TESTING OF SELECTED SAMPLES FROM MAPPING OF INDUSTRIAL CLAY POTENTIAL IN THE MINNESOTA RIVER VALLEY, SOUTH-CENTRAL MINNESOTA

By

John J. Heine and Lawrence M. Zanko

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Natural Resources Research Institute
University of Minnesota, Duluth
5013 Miller Trunk Highway
Duluth, MN 55811-1442

INTRODUCTION

As part of the mapping of industrial clay potential in the Minnesota River Valley (MRV) and Cottonwood River Valley (Zanko et al., 1998), 94 samples were collected for reference and future analysis. The primary focus of that study was to outline areas of potential for industrial clays, primarily kaolins, and ball clays, based on field observations and examining the water well logs for the area. The mapping project's goal was to produce a GIS-based reference tool for land-use planning and clay exploration.

This study was conducted to analyze 27 selected samples from Area 10 of Zanko et al. (1998), along the Cottonwood River in Brown County, Minnesota. This area was selected for additional work, based on field mapping, because of the high potential for the delineation of useful industrial clays. The lack of analytical data about the clays in this area made determining the potential of the area difficult.

The clays included in the study are largely Cretaceous in age, Cretaceous sediments, and secondary sediments (Zanko et al., 1998), and a sample of an uncertain age, possibly a weathered Paleozoic shale. Most of these clays formed from the weathering and reworking of crystalline Archean bedrock, along with mineral contributions from weathered Paleozoic bedrock in the southeastern part of the study area. Similar Cretaceous clays are currently mined by the Ochs Brick and Tile Company, Springfield, Minnesota, and Minnesota Valley Minerals Inc., Mankato, Minnesota, for use in brickmaking and artistic ceramic clays. Other industrial clays in the area come from primary kaolin deposits, clays which formed in place from the intense weathering of crystalline Archean bedrock. No samples of primary kaolins are included in this study, but they do make up the largest tonnage of industrial clays mined in the MRV area, and are dominantly used in the production of portland cement.

Testing on the selected samples for this study included particle size analysis, X-ray diffraction mineralogy, and whole rock and trace element geochemistry. The results of this work are included with this report on an accompanying diskette. The testing results are discussed and compared with similar samples from Minnesota. This information will be useful for individuals and industrial mineral companies looking for new sources of kaolin clays from the MRV.

BACKGROUND

During the evaluation of the industrial clay resources in the MRV (Zanko et al., 1998), 94 samples were collected for further study, but due to the project's short time frame and limited budget, no sample testing was performed. The current project allowed for follow-up work to be conducted, and 27 samples were selected from the 94 previously collected for analysis. All of the selected samples were collected in Brown County, Minnesota, along the Cottonwood River. Seven secondary sediment samples, nineteen Cretaceous sediment samples, and one weathered Paleozoic shale (geologic formation unknown) were selected for further analysis. The testing work included particle size analysis, X-ray diffraction mineralogy, and geochemistry.

Particle size analysis was completed by Natural Resources Research Institute (NRRI) staff in the NRRI laboratories. X-ray diffraction work was also completed by NRRI staff, using the University of Minnesota, Duluth, Department of Geology, Philips Xpert X-ray diffractometer. All samples were sent to Acme Analytical Laboratories Ltd., Vancouver, BC, Canada, for geochemical analysis. The results of this testing were compared with results from similar samples from Minnesota (Hauck et al., 1990; Heine, et al., 1998; Toth, T.A., 1991).

TERMINOLOGY

Cretaceous sediments	Sediments deposited during the Cretaceous period, in generally quiet flow conditions. Typically these contain some amount of lignite and /or organic matter, making them gray in color.
secondary sediments	Sediments deposited before the Cretaceous sediments, probably also Cretaceous, possibly older in age. These sediments were deposited in a wide variety of flow conditions, but most are found in fluvial and lacustrine environments. Typically these sediments are white to light gray in color and underlie Cretaceous sediments.

ACKNOWLEDGMENTS

Funding for this project was provided by the Minerals Diversification Plan of the Minnesota Legislature, distributed by the Minerals Coordinating Committee. The authors would like to thank the many individual land owners who gave access to their property during the previous study.

SAMPLE LOCATIONS AND DESCRIPTIONS

Locations and descriptions for the samples are provided in a Microsoft Excel spreadsheet, SLOCMRV3.xls, on the accompanying diskette. The layout for the spreadsheet data is located in Appendix I. Figure 1 is also available on accompanying diskette in an ArcView 3.1 file along with related dBase IV files (see Appendix V for the various ArcView file descriptions and related metadata file). The reader is referred to Zanko et al., 1998, for more information on sample collection methods. The samples come from eight localities in Brown County, Minnesota, along the Cottonwood River (Fig. 1).

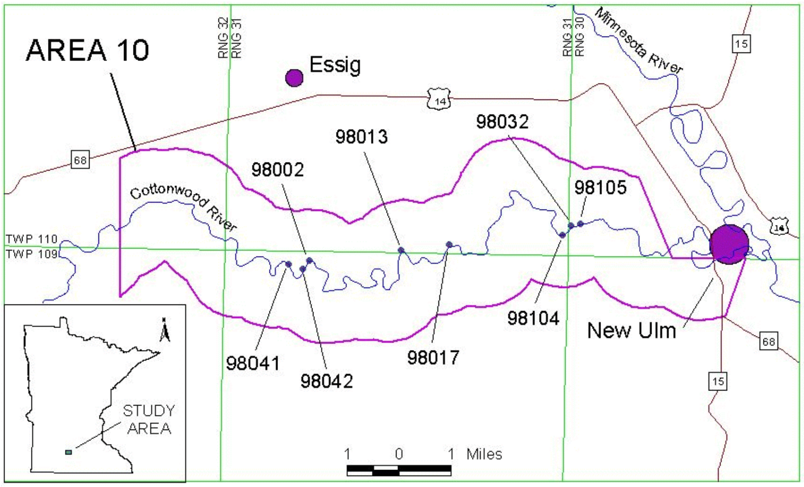

Figure 1. Location map of the sample localities.

LOCALITY 98002

All samples from this locality are Cretaceous sediments. The 5 foot section is composed of two intervals: 2 feet of light gray, iron stain mottled, clay (98002.01) overlying 3 feet of darker gray laminated clay (98002.02). Sample 98002.03 is a resampling of 98002.01.

LOCALITY 98013

One sample of gray Cretaceous clay (98013.01), 5.0 feet thick was collected.

LOCALITY 98017

One 8 foot sample of light gray Cretaceous silty clay (98017.01) was collected.

LOCALITY 98032

One sample, 2 feet, of light gray secondary clay bearing sand (98032.01) was collected.

LOCALITY 98041

Six samples of Cretaceous sediments were collected from this site, totaling 15.5 feet in thickness. The upper 13.5 feet is composed of gray clays with samples 98041.01 through 98041.05 containing varying amounts of lignitic fragments and some concretions. The remaining sample is a dark gray/black lignitic clay.

LOCALITY 98042

A total of 11 samples were collected from this locality, totaling 25.4 feet in thickness. The upper 15.4 feet was composed of Cretaceous clays that range from silty to clay rich, and from gray to dark gray in color (samples 98042.01 to 98042.08). Some iron-staining was present, but may be a near surface deposition of iron related to recent groundwater, similar to other staining of clays reported in other parts of the MRV (Hauck et al., 1990). The remaining 10 feet was composed of a light gray to light blue-gray, silty clay, which was identified as secondary. These last three samples (98042.09 to 98042.11) were collected using a hand auger, making the identification of the textures and bedding difficult. The lack of these identifying features made the identification of these materials as secondary speculative, which was based largely on the abrupt change in color and texture. Similar material was noted by NRRI staff in the Minnesota Valley Minerals Inc. Courtland Mine, east of New Ulm, Minnesota. Based on drilling information from that company, that material was identified as being secondary material, with a source for the material being nearby Paleozoic shales (pers. comm., Scott Gooler, 1998).

LOCALITY 98104

Two samples of secondary sediments and one weathered Paleozoic shale were collected from this 4 foot section. A pisolitic kaolin (98104.01), 0.5 feet thick, occurred at the top of the section. The next 1.5 feet was composed of a white kaolinitic sand, grading into a blue-gray silt. The lower 2 feet of the section was composed of a distinctive, blue-green silty clay, which was similar in appearance to local Paleozoic shales, exposed in the vicinity of New Ulm, Minnesota, and may be a weathered representative of those shales. More rigorous mapping, sampling, and analysis of these shales would be necessary to delineate their position in the area's stratigraphy.

LOCALITY 98105

One sample, 2 feet thick, of well-indurated, secondary white clay (98105.01) was collected at this site.

ANALYTICAL METHODS

PARTICLE SIZE ANALYSIS

Particle size analysis with the settling tube or pipette analysis method (Folk, R.L., 1980) is available for all samples. The results of the analysis are contained in a Microsoft Excel spreadsheet, MRV3PSA.xls, on the diskette included with this report. Appendix II contains the table layout for this spreadsheet The results of the testing will be discussed later in the report.

X-RAY DIFFRACTION

X-ray diffraction mineralogy was conducted on all of the samples. A bulk sample, a 2 micron sample, a 2 micron glycolated sample, and a 2 micron sample heated to 500EC were run on a Philips Xpert X-ray diffractometer. Mineral identification was completed using Philips Xpert software. The results of the analysis were entered into a Microsoft Excel spreadsheet, MRV3XRAY.xls, on the diskette included with this report. Appendix III contains the table layout for this spreadsheet The results of the testing will be discussed later in the report.

GEOCHEMISTRY

All samples were sent to Acme Analytical Laboratories Ltd., Vancouver, BC, Canada, for geochemical analysis. Sixty-six whole rock, trace element, and other analyses were run on each sample. In addition, two duplicates and one standard were submitted, as check on the accuracy of the work. The results of the analyses are contained in a Microsoft Excel spreadsheet, MRV3CHEM.xls, on the diskette included with this report. Appendix IV contains the table layout for this spreadsheet. The results of the testing will be discussed later in the report.

GIS COVERAGE

Appendix V contains a listing of the ArcView 3.1 and dBASE IV files used to produce Figure 1. All files listed are contained on the diskette included with the report.

PARTICLE SIZE ANALYSIS

In the following discussion, the particle size data for the samples are plotted with the fields for similar samples, compiled from other NRRI reports. The reader is referred to Hauck et al. (1990), Heine, et al. (1991), Toth, T.A. (1991), and Heine, et al. (1998), for more information on the samples used to make these fields. One hundred twelve Cretaceous sediments samples and thirty-five secondary sediment samples are used from the historical data for comparison.

CRETACEOUS SEDIMENTS

The ternary diagram (Fig. 2) for the Cretaceous sediments samples plotted against the field of other Minnesota samples shows that most of the data plots well in the clay- and silt-rich fields of the diagram. There is a good correlation of the data with the historic Minnesota samples, many of which come from the active Ochs Springfield Mine, indicating that the current samples may be useful for a similar use, i.e., brickmaking and ceramic clays. In addition, some of the clays are similar to those seen in the Minnesota Valley Minerals Inc. Courtland Mine. Firing tests would be necessary to better determine the characteristics that would define their true value in those applications.

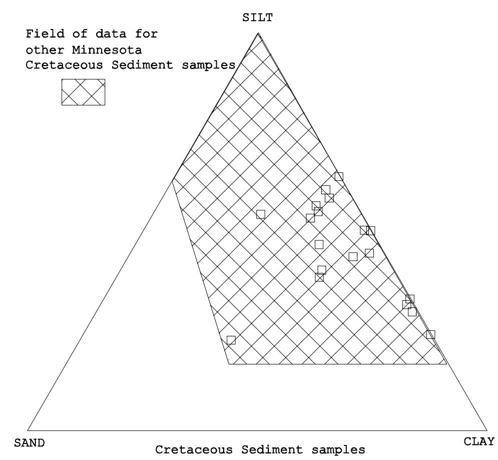

Figure 2. Particle size analysis plot for Cretaceous sediments.

SECONDARY SEDIMENTS

The secondary sediment sample particle size data are shown plotted against the field of historical data for Minnesota in Figure 3. The current data plot in the clay-rich and silty clay fields of the diagram. When compared with the field of historical data, these materials would seem to be good targets for further investigation, being among the most clay-rich samples collected to date. These materials may be used in ceramic and filler applications that could be determined through further testing. The wide range in the historical data reflects the wide range of environments of depositions in which the secondary sediments were deposited, plus the inclusion of 29 pisolitic kaolins in the sample set. Many of the historically sampled secondary samples come from fluvial depositional environments, and include many kaolinitic sands samples. Pisolitic kaolins are typically well-indurated and do not disperse well for particle size analysis, which also skews the data to the sand field.

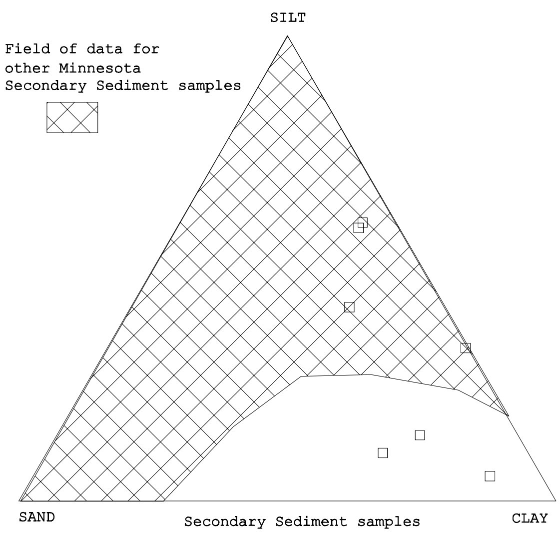

Figure 3. Particle size analysis plot for secondary sediments.

PALEOZOIC SHALE

The sample of weathered Paleozoic shale is shown plotted against the data for Cretaceous sediments in Figure 4. The Cretaceous sediment data set was chosen as a reference, due to a lack of available data for similar materials. The sample plots well into the field for clayey silt. The particle size data, with the mineralogy, which will be discussed later in the report, suggest this material may have value in similar applications as the

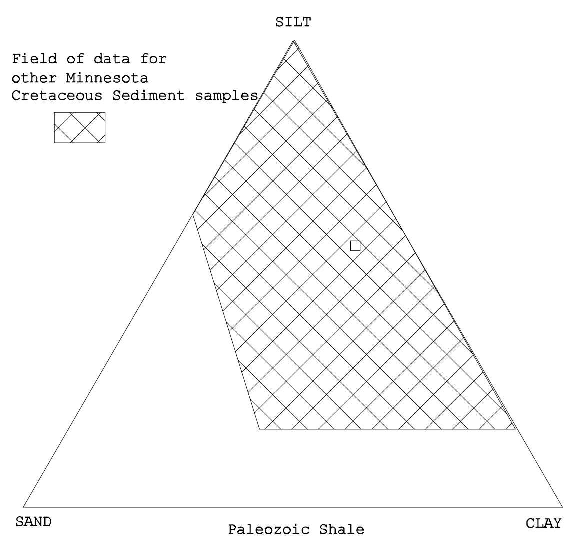

Figure 4. Particle size analysis plot for Paleozoic shale.

Cretaceous sediments, i.e., brickmaking and ceramics. Further testing, such as firing tests, would be needed to determine possible uses for this material.

X-RAY DIFFRACTION

X-ray diffraction work on the samples was completed to determine the mineralogy of the materials. The clay mineralogy of the materials is important to this study because all of the currently mined industrial clays in Minnesota are kaolinite-rich.

CRETACEOUS SEDIMENTS

Kaolinite is the dominant clay mineral in the Cretaceous sediment samples, with minor to trace amounts of illite present. Other trace clay minerals include montmorillonite, halloysite, and mixed-layer clays. A trace amount of dickite and gibbsite was found in one sample. The other major mineral present is quartz, with trace amounts of muscovite and chlorite present in some samples. This is very similar to other Cretaceous sediments examined by NRRI staff (Hauck et al., 1990; Heine, et al., 1991; Toth, T.A., 1991; and Heine, et al., 1998).

SECONDARY SEDIMENTS

The secondary sediments are composed of a simple mineralogy of quartz and kaolinite, with minor illite. In contrast to other secondary samples examined by NRRI staff, the elevated amount of illite was unexpected in the samples. This may be an indication of the source of these materials. The nearby Paleozoic shales are all rich in illite (Hauck et al., 1990) and may contribute to the elevated presence in these samples. Previously studied secondary sediment samples have come from areas where the dominate source for the materials is weathered Archean bedrock (Hauck et al., 1990; Heine, et al., 1991; Toth, T.A., 1991; and Heine, et al., 1998). The difference in the source of the materials making up these outcrops could lead to the difference observed in the mineralogy. These mineralogical differences make it somewhat difficult to determine the value of these materials, in comparison to their less illitic counterparts, without more rigorous laboratory testing.

PALEOZOIC SHALE

The Paleozoic shale mineralogy is quartz, kaolinite, and illite, similar to that seen in the secondary sediments. Again, the elevated illite makes determining the usefulness of this material difficult without further testing.

GEOCHEMISTRY

Whole rock and extensive trace element geochemistry was run on the samples to provide a wide range of elements (66) for these materials. The following discussion focuses on the most common detrimental components for the current uses of these clay materials, i.e., brickmaking, portland cement, and ceramic clays. K_2O, TiO_2, SiO_2, and total Fe_2O_3 (TFe_2O_3) are the most common of these detrimental elements, and are shown plotted against Al_2O_3 in the following discussions. K_2O is detrimental in portland cement production, because it forms an alkaline hazardous waste product in the kiln. Typically, K_2O values less than 1% are acceptable for portland cement production. In brick and ceramic clays, higher values are acceptable. TiO_2-bearing minerals and free quartz (SiO_2) act as abrasive compounds, wearing down manufacturing equipment. TFe_2O_3 can affect firing color of the material.

Sulfur and fluorine were also run, because these elements can produce gases when fired, which are considered pollutants under the Clean Air Act and the 1990 Amendments. Sulfur ranges from below detection limits (0.01%) to 0.25% for all samples except 98041.06, a lignitic shale containing 1.0% sulfur. Sulfur contents of these clays are similar to the range for 64 samples analyzed (below detection-0.85%) from the Ochs Brick and Tile Springfield pit (Hauck et al., 1990). The Ochs Brick and Tile materials are currently used for the production of brick. Fluorine ranges from 40 to 690 ppm. Additional firing tests and analysis of the fired materials would be necessary to determine the amount of fluorine released during the firing process, producing hydrogen fluoride (HF) gas. In general, the more illite present in the clay, the greater the potential for HF production. Fluorine is a recently added element to the NRRI geochemical analysis requirements. No historical data is available for currently used materials from the MRV. To determine the amount of HF produced from these materials during firing, additional testing would be required.

Outlined fields are shown for historical data for comparison purposes (Hauck et al., 1990; Heine, et al., 1991; Toth, T.A., 1991; and Heine, et al., 1998). One hundred twelve Cretaceous sediments samples and thirty-five secondary sediment samples were used from the historical data for comparison.

A duplicate, triplicate, and National Bureau of Standards (NBS) Reference Sample (NBS 679) were submitted with the samples to determine the quality of the analysis. The duplicate and triplicate sample analyses varied by less 10%, indicating reproducibility. NBS 679 analysis varied less than 10% for the major elements and trace elements provided by the NBS.

CRETACEOUS SEDIMENTS

Figure 5 is an SiO_2 plot for the Cretaceous sediments. The samples plot high in the field of historical data, indicating a slight increase in SiO_2. The data indicate SiO_2 is not a problem for these samples.

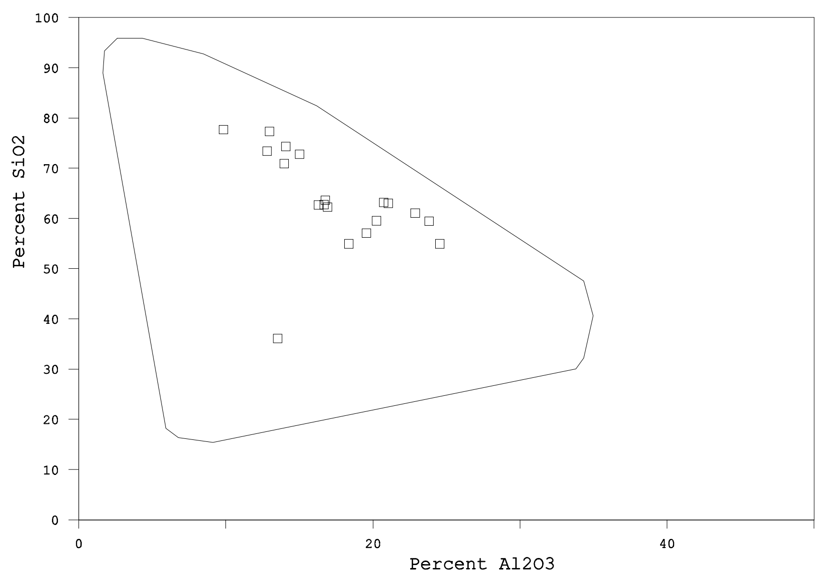

Figure 5. SiO_2 plot for the Cretaceous sediments.

Figure 6 is a TFe_2O_3 plot of the samples and shows good correlation of most of the samples with the historical data. The two exceptions of increased iron may be the result of deposition by recent groundwater movement. This feature is commonly noted in the MRV and usually fades as the section advances deeper into the hillsides.

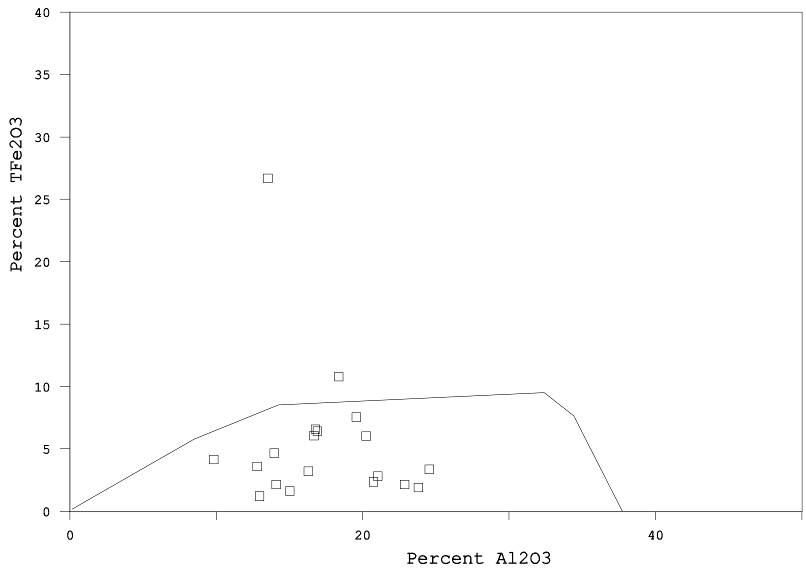

Figure 6. TFe_2O_3 plot for the Cretaceous sediments.

Figure 7 is a K_2O plot, which shows strong similarity to the historical data. K_2O is a measure of the amount of illite and muscovite in the samples. The data show K_2O is not detrimental in these samples for the current uses of similar materials.

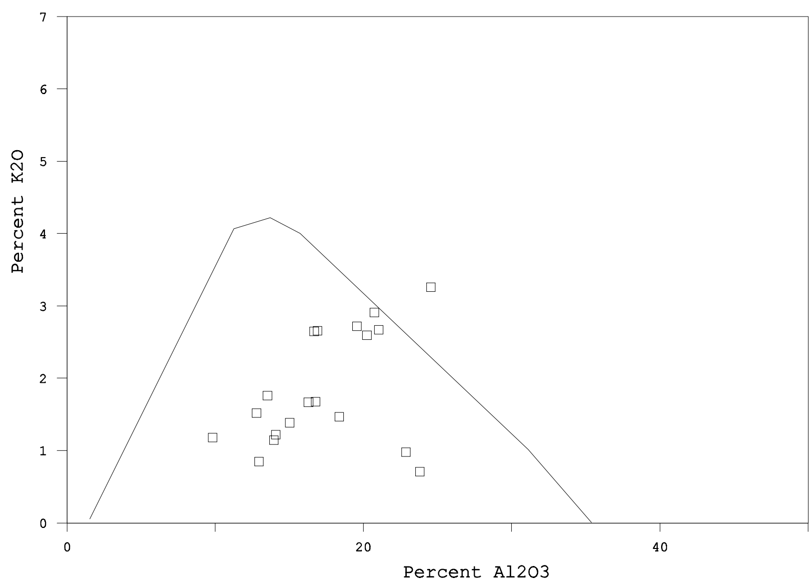

Figure 7. K_2O plot for the Cretaceous sediments.

Figure 8 is a TiO_2 plot of the Cretaceous sediments, which again shows good correlation with the historical samples. TiO_2 acts as an abrasive that can wear down equipment used to process this material.

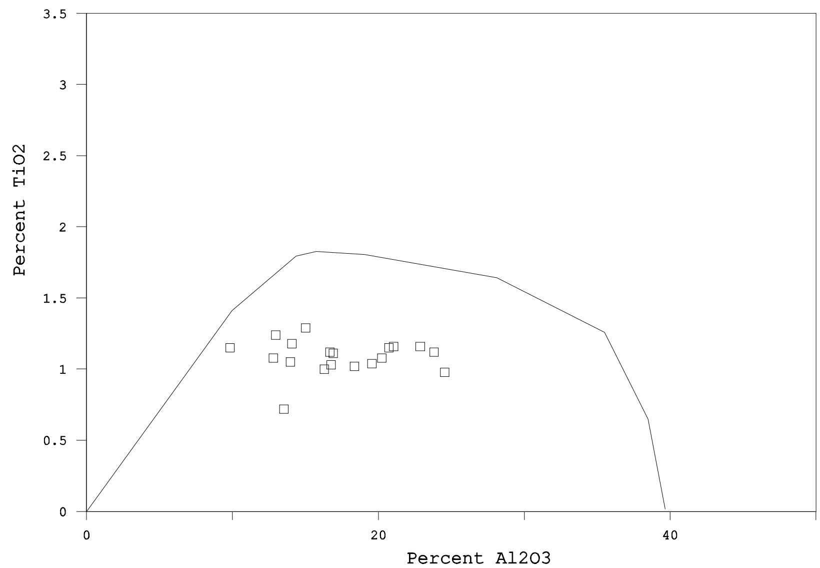

Figure 8. TiO_2 plot for the Cretaceous sediments.

SECONDARY SEDIMENTS

Figure 9 is an SiO_2 plot for the secondary sediments. The samples plot in and to the left of the field of historical data, indicating a slight increase in SiO_2. Fine-grained quartz is probably the cause of this increase. The particle size data show much of this material to be very fine grained.

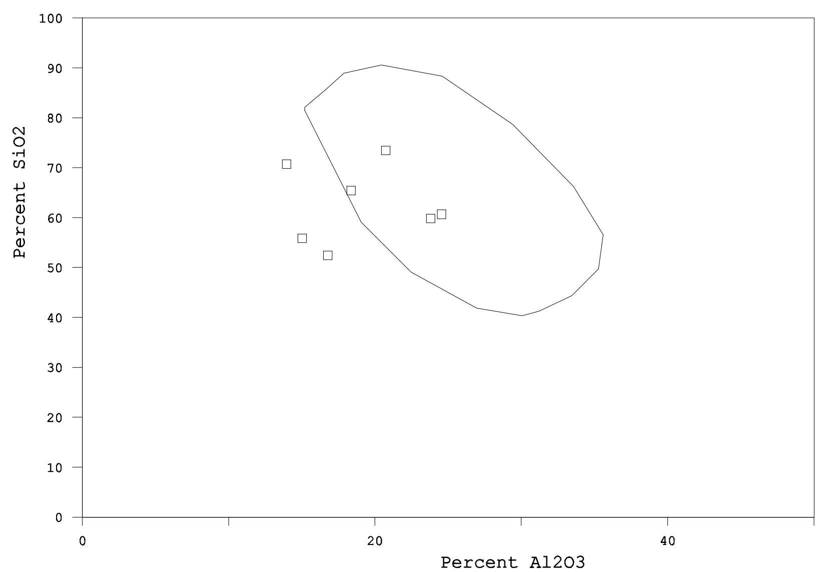

Figure 9. SiO_2 plot for the secondary sediments.

Figure 10 is a TFe_2O_3 plot of the samples that shows good correlation of most of the samples with the historical data. The one exception of increased iron may be the result of deposition by recent groundwater movement.

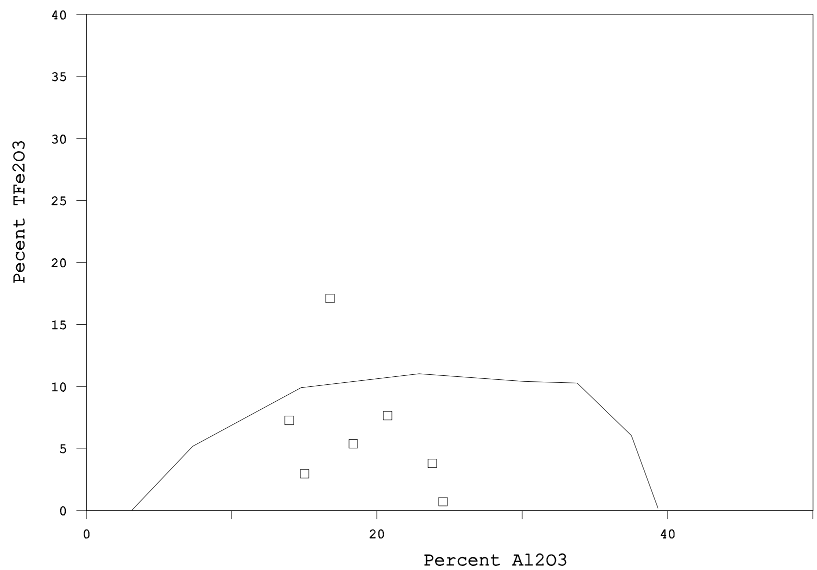

Figure 10. TFe_2O_3 plot for the secondary sediments.

Figure 11 is a K_2O plot, which shows strong similarity to the historical data. K_2O is a measure of the amount of illite and muscovite in the samples. Again, the data show K_2O is not detrimental in these samples for the current uses of similar materials.

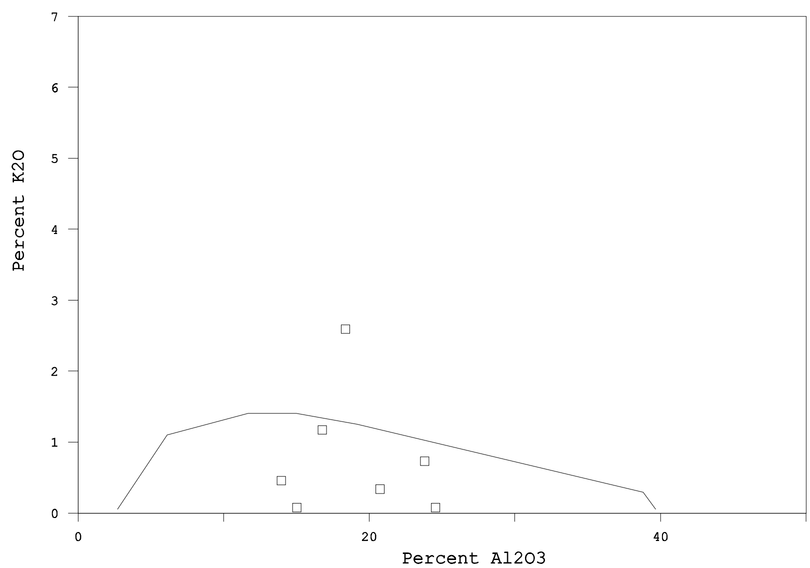

Figure 11. K_2O plot for the secondary sediments.

Figure 12 is a TiO_2 plot of the secondary sediments, which again shows good correlation with the historical samples.

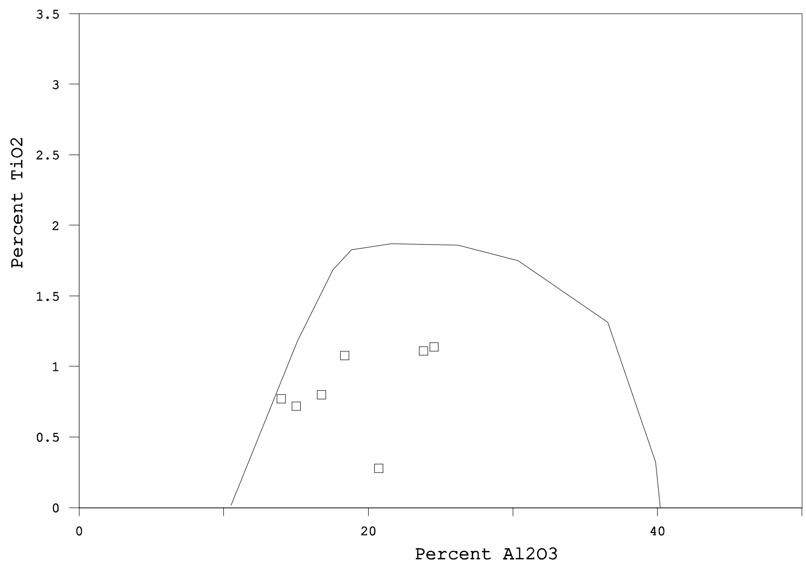

Figure 12. TiO_2 plot for the secondary sediments.

PALEOZOIC SHALE

Because of the lack of historical data, the Paleozoic shale sample is compared with the historical data for the Cretaceous sediments. Figure 13 is an SiO_2 plot for the Paleozoic shale. The sample plots well in the field of the Cretaceous data, indicating it may be of value for similar uses.

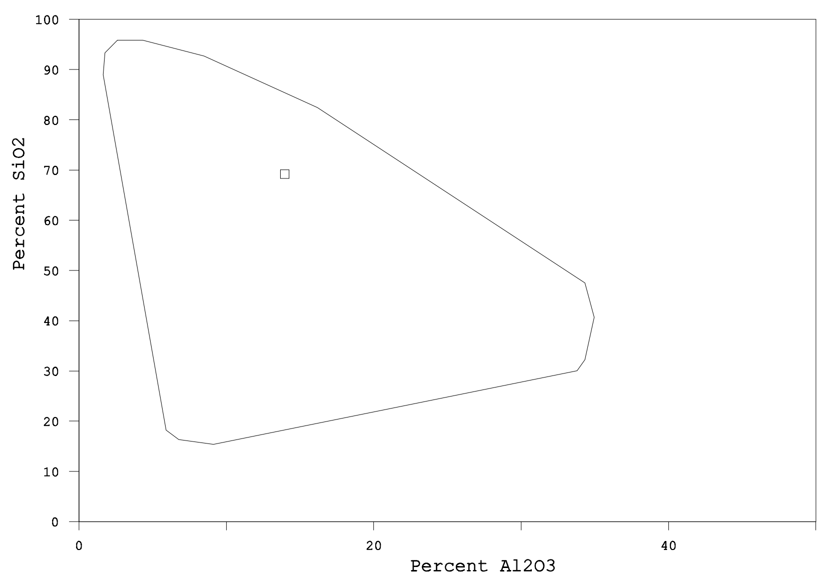

Figure 13. SiO_2 plot for the Paleozoic shale.

Figure 14 is a TFe_2O_3 plot of the samples, and shows good correlation with the historical data. The low iron content may indicate that the material would be light firing in color. Light firing Cretaceous shales are highly valued in the MRV industrial clay production. Firing tests would need to be conducted to determine the true firing characteristics of this material.

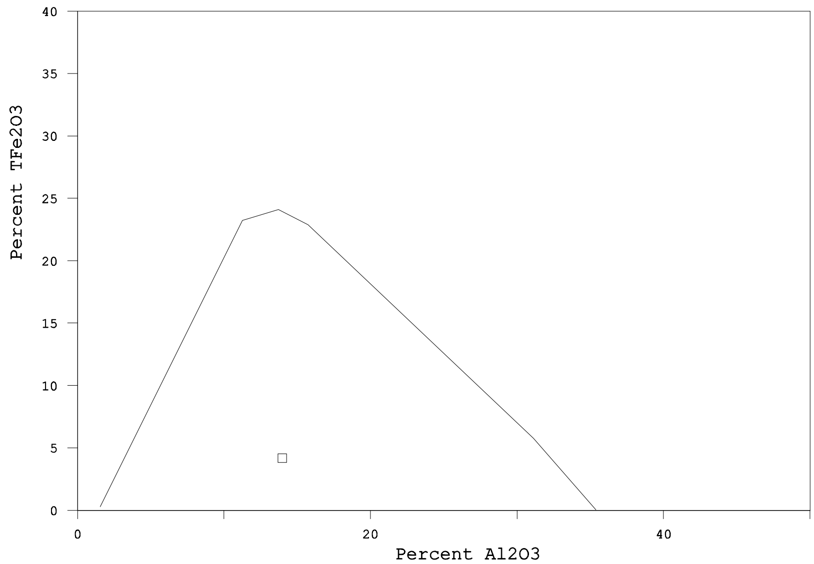

Figure 14. TFe_2O_3 plot for the Paleozoic shale.

Figure 15 is a K_2O plot, which shows strong similarity to the historical data. Again, K_2O is a rough measure of the amount of illite and muscovite in the samples. The data show K_2O is not detrimental in these samples for the current uses of similar materials.

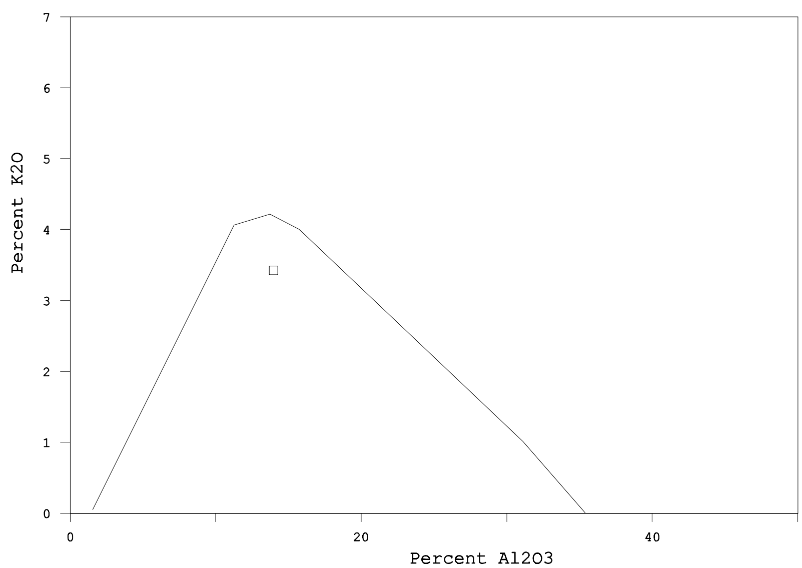

Figure 15. K_2O plot for the Paleozoic shale.

Figure 16 is a TiO_2 plot of the Paleozoic shale, which again shows good correlation with the historical samples.

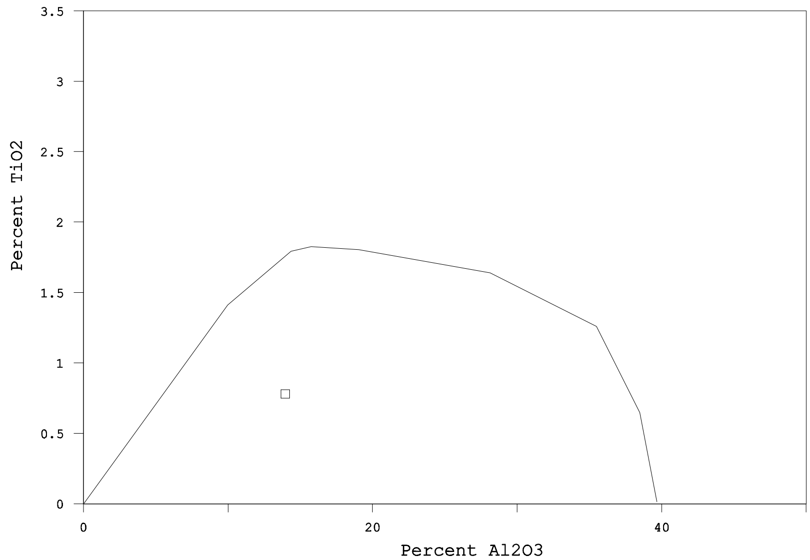

Figure 16. TiO_2 plot for the Paleozoic shale.

RARE EARTH AND OTHER GEOCHEMISTRY

The trace element geochemistry (Figs. 17-19) shows the Paleozoic shale sample 98104.03, marked with a cross in Figures 17 and 20, to be strongly anomalous in the rare earth elements (REE), with a strong Ce depletion. Sample 98105.01, marked with a diamond in Figures 17 and 20, appears enriched in the light REE, with similar Ce depletion. The REE enrichment of the samples is not fully understood. It may be the result of concentration due to weathering of the Paleozoic shales, or enrichment by fluids moving through the material along the unconformity. More detailed

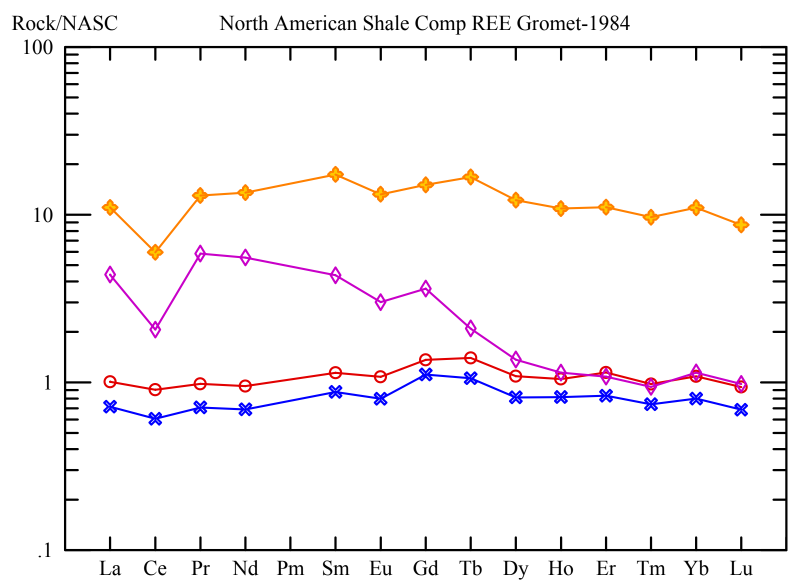

Figure 17. REE plot of the Paleozoic shale sample and selected samples.

sampling in the area, with additional geochemical analyses, would be necessary to determine if these or other processes were involved in the REE enrichment.

Samples 98042.04 and 98042.09, marked as X and a circle, respectively, on Figures 17 and 20, appear to have an REE pattern similar to the Cretaceous sediments, marked as triangles in Figure 18, but show a slight enrichment in P_2O_5 and CaO in Figure 20. This enrichment may be due to the presence of apatite, which is not detected in the X-ray diffraction mineralogy. If apatite is present in trace amounts in the sample, the methodology used for X-ray diffraction mineralogy would not detect it. The presence of apatite in only two of the eight Cretaceous sediments in the stratigraphy at locality 98042 may indicate input of sediments from an intermittent source area, or be the result of concentration of apatite due to depositional factors.

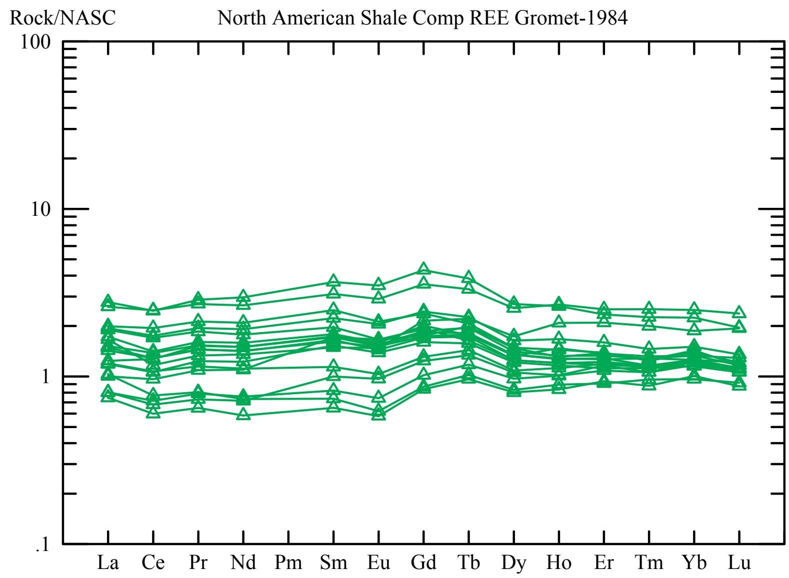

Figure 18. REE plot of the Cretaceous sediments.

Figure 19 is an REE plot of the secondary sediments, depicted as squares. Of note, is sample 98104.01, which plots lowest in heavy REE in Figure 19. If the REE data of this sample is combined in a weighted average with the data for 98104.03 (Fig. 17; cross symbol), it is possible to produce a pattern similar to 98105.01 (Fig. 17; diamond symbol). This and the close spacial location of the localities of 98104 and 98105, may indicate that sample 98105.01 is composed of materials similar to the differing sources for 98104.01 and 98104.03.

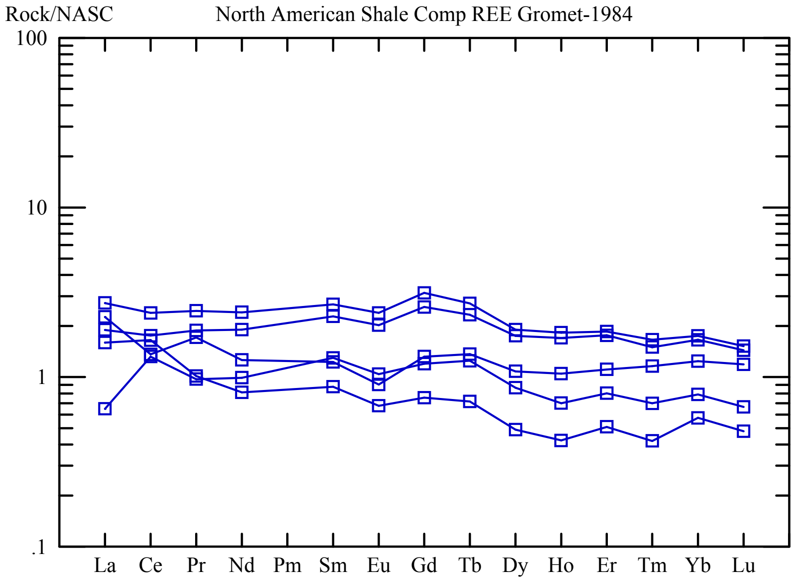

Figure 19. REE plot of the Secondary sediments.

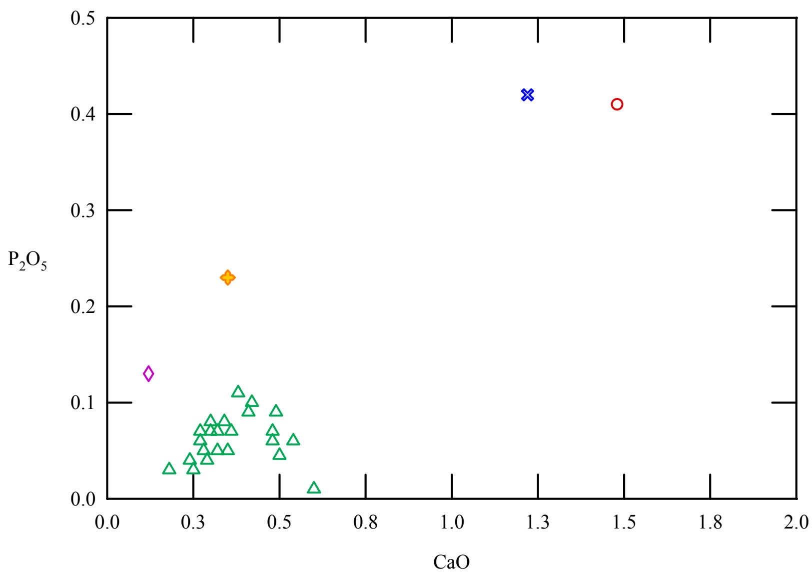

Figure 20. P_2O_5 verses CaO plot for selected samples.

CONCLUSIONS

The clay samples from the Cottonwood River Valley, Area 10, analyzed in this report show high potential for use in the traditional applications typically associated with similar materials found elsewhere in the MRV. Potential markets for these clays are brick manufacture, ceramic clay, and artistic clay, especially the more clay-rich samples. Other possible uses for these clays include industrial filler and pigment applications. With much of the land in the MRV currently under lease, the Cottonwood River Valley would open opportunities for new areas of exploration.

This project has focused on the analysis of the 27 selected samples, and the analyses suggest that potential uses exist for many of them. Other testing, specifically firing tests, are needed to better determine their value in the mentioned potential markets. In addition, Zanko et al. (1998) performed a large scale reconnaissance mapping of the area. The nature of this work is to cover a lot of ground quickly and to visit and find as many sites as possible. More detailed mapping work should be completed in Area 10, as well as other areas in that report, with the collection and testing of more samples to determine the true potential of the area as a new source for industrial clay.

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APPENDIX I

SAMPLE LOCATION DATA

The Microsoft Excel file SLOCMRV3.xls contains the sample locations for this project. Listed below are the columns and names for this data.

COLUMN	NAME
A	SAMPLES #
B	SAMPLE METHOD
C	SAMPLE TYPE
D	S-CODE
E	THICKNESS (ft)
F	DESCRIPTION
G	COUNTY
H	QUAD
I	QUARTER
J	SECTION
K	TOWNSHIP
L	RANGE
M	LOCATION

APPENDIX II

PARTICLE SIZE ANALYSIS DATA

The Microsoft Excel file MRV3PSA.xls contains the particle size analysis data for this project. Listed below are the columns and names for this data.

COLUMN	**SIZE (mm)**	**NAME**
A		Sample #
B		S-code
C	62.5	SAND
D	62.5	4 phi
E	44.0	4.5 phi
F	31.0	5 phi
G	23.3	5.5 phi
H	15.6	6 phi
I	7.8	7 phi
J	3.9	8 phi
K	2.0	9 phi
L	0.98	10 phi
M		BLANK
N		% SAND
O		%SILT
P		%CLAY

APPENDIX III

X-RAY DIFFRACTION DATA

The Microsoft Excel file MRV3XRY.xls contains the X-ray diffraction results for this project. Listed below are the columns and names for this data.

COLUMN	**NAME**
A	SAMPLES
B	Quartz
C	Muscovite
D	Kaolinite
E	Halloysite
F	Dickite
G	Gibbsite
H	Illite
I	Montmorillonite
J	Clinochlore
K	Tosudite
L	Rectorite
M	Chlorite-Vemicullite-Montmorillonite
N	Illite-Montmorillonite

APPENDIX IV

GEOCHEMISTRY DATA

The Microsoft Excel file MRV3CHEM.XLS contains the geochemistry run for this project. Listed below are the column, field , and unit of measure for this data. Ni, Nb, Sr, Y, and Zr were run twice because they were duplicated in two different packages. These packages were run to produce the analyses at a lower cost.

A	SAMPLES	
B	Duplicate	samples
C	COUNTY	
D	QUAD	
E	QUARTER	
F	SECTION	
G	TOWNSHIP	
H	RANGE	
I	LOCATION	
J	BLANK	
K	SiO2	%
L	Al2O3	%
M	TiO2	%
N	TFe2O3	%
O	FeO	%
P	CaO	%
Q	MgO	%
R	MnO	%
S	Na2O	%
T	K2O	%
U	P2O5	%
V	Cr2O3	%
W	LOI	%
X	C/TOT	%
Y	ORG/C	%
Z	SO4	%
AA	H2O+	%
AB	H2O-	%
AC	S/TOT	%
AD	TOTAL	%
AE	Sb	ppm
AF	As	ppm
AG	Ba	ppm
AH	Bi	ppm
AI	Cd	ppm
AJ	Ce	ppm
AK	Cs	ppm
AL	Co	ppm
AM	Cu	ppm
AN	Dy	ppm
AO	Er	ppm
AP	Eu	ppm
AQ	F	ppm
AR	Gd	ppm
AS	Ga	ppm
AT	Hf	ppm
AU	Ho	ppm
AV	La	ppm
AW	Pb	ppm
AX	Lu	ppm
AY	Mo	ppm
AZ	Nd	ppm
BA	Ni	ppm
BB	Ni	ppm
BC	Nb	ppm
BD	Nb	ppm
BE	Pr	ppm
BF	Rb	ppm
BG	Sm	ppm
BH	Sc	ppm
BI	Sr	ppm
BJ	Sr	ppm
BK	Ta	ppm
BL	Tb	ppm
BM	Tl	ppm
BN	Th	ppm
BO	Tm	ppm
BP	Sn	ppm
BQ	W	ppm
BR	U	ppm
BS	V	ppm
BT	Yb	ppm
BU	Y	ppm
BV	Y	ppm
BW	Zn	ppm
BX	Zr	ppm
BY	Zr	ppm

APPENDIX V

LISTING OF ARCVIEW 3.1 and dBASE IV FILES
USED TO REPRODUCE FIGURE 1
IN ARCVIEW GIS FORMAT

mrv3area10.apr	An ArcView 3.1 project file displaying the study area and the referenced sample location points and containing linked data tables for geochemistry, particle size analysis, sample locations and descriptions, and X-ray diffraction analysis.
Mrv3area10.html	Netscape hypertext document containing the metadata for project Mrv3area10: Testing of Selected Samples From Mapping of Industrial Clay Potential. These data were created using the Minnesota Geographic Metadata Guidelines, version 1.2.

File types:

*.aih *.ain	A pair of ArcView 3.1 files that store the attribute index of the active fields in a table or a theme's attribute table.
*.dbf	A dBase IV file containing the attributes of the accompanying shape file.
*.shp	An ArcView 3.1 shape file.
*.shx	An ArcView 3.1 file that stores the index of the accompanying shape file.

Clippedcover

area10clip	The bounding polygon of the study area.
clayptclip	The referenced sample locations contained in the study area.
clayresclip	Outline of clay resource Area 10 as defined in Zanko et. al., 1999.
rdclip	Highways contained in the study area.
rivclip	Rivers contained in the study area.
Statepy3	Bounding polygon of the state of Minnesota.
townloc	Towns located in the study area..
twpclip	Townships contained in the study area.

Databasefiles

MRV3CHEMgis	Table of geochemistry data for the referenced Area 10 samples.
MRV3PSAgis	Table of particle size analysis data for the referenced Area 10 samples.

MRV3XRAYgis	Table of X-ray diffraction analysis data for the referenced Area 10 samples.
SLOCMRV3gis	Table of location data and descriptions for the referenced Area 10 samples.