (1975), Gamble (1971), Franklin and Chandra (1972), and Dick and Shakoor (1995), the Lawrence Formation contains predominately low durability materials in the orders of: 61-65% Low Durability, 15-31% Medium Durability, and 8-23% High Durability. Dick and Shakoor (1995) also developed a slope classification scheme based on the materials slake durability after two cycles. Within the Lawrence Shale, 62% of the materials tested were classified as “probable” indicators for slump or debris flow (with “probable” excess erosion: 5-10 cm/yr of undercutting), while 31% resulted in “potential” indicators (with “unlikely” excess erosion: 3-5 cm/yr of undercutting), and 8% unlikely of failure (with “unlikely” excess erosion: 2-3 cm/yr of undercutting).

Arranging the data in order of increasing slake durability, there is a strong relationship between the microfacies within the Lawrence Shale. Based on the slake durability results, after two cycles, the paleosols are designated as being the least durable (Id = 0-10.7) and thus most susceptible to rock/slope failure. The sandy/silty shales represent the microfacies that are more resistant to slaking and are located at greater depths. Figure 3.1 provides slake durability results by microfacies.
**Jar Slake Test**

The Jar Index is a simple and fast test to identify the effects of submersing a rock sample in water. As a secondary procedure to the jar index, water absorption can be calculated. There is an adequate relationship between the slake durability and water absorption within the Lawrence Formation. As water absorption increases, the durability of the material is reduced (Fig. 3.2).
Using the Jar Slake classification in Table 3.1, 63% of the Lawrence Shale tested consists of low durability, 22% medium durability, and 14% high durability. These percentages correlate well with the slake durability classification results: Low: 61-65%, Medium: 15-31%, and High: 8-23%.

**Table 3.1: Jar Slake Classification**

<table>
<thead>
<tr>
<th>Durability Classification</th>
<th>Jar Index</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1</td>
<td>Degrades into a pile of flakes or mud</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Breaks rapidly and/or forms many chips</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Breaks rapidly and/or forms few chips</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
<td>Breaks slowly and/or develops several fractures</td>
</tr>
<tr>
<td>High</td>
<td>5</td>
<td>Breaks slowly and/or develops few fractures</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>No Change</td>
</tr>
</tbody>
</table>
The relationship between microfacies and water absorption is provided in Figure 3.3.

**Figure 3.3:** Percent Water Absorption by Microfacies; average and range values

* Microfacies: (1) Churned Shale; (2) Shale; (3) Clayshale; (4) Coal (N/A); (5) Paleosol; (6) Carbonate-rich Shale; (7) Lenticular Shale; (8) Sandy/Silty Shale; (9) Weathered Shale. Average and range of percent calcium carbonate are indicated by a circle and whiskers.

**Calcium Carbonate Content (Chittick)**

The calcium carbonate (CaCO₃) content within the Lawrence Shale was determined using the chittick test. Calcium carbonate is a cementing agent in sedimentary rocks and can give insight into the durability of the material. Shown below in Figure 3.4, the chittick results consist of predominately low concentrations of calcium carbonate throughout the Lawrence Formation. According to Miller & McCahon (1997), calcium carbonate content < 35% will likely have low durability, while content > 35% will
likely have medium to high durability. In relation to durability, there is no correlation between calcium carbonate content and slake durability within the Lawrence Formation (Fig. 3.4).

**Figure 3.4:** Slake Durability vs. Calcium Carbonate in the Lawrence Shale

![Slake Durability vs. Calcium Carbonate in the Lawrence Shale](image)

The high “outliers” in Figure 3.4 are due to the high concentration of calcium carbonate in the Carbonate-rich Shale and Paleosol microfacies.
The relationship between microfacies and calcium carbonate is provided in Figure 3.5.

**Figure 3.5:** Percent Calcium Carbonate by Microfacies; average and range values

![Calcium Carbonate by Microfacies](image)

*Microfacies: (1) Churned Shale; (2) Shale; (3) Clayshale; (4) Coal (N/A); (5) Paleosol; (6) Carbonate-rich Shale; (7) Lenticular Shale; (8) Sandy/Silty Shale; (9) Weathered Shale. Average and range of percent calcium carbonate are indicated by a circle and whiskers.*

**Mineralogy – Clay and Silt**

Mineralogy of both the silt and clay fraction was identified using X-ray diffraction (XRD) of the major microfacies (Table 3.2). Fractionation results (Table 3.3) show that all of the microfacies are dominated by the silt fraction (50.2% – 58.2%), with the exception of the paleosol being influenced by higher concentrations of clay (55.9%). The lenticular, sandy/silty, and weathered shales consist of higher sand concentrations that are associated with significantly lower amounts of clay.
Table 3.2: Identification for XRD Analysis

<table>
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<th>XRD Sample ID</th>
<th>Microfacies</th>
<th>Location</th>
<th>Elevation (ft)</th>
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<tbody>
<tr>
<td>1</td>
<td>Lenticular Shale</td>
<td>DH2-12</td>
<td>1001.1 – 1000.5</td>
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<tr>
<td>2</td>
<td>Churned Shale</td>
<td>DH1 Box 3 Core 10</td>
<td>1047.7 – 1047.62</td>
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<td>3</td>
<td>Sandy/Silty Shale</td>
<td>NFH1-4</td>
<td>1032.8 - 1032</td>
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<tr>
<td>4</td>
<td>Shale</td>
<td>BH1-7</td>
<td>905.4 – 904.4</td>
</tr>
<tr>
<td>5</td>
<td>Weathered Shale</td>
<td>BH1-2</td>
<td>926.3 – 925.9</td>
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<tr>
<td>6</td>
<td>Carbonate-rich Shale</td>
<td>NFH1-5</td>
<td>1029.8 – 1028.8</td>
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<td>Paleosol</td>
<td>SF1-4</td>
<td>1035.2 – 1034.1</td>
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<tr>
<td>8</td>
<td>Clayshale</td>
<td>DH1 Box 4 Core 12</td>
<td>1039.7 – 1039.55</td>
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Table 3.3: Fractionation Results During XRD Preparation

<table>
<thead>
<tr>
<th>XRD Sample</th>
<th>Microfacies</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
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<td>1</td>
<td>Lenticular</td>
<td>17.8</td>
<td>51.2</td>
<td>31.0</td>
</tr>
<tr>
<td></td>
<td>Churned</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale</td>
<td>35.6</td>
<td>57.0</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Sandy/Silty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shale</td>
<td>23.9</td>
<td>56.7</td>
<td>19.4</td>
</tr>
<tr>
<td>4</td>
<td>Shale</td>
<td>42.3</td>
<td>57.2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Weathered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Shale</td>
<td>27.9</td>
<td>58.2</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td>Carbonate-rich</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Paleosol</td>
<td>55.9</td>
<td>43.2</td>
<td>0.9</td>
</tr>
<tr>
<td>7</td>
<td>Clayshale</td>
<td>47.6</td>
<td>50.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Analyzing the XRD patterns of the silt fractions, all of the microfacies contained quartz, albite, orthoclase, calcite and 2:1 layered silicates (Table 3.4). Dolomite was identified only in the lenticular shale.

Table 3.4: XRD Silt Mineralogy

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
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<tbody>
<tr>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
</tr>
<tr>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
<td>Albite</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
<td>Calcite</td>
</tr>
<tr>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
</tr>
</tbody>
</table>
The identification of the clay mineralogy, using the X-ray diffractograms, was determined using procedures by Jackson (1975). The clay mineral species and their relative amounts were characterized by analyzing the peak geometry and peak intensities produced on the X-ray diffractograms. The various chemical and heating treatments used in preparation for XRD, assisted in identifying clay mineral species.

Kaolinite was characterized by a 7.1 Å (d001) peak with both K and Mg cation saturations and heat treatments of K-25°C and K-350°C. However, the same peak is absent after heating to 550°C as the structure of kaolinite collapses.

Clay mica (Illite) was identified by 10 Å (d001), 5 Å (d002) and 3.3 Å (d003) peaks using the Mg-25°C treatment. The 10 Å peak remained persistent through all of the chemical and heat treatments.

Like chlorite, hydroxy interlayered 2:1 mineral (HIM) was identified by a 14 Å peak that remained throughout the entire chemical and heat treatments. Upon heating at K-550°C, the 7 Å peak disappeared from all of the diffractograms indicating the presence of HIM. If the 7 Å peak remained at K-550°C, this supports the presence of chlorite.

Chlorite and other 2:1 layered silicates were identified by a 14 Å (d001) peak using Mg-25°C. Both chlorite and kaolinite are characterized by a 7 Å peak. However, upon heating to 550°C, the presence or absence of this 7 Å peak differentiates either chlorite or kaolinite. Kaolinite is characterized by a collapse of the 7 Å peak, while chlorite is recognized by the presence of the 7 Å peak upon heating to 550°C. All of the microfacies X-ray diffractograms generated no 7 Å peaks at 550°C, thus indicating kaolinite is present and not chlorite.
The absence of the 7 Å peak at 550°C, in combination with the presence of the 14 Å peak with Mg-25°C, now suggests either 2:1 layered silicate, hydroxy interlayer, or a interstratification of 2:1 and hydroxyl interlayer. Within the Lawrence Shale, it is important to identify the presence of vermiculite and/or smectite. Both vermiculite and smectite are expandable 2:1 layer silicates that cause rock/slope stability problems due to their shrink/swell capabilities. The presence of vermiculite is characterized by a 14-15 Å \((d_{001})\) peak with both EG and GLY treatments. Upon heating, the 2:1 layered structure of vermiculite collapses to 10 Å \((d_{001})\) and remains constant throughout the remaining heat treatments. Smectite is identified by its expansive response to both Eg and GLY treatments. With the Mg-EG, smectite was identified by a 17 Å \((d_{001})\) peak, and by an 18 Å \((d_{001})\) peak with Mg-GLY treatment. Upon treating with K-25°C, smectite is recognized by a 12 Å \((d_{001})\) peak. With further heating (K-350°C and K-550°C), both smectite and vermiculite generated a peak at 10 Å \((d_{001})\).

Randomly interstratified clay minerals were determined by diffraction peaks becoming broad and weak upon Mg-EG and K-25 treatments (Gunal, 2001). Broad peaks were identified between 14 Å and 10 Å. Because these peaks are characteristic of smectite, vermiculite, HIM, and clay mica, it was established that randomly interstratified hydroxy/2:1 expandable clay was present. In the case of a distinct 14 Å peak persisting upon heating to 550 °C, this is interpreted as the presence of more crystalline HIM.

Analyzing the peak geometries and peak intensities produced on the X-ray diffractograms, a semi-quantitative analysis was performed to determine the relative distribution of clay mineral species, within each microfacies (Table 3.5). Kaolinite and
clay mica dominated the clay fractions in all of the microfacies. To a lesser extent, 2:1 expanding clays and HIM existed in most of the microfacies. Both smectite and vermiculite were recognized within the microfacies. Vermiculite was the most dominant expandable clay mineral, with the exception of the clayshale microfacies (XRD #8) where smectite and vermiculite relative concentrations were approximately the same.

Table 3.5: Clay minerals and relative quantitative abundance. See Table 3.7 for rating explanation.

<table>
<thead>
<tr>
<th>XRD Sample</th>
<th>Quartz</th>
<th>Kaolinite</th>
<th>Clay Mica</th>
<th>Expandable Clays</th>
<th>Hydroxy Interlayered 2:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TRACE</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XX</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>XXXX</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>TRACE</td>
<td>XXXX</td>
<td>XXX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>5</td>
<td>TRACE</td>
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<td>XXXX</td>
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<tr>
<td>6</td>
<td>X</td>
<td>XXXX</td>
<td>XXXX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>XXXX</td>
<td>XXXX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>XXX</td>
<td>XXXX</td>
<td>XXX</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 3.6 Rating system for quantitative abundance.

<table>
<thead>
<tr>
<th>Approximate Corresponding</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Strong</td>
<td>XXXX</td>
</tr>
<tr>
<td>Strong</td>
<td>XXXX</td>
</tr>
<tr>
<td>Medium</td>
<td>XXXX</td>
</tr>
<tr>
<td>Weak</td>
<td>XX</td>
</tr>
<tr>
<td>Very Weak</td>
<td>X</td>
</tr>
<tr>
<td>Trace</td>
<td>Trace</td>
</tr>
</tbody>
</table>

The origin of the clay minerals within these sedimentary rocks is interpreted as inherited (detrital) from parent materials, with the exception of the paleosol microfacies. During the Carboniferous, tropical conditions prevailed which resulted in abundant rainfall and increased rates of erosion and clastic sedimentation. Sources of clastic sediments, as discussed previously, originated from the northeast where the craton was subaerially exposed to weathering and pedogenic processes. This highly weathered
environment is consistent with the abundance of kaolinite that was inherited within the microfacies. Also, associated with the Carboniferous are the vast coal deposits indicating waterlogged regions. These wetlands provide an acidic environment for organic debris and the formation of HIM’s. Other than the origin of these clay minerals being inherited by weathering on the surface of the craton, pedogenic processes formed additional clay minerals in-situ. The parent material of the paleosol, presumably shale or alluvium (consisting of inherited clay minerals), was superimposed/masked by pedogenic process that formed additional clay minerals. Upon subaerial exposure, weathering of these paleosols would have contributed additional clay minerals that would later be deposited/inherited within the microfacies of the Lawrence Shale. The depositional environments in which these clays were inherited include: near shore (fluvial-deltaic to estuarine), subtidal to intertidal flats, and marginal/open marine.
CHAPTER 4: SUMMARY

In northeastern Kansas, the Lawrence Formation (Virgilian Series, Douglas Group) was deposited, within the Forest City Basin, during the Upper Carboniferous (Pennsylvanian) Period approximately 320 million years ago. Numerous cases of rock and slope instability within the Lawrence Shale were encountered in previous highway, excavation, and construction projects. The Kansas Department of Transportation is planning a realignment of Highway 59, that will be exposing 75 foot road-cuts of this problematic formation, within Pleasant Grove Hill. Detailed sedimentological descriptions and geotechnical tests were performed to identify the areas that might be most susceptible to failure.

Figure 4.1 provides the relative paleoenvironments during the late Carboniferous Period. The microfacies of the Lawrence Shale, within Pleasant Grove hill, have been identified with corresponding depositional processes and environments (Table 4.1).
Figure 4.1: The Lawrence and Stranger Formations are dominated by non-marine/clastic environments, unlike the marine/carbonate-rich environments of the Oread and Stanton Limestones.
<table>
<thead>
<tr>
<th>Microfacies</th>
<th>Depositional Process</th>
<th>Depositional Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churned Shale</td>
<td>Disruption or reformation of the primary sedimentary bedding due to bioturbation</td>
<td>Marginal marine (bivalves); continental (root whisps and plant fossils)</td>
</tr>
<tr>
<td>Shale</td>
<td>Low energy, sediment fall out</td>
<td>open marine environment below wave base</td>
</tr>
<tr>
<td>Clayshale</td>
<td>Suspension fall out</td>
<td>Ponded water (lagoons or abandoned tidal creeks and channels)</td>
</tr>
<tr>
<td>Coal</td>
<td>Peat accumulation and coalification</td>
<td>Wetland</td>
</tr>
<tr>
<td>Paleosol</td>
<td>Weathering and pedogenesis of pre-existing facies in reducing environments</td>
<td>Waterlogged soil</td>
</tr>
<tr>
<td>Carbonate-rich Shale</td>
<td>Both marine and pedogenic processes</td>
<td>Subaerially exposed limestone with overlying soil development</td>
</tr>
<tr>
<td>Lenticular Shale</td>
<td>Alternating periods of high energy (turbulent water) and low energy (slack water)</td>
<td>Subtidal, intertidal, or mid-mud flat</td>
</tr>
<tr>
<td>Sandy/Silty Shale</td>
<td>High energy with rapid sedimentation</td>
<td>Near-shore, fluvial-deltaic to estuarine</td>
</tr>
<tr>
<td>Weathered Silty/Sandy Shale</td>
<td>High energy with rapid sedimentation; churned and altered by modern pedogeneisis</td>
<td>Near-shore, fluvial-deltaic to estuarine; altered by modern weathering and pedogenesis</td>
</tr>
</tbody>
</table>

A summary of all microfacies test results is given in Table 4.2.
Table 4.2: Summary of Microfacies Durability Results

<table>
<thead>
<tr>
<th>Microfacies</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churned Shale</td>
<td></td>
<td>Shale</td>
<td>Clayshale</td>
<td>Coal</td>
<td>Paleosol</td>
<td>Carbonate-rich Shale</td>
<td>Lenticular Shale</td>
<td>Sandy/Silty Shale</td>
<td>Weathered Shale</td>
</tr>
<tr>
<td>Slake Range</td>
<td>4.03 - 79.5</td>
<td>46.3 - 49.6</td>
<td>18.3 - 63.34</td>
<td>---</td>
<td>0 - 10.27</td>
<td>39 - 56.8</td>
<td>13.65 - 89.8</td>
<td>78.1 - 92.3</td>
<td>4 - 39.4</td>
</tr>
<tr>
<td>Slake Avg.</td>
<td>41.2</td>
<td>47.9</td>
<td>27.8</td>
<td>---</td>
<td>2.15</td>
<td>47.9</td>
<td>56.5</td>
<td>84.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Water Abs. Range</td>
<td>19.5 - 47.4</td>
<td>26.7 - 31.3</td>
<td>25.4 - 37.3</td>
<td>---</td>
<td>33.5 - 42.9</td>
<td>30.6 - 36.9</td>
<td>12.7 - 28.6</td>
<td>9.5 - 28.4</td>
<td>20.6 - 38.6</td>
</tr>
<tr>
<td>Water Abs. Avg.</td>
<td>35.7</td>
<td>29</td>
<td>32.8</td>
<td>---</td>
<td>40.8</td>
<td>33.7</td>
<td>20</td>
<td>15.7</td>
<td>28.5</td>
</tr>
<tr>
<td>CaCO3 Range</td>
<td>0.35 - 10.13</td>
<td>1.6 - 3.2</td>
<td>0.48 - 9</td>
<td>---</td>
<td>4.35 - 22</td>
<td>36.2 - 47.7</td>
<td>0.44 - 3.55</td>
<td>0.43 - 4.75</td>
<td>0.32 - 21</td>
</tr>
<tr>
<td>CaCO3 Avg.</td>
<td>2.9</td>
<td>2.4</td>
<td>2.4</td>
<td>---</td>
<td>12.4</td>
<td>41.9</td>
<td>2.4</td>
<td>3</td>
<td>4.3</td>
</tr>
</tbody>
</table>
The slake durability results proved to be the most useful/reliable in terms of determining the materials resistance/durability. Of the materials tested, ~65% of the Lawrence Shale was classified as soil-like with low durability. The slake durability of the microfacies, in terms of increasing durability, is as follows: paleosols < weathered shale < clay shale < churned shale ≤ shale < carbonate-rich shale < lenticular shale < silty/sandy shale. The least resistant facies was identified as the paleosols (Id = 0-10.7), located at elevation of ~1038’ – 1029’. The sandy/silty shales are the most durable (Id2 = 74.7-92.3) and are located near the base of Pleasant Grove Hill. Slake durability values are inversely proportional to the materials water absorption and proportional to the amount of sand content. No durability relationship was identified for the amount of calcium carbonate (used as a cementing agent) within the rock material.

Using X-ray diffraction, kaolinite and clay mica were the most abundant clay minerals within all of the microfacies. More importantly, within the clay fraction was the presence of 2:1 expandable layer silicates that are characterized by their ability to shrink/swell. Vermiculite was the dominant expandable 2:1 layer silicate within most of the microfacies. Relative quantities of smectite and vermiculite were approximately the same in the clayshale microfacies.
CHAPTER 5: CONCLUSION

Overall, the concerns associated with rock and slope instability within the Lawrence Shale are attributed to the material's predominately low durability (soil-like), and the presence of 2:1 expandable clays. The microfacies that pose the most potential for rock/slope failure are the paleosols, clayshale, weathered shale, lenticular shales, and the interface between the more durable heterogeneous shales and the overlying less resistant materials. The microfacies that are potentially the most susceptible threat of rock/slope failure are as follows: Paleosol (High Concern), Weathered Shale and Clayshale (High-Medium Concern), and Lenticular Shale (Moderate Concern).

The paleosols are the most susceptible microfacies for potentially inducing rock/slope failure. The slake durability average was 2.15% with a range of 0-10.27%. The paleosols contain abundant ancient root traces/channels and angled shear planes with slickensides. The root traces/channels provide conduits for water to infiltrate into the paleosol and result in the high water absorption values (33.5 – 42.9), supported by the Jar Slake test. The water disrupts the thin platy ped structure of the paleosols causing the material to disintegrate into a pile of flakes, as indicated by the slake durability results. Throughout the paleosol, numerous angled shear planes, with slickensides, occur at various directions and angles. The shear planes were generated by either one or a combination of the following processes: pedogenesis, compactional/overburden forces, or shrink/swell. Most of the angled shear planes were identified as having smooth, striated, and thinly coated clay surfaces which create numerous planes of weakness within the paleosol.
The weathered shale microfacies is classified as high-medium concern for rock/slope instability as the slake durability average was 31.5% with a range of 4-39.4%. This microfacies was originally a member of the more resistant sandy/silty shale microfacies, found toward the base of Pleasant Grove Hill. However, because the material is located at the toe of the back slope and with close proximity to the ground surface, modern weathering and pedogenic processes have altered the material to its weathered shale microfacies. The effects of weathering and pedogenic processes, on rock materials close to the surface, are most extensive at the base or toe of the hill. Abundant fractures and oxidation of the Lawrence Shale is a result of the high amounts of water accumulation/percolation, due to surface runoff from hill slopes, and more vegetative growth (root penetration). Along the slopes of the hill, the degree and extent of weathering and pedogenisis is less. The most distinguishing feature throughout the weathered shale microfacies was the abundant vertical fractures. This will not only lead to rock/slope stability problems when exposed on the road-cut, but it may also cause problems beneath the subgrade of the new highway. It is recommended to consider removing the interval of weathered shale where exposed during road-cut excavation.

The clayshale microfacies is classified as high-medium concern for rock/slope instability with an average slake durability of 21.8%. This microfacies occurred randomly throughout the Lawrence Shale in thin, isolated beds. Compared to the other microfacies, the clay mineralogy indicated that there were higher relative quantities of smectite. Smectite’s ability to shrink/swell exceeds that of vermiculite. Because of this, not only is the clayshale durability of concern, but also the stability of the material both above and below this more notably expandable microfacies.
Although the lenticular shale microfacies performed moderately well in the slake durability (avg. $I_d = 56.5$) and water absorption (20%) tests, the fabric and structure of the material poses moderate concern for rock/slope failure. The lenticular shale microfacies contains alternating silty/sandy lenticels (isolated or connected) that abruptly overlie clay and organic rich layers. Because of the materials heterolithic nature, the geotechnical behavior of the lenticular shale is complex. The coarser grained lenticels allow water to infiltrate the lenticular shale. With the presence of expandable clays, exposure of this material to seasonal conditions (wetting and drying cycles) will generate fractures, due to shrinking and swelling, along the abrupt interface between the clay and sand/silt lenticels. In addition to fracturing, the saturated clays become very slick, due to reduced friction/cohesion between the sand/silt-shale laminae interface, and may lead to rock/slope failure. One factor that may be influencing the durability of the lenticular shale is the amount of organic material within the clay. The lenticular shales that lie at great depths, within Pleasant Grove Hill, contain black shale with alternating white sand/silt lenticels. The black color implies reducing conditions as well as abundant organic material. Organic matter is characterized as having very high surface charge areas, which might in turn impede the shrink/swell capabilities of the expandable clays. Organic matter significantly increases the liquid and plastic limits of clay.

Within the geologic profile of Pleasant Grove Hill lie potential planes of weakness between the interface of durable and nondurable microfacies that might promote slope failure. For example, there may be a potential plane of weakness both above and below the interface between the less durable paleosol. Other interfaces that might be
susceptible to slope failure include: sandy/silty shale and lenticular shale, lenticular shale and overlying shale, and the Toronto Limestone and upper Lawrence Shale.

Identifying these areas most susceptible to rock/slope failure, engineers may take preventative measures to manage slope stabilization. Slope stabilization efforts may include: regrading and benching of slopes to reduce their steepness (slope angle), reduce water absorption by installing drainage and runoff channeling structures, vegetate slope, and/or construct retaining walls, sunken pylons, and backfilled supports. Although repair of slopes can be performed following slope failure, the economic consequences far outweigh the initial remedial costs, even in a short period of time.
APPENDIX A: METHODS AND MATERIALS FOR SAMPLE PREPARATION

SAMPLE PREPARATION FOR SLAKE DURABILITY

The slake durability test method and procedures below follow the American Society for Testing and Materials (ASTM) Standards (ASTM D 4644). Slake Durability is a geotechnical testing method that determines the durability of shales and other similar weak rocks after two drying and wetting cycles with abrasion. Results are given in terms of how the material is retained (Type I-III) and by calculating a slake durability index after the second cycle.

SAMPLE PREPARATION FOR JAR SLAKE

The Jar Index test (FHWA, 1977) is a fast and simple method to determine how dry samples of rock material respond when immersed in water. A rock sample of ~20g is oven dried and immersed in distilled water. The resulting behavior of the sample is then observed after 2 hours of being immersed and assigned a jar index value according to specific criteria (Table 2.8).

Table 2.8: Jar Index values and descriptions

<table>
<thead>
<tr>
<th>Jar Index</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Degrades into a pile of flakes or mud</td>
</tr>
<tr>
<td>2</td>
<td>Breaks rapidly and/or forms many chips</td>
</tr>
<tr>
<td>3</td>
<td>Breaks rapidly and/or forms few chips</td>
</tr>
<tr>
<td>4</td>
<td>Breaks slowly and/or develops several fractures</td>
</tr>
<tr>
<td>5</td>
<td>Breaks slowly and/or develops few fractures</td>
</tr>
<tr>
<td>6</td>
<td>No Change</td>
</tr>
</tbody>
</table>

(FHWA, 1977)

Water absorption (Abs. %) is determined as a secondary procedure during the jar index tests. Samples were weighed prior to and after oven drying and then after
immersion during the jar index test. The percentage of water absorbed, by weight, is then obtained from this equation:

\[
\% \text{ Abs.} = \frac{\text{Saturated weight (after immersion)} - \text{Oven dry weight (post Jar test)}}{\text{Saturated weight (after immersion)}} \times 100
\]

**SAMPLE PREPARATION FOR CHITTICK**

The principles and procedures for the Chittick Analysis, follows that given by Machette (1986). The purpose of the Chittick Analysis is to provide a relatively quick and inexpensive method of measuring calcium and magnesium carbonate in rock/soil material. The amount of calcium carbonate is determined by dissolving the sample material in hydrochloric acid and measuring the volume of carbon dioxide gas produced by the reaction.

Calcium carbonate is a common cementing agent in shale rock types. A useful predictor of durability is calculating the percentage of carbonate in the sample material by using the Chittick apparatus (Fig. 2.5). The volume of carbon dioxide is proportional to the amount of calcium carbonate.

In a previous study by Miller and McCahon (1997), the % CaCO₃ was found to increase with slake durability index (Iᵩ₂) values. Samples with >35% calcium carbonate have medium to high durability.
METHODS FOR CLAY/SILT MINERALOGY

Identification of clay mineralogy involves variable pre-treatments of the rock samples in order to get accurate and recognizable X-ray diffraction (XRD) patterns (diffractograms). Analysis of the rock samples was done by determining the peaks, generated on the XRD patterns, and comparing them to XRD patterns of known minerals. The XRD pretreatments and procedures used for identifying clay and silt mineralogy follows that given by Jackson (1975).

MICROFABRIC ANALYSIS USING PHOTOMICROGRAPHY

For selected microfacies, petrographic thin sections were made by a commercial laboratory in order to analyze the microfabric and sedimentary bedding features. In order to identify bedding features, all thin sections were prepared vertically, most at a size of 1” x 2” (25 x 45 mm) and a few at 2” x 3” (51 x 75 mm). Thin sections were examined using a Nikon Optiphot-Pol petrographic microscope with the Nikon UFX camera system attachment. Photomicrographs were taken under both plane-polarized and crossed-polarized light. The terminology used to describe the micromorphology of the thin sections was from Stoops (2003).
## APPENDIX B

### STRATIGRAPHIC BORE LOGS OF PLEASANT GROVE HILL

<table>
<thead>
<tr>
<th>APPENDIX  B</th>
<th>PAGE</th>
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<td>B-1 Station 506+36, 200’ Rt CL Deep Hole #1 (DH1)</td>
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<td>B-3 Station 512+00 Soybean field (SF1)</td>
<td>100</td>
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<tr>
<td>B-6 Station 531+50, 25’ Rt CL Base of hill (BH1)</td>
<td>125</td>
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</table>
APPENDIX B-1: STATION 506+36, 200' RT CL - DEEP HOLE #1 - DH1

Project Number: 59-23 K-7888-01
Project Name: Realignment of Hwy 59, south of Lawrence, KS
Site: Pleasant Grove, KS in Douglas County

<table>
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<tr>
<th>Depth</th>
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**Surface Elevation:** 1083.5'

**Location:** Sta. 506 + 36 200' Rt

**Material Description**

Not recovered

2.3

**Plattsmouth Limestone:** Very Pale Orange (10YR 8/2) to White (N9) and stained Dark Yellowish Orange (10YR 6/6) dense hard limestone. Few calcite filled fractures (vertical angled). Gravish Brown (5YR 3/2) claystone interbeds at 2.3 - 2.5 and 3.2 - 3.3.

8.7

**Heebner Shale:** Light Tan Gray to Grayish Orange (10YR 7/4) with Dark Yellowish Orange (10YR 6/6). Moderate Brown (5YR 3/4) and Grayish Black (N2) staining oxidation. Horizontal, vertical, and step fractures. Medium Light Gray (N6) to Grayish Black (N2) silted shale with horizontal fractures. Becomes more resistant and darker downward. Light Tan Gray to Grayish Orange (10YR 7/4) shale band at 10.1 -

11.5

10.2' Very Light Gray (N8) silted starred ripple near base.

**Remarks:**

Hole 14, near Pleasant Grove, KS in Douglas County.

**Sample:**

- Completion Depth: 802
- Date Started: 01/29/04
- Date Completed: 05/29/04

**JAR INDEX**

- 1. Degraded into pile of flakes or mud
- 2. Breaks rapidly and or forms many chips
- 3. Breaks rapidly and or forms few chips
- 4. Breaks slowly and or develops several fractures
- 5. Break slowly and or develops few fractures

- No change

**CatCO3 %**

- High to Medium Durability - 50%
Kansas State University

Project Number: 59-23 K-7888-01
Project Name: Realignment of Hwy 59, south of Lawrence, KS
Site: Pleasant Grove, KS in Douglas County

Surface Elevation: 1083.5'
Location: Sta. 506 + 36 200' Rt

Material Description
Gravish Black (N5) well indurated (resistant) shale with abundant horizontal fractures. sparse rhyolitic balling and heterogenous root traces. Moderate
Yellowish Brown (10YR 5.4) shale bands near top with Very Light Gray (10Y) sands. layers beneath them (some with more resistant concretions). White (N9) to Very Light Gray (N8) more resistant fine sand and silt interbedded at 13'-0.1' thick.

LEAVENWORTH LIMESTONE
Medium Gray (N5) to White (N9) and Light Brownish Gray (5YR 6/1) limestone. Small recrystallized calcite shells. Stained Dark Yellowish Orange (10YR 6.6), Bottom 0.4', Dark Yellowish Orange (10YR 6.6) to Pale Yellowish Brown (10YR 6.2) less indurated limestone with White (N9) carbonate inclusions, silted ripples. Sharp contact at base.

S NYDERVILLE SHALE Pale Blue (5B 6/2), Greenish Gray (5GY 6/1), to Medium Light Gray (N6) palaeosol. Top 0.6' is less resistant and irregularly fractured while the bottom 0.6' is more resistant and contains White (N9) carbonate concretions (thecocysticrines), root traces, and irregular fractures.
Similar palaeosol as above but Greenish Gray (5B 6/2) with more White (10Y) carbonate (powdery) thecoscycticrines. Irregular fractures and sheared planes with pedogenic slicks (shrink swell). Shear planes at 20° (-40°), 20.6° (-40°), 21' (-20°).

Remarks:
Hole 1, near Pleasant Grove, KS in Douglas County

Field Data
Graph. Log Depth (ft) Sample Log Sample Type RQD Mudstone FM Plastic Unit Plastic Limit Plastic Index Unidentified Components Argillite CaCO3 % Silica (Dolomite) Silt Type

Laboratory Data

JAR INDEX
1. Degraded to a pile of flakes or mud
2. Breaks rapidly and or forms many chips
3. Breaks rapidly and or forms few chips
4. Breaks slowly and or develops several fractures
6. No change
CaCO3 % (High to Medium Durability) 35 %

76
**Project Number:** 59-23  K-7888-01  
**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS  
**Site:** Pleasant Grove, KS in Douglas County

<table>
<thead>
<tr>
<th>Surface Elevation: 1083.5</th>
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<td><strong>Location:</strong> Sta. 506 + 36 200' Rt</td>
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### Material Description

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**Remarks:**
Hole #1, near Pleasant Grove, KS in Douglas County.

**Completion Depth:** 38 ft  
**Date Started:** 06/29/94  
**Date Completed:** 07/20/94  
**Drilled By:** 
**Logged By:** 
**Site Type 1:** Retained material consists of large and small pieces  
**Site Type 2:** Retained material consists of large and small fragments  
**Site Type 3:** Retained material is exclusively small fragments  
**JAR INDEX**
1. Degrades into pile of flakes or mud  
2. Breaks rapidly and/or forms many chips  
3. Breaks rapidly and/or forms few chips  
4. Breaks slowly and/or develops several fractures  
5. Breaks slowly and/or develops few fractures  
6. Not change  
**CaCO3 %**  
High to Medium Density - 35%
### Kansas State University

#### Project Number: 59-23  K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

### Surface Elevation:
1083.5'

**Location:** Sta. 506 + 36.200' Rt

### Material Description

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<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>ROD</th>
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<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Atterberg Limits</th>
<th>Particle Size Distribution</th>
<th>JAR Index</th>
<th>Calcite %</th>
<th>Slake Durability Index</th>
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</table>

- *Core* 48.7 ft: Smooth, slick, and shiny glossy; other organic debris is oxidized black to deep red maroon.
- *Continued Next Page*
- More resistant Medium Light Gray (T66) to Greensh (T50) 6.4 ft pale ale with root traces and angled shear planes with slickensides at 48° (−30°) and 48.4° (−30°)
- Grades to more clay-rich pale ale with abundant irregular fractures (shrink-swell deccoration). Columnar ped structure. Similar pale ale as above (irregular angled fractures). Pale reddish brown (10YR 5.4) oxidation along fractures at base. Becomes more resistant towards base with sharp contact.

- *Pale Green (5G 7.2) to Pale Yellowish Green (10GY 7.2) shale with resistant carbonate nodules lenses (1/4" thick).*

- *Soft weak fractured zone (clay rich) at 55.8' (0.3 thick).*
- Thin (< 0.1") Liney lenses at 55.8', 56.6', 56.8'.

- Grades into channeled shale with bivalve fossils and no carbonate concretions lenses.
- Graysish Orange (10YR 7.4) dense hard limestone with clastic filled biostrome at 58.9'.

**Remarks:**

Hole #1, near Pleasant Grove, KS in Douglas County.

**Completion Depth:** 58.2'
**Date Completed:** 06/20/04
**Dilled by:**
**Description:**

- Slake Type 1: Remained pieces virtually unaltered
- Slake Type 2: Remained material slightly altered and small pieces
- Slake Type 3: Remained material is exclusively small fragments

<table>
<thead>
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<th>JAR INDEX</th>
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<tbody>
<tr>
<td>1. Degraded into pile of flakes or mud</td>
</tr>
<tr>
<td>2. Breaks rapidly and/or forms many slumps</td>
</tr>
<tr>
<td>3. Breaks rapidly and/or forms few slumps</td>
</tr>
<tr>
<td>4. Breaks slowly and/or develops several fractures</td>
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<tr>
<td>5. Breaks slowly and/or develops few fractures</td>
</tr>
<tr>
<td>6. No change</td>
</tr>
</tbody>
</table>

**Calcite %**

- High to Medium Durability: 30%
Surface Elevation: 1083.5 ft

Location: Sta. 506 + 36 200' Rt

Material Description:

60.2 (60.2" thick) with sharp basal contact. Contains abnormally horizontal fractured Medium Gray (NS) and Brownish Gray (5YR 4.1) shale with silticement. Grades into a finer interlayered shale (0.3" thick) with scaly coal laminations.

60.9

Very fine to fine wavy to lenticular bedding of coal organic rich (sooty) layers with Medium Blush Gray (5B 5.5) to Light Gray (N7) and at top (0.2") Graded to thin wavy bedding Greenshield Gray (5G 6.1) shale that is finely mottled Brownish Gray (5YR 4.1). Leafy plant fossils and other plant organic debris.

66.2 Medium Gray (NS) to Greenshield Gray (5GY 6.1) finely laminated shale with plant leafy debris. Abundant fractures along horizontal bedding plane. Some areas with lenticular to flaser bedding towards the bottom.

67.7 Soft weak clay rich zone at 65.6 and 66.5" (0.1" thick). Plant and root fossils.

68.7 Medium Gray (NS) to Medium Dark Gray (N4) shale with thin lenticular to streaked bedding with White (N0) very fine sand to silt laminations. Few areas with flaser bedding. Very thinly laminated and fractures along horizontal bedding plane.

Similar to above but with more lenticular bedding with few areas of flaser bedding. Munsens with few organic debris. Few areas with dense hard ironstone bands (cementation) and concretions. Soft weak clay rich zone at 71.6 (0.2" thick). Sharp basal contact.

Remarks:

Hole #1, near Pleasant Grove, KS in Douglas County.

Project Number: 59-23 K-7888-01
Project Name: Realignment of Hvy. 59, south of Lawrence, KS
Site: Pleasant Grove, KS in Douglas County

FIELD DATA

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JAR INDEX

1. Drains into pile of clays or mud
2. Breaks rapidly and forms many chips
3. Breaks rapidly and forms few chips
4. Breaks slowly and develops several fractures
5. Breaks slowly and develops few fractures
6. No change

CaCO3 %

High to Medium Deleterious - 35%
**Surface Elevation:** 1083 ft

**Location:** Sta. 506 + 36 200' Rt

**Material Description**

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**Remarks:**

- **Core:** Hole = 1, near Pleasant Grove, KS in Douglas County.
- **Completion Details:**
  - Date Started: 02/28/04
  - Date Completed: 02/29/04
  - Edited By: [Redacted]

**JAR INDEX**

- 1. Degrades into pile of flakes or mud
- 2. Breaks rapidly and crumbles into many chips
- 3. Breaks rapidly and crumbles into few chips
- 4. Breaks slowly, and/or develops several features
- 5. Breaks slowly and/or develops few fractures
- 6. No change

- **CaCO₃ %:** High to Medium Durability - 30%
Surface Elevation: 1083.5 ft

Location: Sta. 506 + 36 200' Rt

Material Description

84.4 Micaceous and organic rich silty shale with soft sediment deformation and sunken ripples (load structures) at 83.5 ft to

84.4 'Continued Next Page'

85.7 Much thinner interbedded consisting of lenticular to pinstripe bedding with minor amounts of flaser bedding. Fractures along shale and sandy lenticule interface

86.2 Sandy shale at 85.7 to 86.2 with White (NP) stratified ripples load structures.

Similar heterolithic shale with thin lenticular pin stripe bedding as above.

Micaceous and organic debris present.

88.2

Project Number: 59-23 K-7888-01

Project Name: Realignment of Hwy. 59, south of Lawrence, KS

Site: Pleasant Grove, KS in Douglas County

FIELD DATA

LABORATORY DATA

Graph: Log

Sample Type

RQD

Mass %

Liquid Limit

Plastic Limit

Plastic Index

Unconsolidated

Consolidated

Jar Index

CaCO3 %

Shale Fragility

Shale Type

Remarks:

Hole #1 near Pleasant Grove, KS in Douglas County

Deformation: Blunt Pointed

Sample Date: 06/29/01

Sample Drilled: 06/29/01

Deformed By:

Fracture Type:

1. Degrades into pile of flakes or mud

2. Breaks rapidly and/or forms many chips

3. Breaks rapidly and/or forms few chips

4. Breaks slowly and/or develops several fractures

5. Breaks slowly and/or develops few fractures

6. No change

CaCO3 %

High to Medium Density: 3%
### Project Number: 59-23  K-7888-01
### Project Name: Realignment of Hwy. 59, south of Lawrence, KS
### Site: Pleasant Grove, KS in Douglas County

<table>
<thead>
<tr>
<th>Surface Elevation: 1083.5’</th>
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<tbody>
<tr>
<td>Location: Sta. 506 + 56, 209 Rt</td>
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</table>

**Material Description**
- Same as above but with more areas with streaked starved bedding downward of Light Olive Gray (5Y 6/1) to Very Light Gray (N18) fine sand-silt. Sharp contact at base.

<table>
<thead>
<tr>
<th>Depth (ft)</th>
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**Remarks:**
- Hole #2, near Pleasant Grove, KS in Douglas County.

**JAR INDEX**

- Calcite Index
- 1. Degraded into pile of flakes or mud
- 2. Breaks rapidly and/or forms many chips
- 3. Breaks rapidly and forms few chips
- 4. Breaks slowly and develops several fractures
- 5. Breaks slowly and/or develops few fractures
- 6. No change

- Calcium Carbonate %
- High to Medium Densitity: 35%
APPENDIX B-2: STATION 506+36, 200' RT CL - DEEP HOLE #2 - DH2

**Department of Geology**

Kansas State University

**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

<table>
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<td><strong>Location:</strong></td>
<td>Sta. 506+36 200' RT</td>
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</table>

**Material Description**:

- Greenish Gray (5G 6/1) pebbled with abundant White (10Y 7/1) carbonate concretions (1mm - 1")
- Some shale as above but with much more weathering. Staining of Pale Yellowish Orange (10YR 8/6) to Light Brown (5YR 5/6).
- Some stained shale as above but more resistant and contains small Gravish Yellow Green (5Y 7/2) clay filled vughs and vughs.
- Sharp contact at base.

- Toronto Limestone: Hard resistant Yellowish Gray (5Y 7/2) fossiliferous limestone with Dark Yellowish Orange (10YR 6/6) staining. Few small clay filled vughs at top. Few biogenic traces.

- Some fossiliferous limestone as above but with no vughs. More biogenic traces and staining downward. Grades at base.

**Remarks**:

- Hole #2, near Pleasant Grove, KS in Douglas County.

**Completion Depth:** 102'-6"

- Date Drilled: 06/30/01
- Date Completed: 07/01/01
- Drilled by:
- Logged by:

**JAR INDEX**

- 1. Degraded into pile of flakes or mud
- 2. Breaks rapidly and/or forms many chips
- 3. Breaks slowly and/or develops several fractures
- 4. Breaks slowly and/or develops few fractures
- 5. No change

- **CaCO3 %**
  - High to Moderate Durability - 35%±

- **CaCO3 %**
  - High to Moderate Durability - 35%±
**Project Number:** 59-23  K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

### Surface Elevation:
1083.5'

### Location:
Sta. 306 + 36 200' Rt.

### Material Description

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>92.9</td>
<td>Medium Light Gray (66) silty sandy, micaceous shale with black organic particles debris. Some biogenic traces toward top. Micaceous sandstone at 93.1' (0.5 thick) with soft sediment deformation of unknown starved ripples (load structure). Some silty sandy, micaceous shale as above with black organic debris and plant fragments. Organic debris and mica decrease downward.</td>
</tr>
<tr>
<td>94.2</td>
<td></td>
</tr>
</tbody>
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### Field Data

<table>
<thead>
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<th>Sample Type</th>
<th>RQD</th>
<th>RQD Value</th>
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</tr>
</tbody>
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### Laboratory Data

<table>
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<tr>
<th>Unconfined Compression</th>
<th>ITI</th>
<th>CPT-SC</th>
<th>Side Slope Stability</th>
<th>Side Type</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>2.3</td>
<td>77.47</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Remarks:

Hole #2, near Pleasant Grove, KS in Douglas County.

---

**Completion Depth:** 92.8'

**Date Started:** 06/30/01

**Date Completed:** 06/30/01

**Dilled By:**

**Legend By:**

- Slate Type 1: Retained pieces virtually unchanged.
- Slate Type 2: Retained material consists largely and small particles.
- Slate Type 3: Retained material is exclusively small fragments.

**JAR INDEX**

1. Breaks under pile of Dolines or mud
2. Breaks rapidly and or forms many chips
3. Breaks rapidly and or forms few chips
4. Breaks slowly and develops several fractures
5. Breaks slowly and or develops fine fractures
6. No change

**CaCO3 %:**

High to Medium Durability - 33%
### Field Data

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<tr>
<th>Sample No.</th>
<th>Sample Type</th>
<th>IPSH</th>
<th>Plaque Index</th>
<th>UCS Index</th>
<th>CalCO3 %</th>
<th>Splitting Factor</th>
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<td>102.8</td>
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<td></td>
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<td></td>
<td>3.5</td>
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### Laboratory Data

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
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<tbody>
<tr>
<td>UCS</td>
<td>86.65</td>
</tr>
</tbody>
</table>

### Remarks

- **Sample Description:**
  - Located: Sta. 506 + 36 200' Rl.
  - Material Description:
    - Same silt, sandy, micaceous shale as above with black organic debris and plant fragments. Organic debris and mica decrease downward.
    - 97.7
    - Similar to above shale but little organic debris and less mica. More indurated Light Gray (N5) to Medium Gray (N5) shale with areas of abundant mica and organic debris. Becomes more sandy downward.
    - 98.0
    - Medium Light Gray (N6) heterolithic shale with mostly very thin fine lenticular bedding. Minor amounts of flaser bedding. Abundant mica and black organic particles.

- **Remarks:**
  - Hole #2, near Pleasant Grove, KS in Douglas County.
**Project Number:** 59-23  K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1083.5'

**Location:** Sta. 506 + 36 2007 Rt

**Material Description**

- Same green shale as above but without carbonate concretions, churned bedding with biovcale fossils. Continued Next Page

- Top 0.1' is interlaminated coaly, gray material that grades to Light Gray (N7) to Medium Dark Gray (N4) and Greenish Gray (5G 6/1) churned shale (weak paleoscleres) with irregular fractures (clay-rich). Greenish Orange (10YR 7/4) limestone nodules (3mm-2').
- Greenish Gray (5G 6/1), Medium Dark Gray (N4), and Brownish Gray (5YR 4/1) finely mottled, silty churned shale with abundant plant and leaf material debris. Greenish Orange (10YR 7/4) limestone interbeds (discontinuous erosional?) at 55.5' (-0.1' thick) and 64.1' (-0.2' thick) with black plant debris - both Ls. interbeds have sharp contacts (undulating bottom).

- Finely mottled Medium Gray (N5) and Greenish Gray (5G 6/1) churned shale.
- Discontinuous Greenish Orange (10YR 7/4) limestone interbed at 64.0' (-0.1' thick). Note mottling downward and becomes more sandy silty.

**FIELD DATA**

**LABORATORY DATA**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Sample</th>
<th>RQD</th>
<th>Maximum RCP</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Unconfined Compression</th>
<th>In (in)</th>
<th>CaCO3 %</th>
<th>Sk1</th>
<th>Shale Type</th>
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<td>1021</td>
<td>3</td>
<td>4.71</td>
<td>79.51</td>
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<td>1020</td>
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<td>37.16</td>
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<tr>
<td>1016</td>
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<td>67.5</td>
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</table>

**Remarks:**

- Hole #2, near Pleasant Grove, KS in Douglas County.
- Completion Depth: 1022.8'
- Core Sorted: 06/14/04
- Core Completed: 06/16/04
- Logged By:
- Noted By:

**JAR INDEX**

1. Debris into pile of flakes or mud
2. Flakes rapidly and/or form many chips
3. Flakes rapidly and/or form few chips
4. Splinters slowly and/or develops several fractures
5. Splinters slowly and/or develops few fractures
6. No change

CaCO3 %
High to Medium Durability - >35%
**Project Number:** 59-23  K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1083.5'

**Location:** Sta. 506 + 36 20' R1

### Material Description

48.3 Grayish Green (5GY 6 1) to Medium Gray (N5) paleosol with top 0.5' resistant and the rest weaker with irregular fractures. Bottom 0.2 Grayish Red Purple (5RP 4 2) oxidized paleosol Carbonated Near Past

49.8 Grades to Greenish Gray (5G 6 1) angular blocks paleosol with Light Olive Brown (3Y 5 6) root traces.

53.5 Pale Yellowish Green (10GY 7 2) to Light Greenish Gray (5G 8 1) silty shale with White (N9) carbonate inclusions (2mm-3'). Near base inclusions are replaced by few White (N9) providing carbonate concretions zones. Minor amounts of lenticular bedding near base. Bivalve fossils and biogenic trace fossils.

58.0 Same green shale as above but without carbonate concretions. Channeled bedding with bivalve fossils.

<table>
<thead>
<tr>
<th>Graphs Log</th>
<th>Depth (m)</th>
<th>Simple Type</th>
<th>RQD</th>
<th>Maximum v, %</th>
<th>Plastic Limit</th>
<th>Liquid Limit</th>
<th>Plastic Index</th>
<th>Unconfined Compressibility</th>
<th>Jar Index</th>
<th>CaCO3 %</th>
<th>Shot Drivability Index</th>
<th>Shale Type</th>
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</thead>
<tbody>
<tr>
<td>1035.2</td>
<td>1033.7</td>
<td>50</td>
<td>1</td>
<td>14.24</td>
<td>.83</td>
<td>3</td>
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<tr>
<td>1030.0</td>
<td>1025.5</td>
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<td>2</td>
<td>10.13</td>
<td>25.08</td>
<td>2</td>
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</tr>
</tbody>
</table>

**Remarks:**

Hole #2, near Pleasant Grove, KS in Douglas County.

**Completion Depth:** 102.9'

**Date Drilled:** 06/20/04

**Date Complated:** 06/30/04

**Borehole:**

**CaCO3 %**

| High to Medium Durability: 35% |

---

88
# APPENDIX B-3: STATION 512+00 CL - SOYBEAN FIELD AT TOP OF HILL - SF1

## Surface Elevation: 1082.5'

<table>
<thead>
<tr>
<th>Location</th>
<th>512+00 LC</th>
</tr>
</thead>
</table>

### Material Description

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>ECQ</th>
<th>organic</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
<th>Unconfined Compress.</th>
<th>CBR</th>
<th>Cal, %</th>
<th>Sludge Index</th>
</tr>
</thead>
</table>

- **Mantle**

  - **Plattsmouth Limestone**: Yellowish Gray (5Y 8/1) and Very Light Gray (8R) hard dense weathered limestone (broken blocks), stained Dark Yellowish Orange (5YR 6/6) to Medium Yellowish Brown (10YR 5/4). Some fossils (cristallized by calcite). Top 12' contains vugles, calcite lined vug at 2.7 (0.15' thick).
  - Same weathered limestone as above, more massive toward base of core.

- **Less weathered limestone, more massive.**

- **Same limestone as above, but thinly bedded with sharp contact at base.**

- **Heber Shale**: Yellowish Yellow to Grayish Yellow (5YR 4/4) weathered shale; Light Gray (7.5Y) to Medium Dark Gray (5N) fresh color. Stained Dark Yellowish Orange (10YR 6/6) with black, calcified spots.
  - Marl Shells present.
  - Darker and firmer shale: Medium Gray (7.5N) to Medium Dark Gray (4.5N) shale with Pale Yellowish Brown (10YR 6/2) weathered bands at 11.7 (0.1' thick) and 11.9 (0.1' thick).
  - Darker and firmer shale: Medium Dark Gray.

### Remarks:

- Northeast corner of soybean field.
**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1082.5’

**Location:** Sta. 512+00 Le

### Material Description

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Graphite Log</th>
<th>Sample Type</th>
<th>RD</th>
<th>VDF</th>
<th>Volume %</th>
<th>Lumped Limit (g/cm³)</th>
<th>Plastics Index</th>
<th>Unidentified Compounds</th>
<th>Air Index</th>
<th>CaCO₃ %</th>
<th>Salt Deposits</th>
<th>Salt Type</th>
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<tbody>
<tr>
<td>13.7</td>
<td></td>
<td></td>
<td>15</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Leavenworth Limestone:** Very Light Gray (6B) to Medium Light Gray (6N) thinly bedded and hard dense fossiliferous limestone. Some Dark Yellowish Orange (10YR 6/6) staining. Sharp contact at base.

**Slyderville Shale:** Greenish Gray (5GY 6/1) to Medium Blush Gray (5B 5/1) firm calcarenite paissed with a shear plane (with slicks) at 17.8’ (48%). Root or burrow trace.

**Remarks:**

Northwest corner of soybean field.
Surface Elevation: 1082.5' 

Location: Sta. 512+00 Le

Material Description

25.2 - Same calcite, paler as above with shear planes at 23.4°, 35°, and 24.4°.

26.2 - Lighter green (Light Greenish Gray 5G 8/1 to Pale Blue Green 5G 7/2) downward. Continued on next page. 

27.5 - Toronto Limestone: Weathered Pale Yellowish Orange (10YR 8/6) dense hard medium bedded blocky limestone with vugs toward the top. Stained Dark Yellowish Orange (10YR 6/6). Shaly, limy interbeds at 27° (0.1° thick) with sharp undulating contact. Less weathered, more indurated and massive limestone. White (N9) to Medium Light Gray (4). 

30.0 - Similar Gray (N7) dense hard, massive to blocky limestone as above. Shale breaks at 29.2° (0.1° thick) and 29.3° (0.1° thick) all with sharp contacts. More weathered dense hard limestone. Top 0.6' is very muddy limestone with clay filled vugs and mud drapes. Fewer vugs and drapes downward. Mud breaks, with limy interbeds (1-3mm) at 32-4° (0.1° thick). Vertical (70°) fracture plane at 32.4°-32.8°. 

33.1 - Weathered limestone with Dark Yellowish Orange (10YR 6/6) staining. Abundant bioturbation (calcite-filled White N9) and limey sandy inclusions (1mm-7cm). Sharp contact at base.

Remarks:
Northwest corner of soybean field

<table>
<thead>
<tr>
<th>Completion Depth: 38'</th>
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<tbody>
<tr>
<td>Date Started: 1/9/98</td>
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<tr>
<td>Date Completed: 1/9/98</td>
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<tr>
<td>Drilled By: Bob Brown</td>
</tr>
<tr>
<td>Logged By: Randy Bullough</td>
</tr>
</tbody>
</table>

JAR INDEX
1. Degraded into pile of flakes or mud
2. Breaks rapidly and/or forms many chips
3. Breaks slowly and/or forms few chips
4. Breaks slowly and/or develops several fractures
5. No change

CaCO₃ %
High to Medium Durability: 35%
**Spilsby River, Laurens County, KS**

**Surface Elevation:** 1082.5'

**Location:** Sta. 512+00 Le

**Materials Description**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Graphical Log</th>
<th>Sample Type</th>
<th>RQD</th>
<th>Material</th>
<th>Initial Data</th>
<th>Plastic Indices</th>
<th>Unidentified Comp.</th>
<th>Jar Index</th>
<th>CaCO₃ (%)</th>
<th>Site Duration</th>
<th>Sk-1 Type</th>
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<td>37.8</td>
<td>1044.7</td>
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<td>98</td>
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<td>0.79</td>
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<td>20.47</td>
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<tr>
<td>38.6</td>
<td>1043.7</td>
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<td>42.9</td>
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<td>45.3</td>
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<td>46.5</td>
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</table>

**Remarks:**
Northwest corner of soybean field

**CaCO₃ %:**
High to Medium Dacitohility - 35%
### Field Data

<table>
<thead>
<tr>
<th>Depth</th>
<th>Sample Type</th>
<th>RQF</th>
<th>Nisde %</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plast. Index</th>
<th>Consistency</th>
<th>Jar Index</th>
<th>Cacoal %</th>
<th>Shore Index</th>
<th>Material Description</th>
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<td>60.4</td>
<td>1022.2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dry hard, dark-greenish gray (5G 4.1 to 5G 4.1) fine mudstone.</td>
</tr>
<tr>
<td>61.0</td>
<td>1021.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Some shale as in 58.2. Grainy-green (5G 5.2) argillaceous mudstone.</td>
</tr>
<tr>
<td>61.7</td>
<td>1020.3</td>
<td></td>
<td>90</td>
<td></td>
<td></td>
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<td></td>
<td>2</td>
<td>0.18</td>
<td>20.85</td>
<td>Weak, crumbly. Grassy black (N2) organic rich (carbonaceous) shale (some woody and fibrous areas with minor amounts of yellow sulfur present).</td>
</tr>
<tr>
<td>64.9</td>
<td>1020.6</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Medium gray (N5) to medium dark gray (N4) clayey shale with irregular fractures. Soft, weak, material with woody, fibrous, leafy debris.</td>
</tr>
<tr>
<td>65.6</td>
<td>1020.4</td>
<td></td>
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<td></td>
<td></td>
<td>2</td>
<td>4</td>
<td>4.35</td>
<td>10.27</td>
<td>Clayey shale with abundant fractures (poor shale). Becoming silty to sandy at -65. Very soft, clay rich.</td>
</tr>
<tr>
<td>68.0</td>
<td>1014.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td>Same shale as above, but with lesser amounts of soft clay rich and crumbly zones. Waxy, heterogeneous (very thinly laminated) with white (N9) sandy interbeds and becoming finer faint down.</td>
</tr>
</tbody>
</table>

### Laboratory Data

<table>
<thead>
<tr>
<th></th>
<th>Cacoal %</th>
<th>Shore Index</th>
<th>CaCO3 %</th>
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<tbody>
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<td></td>
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</tbody>
</table>

### Remarks

Northwest corner of soybean field.

**CaCO3 %**

- Degrades into pile of fibrous or mud (4).
- Breaks rapidly and/or forms many chips (5).
- Breaks slowly and/or forms few chips (6).
- No change (5).

High to Medium Durability: 30-35%
<table>
<thead>
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<th>Depth (ft)</th>
<th>Sample Type</th>
<th>RQD</th>
<th>Martime (%)</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
<th>Unswelled Compaction</th>
<th>Jar Index</th>
<th>CaCO3 (%)</th>
<th>Silt + Clay</th>
<th>Sand Type</th>
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**Remarks:**
Northwest corner of soybean field

**JAR INDEX**

<table>
<thead>
<tr>
<th>Stiff Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Degrades into pile of fibrous material</td>
</tr>
<tr>
<td>2.</td>
<td>Breaks rapidly and forms many chips</td>
</tr>
<tr>
<td>3.</td>
<td>Breaks rapidly and forms few chips</td>
</tr>
<tr>
<td>4.</td>
<td>Breaks slowly and develops several fractures</td>
</tr>
<tr>
<td>5.</td>
<td>Breaks slowly and develops few fractures</td>
</tr>
<tr>
<td>6.</td>
<td>No change</td>
</tr>
</tbody>
</table>

**CaCO3 (%)**
High to Moderate Durability - 35%
**Surface Elevation:** 1082.5 ft

**Location:** Sta. 512+00 Lc

### Material Description

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Graph Flag</th>
<th>Sample Type</th>
<th>ROC</th>
<th>Moore's %</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plasticity Index</th>
<th>Compilation</th>
<th>Jar Index</th>
<th>CEC (meq/100g)</th>
<th>Skew Drainable Index</th>
<th>Shore Type</th>
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<td>10033</td>
<td></td>
<td>65</td>
<td></td>
<td>1</td>
<td>10.67</td>
<td>0.28</td>
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<td>1</td>
<td>10.67</td>
<td>0.28</td>
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<td>10.67</td>
<td>0.28</td>
<td>3</td>
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<td>58.2</td>
<td>10024</td>
<td></td>
<td>74</td>
<td></td>
<td>1</td>
<td>7.11</td>
<td>55.21</td>
<td>2</td>
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</tbody>
</table>

### Remarks:
- Northwest corner of soybean field

### JAR INDEX
- CatCO3 %
  - 1. Degraded into pile of debris or mud
  - 2. Breaks rapidly and forms many chips
  - 3. Breaks rapidly and forms few chips
  - 4. Breaks slowly and or develops few fractures
  - 5. Breaks slowly and or develops few fractures
  - 6. No change

- High to Medium Durability = 30%
APPENDIX B-4: STATION 524+25, 25’ LT CL - NORTH FACE OF HILL - NFH1

**Project Number:** 59/23 K-7888-01

**Project Name:** Realignment of Hwy 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>RCL</th>
<th>Volume %</th>
<th>Lcd %</th>
<th>Bulk Density</th>
<th>Unconfined Compress</th>
<th>CPT %</th>
<th>PI Type</th>
<th>SI Type</th>
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<tr>
<td>0.3</td>
<td>Thin covering of soil</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Plattemouth Limestone: Weathered</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dark Yellowish Orange (10YR 6/3) and White</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(30%) thin-bedded. Overall light tan gray limestone</td>
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<tr>
<td></td>
<td>Dense hard with few vugs</td>
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</tr>
<tr>
<td></td>
<td>Top 0.3” broken fractured.</td>
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</tr>
<tr>
<td>2.1</td>
<td>Limestone more weathered stained</td>
<td>1054.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Thin soft Dark Yellowish Orange (10YR 6/6) shale band at 0.3” to 0.6” thick.</td>
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</tr>
<tr>
<td>4.6</td>
<td>Same limestone as above, less weathered.</td>
<td>1053.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>Very Light Gray (5Y) to White (10Y) dense and thick to very thickly bedded limestone</td>
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</tr>
</tbody>
</table>
| | with areas of Dark Yellowish Orange (10YR 3/4) staining weathering. Thin shale break at 5” to 0.1” thick. Bottom 0.7” heavy 
| | bituminous filled with White (10Y) calcite and bottom 0.3” more weathered. Sharp 
| | contact at base. | | | | | | | | | | |
| 8.1 | Lawrence Shale: Top 0.2” in Grayish | 1049.9 | - | - | - | - | - | - | - | - | - |
| | Yellow Green (5G 1/2) soft clayey shale | | | | | | | | | | |
| | Rest is well indurated Grayish Yellow Green | | | | | | | | | | |
| | (5Y 7/2) to Grayish Green (5G 2/2) sandy shale with heterolithic bedding. | | | | | | | | | | |
| | Thin connections and single lines for 
| | limestone vary bedding. Wacke shale 
| | indurated at 10” to 0.2” thick and 12.6” 
| | (0.1” thick). Arched fractures at 11.6” (60°) 
| | and 12” (50°) vertical fractures from 12.2” 
| | to 12.5”. Modern root exist at bottom 2.0” 
| | Bottom 0.2” becoming more calcareous with 
| | limestone inclusions lenses. Thin White 
| | (10Y) limestone bed at 0.1” thick at base with 
| | sharp contacts. | | | | | | | | | | |

**Remarks:**

Rock is similar on north face of hill.
**Surface Elevation:** 1058.0

**Location:** Sta. 524+25.25 ft L14

### Field Data

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample</th>
<th>RQD</th>
<th>Mineral</th>
<th>Jar Index</th>
<th>CaCO3 %</th>
<th>shale, fracture</th>
<th>Shale Type</th>
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<tbody>
<tr>
<td>13.1</td>
<td>1044.0</td>
<td></td>
<td></td>
<td>90</td>
<td>3</td>
<td>0.72</td>
<td>20.72</td>
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<td>15.1</td>
<td>1042.9</td>
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<td>18.0</td>
<td>1040.9</td>
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<tr>
<td>19.3</td>
<td>1038.2</td>
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<td>21.4</td>
<td>1036.0</td>
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<tr>
<td>22.5</td>
<td>1035.8</td>
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</table>

### Laboratory Data

<table>
<thead>
<tr>
<th>Jet Index</th>
<th>CaCO3 %</th>
<th>Shale, Fracture</th>
<th>Shale Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.53</td>
<td>N/A</td>
<td>N/A</td>
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</tbody>
</table>

### Remarks:

- Back in timber on north face of hill

**Completion Depth:** 102.3 ft

**Date Started:** 11/03/04

**Date Completed:** 11/03/04

**Drilled By:**

**Logged By:**

**Shale Type:**

**Stain Type:** 1. Stained places, mostly gold-colored
2. Stained material consists of large and small pieces
3. Stained material is exclusively small fragments

**Co2%:**

- High to Medium Durability: 55%
<table>
<thead>
<tr>
<th>Surface Elevation: 1058.0</th>
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</thead>
<tbody>
<tr>
<td>Location: Sta. 524+25, 25 ft.</td>
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</tr>
</tbody>
</table>

**Material Description**

24.5 More indurated and well developed paleosol. 0.5" same broken angular blocks paleosol as above. Greenish Gray (5GY 6/1) paleosol with shear planes at 24° 2' (40°) and 24° 6' (30°). Becoming Medium Light Gray (8/1) and Grayish Purple (7R 4/2) at 24° 9' with coccolid Moderate Yellow (5Y 7/6) to Light Olive Brown (5Y 5/6) root traces. Continued Next Page

27.3 Top 0.5" same Grayish Purple (7PR 4/2) paleosol as above then grades to Medium Light Gray to Pale Blue (5G 6/2) paleosol. Shear planes (with slicks) at 24° 9' (20°), 25° 4' (60°), 26° 5' (20°), 26° 0' (20°), 26° 8' (25°), 26° 9' (25°), 27° 1' (40°), 27° 3' (80°).

28.1 Dark Greenish Gray (5G 4/1) weak paleosol with shear planes at 2/2 (80°) and 27° 6' (40°). Grades to Light Greenish Gray (5G 8/1) shale paleosol with Medium Gray (5N), Brownish Gray (5Y 4/1), to White (N) calcareous inclusions (chips, concretions, 0.1mm-0.1"").

10.5 Same Light Greenish Gray (5G 8/1) shale with abundant White (N) to Brownish Gray (5Y 4/1) limestone inclusions pebbles throughout. Very hand dense limestone lenses at 28° 8' (0.1"") thick. with bioturbation. Broken zone with abundant pieces of limestone at 28° 4' (0.2"") thick. Very hand dense limestone lenses with shale breaks (sharp contacts) at 28° 8' (0.1"") and 29° 9' (0.1"") thick. 30° (0.1"") w. bioturbation). 30° (0.1"") and 30° (0.1""). Sunken pieces of weathered limestone?

22.9 Greenish Gray (5G 6/1) to Light Greenish Gray (5G 8/1) heterolithic shale becoming more sandy downward. Wavy Lenticular (thick, white connecting lenses) bedding. 0.1"").

33.4 White (N) to Grayish Orange (10YR 5/4) limestone inclusion at 31° 5' (0.4"") thick. with stromatolitic growth (weathered limestone included into shale). Thin (3mm) White (N) sandy stringer at 32° 4' and a thin (2mm) hard dense lumpy White (N) and Brownish Gray (5Y 4/1) stringer at 32° 5'.

Better shale than above (un core 81).

36.1 Greenish Gray (5G 6/1) shaly, friable shale with few Yellowish Gray (5Y 8/1) sandy starved ripples near top of core. Breaks easily along horizontal bedding planes.

**Remarks:**

Back in timber on north face of hill

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>ROC (%)</th>
<th>Measure (%)</th>
<th>Liquid Unit</th>
<th>Plastic Index</th>
<th>Unconfined Compression</th>
<th>Jar Index</th>
<th>CaCO3 %</th>
<th>Washable Material</th>
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<td>96</td>
<td>1 10.45</td>
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<tr>
<td>30</td>
<td></td>
<td>66</td>
<td>2 47.66</td>
<td>39</td>
<td>2</td>
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</tr>
<tr>
<td>30</td>
<td></td>
<td>66</td>
<td>2 3.58</td>
<td>17.98</td>
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<tr>
<td>35</td>
<td></td>
<td></td>
<td>2 43.35</td>
<td>2</td>
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</table>

**CaCO3 %**

- High to Medium Durability: 30%
### Kansas State University

#### Project Number: 59-23 K-7888-01

#### Project Name: Realignment of Hwy. 59, south of Lawrence, KS

#### Site: Pleasant Grove, KS in Douglas County

---

**Surface Elevation:** 1058.00

**Location:** Sta. 524+25.25 ft L 14

---

#### Material Description

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>36.2</td>
<td>Sharp contact at base.</td>
</tr>
<tr>
<td>36.5</td>
<td>Same shale as above, but less firm and more clay rich. Weak, soft zones (drift, swell w/larger irregular fractures) at 33.7 (0.1' thick), 34.2 (0.1' thick), 34.6 (0.1' thick), 35.1 (0.2' of broken, crumbly shale).</td>
</tr>
<tr>
<td>37.3</td>
<td>Grassy Black coaly seam at 36.2'-36.5' coal seam (top 0.1' is more of a Medium Dark Gray (N4) carbonaceous shale) with sharp contact at base.</td>
</tr>
<tr>
<td>40.5</td>
<td>Moderate Light Gray (N6) to Medium Gray (N5) and Greenish Gray (5G 6 1) clay rich shale.</td>
</tr>
<tr>
<td>40.8</td>
<td>Top 0.5' is Greenish Gray (5G 6 1) and Medium Gray (N5) shale with a Dark Yellowish Orange sandy silt at 40.7 (0.1'). 38.4-40.5' shale becomes more flaccid to shaly and breaks easily on horizontal planes (swelling shale).</td>
</tr>
<tr>
<td>42.7</td>
<td>Shale becomes more sandy with very thin flat connecting lenses of White (N9) fine sand silt for lenticular bedding. White (N9) sandy silt ripples at 40.5-40.6'. Grayish Orange (10YR 7 4) dense hard calcitic band at 41' (0.1' thick) with lenticular bedding of thin connecting lenses. Thin Wavy bedding at 40.6'-41'. 41.2' (0.1').</td>
</tr>
<tr>
<td>42.8</td>
<td>Medium Light Gray (N6) to Medium Blush Gray (5B 5 1) clay rich, swelling shale. Abundant soft clay rich zones (drift, shale) with irregular fractures from 43.5' to the base of the core. Dense hard sandstone at 42.9-43.3' with the top 0.1' being Light Olive Gray (5Y 6 1) finely interlayered with less inclined bedding (-3') and structure. Rest of the sandstone is White (N9) with few sand drapes. Dense hard Yellowish Orange dolomite beds intercalated towards base at 44.3 (0.1' thick), 45.7 (0.1'), and 46.2 (broken -0.1') with sharp contacts.</td>
</tr>
<tr>
<td>46.2</td>
<td>Black (N1) bristle, sooty, and vitreous coal seam with sharp contacts.</td>
</tr>
<tr>
<td>46.6</td>
<td>Blush Gray (5B 5 6) to Medium Light Gray (N6) paleos with black, organic debris and root traces and weathered resistant root exists. Grades to Light Blush Gray (5G 7 1).</td>
</tr>
</tbody>
</table>

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**FIELD DATA**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Sample Type</th>
<th>ROD</th>
<th>Drying %</th>
<th>Initial Limit</th>
<th>Plastic Limit</th>
<th>ROD Limit</th>
<th>Unconfined Compression</th>
<th>Jar Index</th>
<th>CaCO₃ %</th>
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<td>36.5</td>
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<tr>
<td>46.6</td>
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**Remarks:**

Back in timber on north face of hill

---

**JAR INDEX**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Degrades into pile of flake or mud</td>
</tr>
<tr>
<td>2</td>
<td>Breaks rapidly and forms many chips</td>
</tr>
<tr>
<td>3</td>
<td>Breaks rapidly and forms few chips</td>
</tr>
<tr>
<td>4</td>
<td>Breaks slowly and develops several fractures</td>
</tr>
<tr>
<td>5</td>
<td>Breaks slowly and develops few fractures</td>
</tr>
<tr>
<td>6</td>
<td>No change</td>
</tr>
</tbody>
</table>

---

**CaCO₃ %**

High to Medium Durability - 35%
**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

<table>
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<th>Surface Elevation:</th>
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<td><strong>Location:</strong> Sta. 524+25, 25 ft.11</td>
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### Material Description

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<tr>
<th>Depth</th>
<th>Sample Type</th>
<th>RQD</th>
<th>Material Description</th>
</tr>
</thead>
</table>
| 51.8  |             |     | Medium Gray (55) shale with three dense hard 
|       |             |     | Greenish Gray (5G-6.1) sandy, 
|       |             |     | Yellowish Orange (10YR 6.6) sandy 
|       |             |     | Interlamination and some minor deformation 
|       |             | 5   | Bottom 0.5' is sandy shale |
| 52.8  |             |     | Top 0.5' is same sandy shale as in bottom of 
|       |             | 5   | Medium Light Gray (56) to Medium Dark 
|       |             |     | Gray (54) sandy, unconsolidated interlamination 
|       |             |     | Medium Light Gray (56) to Medium Dark 
|       |             | 55  | Medium Light Gray (56) to Medium Dark 
|       |             |     | Gray (54) sandy, unconsolidated interlamination 
|       |             |     | Dense hard sandstone with lenticular wavy bedding 
|       |             |     | Dense hard sandstone at 58.6' (0.2' thick) 
|       |             | 60  | Same interlamination lenticular wave shale |

### Remarks:

- Back in timber on north face of hill

### JAR Index

1. Degrades into pile of flakes or mud
2. Breaks rapidly and/or forms many chips
3. Breaks slowly and/or forms few chips
4. Breaks slowly and/or develops few fractures
5. No change

**CaCO3 %**

100

High to Medium Durability - 35%
**Surface Elevation:** 1058.0

**Location:** Sta. 524+25, 25 ft Lt

---

**Material Description**

- **62.3:** Same shale, but much thinner interlayers with pinstripe lenticular wave bedding of White (N9) fine sand silt. Few sunken pillows visible. Thin White (N9) sandstone lenses at 62.5 (0.1), 62.5 (0.1), and 62.6 (0.1). Breaks easily along horizontal bedding planes.

---

**67.3** Top 0.4 is the same interlayered shale as above, then lose bedding downward. Medium Gray (N5) sandstone with clay-rich (soft) zone at 67.5 (0.1) thick with sharp contact. Breaks easily along horizontal bedding planes. Bottoms 0.7 is more resistant Light Gray (N7) to Medium Gray (N5) sand/micaceous shale to shaley sandstone with black organic debris.

---

**995.7**

- **996.0:**

---

**Remarks:** Back in timber on north face of hill

---

**FIELD DATA**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Sample Type</th>
<th>RUD</th>
<th>Silt</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Unconfined Compressive</th>
<th>CaCO3 %</th>
<th>Silt/Peat Ratio</th>
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<tr>
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<td>5</td>
<td>83.60</td>
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</table>
**Surface Elevation:** 10588.0'

**Location:** Sta. 524+25, 25 ft Lt

**Material Description**

72.3 Top 0.7 in the same resistant sandy micaceous shale as above, but with little to no black, organic debris. 70.5-70.7' sandy shale becomes less resistant, breaks easily along horizontal bedding planes. 70.7-72.3' shale becomes very sandy micaceous with black organic particles debris. No noticeable bedding planes and is more dense resistant than above (good core), few smaken pillows of White (N9) fine sand.

---

**Remarks:**

Black in timber on north face of hill

**Field Data**

**Laboratory Data**

---

**Project Number:** 59-23  K-7888-01

**Project Name:** Realignment of Hlv. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

---

**Notes:**

1. serene depth: 102.5'
2. date measured: 11/05/04
3. date completed: 11/05/04
4. reported by:
5. notes:
6. lithology type 1: Retained pieces virtually uncrushed
7. lithology type 2: Retained pieces consists of large and small pieces
8. lithology type 3: Retained material is exclusively sand fragments.

---

**CaCO3 %**

High to medium durability: 35%
**DEPARTMENT OF GEOLOGY**

**Kansas State University**

**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1058.0'

**Location:** Sta. 524+25, 25 fl. ft.

---

### Field Data

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>84.9</td>
<td>Shale interbedded with White (NP) fine sandy layers (pin stripes) with major deformation of convolute and vertical bedding (good core reduce). Continued Next Page. Medium Light Gray (N6) to Medium Dark Gray (N4) sandy interbedded with some black organic debris.</td>
</tr>
<tr>
<td>87.9</td>
<td>Same sandy macaceous shale with black organic debris. Less resistant sandy shale with visible wavy, lenticular bedding. Gray sandy silty shale with brown to pinkish hue. Low angle cross lamination. Low angle of cross lamination.</td>
</tr>
<tr>
<td>92.4</td>
<td>Same sandy macaceous shale with black organic debris. Sandy silty shale with low angle cross lamination.</td>
</tr>
<tr>
<td>94.5</td>
<td>Medium Light Gray (N6) to Medium Gray (N5) silty; sandy shale with black organic debris. Gets slightly darker downward. Good core.</td>
</tr>
</tbody>
</table>

---

### Laboratory Data

- **Sample Type:** 
- **Mineral %:**
- **Liquid Limit:**
- **Plastic Limit:**
- **Unconfined Compressive Test:**
- **Cai %:**
- **Skew Suspensibility:**
- **Shear Strength:**
- **Stability Type:**

---

**Remarks:**

Back in timber on north slope of hill.

**Completion Depth:** 102.9'

**Date Started:** 11/03/94

**Date Completed:** 11/03/94

**Drawn by:**

**Firm Index:**
1. Degrades into pile of flakes around perimeter.
2. Breaks rapidly and splits into many chips.
3. Breaks rapidly and forms fine powder.
4. Breaks slowly and develops fine fractures.
5. No change.

**CaCO3 %:**

High to Medium Durability: 33%
**Project Number:** 59-23  K-7888-01  
**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS  
**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1058.0'

**Location:** Sta. 524+25.25 ft LA

**Material Description**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
<th>Unconsolidated Compaction</th>
<th>CaCO3 %</th>
<th>Shale Type</th>
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<td>97.6</td>
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</table>

**Remarks:**
Back in timber on north face of hill

**Completion Depth:** 102.5'

**CaCO3 %:**
High to Medium Durability - 35%

<table>
<thead>
<tr>
<th>JAR INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Degrades into pile of flakes or mud</td>
</tr>
<tr>
<td>2. Breaks rapidly and or forms many chips</td>
</tr>
<tr>
<td>3. Breaks rapidly and or forms few chips</td>
</tr>
<tr>
<td>4. Breaks slowly and or develops several fractures</td>
</tr>
<tr>
<td>5. Breaks slowly and or develops few fractures</td>
</tr>
<tr>
<td>6. No change</td>
</tr>
</tbody>
</table>

**Graph:**
- Depth ranges from 97.6 to 102.5 ft
- Markings indicate notable changes in material properties.
**APPENDIX B-5: STATION 526+30, 7’ RT CL - MIDDLE OF HILL - MH1**

![Image of the page with geological data and diagrams]

**Department of Geology**  
Kansas State University

**Project Number:** 59-23  K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Surface Elevation:** 1024.0’

**Location:** Sta. 526+30

**Material Description**

Not Recovered

---

**Field Data**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>ROC</th>
<th>Atterberg Limit</th>
<th>Static Compressibility</th>
<th>Plastic Index</th>
<th>CaCO3 %</th>
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**Remarks:**

Middle of Pleasant Grove Hill

---

**Laboratory Data**

**Jar Index**

1. Degrades into pile of flakes or mud
2. Breaks rapidly and or forms many chips
3. Breaks slowly and or forms few chips
4. Breaks slowly and or develops several fractures
5. Breaks slowly and or develops free fractures
6. No change

CaCO3 %

High to Medium Durability - 35%
Kansas State University

Project Number: 59-23  K-7888-01
Project Name: Realignment of Hwy. 59, south of Lawrence, KS
Site: Pleasant Grove, KS in Douglas County

Surface Elevation: 1024.0'
Location: Sta. 526+30

Material Description

Medium Gray (N5) sandy micaceous shale with White (N9) sandy siltstone ripples. Top 0.5 contains faint lenticular to flaser bedding and becoming more distinct downward. Bottom 0.4 flaser bedding. Continued Next Page.

27.5

Medium Dark Gray (N4) to Medium Gray (N5) sandy micaceous shale with abundant black organic particles. Top 0.5 lenticular bedding becoming faint none downward. 28.1-29.1 clay rich, bottom 0.5 flaser lenticular.

20.5

Medium Light Gray (N6) to Medium Gray (N5) lenticular shale (very thinly laminated) with black organic particles. Top 0.2 sandy shale with striaed siltstone ripples. 29.7-30' flaser bedding, inclined disturbed bedding at 31.4'.

32.4

Medium Gray (N5) sandy micaceous shale with lenticular bedding of White (N9) to Light Olive Gray (5Y 6/1) fine sand silt lenses. Becoming faint very fine downward while black organic debris increases. Flaser zones at 36.7 (~0.1' thick) and 36.8 (~0.1' thick).

Completion Depth: 62.6'
Date Started: 09/19/05
Date Completed: 09/19/05
Drilled By:
Legged By:

SITE INDEX
1. Rotted pieces: extremely rockous
2. Rotted material consists of large and small pieces
3. Rotted material is exclusively small fragments

CaCO3 %
High to Medium Durability - 35%
Project Number: 59-23 K-7888-01

Project Name: Realignment of Hwy. 59, south of Lawrence, KS

Site: Pleasant Grove, KS in Douglas County

Surface Elevation: 1024.0

Location: Sta. 526+30

Material Description

12.6 Weathered shale becoming more sandy micaceous with black organic debris.
   Very thinly laminated with lenticular bedding. Continued on next page.

13.5 Dark Yellow (5Y 6/4) weathered shale;
   stained Dark Yellowish Orange (10YR 6/6) to Moderate Brown (5YR 4/4). Fresh Light
   Gray (N7) to Light Blush Gray (SB 7 1).
   Top 0.6: lenticular shale with lenticular bedding; thinly laminated.
   Light Blush Gray (SB 7 7 1) shale with black organic fragments/debris.

17.3

17.5 Vitrinous coal with sharp contact
   Light Blush Gray (SB 7 7 1) to Light Gray (N7) salt-churned shale paleosol? (1006)

18.6 Sandy/silty micaceous shale

19.0 Light Gray (N7) to Medium Light Gray:
   Sandy/silty micaceous shale with White (N9) lenticular lenses of fine sand and salt
   Minor amounts of disturbed bedding.

21.6

Very sandy micaceous shale with soft
   sediments deformation. Bottom 0.7 starved ripples and black organic particles

22.5 Medium Gray (N5) sandy/micaceous shale
   with White (N9) sandy starved ripples. Top 0.5 contains faint lenticular to flaser
   bedding and becoming more distinct downward. Bottom 0.4 flaser bedding.

Remarks:
Middle of Pleasant Grove Hill

Completion Date: 6-2-0
Date Started: 6-16-0
Date Completed: 6-16-0

JAR INDEX
1. Degrades into pile of flakes or mud
2. Breaks rapidly and/or forms many chips
3. Breaks rapidly and/or forms few chips
4. Breaks slowly and/or develops few fractures
5. Breaks slowly and/or develops few fractures
   No change
CaCO3 %
   High to Medium Durability - 33 %
**DEPARTMENT OF GEOLOGY**

Kansas State University

**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

---

**Surface Elevation:** 1024.0'  
**Location:** Sta. 526+30

**Material Description**

- **37.2**
  - Top 0.2 ft. flaser to lenticular bedding. Mud drapes at top 0.3'. Wavy disrupted bedding of White (N0) sandy ripples. 305-40.3'. Light Gray (N7) to White (N0) dense hard fine grained micaceous sandstone; sharp contacts. 40.3'-40.6' sandy micaceous shale with black organic debris.

- **40.6**
  - Medium Gray (N5) and Medium Light Gray (N6) to Light Olive Gray (2.5 Y 6/1) sandy micaceous shale with black organic debris. Becoming more micaceous downward. Sandy siltstone ripples at base (~4 cm thick). Well indurated (good core).

- **41.9**
  - Medium Light Gray (N6) to Medium Gray (N5) siltstone micaceous shale with black organic debris and minor amounts of leafy debris. 43-6'-44.2' siltstone pillow of White (N0) fine sand (~0.1'-0.2' thick) with deformation. 45'-45.4' siltstone ripples (0.1'-0.5' thick). Sandy siltstone ripple (0.3' thick). Angled fracture at 43.8' (~40').

- **46.8**
  - Medium Gray (N5) sandy micaceous shale with black plant debris particles.

---

**Remarks:**

Middle of Pleasant Grove Hill

**FIELD DATA**

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<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>ROC</th>
<th>Matrix Type</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
<th>Unified Soil Classification</th>
<th>CaCO3 %</th>
<th>Silt</th>
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<th>Clay</th>
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**LABORATORY DATA**

| 986.8 | 4 | 2.38 | 80.27 | I |
| 983.4 | 5 | 3.15 | 78.12 | I |
| 982.1 |      |      |       |   |

---

**JAR INDEX**

- 1. Degrades into pile of flakes or mud
- 2. Breaks rapidly and or forms many chips
- 3. Breaks slowly and or forms fine chips
- 4. Breaks slowly and or develops several fractures
- 5. No change

- CaCO3 %
  - High to Medium Durability - 35%
**Surface Elevation:** 1024.0'  
**Location:** Sta. 526+30  

### Material Description

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<th>Plastic Limit</th>
<th>Shrinkage Index</th>
<th>Unconfined Compressibility</th>
<th>Jar Index</th>
<th>CaCO3 %</th>
<th>Site Compressibility</th>
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</tbody>
</table>

- **57.2:** Medium Gray (N5) sandy micaceous shale, low inclined bedding at 59.8 of 60.7, wavy bedding at 60.5 to 60.7, wavy, low-angled lenticular zone of White (N5) sand lenses at 64.3' of 0.1' thick.

### Remarks:

- Middle of Pleasant Grove Hill

### JAR INDEX

- 1. Degrades into pile of blocks or mud
- 2. Breaks rapidly and forms many chips
- 3. Breaks rapidly and forms fine chips
- 4. Breaks slowly and develops several fractures
- 5. Breaks slowly and develops fine fractures
- 6. No change

**CaCO3 %:**

- High to Medium Durability - 35%
**Department of Geology**

**Kansas State University**

**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

<table>
<thead>
<tr>
<th>Material Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Gray (N5) sandy micaceous shale. Low inclined bedding at 59°-60°. Varying bedding at 60°-60°. Wavy dispersed lenticular zone of White (N9) sand lenses at 61.3 + 0.1 thick. (Continued Next Page)</td>
</tr>
</tbody>
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### FIELD DATA

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<th>Sample Type</th>
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<th>Liquid Limit</th>
<th>Plastic Limit</th>
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<th>Jar Index</th>
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### LABORATORY DATA

**Remarks:**

Middle of Pleasant Grove Hill

<table>
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<tr>
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<th>Date Started</th>
<th>Date Completed</th>
<th>Drilled By</th>
<th>Logged By</th>
<th>Site Type 1: Retained pieces typically mudcracked</th>
<th>Site Type 2: Retained material consists of large and small pieces</th>
<th>Site Type 3: Retained material is exclusively small fragments</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

**JAR INDEX**

1: Disintegrates into pile of flakes or mud
2: Breaks rapidly and forms many chips
3: Breaks rapidly and forms few chips
4: Breaks slowly and develops several fractures
5: Breaks slowly and develops fine fractures
6: No change

**CaCO3 %**

High to Medium Durability: 35%
APPENDIX B-6: STATION 531+20', 25' RT CL - BASE OF HILL - BH1

**Surface Elevation:** 940.0'

**Location:** Sta. 531+50

**Material Description**

Not recovered

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Sample Type</th>
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<th>Initial Limit</th>
<th>Plastic Limit</th>
<th>Plastic Index</th>
<th>Unconfined Compression</th>
<th>Jar Index</th>
<th>Cc0.25, %</th>
<th>Silica Fraction</th>
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</table>

**Remarks:**

Base of Pleasant Grove Hill

**Notes:**

1. *Brittle Index:
   1. **Degrades into pile of flakes or mud**
   2. **Breaks rapidly and or forms many chips**
   3. **Breaks rapidly and or forms few chips**
   4. **Breaks slowly and develops several fractures**
   5. **Breaks slowly and or develops fine fracture**
   6. **No change**

<table>
<thead>
<tr>
<th>CaCO3, %</th>
<th>Brittle Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High to Medium Durability - 35%</td>
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</tbody>
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**Project Number:** 59-23 K-7888-01

**Project Name:** Realignment of Hvy. 59, south of Lawrence, KS

**Site:** Pleasant Grove, KS in Douglas County

**Completion Depth:** 36.5'

**Drilled By:**

**Logged By:**

**Date Bored:** 09/13/86

**Date Completed:** 09/13/86

111
Kansas State University

Project Number: 59-23 K-7888-01
Project Name: Realignment of Hwy. 59, south of Lawrence, KS
Site: Pleasant Grove, KS in Douglas County

Surface Elevation: 940.0'
Location: Sta. 531+50

FIELD DATA

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<thead>
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<th>Depth</th>
<th>Sample Type</th>
<th>RUO</th>
<th>Nettural%</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Unconfined Compression</th>
<th>Jn Index</th>
<th>CaCO3%</th>
<th>Slip Reliability</th>
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</tr>
</tbody>
</table>

LABORATORY DATA

Material Description


Medium Light Gray (N6) to Medium Gray (N5) shale with abundant horizontal fractures on surface of core. Top 0.5 m oxidized Light Brown (7.5YR 3/4) with vertical joints bedding.

Same shale as above but with fewer fractures.

Remarks:
Base of Pleasant Grove Hill

CaCO3 %
High to Medium Durability - 35%
**Project Number:** 59-23 K.7888-01  
**Project Name:** Realignment of Hwy. 59, south of Lawrence, KS  
**Site:** Pleasant Grove, KS in Douglas County

### Surface Elevation: 940.0 ft

**Location:** Sta. 531+50

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>RQD</th>
<th>Maturity</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
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<th>CaCO3</th>
<th>Shell Permeability Index</th>
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<td>20.03</td>
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<tr>
<td>Same weathered silty shale as above. Vertical bedding fractures at 13.4-15.1.</td>
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<td>15.1</td>
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<td>70</td>
<td>35.21</td>
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<tr>
<td>Same weathered silty shale as above. Vertical bedding fractures at 15.4-16.4 and 17-17.3. Becoming broken blocky shale.</td>
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<td>17.3</td>
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<td>35.21</td>
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<tr>
<td>Yellowish Gray (5Y 7/2) weathered silty sandy shale stained Dark Yellowish Orange (10YR 6/6) with Moderate Reddish Brown (10YR 6/6) iron cementation. Fresh Light Gray (8/8) shale 18.3-22.3 more weathered with vertical bedding fractures. (bad shale).</td>
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<td>70</td>
<td>35.21</td>
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<td>Weathered Pale Olive (10Y 6/2) shale: fresh Medium Light Gray (8/8) to Medium Gray (N5) and stained Moderate Brown (5YR 6/8) vertical bedding at 22.3-24.1 (darker gray shale). 24.3-24.7 Corroded distal bedding at 25.4-25.8.</td>
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</tbody>
</table>

**Remarks:**  
Base of Pleasant Grove Hill

### JAR INDEX

1. Degrades into pile of flakes or mud  
2. Breaks rapidly and/or forms many chips  
3. Breaks rapidly and/or forms few chips  
4. Breaks slowly and/or develops several fractures  
5. Breaks slowly and/or develops few fractures  
6. No change

**CaCO3 %**  
High to Medium Durability - 30%
**Surface Elevation:** 940.0'  
**Location:** Sta. 531+50  

<table>
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<tr>
<th>Material Description</th>
<th>Grapha. Log</th>
<th>Depth (ft)</th>
<th>Sample Type</th>
<th>RQD</th>
<th>Maximum %&lt;sup&gt;+&lt;/sup&gt;</th>
<th>Liquid Limit</th>
<th>Plastic Limit</th>
<th>Plasticity Index</th>
<th>Unconfined Compression</th>
<th>J&lt;sub&gt;u&lt;/sub&gt; Index</th>
<th>C&lt;sub&gt;p&lt;/sub&gt; %&lt;sup&gt;+&lt;/sup&gt;</th>
<th>C&lt;sub&gt;p&lt;/sub&gt; %&lt;sup&gt;+&lt;/sup&gt;</th>
<th>Sku, Angle of Friction</th>
<th>Sku, Type</th>
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**Remarks:**  
Base of Pleasant Grove Hill

**Completion Depth:** 36.9'  
**Date Started:** 05/13/05  
**Date Completed:** 05/15/05  
**Logged By:**

<table>
<thead>
<tr>
<th>JAR INDEX</th>
</tr>
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</table>
| 1. Degrading into pile of flake shaped  
| 2. Breaks rapidly and or forms many chips  
| 3. Breaks rapidly and or forms few chips  
| 4. Breaks slowly and or develops a few fractures  
| 5. Breaks slowly and or develops fine fractures  
| 6. No change  

**CaCO<sub>3</sub> %:**  
High to Medium Durability - 35%
REFERENCES


Deo, P., 1972, Shales as embankment materials, Joint Highway Research Project, Purdue University, W. Lafayette, Ind.


Munsell, 1994, Munsell Soil Color Charts, revised edition: Macbeth Division of Kollmorgen Instruments Corp., New Windsor, N.Y.


