MINNESOTA GEOLOGICAL SURVEY

Priscilla C. Grew, *Director*

Information Circular 27

ISSN 0544-3105

MINNESOTA KAOLIN CLAY DEPOSITS:

A SUBSURFACE STUDY IN SELECTED AREAS OF SOUTHWESTERN AND EAST-CENTRAL MINNESOTA

UNIVERSITY OF MINNESOTA
Saint Paul

1989

MINNESOTA KAOLIN CLAY DEPOSITS:

A SUBSURFACE STUDY IN SELECTED AREAS OF SOUTHWESTERN AND EAST-CENTRAL MINNESOTA

By

D.R. Setterholm, G.B. Morey, T.J. Boerboom, and R.C. Lamons

This work was supported by the Legislative Commission on Minnesota Resources from funds allocated from the Mineral Resources Research Center, University of Minnesota, as part of the Industrial Minerals: Clay Project, 1987–1989.

CONTENTS

APPENDICES

ILLUSTRATIONS

Figures

Table

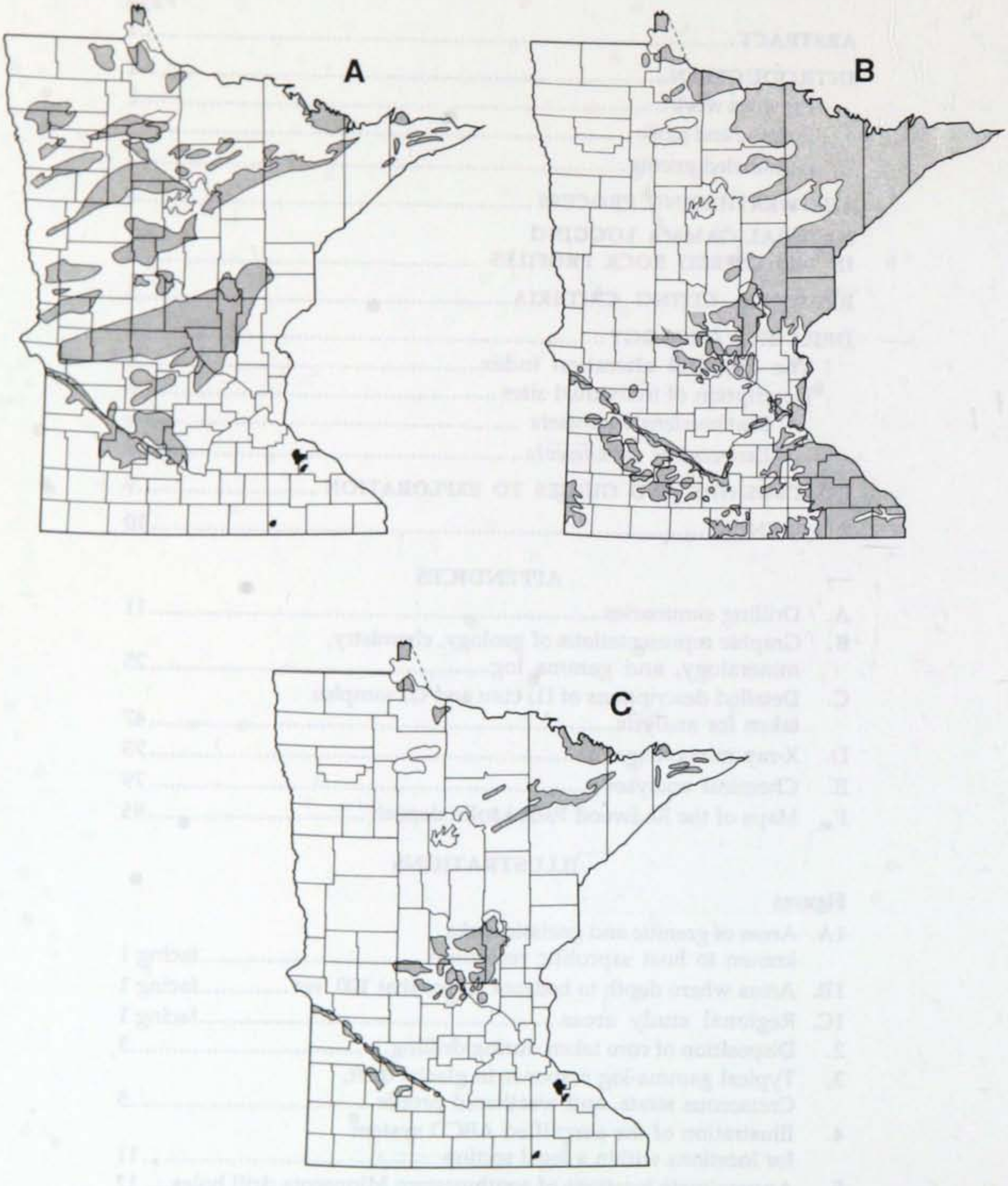


Figure 1. Criteria used to select regional study areas. A, Areas of granitic and gneissic rocks known to host saprolitic residuum (criterion 1); B, Areas where depth to bedrock is less than 100 feet (criterion 2) (Olsen and Mossler, 1982); C, Regional study areas (defined by the intersection of criteria 1 and 2). Black, secondary kaolin deposits (not included in the present study).

ABSTRACT

Large deposits of kaolin—the residual products of the weathering of igneous and metamorphic rocks—are common in southwestern and east-central Minnesota. Thin and discontinuous beds of sedimentary kaolin (resulting from the reworking of the residuum) are less common and volumetrically less significant. The weathering occurred prior to deposition of Late Cretaceous sedimentary strata. Because climatic conditions were uniform within the study area, the differences in the thickness and composition of the residuum are attributable to the mineralogic and hydrologic properties of the parent rock (protolith). Goldich (1938) and others have shown that weathering and the products of weathering are strongly controlled by the mineralogic composition of the protolith. Rocks rich in mafic minerals and plagioclase are generally more extensively weathered, and their residuum is richer in kaolinite. This susceptibility to weathering is evident in the mineralogic composition of the residuum and is reflected in the concentration of kaolin near the top, and in the addition of other minerals with increasing depth.

The weathering process is also dependent on the movement of water and other fluids; therefore, permeability is a second important control on the production of kaolin. In igneous and metamorphic rocks, fractures in the form of joints or faults are the primary paths of fluid movement. Weathering follows these paths, and the resulting kaolin deposits mimic the shape and orientation of the structural features.

Preservation is the final factor controlling the distribution of kaolin clays. The upper part of the residuum contains the largest amount of clay, but it also is the most vulnerable to erosion. Glacial erosion has had a profound effect on the distribution and thickness of kaolin clay deposits in the state. The thickest deposits are found where Late Cretaceous sediments overlie the kaolin and indicate total preservation of the weathered products.

INTRODUCTION

In Minnesota the term kaolin is typically used for natural clays consisting mostly of kaolinite and/or halloysite with lesser amounts of quartz, feldspar, and other primary and secondary accessory minerals.

Kaolin occurs in a variety of geologic settings in the state; the most extensively developed deposits, though, occur as a weathering residuum in much of western Minnesota (Fig. 1A). This residuum—formed by weathering of Precambrian igneous and metamorphic rocks—is largely buried by Upper Cretaceous sedimentary rocks and a variably thick mantle of Pleistocene glacial material. The residuum is rich in kaolinite and quartz, and the relative proportions of these and other minerals is directly related to the composition of the underlying parent rock. Reworking of the upper part of the residuum by fluvial and shallow marine processes during Late Cretaceous time produced kaolinitic sands and sandy kaolinitic clays, as well as relatively pure units of kaolinitic clays. It is the residuum and the overlying kaolinitic sedimentary clays of the Upper Cretaceous sequence that are the focus of recurrent interest by the industrial minerals community.

Much of the information above is taken directly from Parham (1970), which remains today the most comprehensive account of kaolin clays in the state.

Previous Work

> A substance was met with here for the first time which was afterwards seen at a number of places. Its origin seems to be dependent on the granite. Its association with the granite is so close that it seems to be a result of a change in the granite itself. It lies first under the drift, or under the Cretaceous rocks, where they overlie the granite, and passes by slow changes into the granite. It has some of the characters of steatite, and some of those of kaolin. In some places it seems to be a true kaolin. It is known by the people as "Castile soap." It cuts like soap, has a blue color when fresh, or kept wet, but a faded and yellowish ash color when weathered, and when long and perfectly weathered, is white and glistening. The boys cut it into shapes of pipes and various toys. It appears like the pipestone, though less heavy and less hard, and has a very different color. It is said to harden by heating. This substance, which may, at least provisionally, be denominated a *kaolin,* seems to be the result of the action of water on the underlying granite. (Winchell, 1874, p. 163)

The existence of kaolinitic residuum in Minnesota was established by N.H. Winchell in 1873 (Winchell, 1874), and interest in the commercial development of this resource followed shortly afterwards. Since these early efforts, the kaolinitic clays in Minnesota have been the subject of repeated scientific and economic investigations, the most pertinent of which include the work of Grout and Soper (1919), Goldich (1938), Bickford and Price (1947), Parham and Hogberg (1964), Wayland (1964), and Parham (1970).

Interest in kaolin clay, and in its development as a commercial resource, occurs cyclically in Minnesota, peaking most recently in the mid-1940s and 1960s, but the only sustained commercial use of the deposits has been for the production of brick. More recently, material from several localities along the Minnesota River Valley have been utilized for filler in the making of cement Certain components of the kaolin deposits may be suitable in other industrial applications, such as high-technology ceramics and pharmaceuticals. The use of these clays in the paper industry—for example, as high-grade paper coating—is also receiving renewed interest.

Purpose and Scope

Earlier work on the kaolin deposits focused mainly on materials obtained from naturally formed outcrops, from man-made borrow pits of relatively shallow depth, and from samples obtained by churn-drill or hand-auger techniques. All such near-surface sampling—even sampling by these methods today—causes problems, because of the possibility of contamination, principally by ground-water movement in the vadose zone.

The drilling and sampling program described here was designed to acquire by careful core drilling materials that are unlikely to be contaminated. This report summarizes the results of that drilling program, with emphasis on physical descriptions of the materials encountered and on the chemical and mineralogical attributes of a selected suite of samples (Fig. 2). We hope the information presented here will be used by the kaolin clay industries in the exploration and development of this clay resource. Interpretive comments are restricted to the characterization of those attributes we believe will aid exploration. The data will also be of value to geologists interesting in decifering the geologic history of these interesting deposits.

Acknowledgments

This work was supported by the Legislative Commission on Minnesota Resources from funds allocated from the Mineral Resources Research Center, University of Minnesota, as part of Industrial Minerals: Clay Project, 1987–1989.

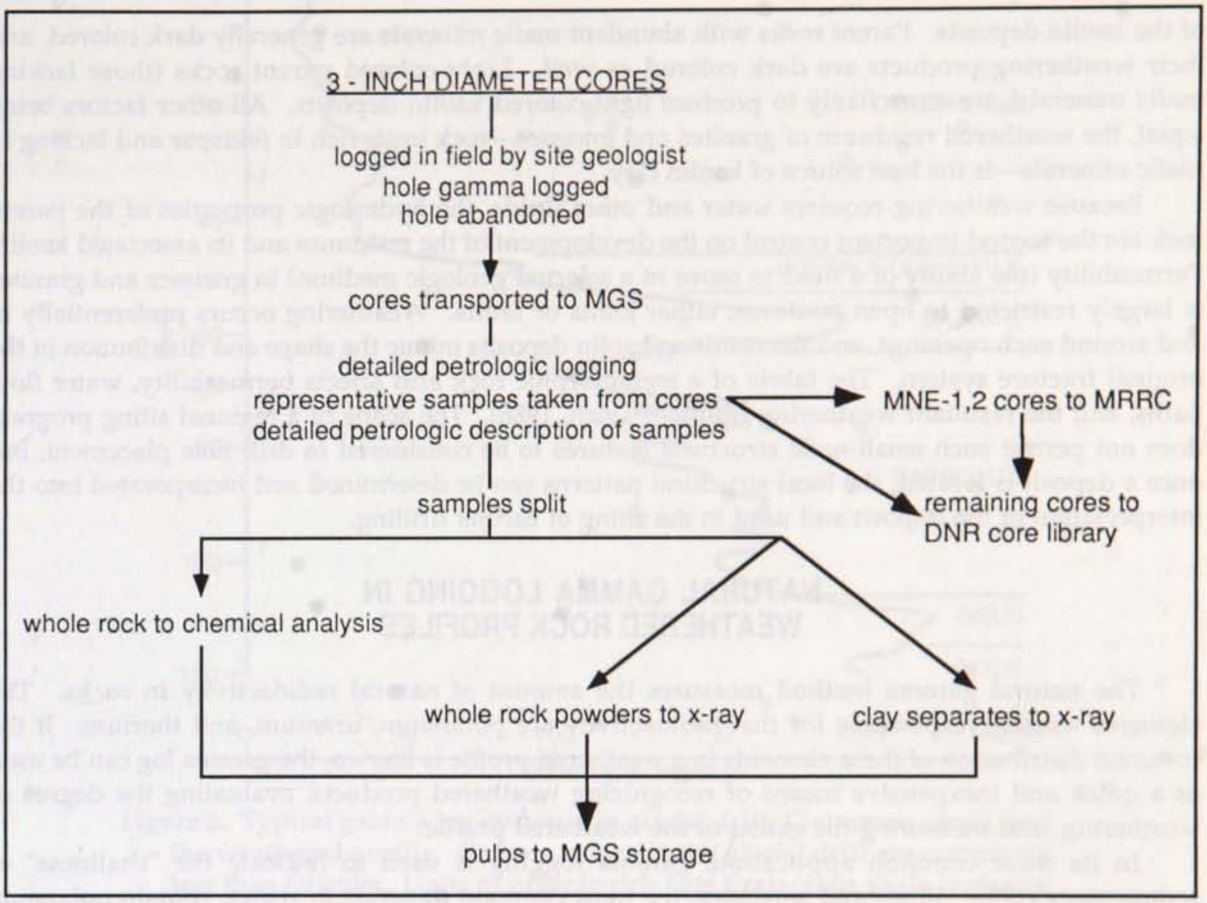


Figure 2. Disposition of core taken during drilling. MGS, Minnesota Geological Survey; MRRC, Mineral Resources Research Center, University of Minnesota, Minneapolis; DNR, Minnesota Department of Natural Resources, Division of Minerals, Hibbing.

THE WEATHERING PROCESS

Kaolinite is a secondary mineral formed by weathering (or hydrothermal alteration) of minerals rich in aluminum and silica and generally of igneous or metamorphic origin. Climate is the major control on weathering processes, but because our study area is relatively small, climatic conditions within it were probably uniform; therefore, differences in the occurrence of kaolin within the area can be attributed to secondary, nonclimatic controls.

The ease with which the various aluminum silicate minerals can be transformed into kaolinite varies considerably. In a classic study of the chemical phenomena associated with weathering, Goldich (1938) devised a stability series that emphasized the relative susceptibility to weathering of the common rock-forming minerals found in the igneous and metamorphic bedrock of southwestern Minnesota. He showed that those rocks rich in iron and magnesium (mafic minerals) or feldspars (especially the calcium-rich feldspars) are most susceptible to weathering.

It is the mineralogic nature of the bedrock (as expressed by the types of aluminum silicates it contains) that is the major control on the concentration of kaolin in the deposits resulting from weathering of bedrock. Bedrock rich in those minerals that are most susceptible to weathering (the mafic minerals and feldspars) will yield the greatest concentration of kaolin in its weathering products. The mineral composition of the original parent bedrock (protolith) also controls the color of the kaolin deposits. Parent rocks with abundant mafic minerals are generally dark colored, and their weathering products are dark colored as well. Light-colored parent rocks (those lacking mafic minerals) are more likely to produce light-colored kaolin deposits. All other factors being equal, the weathered residuum of granites and gneisses—rock units rich in feldspar and lacking in mafic minerals—is the best source of kaolin clay.

Because weathering requires water and other fluids, the hydrologic properties of the parent rock are the second important control on the development of the residuum and its associated kaolin. Permeability (the ability of a fluid to move in a selected geologic medium) in gneisses and granites is largely restricted to open fractures, either joints or faults. Weathering occurs preferentially in and around such openings, and the resulting kaolin deposits mimic the shape and distribution of the original fracture system. The fabric of a metamorphic rock also affects permeability, water flow paths, and the resultant weathering profile (Pavich, 1986). The scope of a regional siting program does not permit such small-scale structural features to be considered in drill hole placement, but once a deposit is located, the local structural patterns can be determined and incorporated into the interpretation of the deposit and used in the siting of further drilling.

NATURAL GAMMA LOGGING IN WEATHERED ROCK PROFILES

The natural gamma method measures the amount of natural radioactivity in rocks. The elements usually responsible for that radioactivity are potassium, uranium, and thorium. If the common distribution of these elements in a weathered profile is known, the gamma log can be used as a quick and inexpensive means of recognizing weathered products, evaluating the degree of weathering, and measuring the extent of the weathered profile.

In its most common application, gamma logging is used to indicate the "shaliness" of sedimentary rocks. Illites and smectites, the most common minerals in shales, contain potassium and cause a high gamma reading compared to that for sandstones and carbonates. In applying gamma logging to weathered profiles, it must be recognized that an inverse relationship exists. Because kaolinite is the dominant clay mineral, and because it contains no potassium (or uranium and thorium), those parts of the profile richest in clay have the *lowest* gamma values. This correlation between the gamma log and the amount of potassium present is the strongest and most consistent logging relationship seen during this study.

In general, gamma values increase with depth through the saprolith and grus and into the protolith (Fig. 3). This trend may be modified or masked by site-specific attributes of the protolith, but gamma and potassium values generally run predictably together. If potassium is irregularily distributed in the protolith (usually as potassium feldspar), it will also be irregularily distributed in the weathered profile. For example, the gneisses of the Minnesota River Valley commonly contain randomly distributed amphibolite rafts with relatively low potassium contents (Nielsen and Weiblen, 1980). This situation results in a "ragged" log with rapidly fluctuating values, but overall the gamma response still increases with depth in the weathered profile. Uranium and thorium in the protolith will similarly affect gamma responses if these elements are abundant, or unevenly distributed, but their effects are typically confined to gamma peaks associated with veining in the protolith or bauxitic intervals.

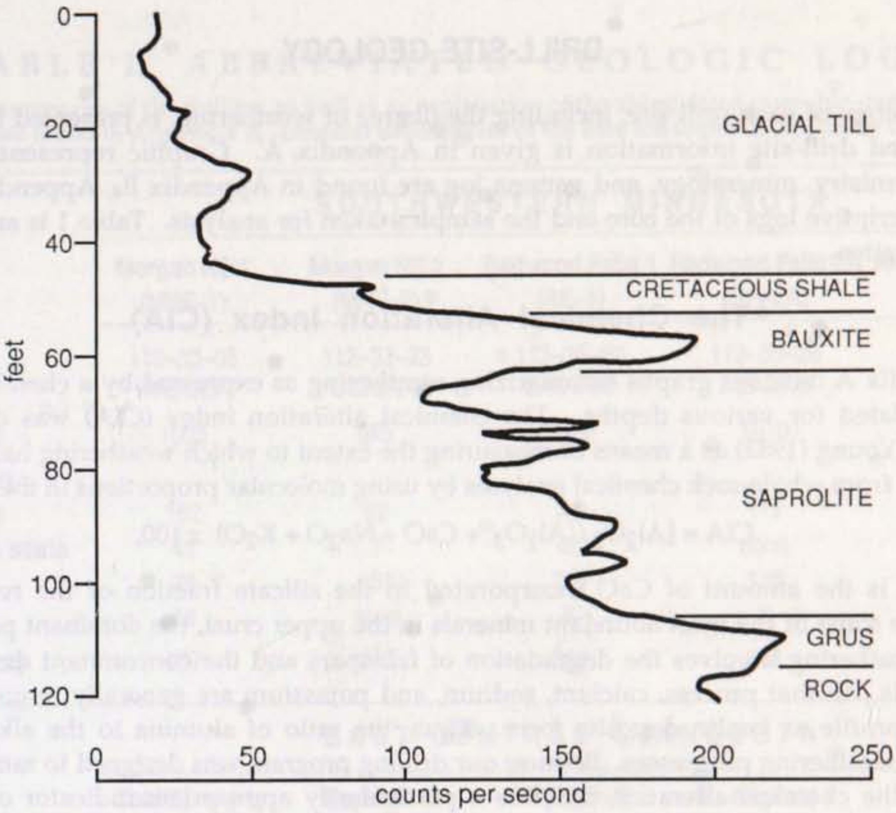


Figure 3. Typical gamma log response in glacial drift, Cretaceous strata, and the weathered profile. Gamma values in the glacial drift are commonly less than 50 units. Units of organic-rich Late Cretaceous shale typically generate approximately 100 gamma units. If a bauxitic units caps the saprolith, its value may exceed 200 units because of concentration of thorium (Hassan and Hossin, 1975). The remainder of the saprolith has readings ranging from 75 to greater than 200. The upper saprolith generally has the lowest gamma values and these values increase gradually as the fresh rock interface is approached. Unweathered rocks commonly have gamma values from 150 to greater than 200.

REGIONAL SITING CRITERIA

Because the potential for large kaolin deposits exists throughout much of western Minnesota, screening criteria were developed to pinpoint smaller areas that could be drilled with a limited budget. In general, kaolin deposits with the best chances of commerical success are light colored, near the land surface (shallow burial), thick, and laterally extensive. As previously noted, kaolin deposits are likely to form from light-colored parent rocks like granite and granitic gneiss. The distribution of these rock types at the bedrock surface (criterion one) is shown in Figure 1A. Figure 1B shows areas where the thickness of the glacial cover is 100 feet or less (criterion two), as inferred from the statewide depth-to-bedrock map (Olsen and Mossler, 1982). Areas defined by the intersection of these two criteria are shown in Figure 1C. Areas where the weathering profile was the thickest and the cover the thinnest were specifically targeted. Ten of these sites were sampled by drilling, and the samples used in part to evaluate the variety of geologic settings encountered.

DRILL-SITE GEOLOGY

The geology of each drill site, including the degree of weathering, is presented briefly below. More detailed drill-site information is given in Appendix A. Graphic representations of the geology, chemistry, mineralogy, and gamma log are found in Appendix B. Appendix C contains detailed descriptive logs of the core and the samples taken for analysis. Table 1 is an overview of all ten drill sites.

The Chemical Alteration Index (CIA)

Appendix A includes graphs summarizing weathering as expressed by a chemical alteration index calculated for various depths. The chemical alteration index (CIA) was developed by Nesbitt and Young (1982) as a means of measuring the extent to which weathering has occurred. It is calculated from whole-rock chemical analyses by using molecular proportions in the formula

$$CIA = [Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O) \times 100,$$

where CaO is the amount of CaO incorporated in the silicate fraction of the rock. Because feldspars are some of the most abundant minerals in the upper crust, the dominant process during chemical weathering involves the degradation of feldspars and the concomitant development of clay minerals. In that process, calcium, sodium, and potassium are generally removed from the weathered profile as kaolin deposits form. Thus, the ratio of alumina to the alkalis typically increases as weathering progresses. Because our drilling program was designed to sample feldspar-rich rocks, the chemical alteration index is a particularily appropriate indicator of weathering intensity at a given locality. Unaltered granitoids typically have CIA values between 45 and 55, whereas kaolinite has a value very close to 100.

Description of Individual Sites

Southwestern Minnesota (Minnesota River Valley)

Morgan NE #1 (MNE–1). The geologic history at this locality is slightly more complex than that of any other drill site. A weathered profile of unknown thickness developed on a bedrock composed predominantly of granitic gneiss. The profile was later eroded and only the lowermost grus-rich part preserved. Abrupt changes in chemical and mineralogical attributes at the top of the grus indicate erosion. Locally derived kaolinitic sandstone and shale were then deposited on top of the grus. Sedimentary structures in the sandstone and shale suggest fluvial deposition.

The clay fractions from the sediments and grus are dominated by kaolinite, but smectite becomes more abundant toward the bottom of the sedimentary sequence. A sandstone unit at the base of that sequence is a high gamma emitter and contains anomalously high values of uranium, thorium, and many rare earth elements. These constituents were probably emplaced by fluids migrating upward through the underlying grus and gneiss. CIA values indicate that weathering at this locality was very intense, and values approach 100 in the upper part of the section.

Morgan NE #2 (MNE–2). Drilling at this locality penetrated a weathered profile developed on an uncertain granitoid protolith. Geologic studies suggest that the area is underlain by gneiss cut by small granitic intrusions; either rock type could be the parent rock intersected here. Although the drilling did not reach fresh rock, textural and chemical trends clearly show that drilling terminated very near the bottom of the profile. A thin bed of Late Cretaceous shale overlies the profile, suggesting that post-Cretaceous erosion did not take place. The CIA profile shows that intense chemical weathering extends deep into the section and produced a thick,

TABLE 1. ABBREVIATED GEOLOGIC LOGS.

[Detailed summaries of the drilling, as well as an explanation of the abbreviated township-range-section system, are found in Appendix A. Detailed descriptions of the core are found in Appendix C, Part 1.]

SOUTHWESTERN MINNESOTA

	Morgan NE 1 (MNE-1)	Morgan NE 2 (MNE-2)	Redwood Falls 1 (RF-1)	Redwood Falls 2A (RF-2A)	Redwood Falls 3 (RF-3)
Location	112-33-35 DADDDA	112-33-23 CCABCC	113-35-33 CADCBC	113-35-26 BDADAB	112-35-1 BCDDCD
Elevation (feet)	1005	975	1020	1010	1003
Thickness (feet)					
Glacial drift	162	82	44	117	133
Cretaceous strata	48	7	45	none	none
Saprolith	28	153	129	136	57
Fresh rock	19	none	6	9	34
Total depth (feet)	257	242	224	262	224

EAST-CENTRAL MINNESOTA

	Cold Spring 1 (CS-1)	Royalton 1 (RY-1)	Royalton 2 (RY-2)	St. Augusta 1 (SA-1)	St. Joseph 1 (SJ-1)
Location	123-30-19 ACBBBA	127-29-8 CACCCB	127-32-33 BCCACB	123-27-19 CBAADC	124-29-24 CDBDCD
Elevation (feet)	1111	1051	1138	1007	1066
Thickness (feet)					
Glacial drift	53	30	80	48	15
Cretaceous strata	none	9	4	8	none
Saprolith	49	77	25	60	118
Fresh rock	10	27	none	5	25
Total depth (feet)	112	143	109	121	158

homogeneous deposit. CIA values for the deepest samples exceed 95. Kaolinite dominates the clay fraction, and only trace amounts of other clays were found. The deposit is light colored throughout. Residual grains of feldspar and quartz are also found throughout the profile, and they increase in abundance with depth.

Redwood Falls #1 (RF-1). This locality was drilled to tie together several separate studies of the clays in the Redwood Falls area. The material obtained here should link the investigations of the nearby mine site by the Natural Resources Research Institute and the large regional assessment of kaolin potential in the surrounding area by International Minerals and Chemical Corporation (IMC) (Wayland, 1964). Data from Wayland's report, which includes kaolin isopach and isograd mapping, correlates well with the chemical and mineralogical data acquired during the current study. Appendix F summarizes the IMC data.

The saprolith at this locality is overlain by a thin sequence of Late Cretaceous shale, indicating that the entire weathered profile has been preserved. Chemical and mineralogical trends show a smooth transition from extremely weathered saprolith, through grus, and into weathered gneiss. The gneiss contains a variety of amphibolite lenses and rafts, which impart a heterogeneity to the weathered profile. The rafts are visible in the saprolith as blocks of darker clay with a fine texture, an obvious foliation, and abundant biotite flakes. The saprolith is also cut by quartz veins, which are high gamma emitters and contain anomalous amounts of uranium and thorium. Chemical alteration indices calculated for the core samples indicate the saprolith was intensely weathered (CIA>90). The thickness of the saprolith as mapped by IMC suggests that weathering was localized in a northeast-trending direction, which corresponds to a northeast-trending fracture set in the bedrock.

Redwood Falls #2A (RF–2A). Drilling at this locality intersected a relatively thin saprolith and a thick section of grus overlying weathered granitic gneiss. The lack of Late Cretaceous strata at this site suggests that some of the original weathered profile has eroded away. Petrologic examination of the core reveals a complex protolith, comprised of intervals of granitic gneiss intercalated with intervals of granodiorite, which are in turn cut by zones of granitic pegmatite. These major rock types grade into each other and are intermixed on a variety of scales. Chemical alteration indices range from very high in the saprolith section (CIA>80), to very low in the weathered rock section (CIA<60). The values change at a constant rate through the cored interval. The clay-size fraction is dominated by kaolinite, but it is a relatively small part of the total weathered profile. Gamma log results show a sharp positive break that corresponds to the first appearance of fresh potassium feldspar at depths greater than 200 feet. This break may represent a chemical alteration front, but it more likely relates to the complex nature of the protolith, indicating a change in rock type.

Redwood Falls #3 (RF–3). The saprolith expected at this locality has been totally eroded and only grus and fresh rock remain. The water-well logs from this area indicate that the site is underlain by a thick, clay-rich sequence that is commonly found in this vicinity. Unfortuantely, the drilling was sited where this blanket is breached by erosion. The core is composed of the weathered remains of at least three major rock types, including tonalitic gneiss, weakly foliated granite, and amphibolitic rafts rich in biotite. The clay fraction is small and dominated by smectite. The lack of kaolinite is reflected in the low chemical alteration indices (CIA<60). The gamma log is highly variable, largely because of the complexity of the protolith.

East-central Minnesota (St. Cloud Area)

Cold Spring #1 (CS–1). Water wells drilled in this area typically intersect weathered residuum within 30 feet of the land surface and often at depths of less than 10 feet. Our drilling, however, encountered 64 feet of Quaternary sand and gravel deposited in a channel that had been eroded into the saprolith. Because of this erosion, the saprolith is relatively thin, and grus and weathered gneiss comprise the bulk of the samples retrieved. Chemical alteration indices of the remaining weathered profile are generally low (CIA<70). The clay fraction is dominated by kaolinite, but clay-size material is generally not very abundant. The parent rock (Richmond Gneiss) shows some variability in composition, particularily in the amount of mafic material. The gamma log has a sharp break near the middle of the grus section that correlates with the presence of potassium below that depth.

Royalton #1 (RY–1). This locality was selected because of nearby outcrops of white clay. Unfortunately, drilling here penetrated a thin, Late Cretaceous shale unit that overlies weathered residuum developed from a garnet–staurolite–biotite schist of the Little Falls Formation. Feldspar (plagioclase) in the schist has been altered to kaolinite, but biotite, garnet, and staurolite are relatively fresh. Clay abundance is relatively low, consistent with CIA values of 70 to slightly more than 80.

Royalton #2 (RY–2). Drilling at this locality encounted a thin layer of Late Cretaceous strata overlying a very thin saprolith. The saprolith overlies a grus section that was not fully penetrated. The regional geologic information used to site this hole indicated a gneissic bedrock, but the saprolith and grus that were recovered had developed from a biotite–schist protolith, similar to that at drill site RY-1. The presence of Late Cretaceous strata indicates that preservation of the weathered profile is probably complete. CIA values in the saprolith and grus are moderately high (75 to more than 95), an indication that the feldspars are very weathered; however, biotite is abundant in the residuum. Kaolinite dominates the clay fraction of the saprolith and grus.

St. Augusta #1 (SA–1). The weathered profile at this locality has both pedogenic features and a cover of Late Cretaceous shale still intact. Late Cretaceous strata are easily distinguished from the underlying weathered products by their high organic content, their lower CIA values, and their mixed clay mineralogy. The thick saprolith is capped by a pisolitic bauxite. This pedogenic unit represents extreme chemical weathering with resultant CIA values greater than 96. The bauxite is clearly indicated on the gamma log by high gamma values, which are probably caused by anomalous thorium values, typical of bauxites in general (Hassan and Hossin, 1975). The remainder of the saprolith is clay rich, and kaolinite is the dominant clay mineral. CIA values are high (75 to 95) but gradually decrease with depth. This section has a low gamma expression, probably because weathering leached potassium from the rocks. The grus section is relatively thin, as is the zone of transition to fresh quartz monzonite. Both are high gamma emitters, because of the presence of potassium feldspars.

St. Joseph #1 (SJ–1). The bedrock geology in this area is dominated by the St. Cloud Granite, which is cut by abundant diabase dikes; both rock types were intersected at this locality. The presence of different kinds of parent material is evident in the textural, chemical, mineralogical, and gamma profiles of the section. A relatively thick saprolith was encountered within 15 feet of the land surface, and it grades downward into grus and fresh rock. The absence of Late Cretaceous strata and other pedogenic features indicates that at least some of the original profile has been eroded. Weathering here extends to a depth of more than 120 feet, but fresh dimension stone is quarried in the same rock type at the land surface less than a quarter of a mile away. This suggests that weathering in this area is probably related to fracturing and attendant hydrologic action. The chemical alteration indices reach high values in the saprolith (CIA>90), but values vary widely. Values in the grus decrease rapidly. The clay fraction is dominated by kaolinite in the saprolith, but a mix of several clays characterizes the grus section.

CONCLUSIONS AND GUIDES TO EXPLORATION

The areal extent and compositional attributes of the kaolin clay deposits of southwestern and east-central Minnesota suggest that intense chemical weathering took place during a period of uncertain length prior to Late Cretaceous time. The climatic factors controlling the weathering processes were probably similar throughout the state; it was the mineralogic composition and local hydrologic characteristics of potential protoliths that were the major controls on the kinds of kaolin deposits that formed. Plagioclase-rich rocks produced kaolin-rich residuum; the lighter colored protoliths produced lighter colored residuum; and zones of increased permeability, like fracture zones, produced the thickest residuum. The kaolin materials formed by weathering may have been eroded in places and then redeposited, but concentrated secondary kaolin deposits typically formed in close proximity to the sites of primary kaolin formation. Kaolinite occurs most abuandantly at the top of a weathered profile, and it is this part of the profile that is most vulnerable to erosion. This study has not addressed the various diagenetic processes that altered the original weathered products, even though features indicative of those processes, such as siderite nodules, are common.

The most commercially promising kaolin clay deposits should therefore be found where the saprolith is covered by Late Cretaceous strata, or where the top of the saprolith is marked by pedogenic features, such as a pisolitic texture. The thickening of kaolin deposits (caused by structural trends and associated hydrologic activity) is best addressed on a local basis as a second phase of exploration.

REFERENCES CITED

Bickford, K.F., and Price, Don, [1947,] Report on work done on clays in summer 1947: Minnesota Geological Survey file report, 20 p.

Goldich, S.S., 1938, A study in rock weathering: Journal of Geology, v. 46, p. 17-58.

Grout, F.F., and Soper, E.K., 1919, Clays and shales of Minnesota: U.S. Geological Survey Bulletin 678, 259 p.

Hassan, M., and Hossin, A., 1975, Contribution a l'étude des comportements du thorium et du potassium dans les roches sédimentaires: Paris, C.R. Acad. Sci., 280 p.

Nesbitt, H.W., and Young, G.M., 1982, Early Proterozoic climates and plate motions inferred from major element chemistry of lutites: Nature, v. 299, p. 715-717.

Nielsen, B.V., and Weiblen, P.W., 1980, Mineral and rock compositions of mafic enclaves in the Morton Gneiss, *in* Morey, G.B., and Hanson, G.N., eds., Selected studies of Archean gneisses and lower Proterozoic rocks in the southern Canadian Shield: Geological Society of America Special Paper 182, p. 95-103.

Olsen, B.M., and Mossler, J.H., 1982, Geologic map of Minnesota, depth to bedrock: Minnesota Geological Survey State Map Series S-14, scale 1:1,000,000.

Parham, W.E., 1970, Clay mineralogy and geology of Minnesota's kaolin clays: Minnesota Geological Survey Special Publication Series SP-10, 142 p.

Parham, W.E., and Hogberg, R.K., 1964, Kaolin clay resources of the Minnesota River valley, Brown, Redwood and Renville Counties; a preliminary report: Minnesota Geological Survey Report of Investigations 3, 43 p.

Pavich, M.J., 1986, Processes and rates of saprolite production and erosion on a foliated granitic rock of the Virginia Piedmont, *in* Colman, S.M., and Dethier, D.P., eds., Rates of chemical weathering of rocks and minerals: Orlando, Fla., Academic Press, p. 552-590.

Wayland, T.E., 1964, The Redwood Falls kaolin deposit, Redwood Falls, Minnesota: Unpublished report of the International Minerals and Chemical Corporation, Industrial Minerals Division, Geology Department, 14 p. text, various unnumbered tables and appendices, 4 over-size plates..

Winchell, N.H., 1874, The geology of the Minnesota valley: Minnesota Geological and Natural History Survey Annual Report, 2nd, for the year 1873, p. 127-212.

APPENDIX A

DRILLING SUMMARIES

Organization of the Data

The following section includes basic data for every hole drilled for this project. The data are organized geographically by region, southwestern Minnesota first, followed by east-central Minnesota. Within a region, the drill holes occur alphabetically and numerically by field number (MNE–1, MNE–2, RF–1). The location of each hole is shown approximately on the appropriate 1:250,000-scale topographic map (Figs. 5 and 6, following two pages). Locations are described precisely on each log in the abbreviated township–range–section (T–R–S) system (see below) and plotted on a 1:24,000-scale topographic map showing all or part of the particular section of land in which the hole was drilled.

Explanation of the Abbreviated T–R–S system

A great majority of townships in Minnesota are north of a zero standard parallel and west of a zero principal meridian. Therefore, every Minnesota township is T.(Y)N., R.(X)W., and, since T. and R. are understood and N. and W. apply to all, a particular township can be specified as Y-X. For examply, T.130N., R.33W., the legal description of Hartford Township would be indicated 130-33-29 in the abbreviated T-R-S system. More precise locations within a legal section can be specified by the ABCD system, which is a simplification of the "NW1/4SE1/4 . . ." system that traditionally has been used in legal land descriptions. In the ABCD system (see example below), A is the northeast quadrant, B is the northwest quadrant, C is the southwest quadrant, and D is the southeast quadrant, and the *largest* quadrant pertaining to a location is given ***first***. For example, the location of a hole is the NE1/4 of the SE1/4 of the SW1/4 of the SW1/4 of the NW1/4 of section 29, Hartford Township, Todd County, would be described as 130-33-29 BCCDA.

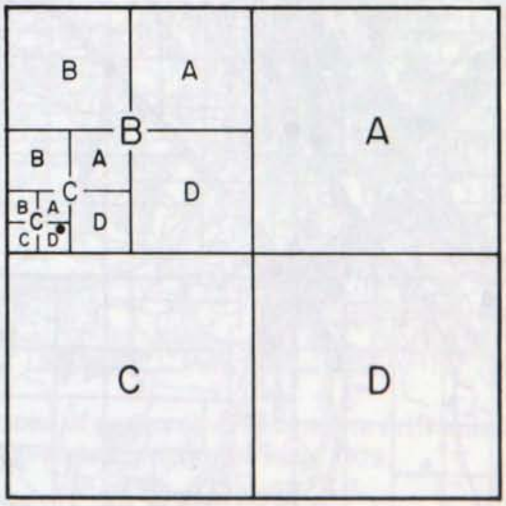


Figure 4. Location of the hole in the example given above.

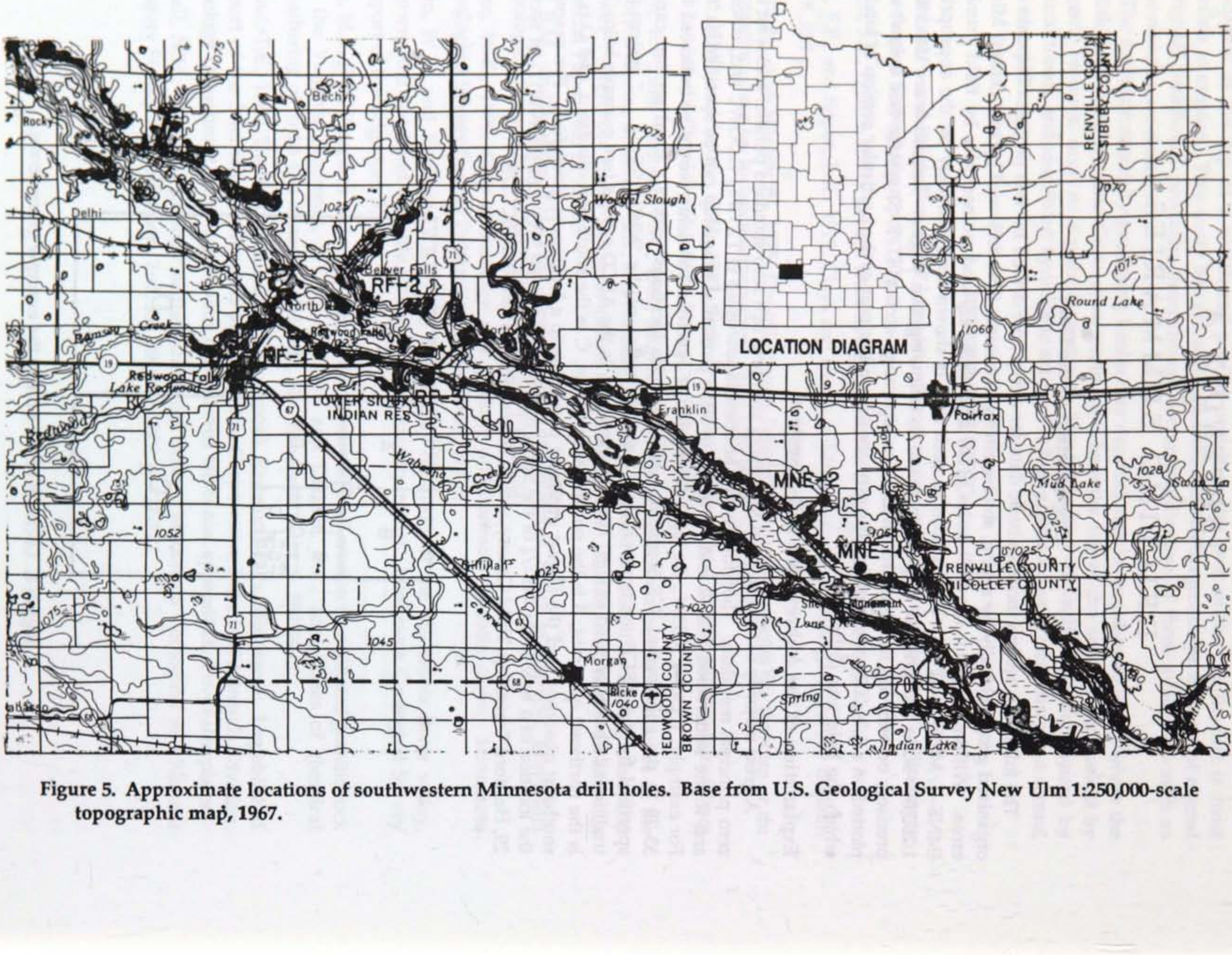


Figure 5. Approximate locations of southwestern Minnesota drill holes. Base from U.S. Geological Survey New Ulm 1:250,000-scale topographic map, 1967.

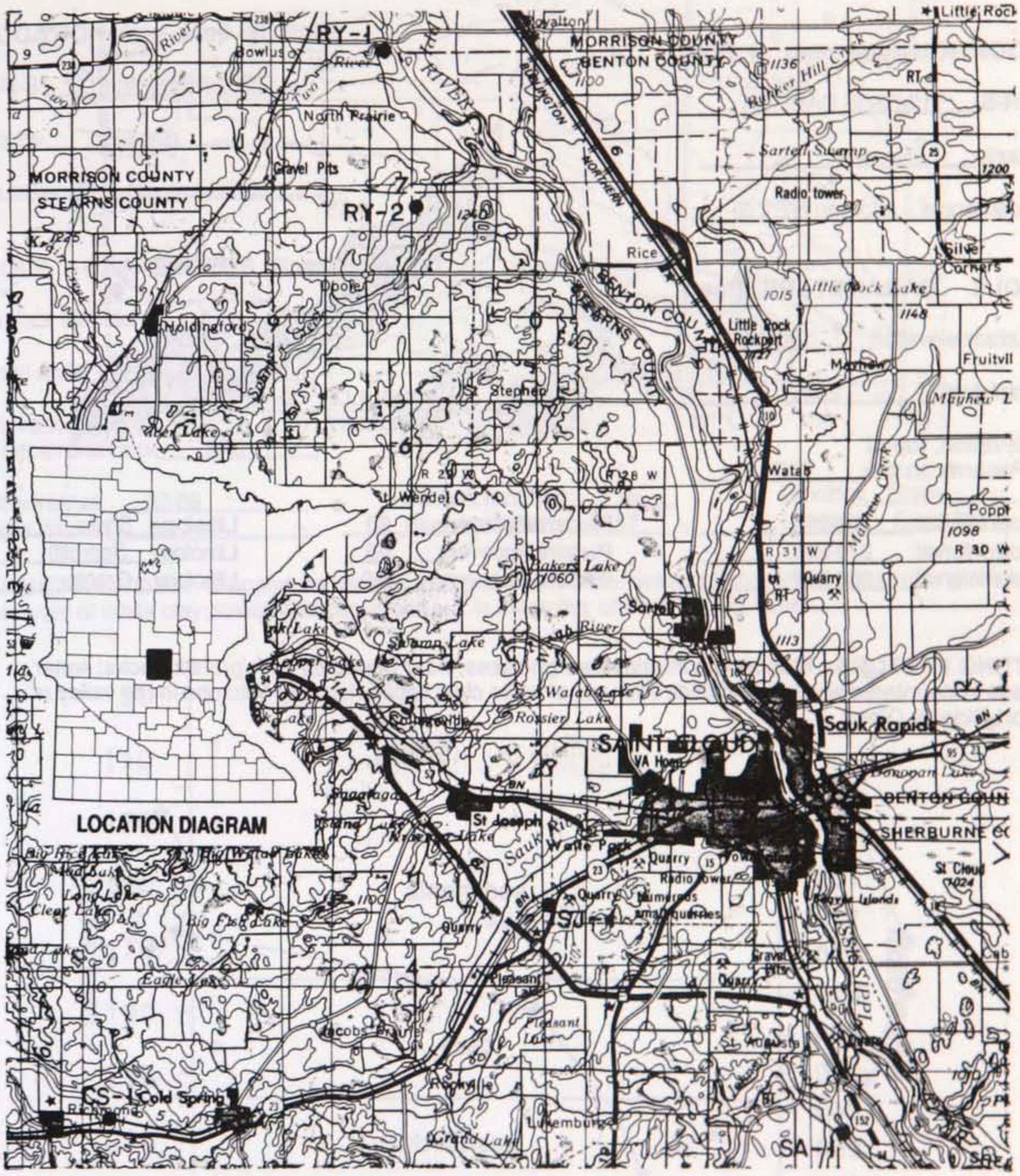
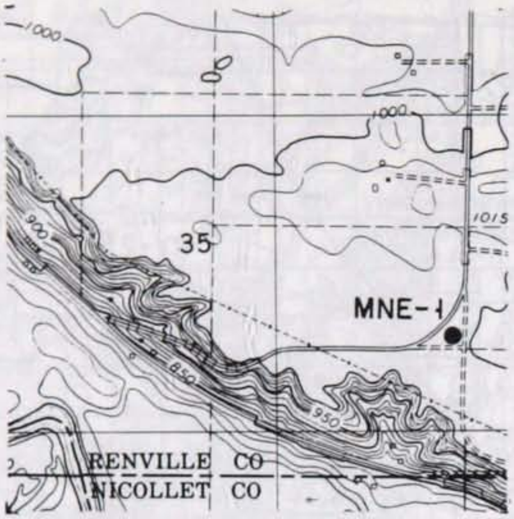


Figure 6. Approximate locations of east-central Minnesota drill holes. Base from U.S. Geological Survey St. Cloud 1:250,000-scale topographic map, 1979.

Field number **MNE-1**

Date completed 7-25-88

MGS unique number 20042



LOCATION (see map at right)

T-R-S 112-33-35 DADDDA

County Renville

Quadrangle Morgan NE 7.5'

HOLE PARAMETERS (feet)

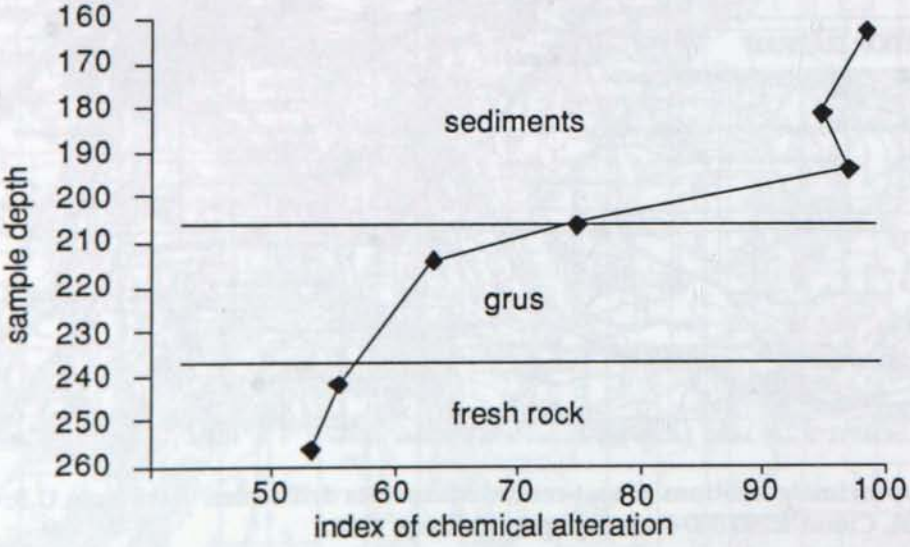
Surface elevation 1005

Total depth 257

Elevation, top of Precambrian rock 795

Core interval 162-210 Percent Recovery 90 Lithology Shale
Core interval 210-238 Percent Recovery 96 Lithology Saprolith
Core interval 238-257 Percent Recovery 100 Lithology Granite

SITING FACTORS: Mapped as interlayered gneisses, near boundary with granitic rocks; water wells encountered shallow and thick intervals of white clay; kaolin-rich clay outcrops in the valley of Fort Ridgely Creek.



Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **MNE-2**

Date completed 7-29-88

MGS unique number 20043

LOCATION (see map at right)

T-R-S 112-33-23 CCABCC

County Renville

Quadrangle Morgan NE 7.5'

HOLE PARAMETERS (feet)

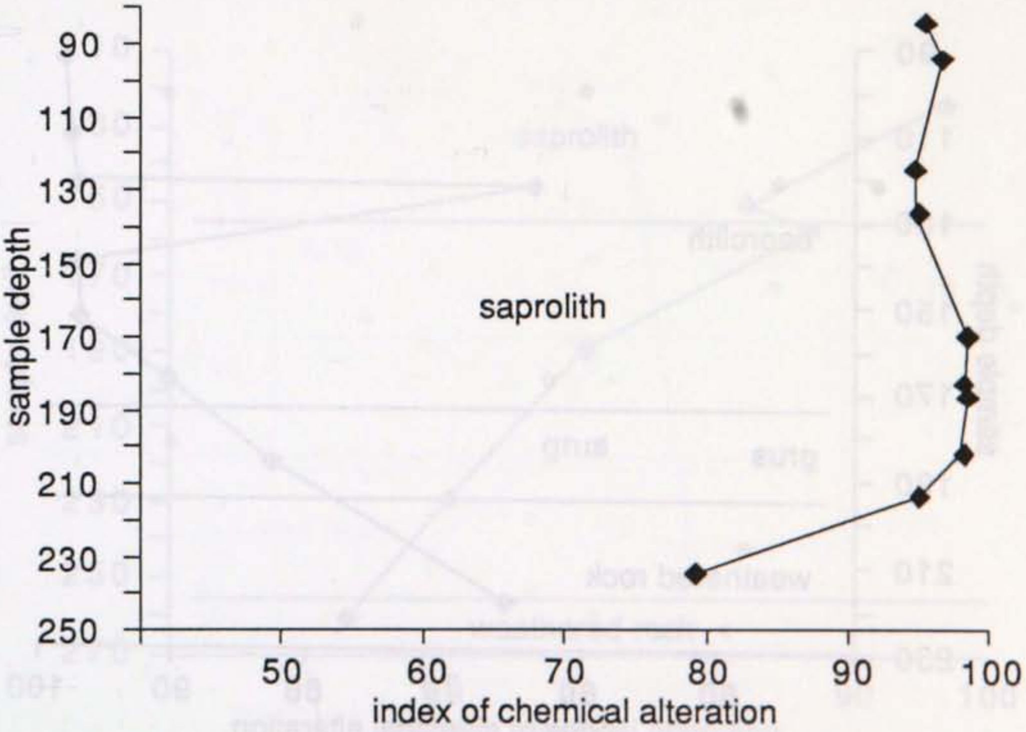
Surface elevation 975

Total depth 242

Elevation, top of Precambrian rock 886

Core interval 82-89	Percent recovery 75	Lithology Shale
Core interval 89-242	Percent recovery 87	Lithology Saprolith

SITING FACTORS: Mapped as interlayered gneisses; water wells encountered shallow and thick intervals of white clay; kaolin-rich clay crops out in the valley of Fort Ridgely Creek.



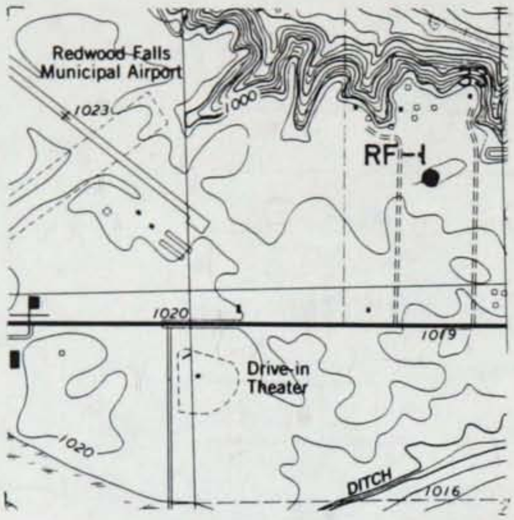
Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **RF-1**

Date completed 6-27-88

MGS unique number 20044

LOCATION (see map at right)



T-R-S 113-35-33 CADCBC

County Redwood

Quad. Redwood Falls 7.5'

HOLE PARAMETERS (feet)

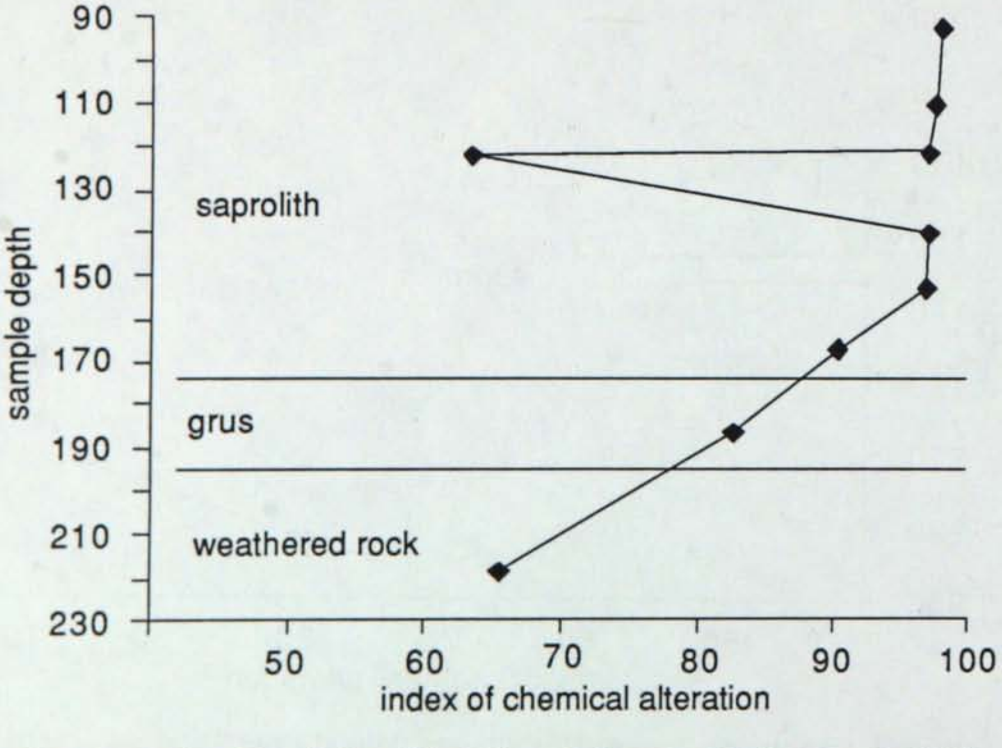
Surface elevation 1020

Total depth 224

Elevation, top of Precambrian rock 802

Core interval 90-218	Percent Recovery 95	Lithology Saprolith
Core interval 218-224	Percent Recovery 100	Lithology Gneiss

SITING FACTORS: Mapped as granitic rocks; supported by previous clay exploration data; outcrops and clay mine in Minnesota River Valley expose saprolith.



Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **RF-2A**

Date completed 7-22-88

MGS unique number 20045

LOCATION (see map at right)

T-R-S 113-35-26 BDADAB

County Renville

Quad. Redwood Falls 7.5'

HOLE PARAMETERS (feet)

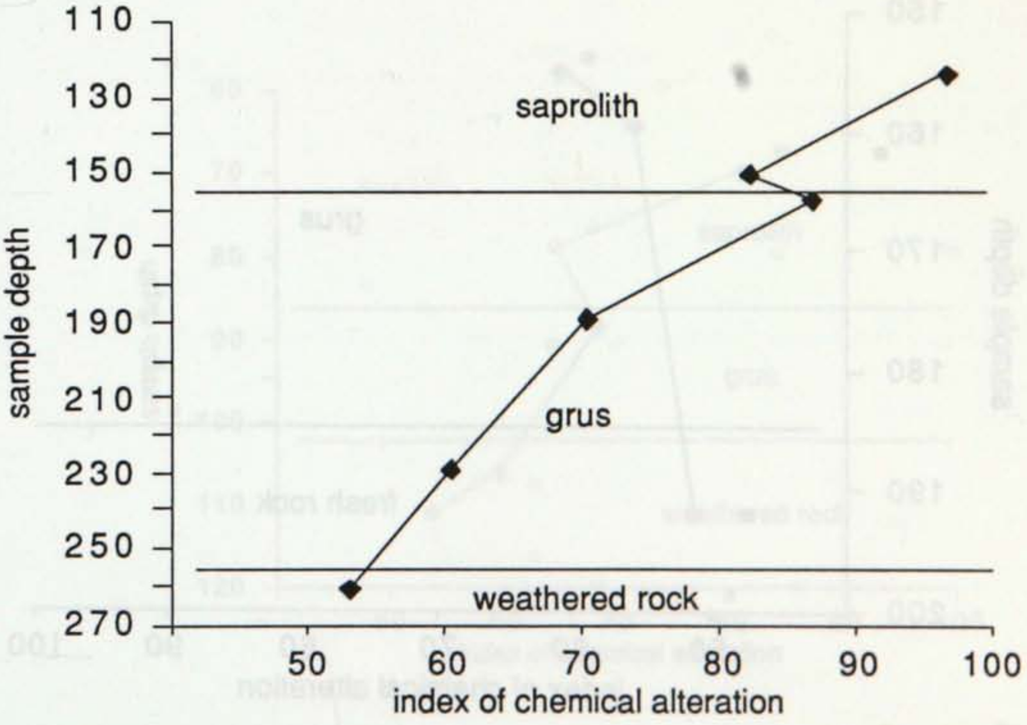
Surface elevation 1010

Total depth 262

Elevation, top of Precambrian rock 893

Core interval 116-124 Percent Recovery 8 Lithology Cobbles
Core interval 124-221 Percent Recovery 97 Lithology Saprolith
Core interval 221-262 Percent Recovery 100 Lithology Gneiss

SITING FACTORS: Area mapped as granitic rocks; outcrops of kaolinitc saprolith are common.



Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **RF-3**

Date completed 7-1-88

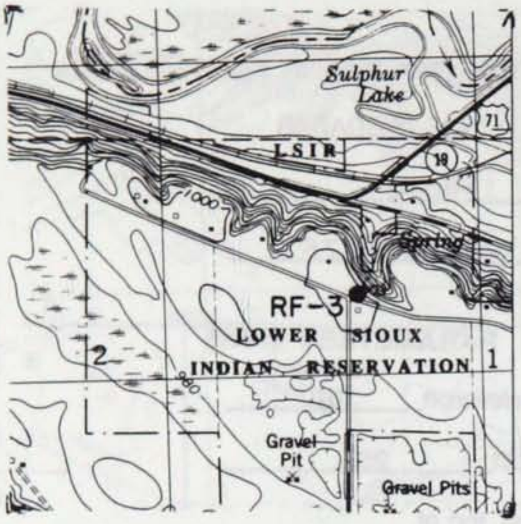
MGS unique number 20046

LOCATION (see map at right)

T-R-S 112-35-1 BCDDCD

County Redwood

Quad. Redwood Falls 7.5'



HOLE PARAMETERS (feet)

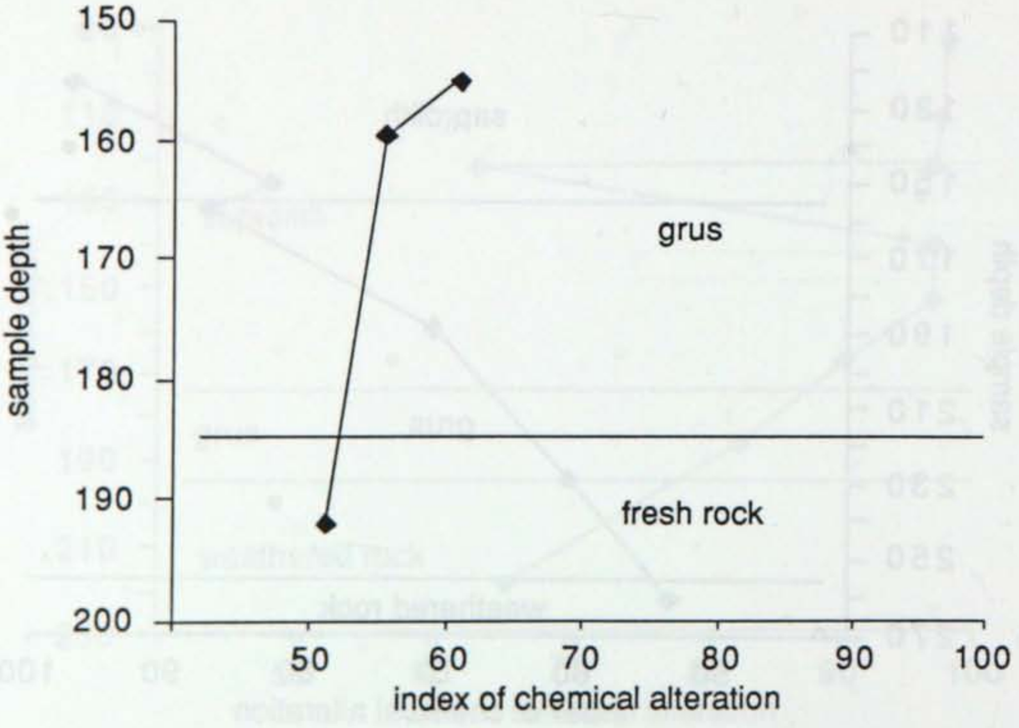
Surface elevation 1003

Total depth 224

Elevation, top of Precambrian rock 870

Core interval 153-224 Percent Recovery 99 Lithology Gneiss

SITING FACTORS: Area mapped as migmatite containing rafts of amphibolite; water wells report shallow and thick clay intervals; outcrops of saprolith are common in vicinity.



Chemical alteration index (Nesbitt and Young, 1982) versus depth

Field number **CS-1**

Date completed 6-22-88

MGS unique number 20049

LOCATION (see map at right)

T-R-S 123-30-19 ACBBBA

County Stearns

Quadrangle Cold Spring 7.5'

HOLE PARAMETERS (feet)

Surface elevation 1111

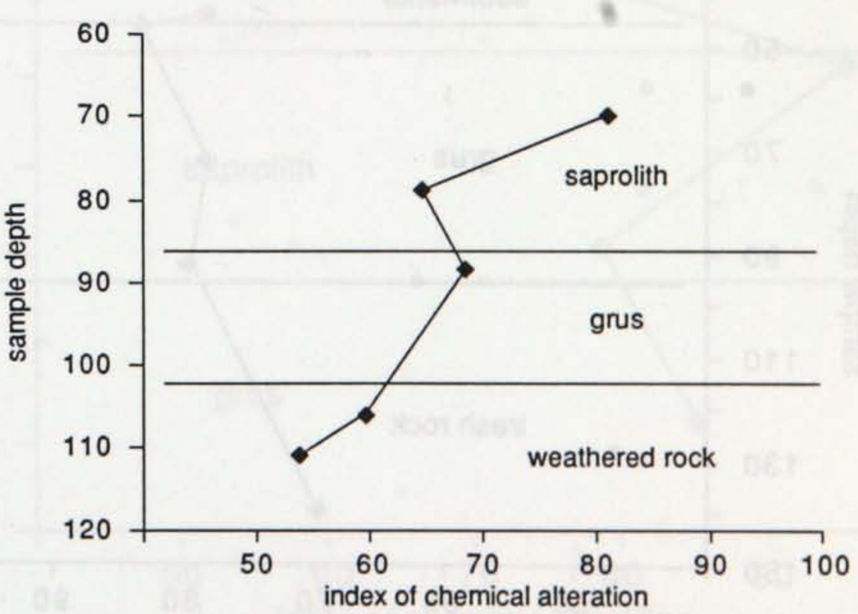
Total depth 112

Elevation, top of Precambrian rock 1013

Core interval 60-98 Percent Recovery 88 Lithology Saprolith

Core interval 98-112 Percent Recovery 100 Lithology Gneiss

SITING FACTORS: Area mapped as Richmond Gneiss; water wells encountered thick, shallow saprolith.

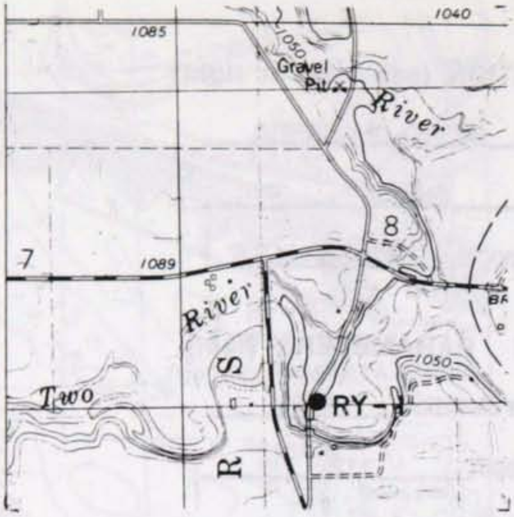


Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **RY-1**

Date completed 6-13-88

MGS unique number 20047



LOCATION (see map at right)

T-R-S 127-29-8 CACCCB

County Morrison

Quadrangle Royalton 7.5'

HOLE PARAMETERS (feet)

Surface elevation 1051

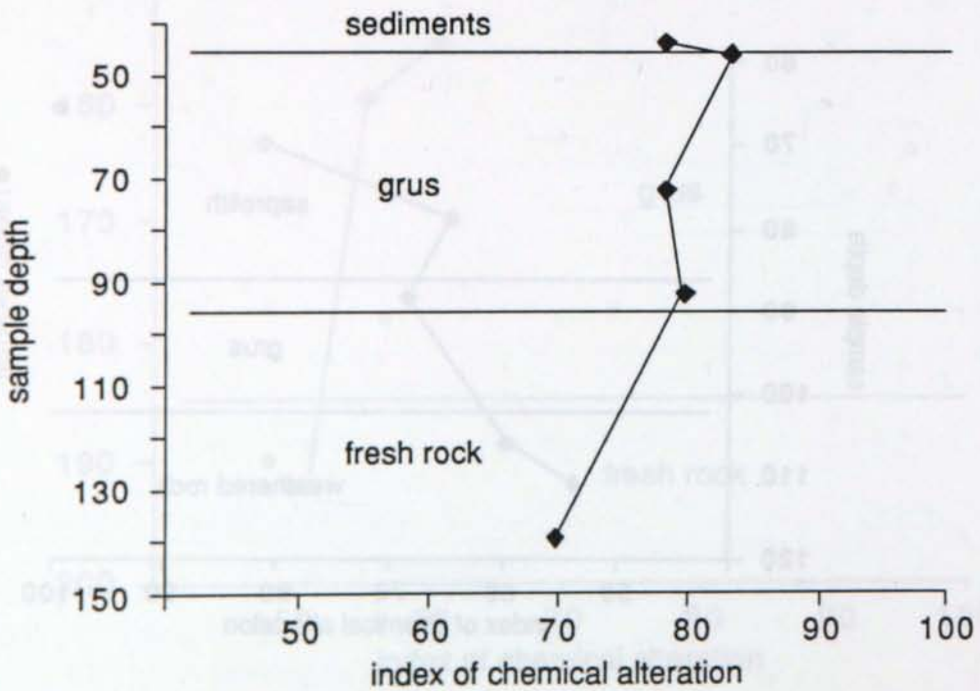
Total depth 143

Elevation, top of Precambrian rock 1012

Core interval 40-130 Percent Recovery 90 Lithology Saprolith

Core interval 130-143 Percent Recovery 100 Lithology Staurolite schist

SITING FACTORS: Area mapped as Mille Lacs Group but very near boundaries with Little Falls Formation and gneissic rocks; water wells encountered thick and shallow saprolith; outcrops of saprolith are common in the Mississippi and Two River valleys.

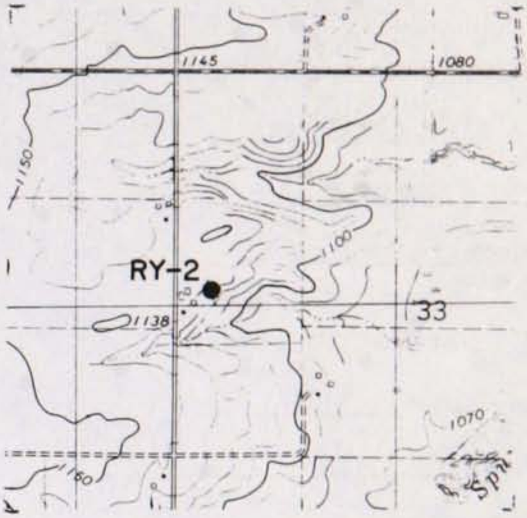


Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **RY-2**

Date completed 6-16-88

MGS unique number 20048



LOCATION (see map at right)

T-R-S 127-32-33 BCCACB

County Stearns

Quadrangle Royalton 7.5'

HOLE PARAMETERS (feet)

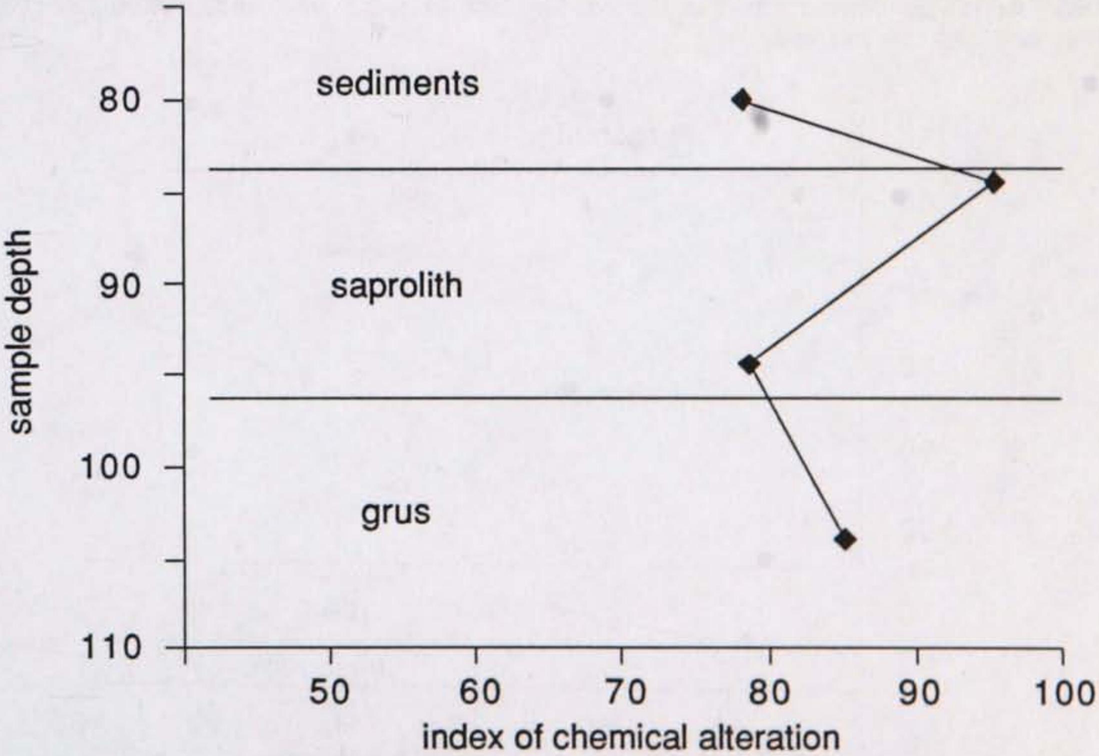
Surface elevation 1138

Total depth 109

Elevation, top of Precambrian rock 1056

Core interval 50-58	Percent Recovery 25	Lithology Glacial till
Core interval 80-109	Percent Recovery 72	Lithology Saprolith

SITING FACTORS: Area mapped as gneiss; water wells encountered thick and shallow saprolith.



Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **SA-1**

Date completed 6-23-88

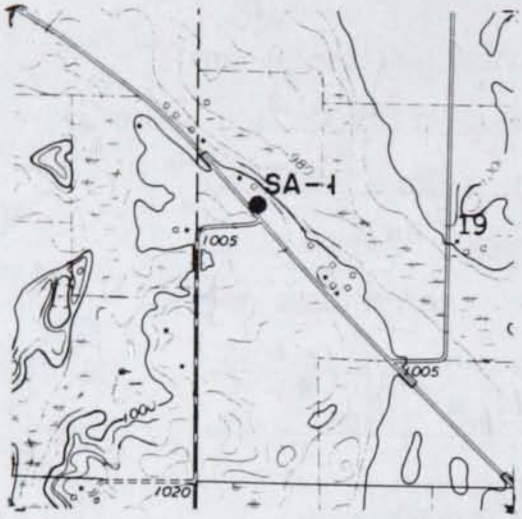
MGS unique number 20050

LOCATION (see map at right)

T-R-S 123-27-19 CBAADC

County Stearns

Quadrangle St. Augusta 7.5'



HOLE PARAMETERS (feet)

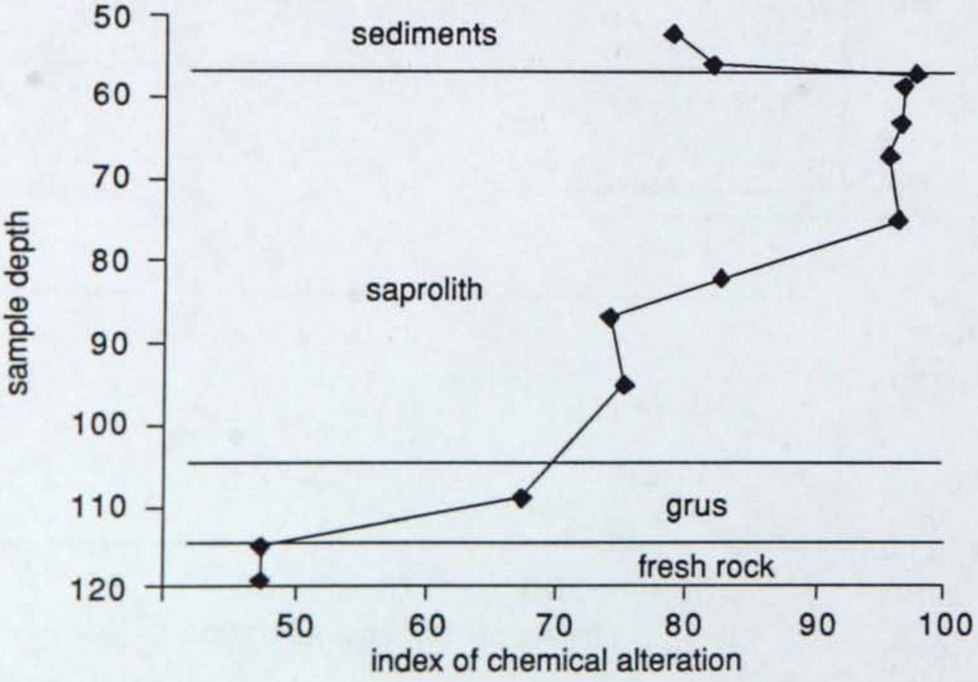
Surface elevation 1007

Total depth 121

Elevation, top of Precambrian rock 897

Core interval 50-55	Percent Recovery 80	Lithology Shale
Core interval 155-110	Percent Recovery 95	Lithology Saprolith
Core interval 110-121	Percent Recovery 100	Lithology Granite

SITING FACTORS: Area mapped as Reformatory Granite; water wells encountered light-colored, shallow, and thick clay intervals.

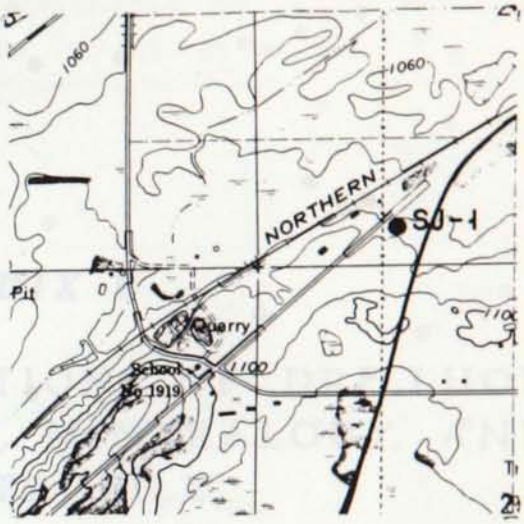


Chemical alteration index (Nesbitt and Young, 1982) versus depth.

Field number **SJ-1**

Date completed 6-18-88

MGS unique number 22071



LOCATION (see map at right)

T-R-S 124-29-24 CDBDCD

County Stearns

Quadrangle St. Joseph 7.5'

HOLE PARAMETERS (feet)

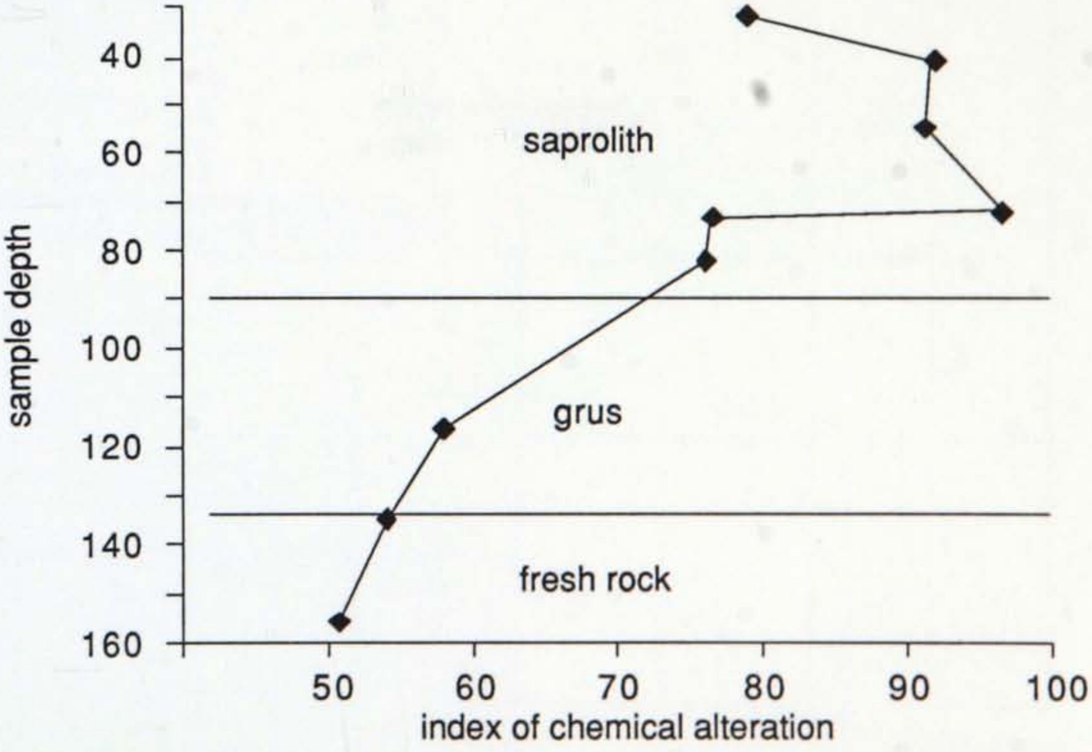
Surface elevation 1066

Total depth 158

Elevation, top of Precambrian rock 1051

Core interval 30-141	Percent Recovery 85	Lithology Saprolith, grus
Core interval 141-158	Percent Recovery 100	Lithology Granite

SITING FACTORS: Area mapped as St. Cloud Granite; water well encountered thick, shallow saprolith.

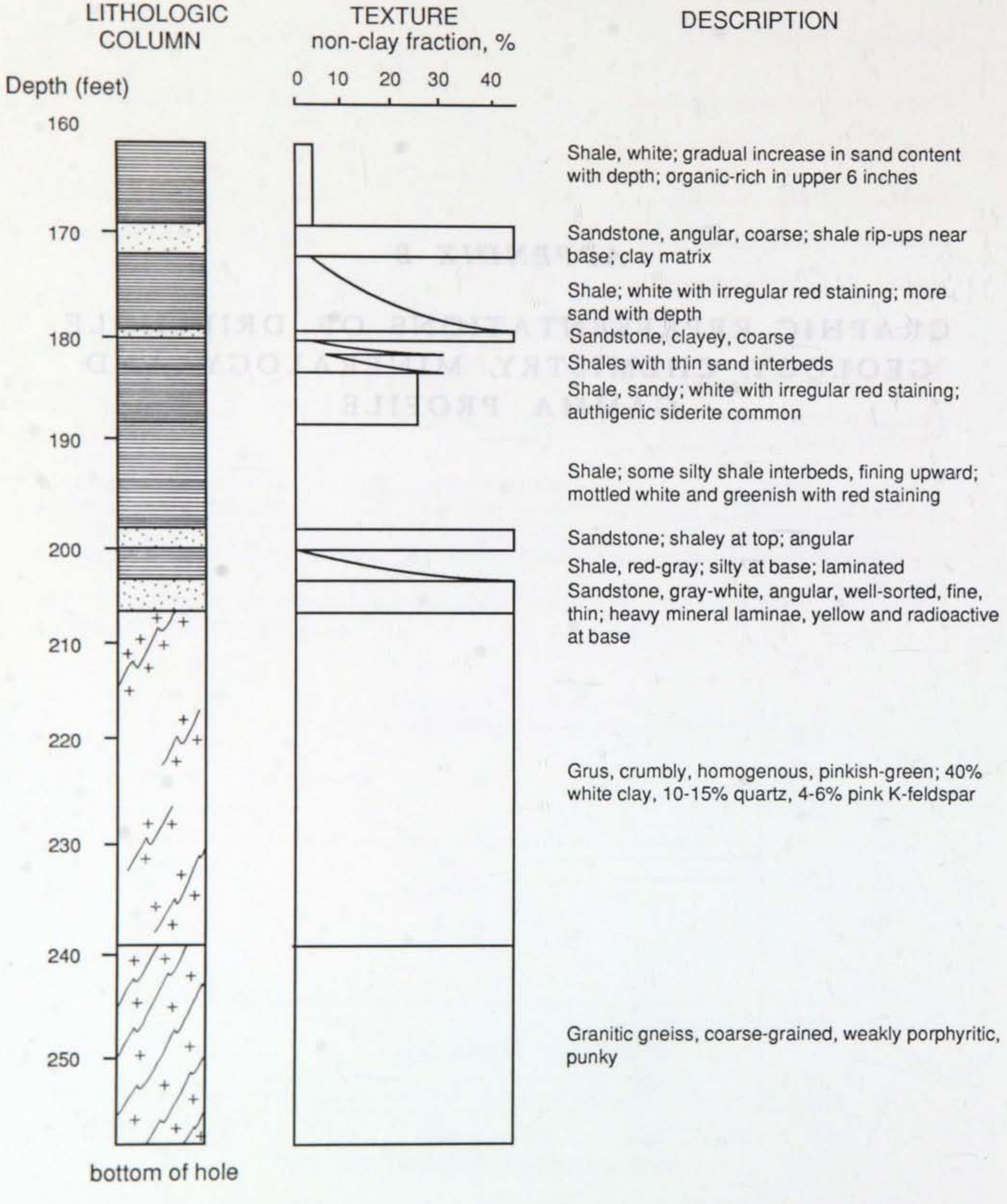


Chemical alteration index (Nesbitt and Young, 1982) versus depth.

APPENDIX B

GRAPHIC REPRESENTATIONS OF DRILLHOLE GEOLOGY, CHEMISTRY, MINERALOGY, AND GAMMA PROFILE

Morgan NE #1 (MNE–1)



Shale, white; gradual increase in sand content with depth; organic-rich in upper 6 inches

Sandstone, angular, coarse; shale rip-ups near base; clay matrix

Shale; white with irregular red staining; more sand with depth

Sandstone, clayey, coarse

Shales with thin sand interbeds

Shale, sandy; white with irregular red staining; authigenic siderite common

Shale; some silty shale interbeds, fining upward; mottled white and greenish with red staining

Sandstone; shaley at top; angular

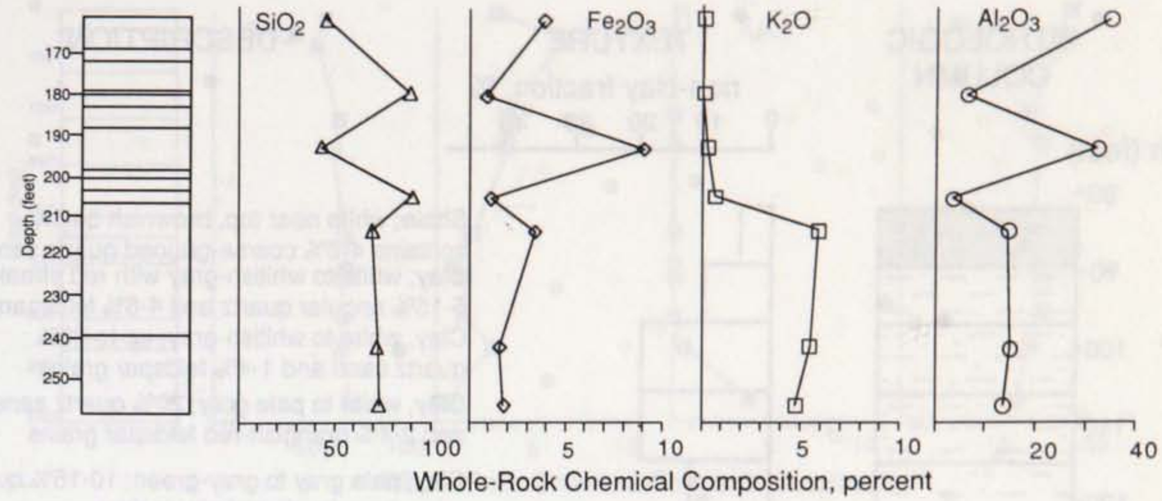
Shale, red-gray; silty at base; laminated

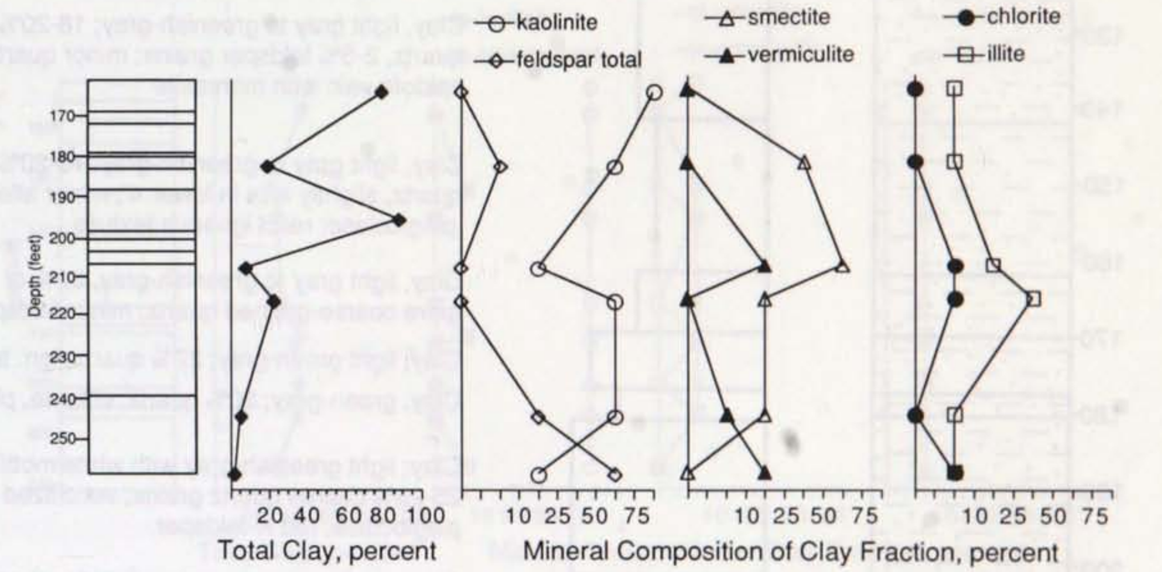
Sandstone, gray-white, angular, well-sorted, fine, thin; heavy mineral laminae, yellow and radioactive at base

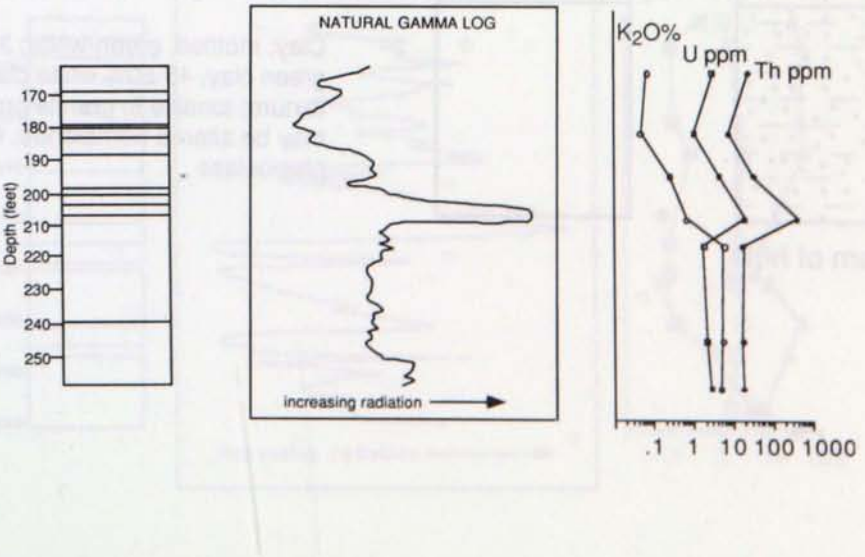
Grus, crumbly, homogenous, pinkish-green; 40% white clay, 10-15% quartz, 4-6% pink K-feldspar

Granitic gneiss, coarse-grained, weakly porphyritic, punky

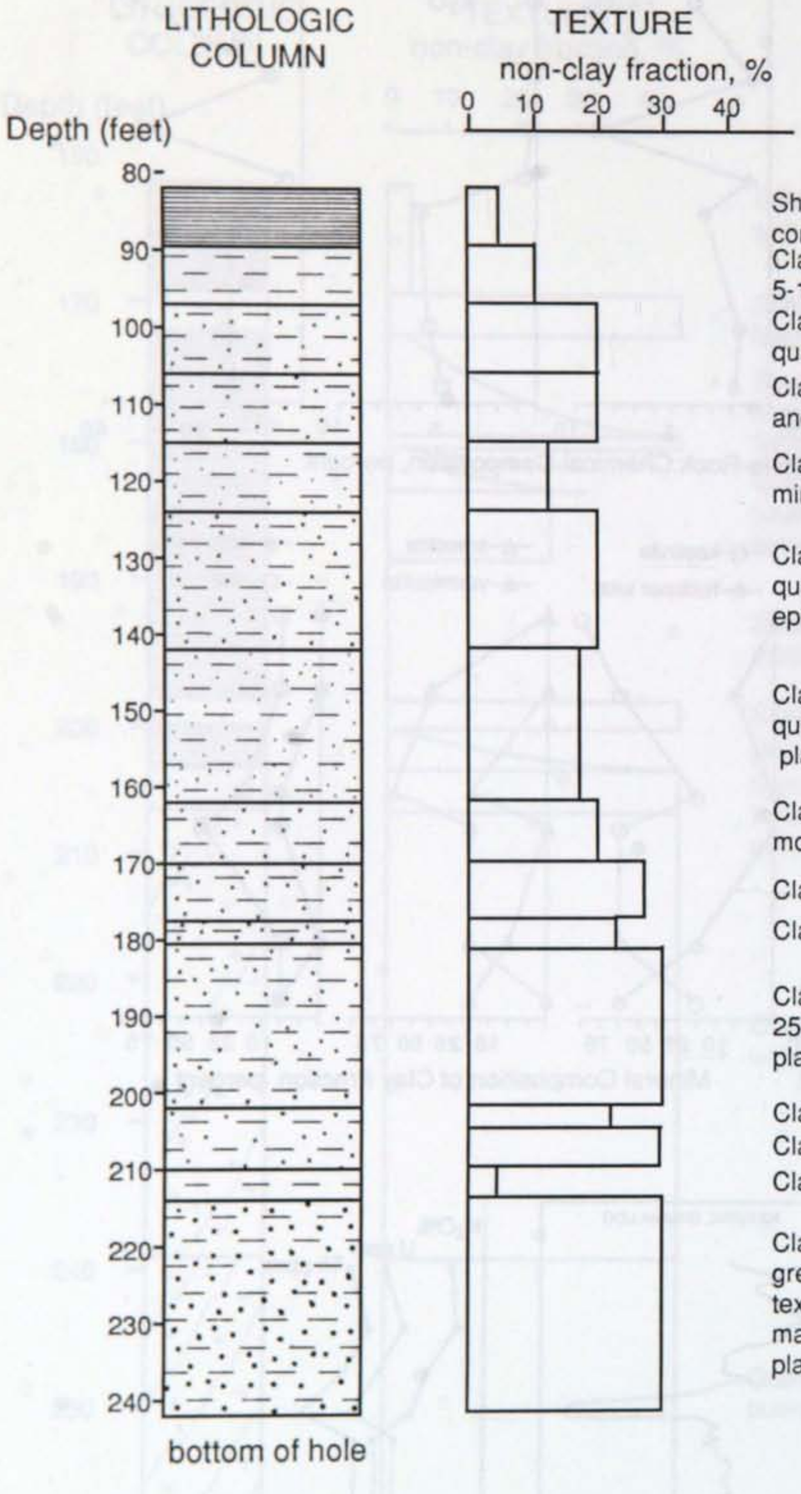
Morgan NE #1 (MNE–1) continued







Morgan NE #2 (MNE–2)



DESCRIPTION

Shale; white near top, brownish below; contains 4-6% coarse-grained quartz sand

Clay; white to whitish-gray with red streaks; 5-15% angular quartz and 4-6% feldspars

Clay, white to whitish-gray; up to 20% quartz sand and 1-4% feldspar grains

Clay, white to pale gray; 20% quartz sand and 2-4% orangish-red feldspar grains

Clay, pale gray to gray-green; 10-15% quartz; minor heavily altered plagioclase

Clay, light gray to greenish-gray; 18-20% quartz, 2-5% feldspar grains; minor quartz-epidote vein with marcasite

Clay, light gray to greenish-gray; 15-20% quartz, slightly less in lower 4'; minor altered plagioclase; relict igneous texture

Clay, light gray to greenish-gray, 20% or more coarse-grained quartz; minor feldspar

Clay, light green-gray; 27% quartz; ign. text.

Clay, green-gray; 20% quartz; chlorite, plag.

Clay; light greenish-gray with white mottling; 25-28% coarse quartz grains; sericitized plagioclase, red K-feldspar

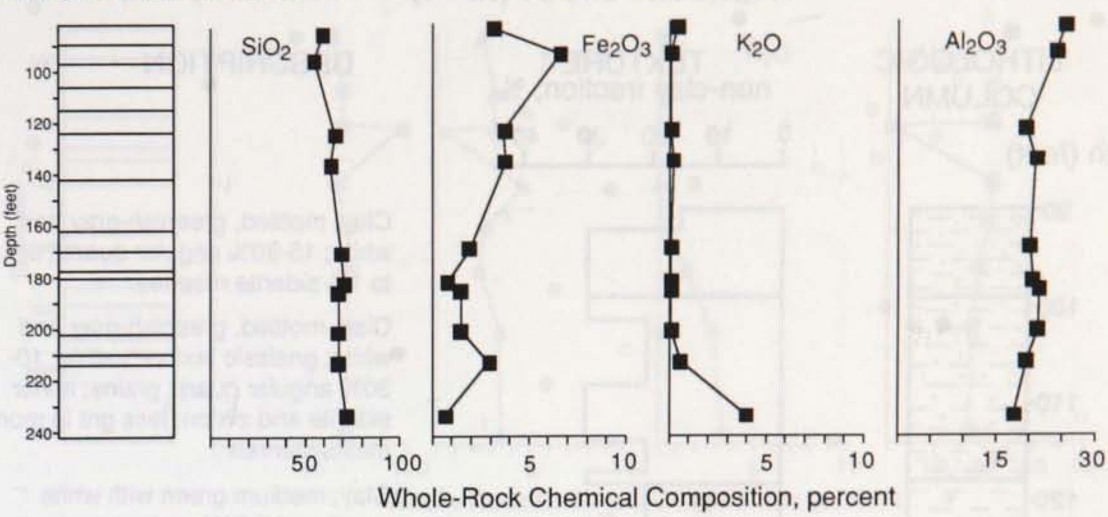
Clay, medium green-gray; gradational contacts

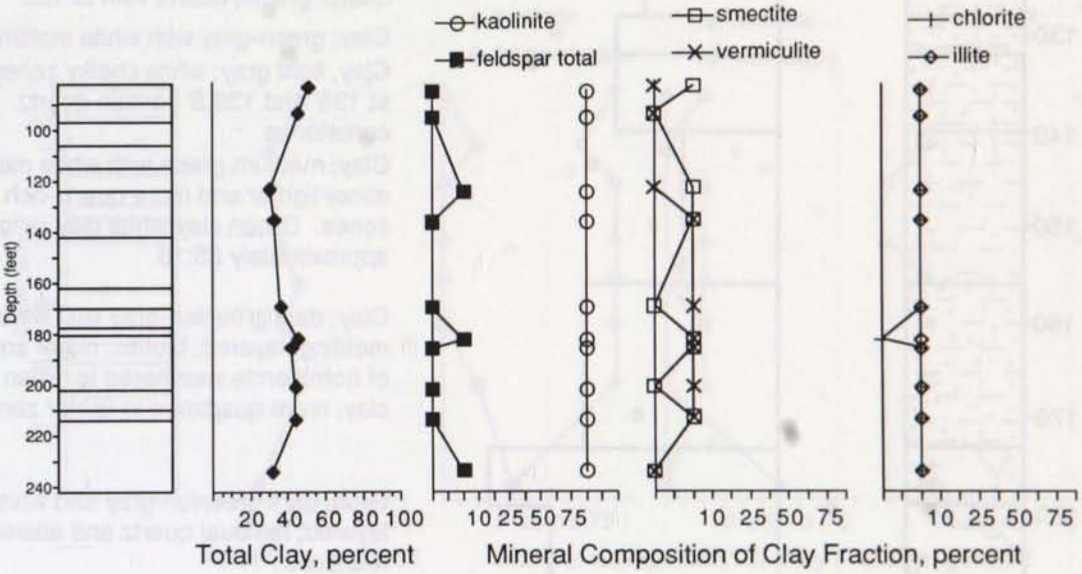
Clay, light green-gray-white; 27% quartz; feldspar

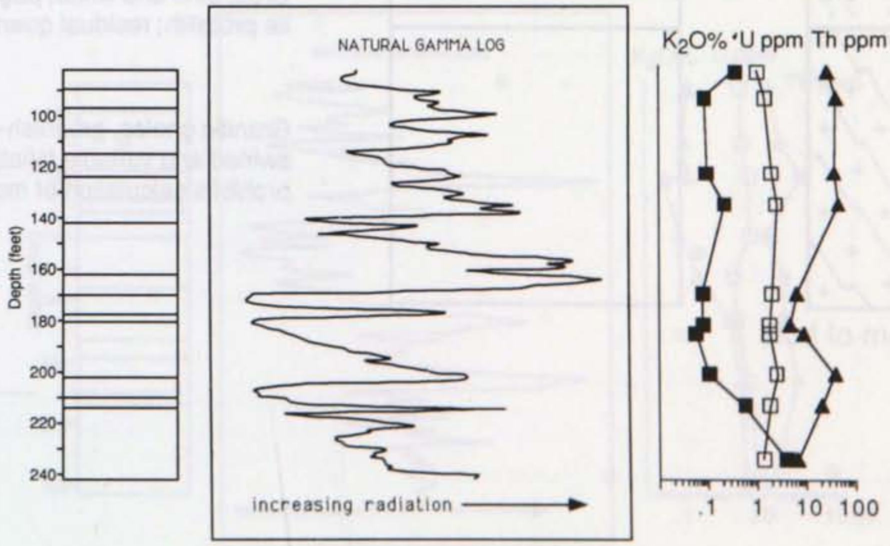
Clay, dark green, chloritic, foliated

Clay, mottled, green-white; 30% quartz, 10-15% green clay, 45-60% white clay; homogenous texture; tonalite to granite protolith. Green clay may be altered hornblende, white clay altered plagioclase

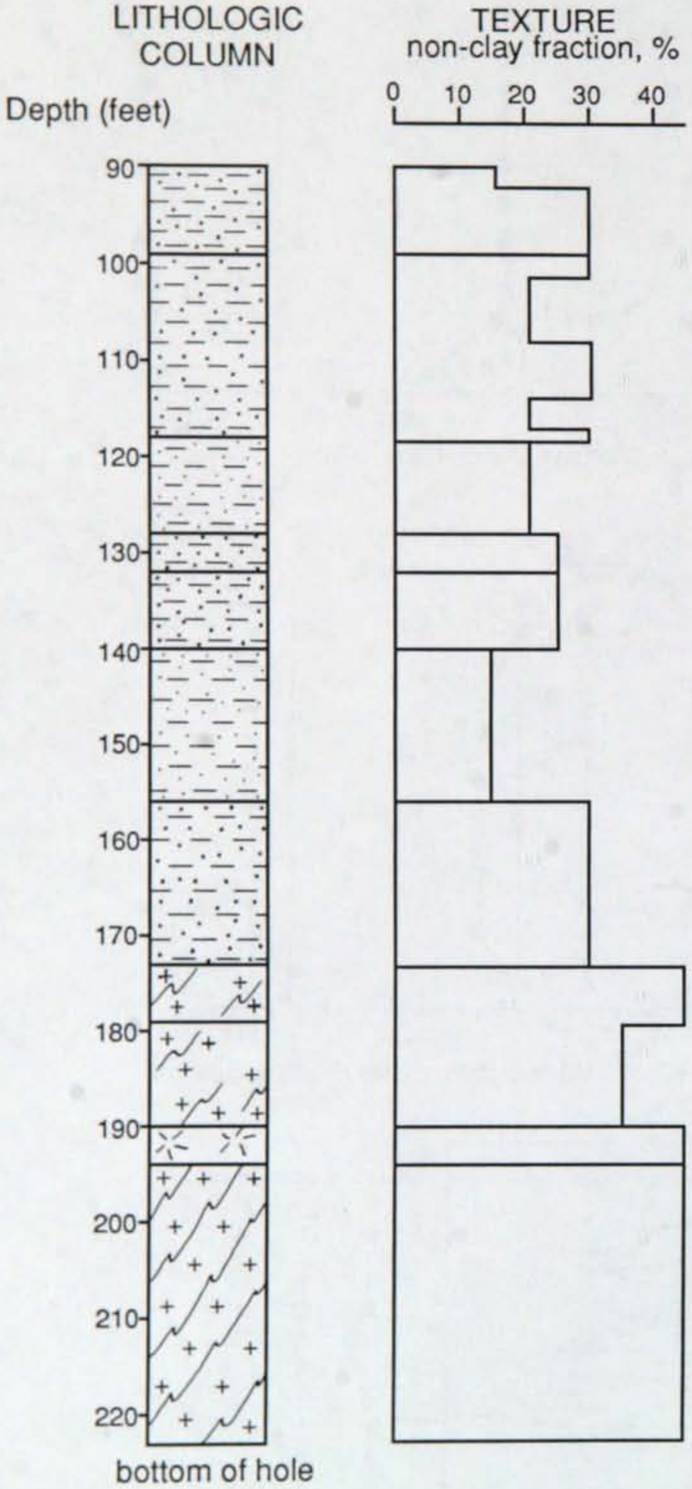
Morgan NE #2 (MNE–2) continued







Redwood Falls #1 (RF–1)



DESCRIPTION

Clay, mottled, greenish-gray and white; 15-30% angular quartz; up to 1% siderite rosettes

Clay, mottled, greenish-gray and white; gneissic texture visible; 10-30% angular quartz grains; minor siderite and zircon; less grit in more mafic intervals

Clay; medium green with white mottling; 15-20% coarse-grained quartz grains; quartz vein at 122'

Clay; green-gray with white mottling

Clay, light gray; white chalky zones at 135' and 138.5' contain quartz corestones

Clay; medium green with white mottling; minor lighter and more quartz-rich zones. Green clay:white clay ratio is approximately 85:15

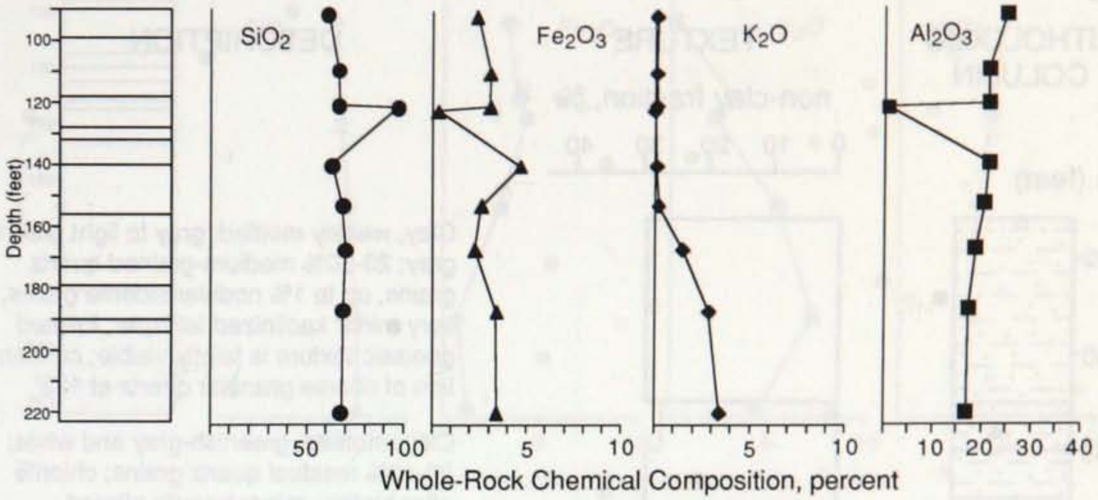
Clay; dark greenish-gray with white mottling; layered; biotitic; minor zones of hornblende weathered to green clay; more quartzose in lighter zones

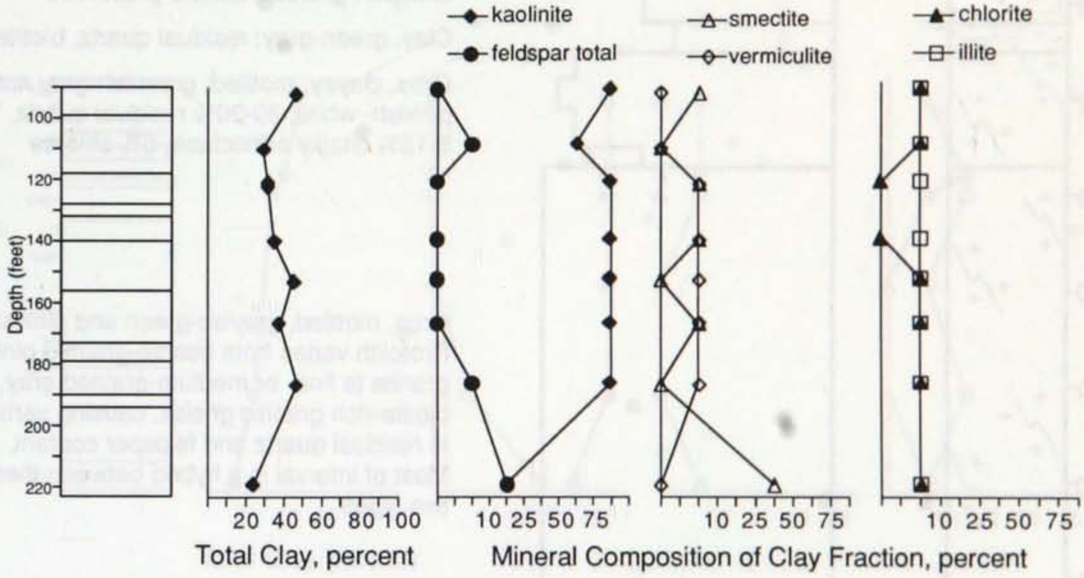
Grus, dark greenish-gray and white, layered; residual quartz and altered feldspars

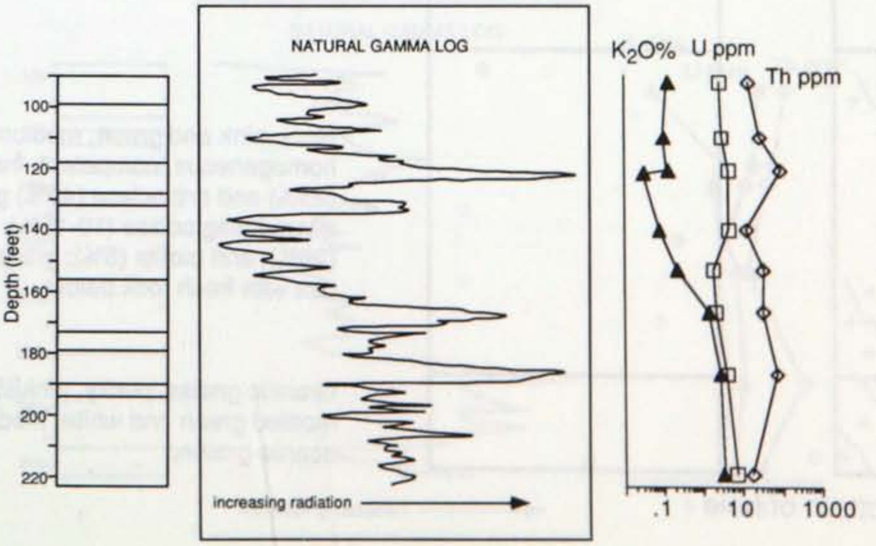
Grus, pink and white; pegmatitic granite protolith; residual quartz and feldspar

Granitic gneiss, greenish-gray and pink; swirled and variable foliation; alteration prohibits calculation of mode

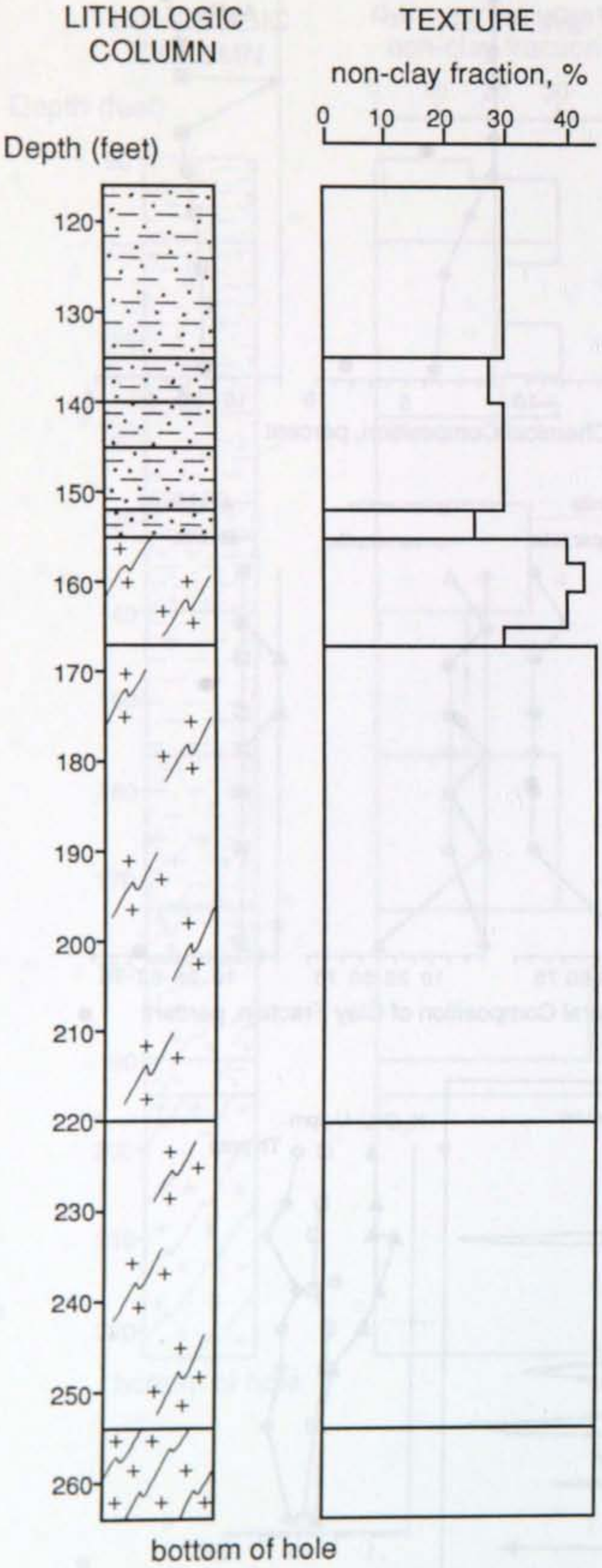
Redwood Falls #1 (RF–1) continued







Redwood Falls #2A (RF–2A)



DESCRIPTION

Clay, weakly mottled; gray to light greenish-gray; 20-30% medium-grained quartz grains, up to 1% nodular siderite grains, very minor kaolinized feldspar; foliated gneissic texture is faintly visible; concentration of coarse granular quartz at 133'

Clay, mottled, greenish-gray and white; 20-40% residual quartz grains; chlorite after biotite; minor heavily altered feldspar; gneissic texture preserved

Clay, green-gray; residual quartz, biotite

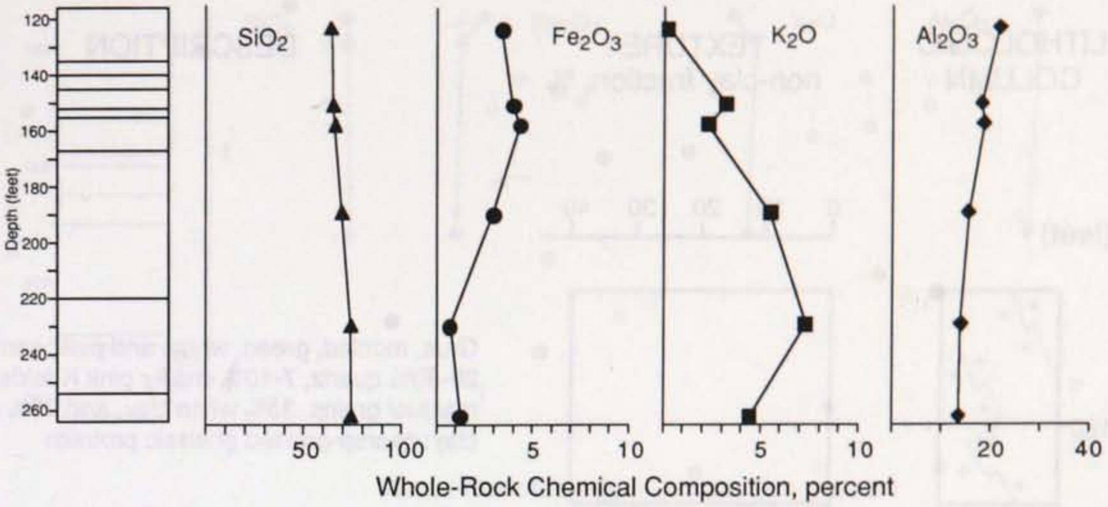
Grus, clayey, mottled, greenish-gray and pinkish- white; 20-30% residual quartz, 5-15% chalky orthoclase, 5% chlorite

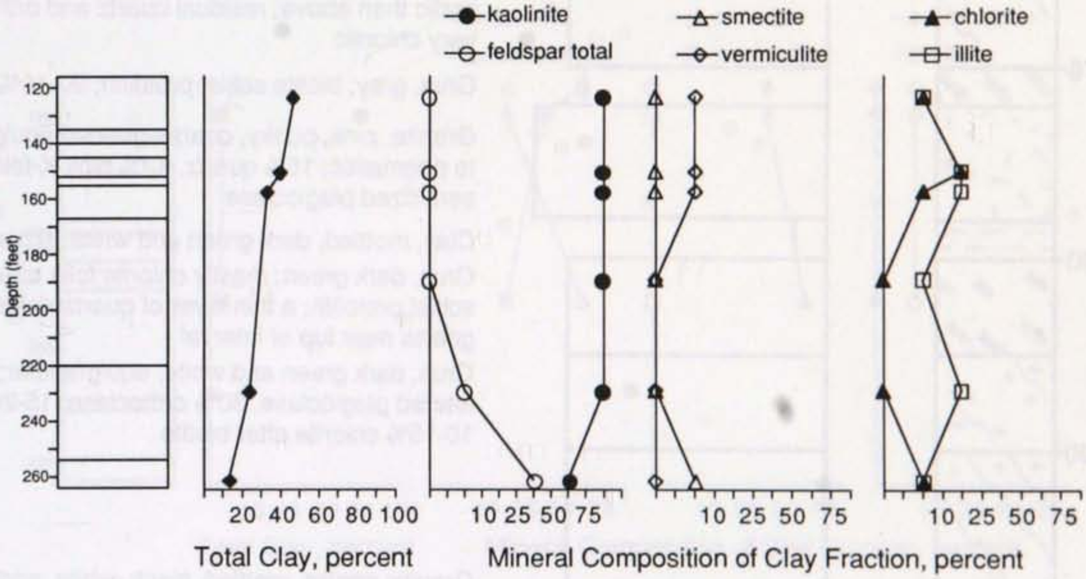
Grus, mottled, grayish-green and pinkish-white. Protolith varies from coarse-grained pink granite to fine- or medium-grained gray, biotite-rich granitic gneiss, causing variation in residual quartz and feldspar content. Most of interval is a hybrid between these two types

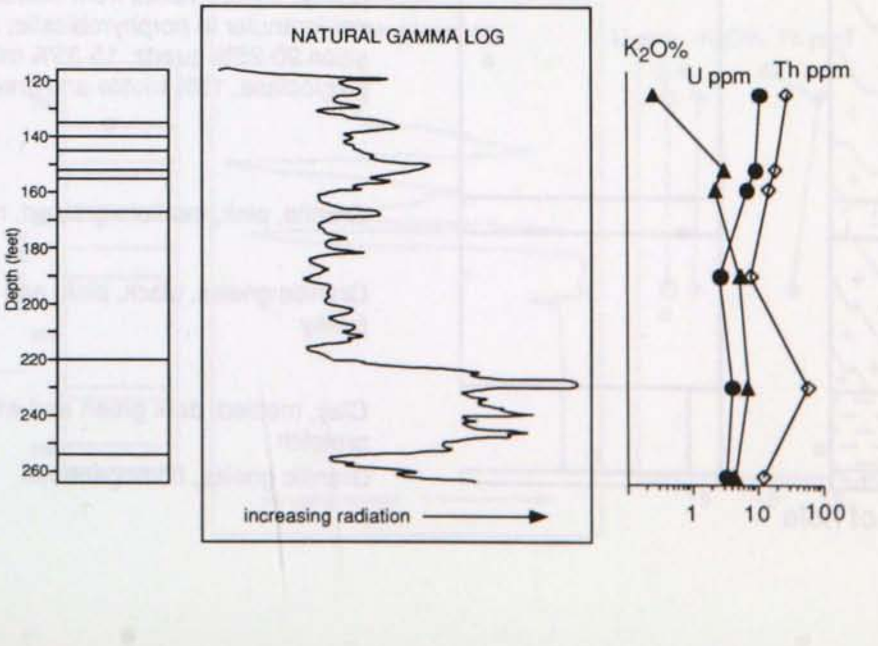
Grus, pink and green, medium-grained, homogeneous, competent; fresh quartz (25%) and orthoclase (40%) grains, altered plagioclase (10-15%), hornblende (20%), and biotite (5%); gradational contact with fresh rock below

Granitic gneiss, punky, pinkish-green to mottled green and white, medium- to coarse-grained

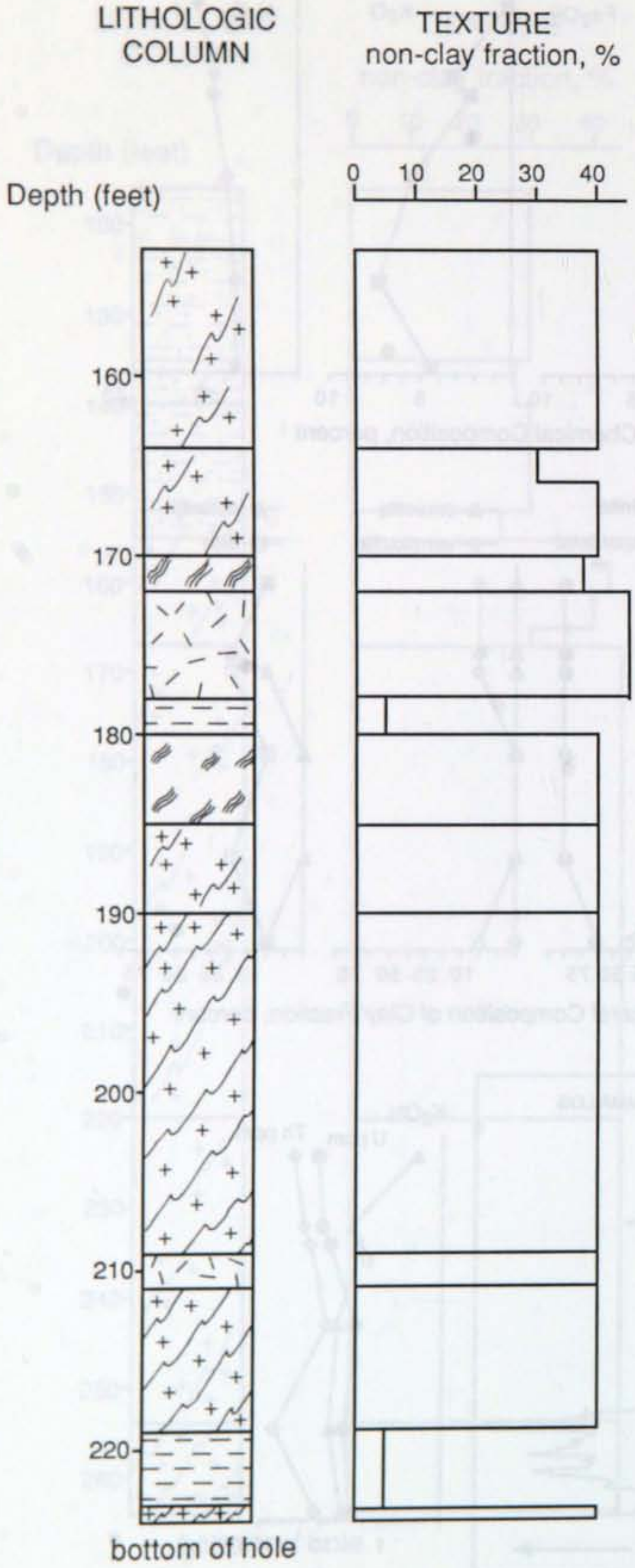
Redwood Falls #2A (RF–2A) continued







Redwood Falls #3 (RF–3)



DESCRIPTION

Grus, mottled, green, white, and pink; contains 20-30% quartz, 7-10% chalky pink K-feldspar residual grains, 35% white clay, and 35% green clay; coarse-grained gneissic protolith

Grus, mottled, green and white, equigranular; more mafic than above; residual quartz and orthoclase; very chloritic

Grus, gray; biotite schist protolith; 30-40% chlorite

Granite, pink, punky, coarse-grained equigranular to pegmatitic; 15% quartz, 43% pink K-feldspar, 42% sericitized plagioclase

Clay, mottled, dark green and white; schist protolith

Grus, dark green; mostly chlorite folia after biotite; schist protolith; a thin layer of quartzofeldspathic gneiss near top of interval

Grus, dark green and white, equigranular; 35% altered plagioclase, 30% orthoclase, 15-20% quartz, 10-15% chlorite after biotite

Granitic gneiss, mottled, black, white, and pink, punky; texture varies from coarse-grained and equigranular to porphyroblastic; average composition 20-25% quartz, 15-35% microcline, 30-40% plagioclase, 15% biotite and green clay

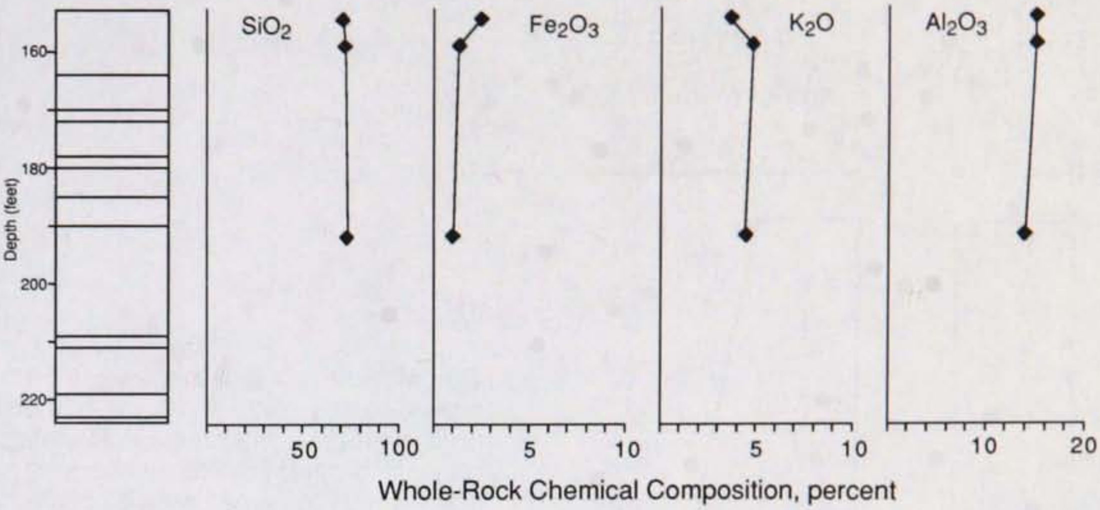
Granite, pink, medium-grained, homogeneous

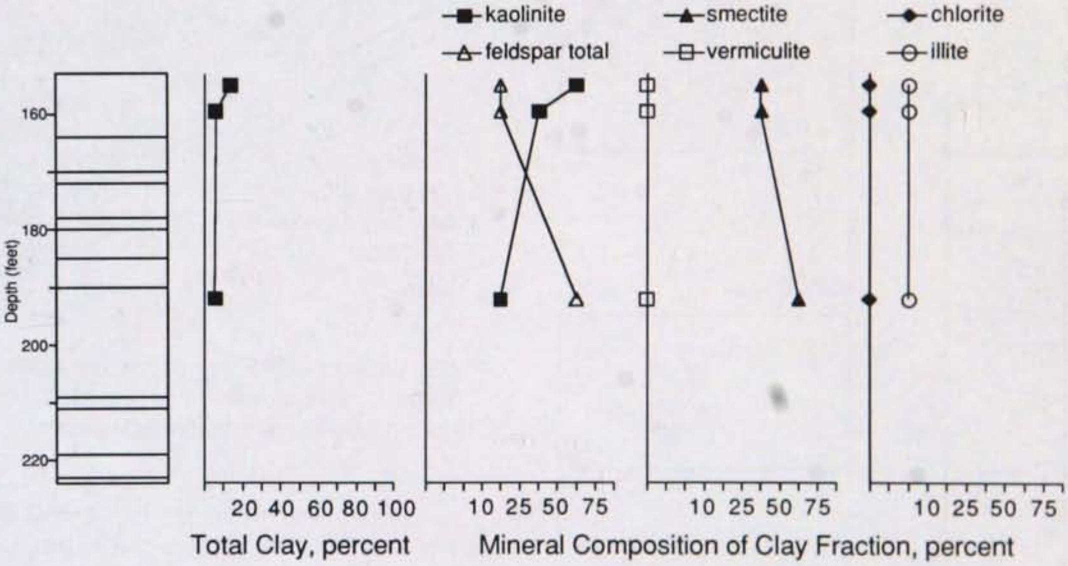
Granitic gneiss, black, pink, and white, moderately punky

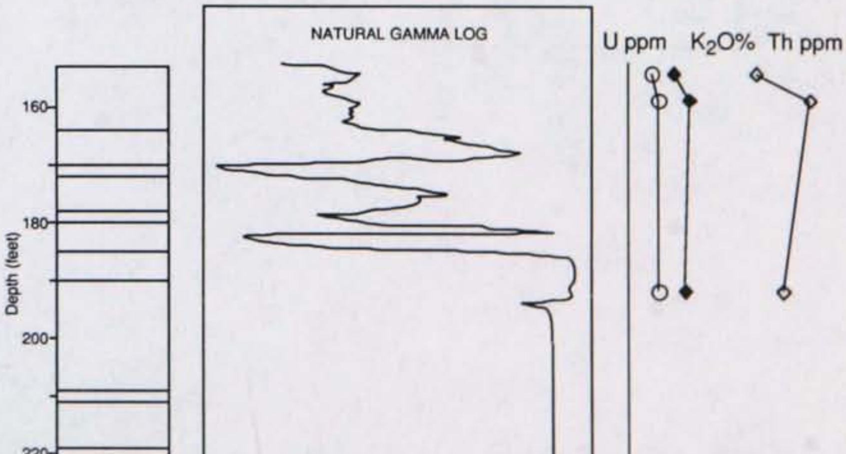
Clay, mottled, dark green and white; amphibolite protolith

Granitic gneiss, homogeneous

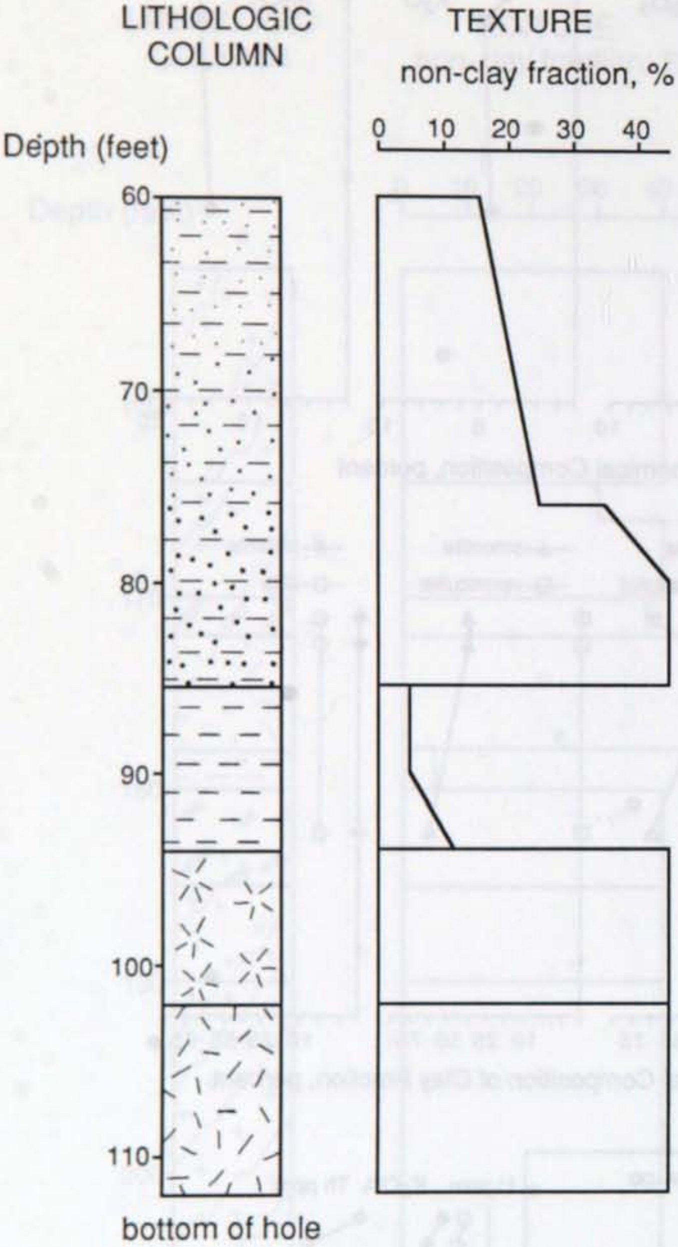
Redwood Falls #3 (RF–3) continued







Cold Spring #1 (CS–1)



DESCRIPTION

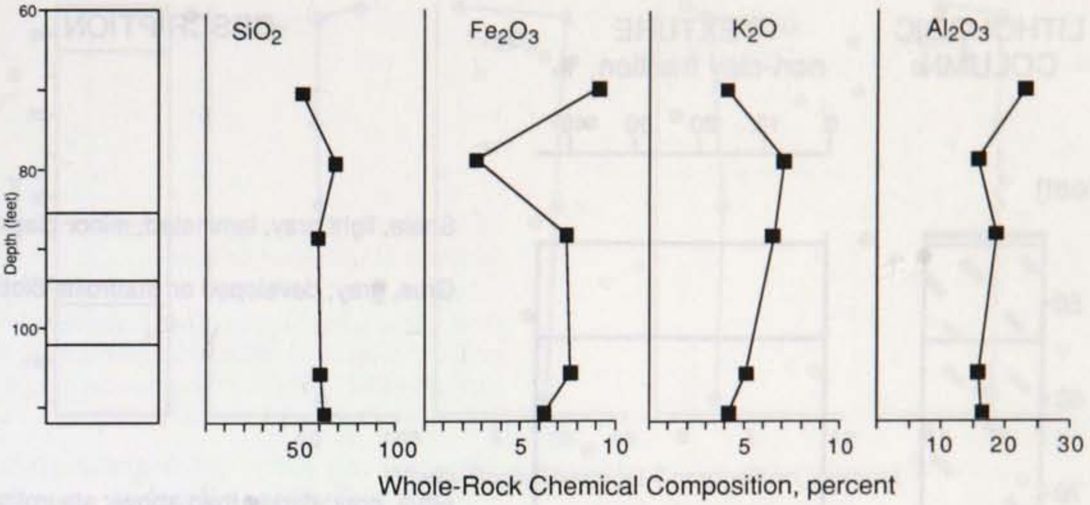
Clay, mottled, dark gray and white; 5-10% medium-grained quartz and 3-5% medium-grained K-feldspar residual grains; both increase in abundance gradually with depth to 76' and then increase greatly; granite protolith; a small inclusion of fine-grained biotite schist at 71'6"

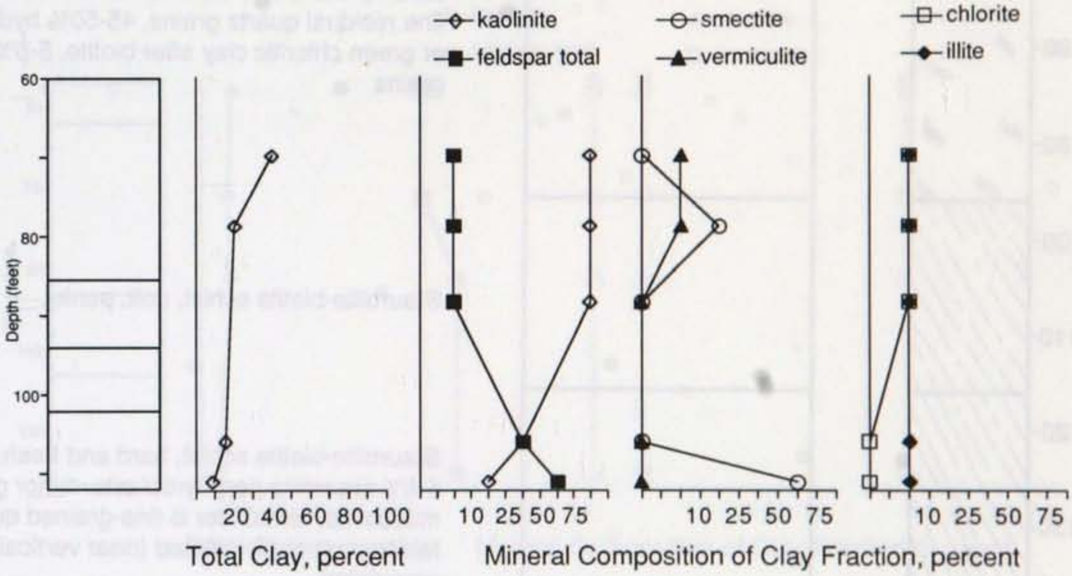
Clay; dark greenish-black with white mottling; 2-5% medium-grained quartz and 2-5% medium-grained K-feldspar residual grains; protolith more mafic than above

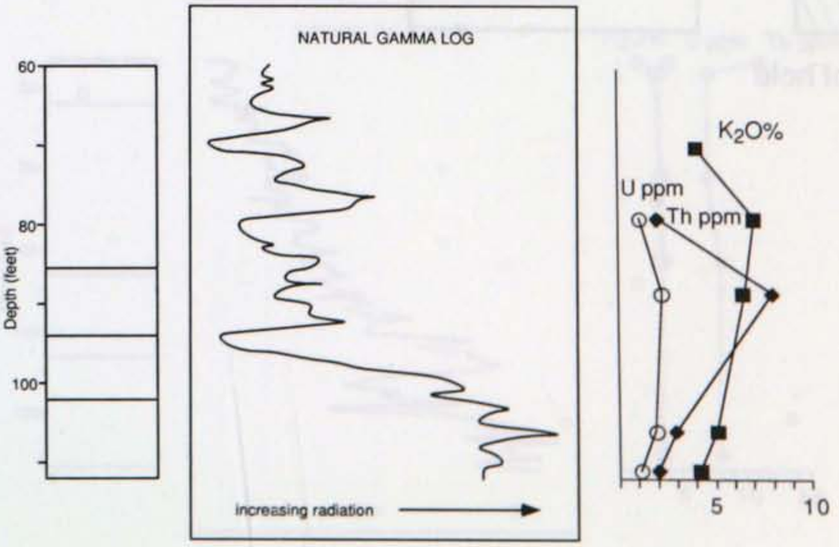
Grus; dark greenish-pink with white mottling; 25-40% coarse pink orthoclase and 10-15% medium-grained quartz residual grains

Granite, pink and green, punky; 12-13% quartz, 20-35% K-feldspar, 15-35% chalky plagioclase, 40-50% mafic minerals (mostly biotite and hornblende); rapakivi texture

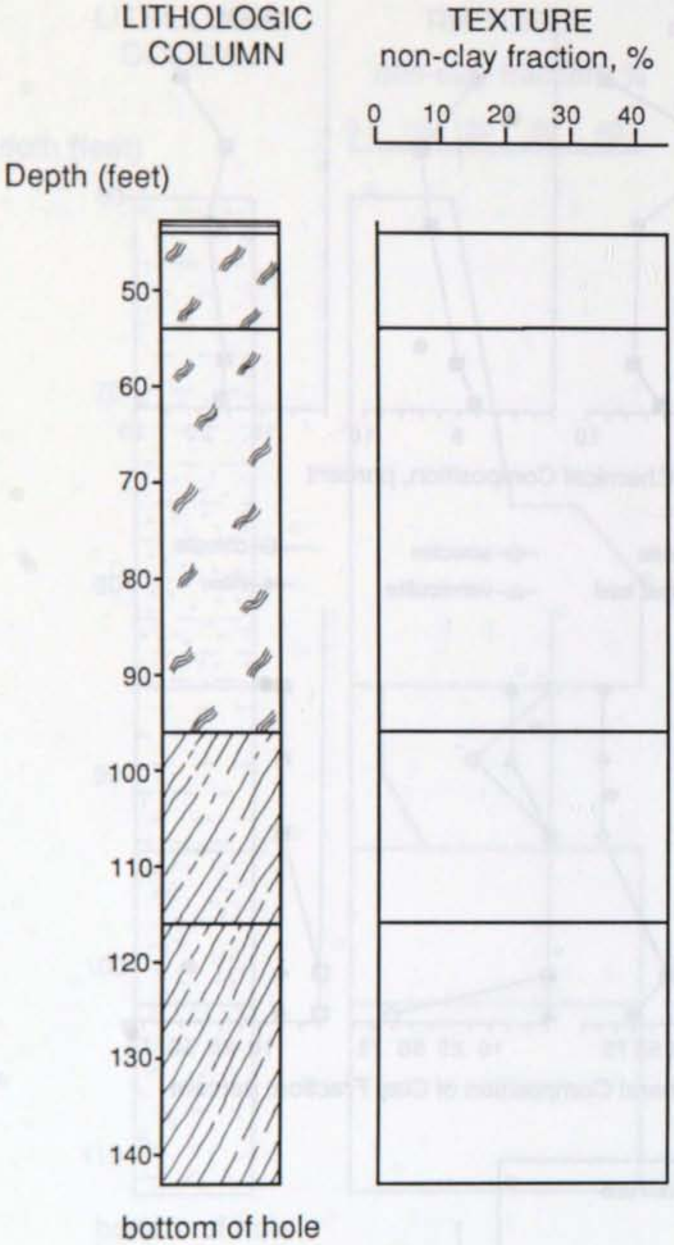
Cold Spring #1 (CS–1) continued







Royalton #1 (RY–1)



DESCRIPTION

Shale, light gray, laminated; minor black organics

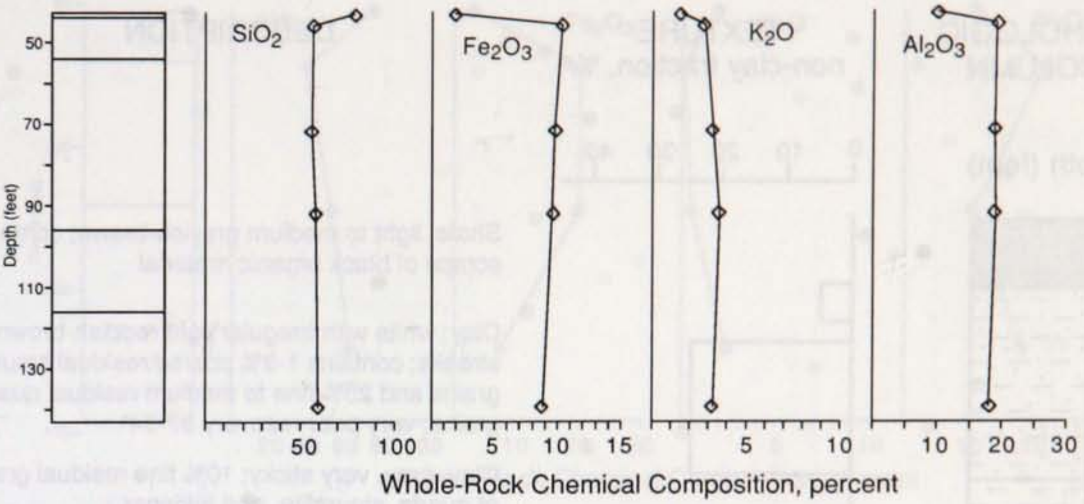
Grus, gray; developed on staurolite-biotite schist

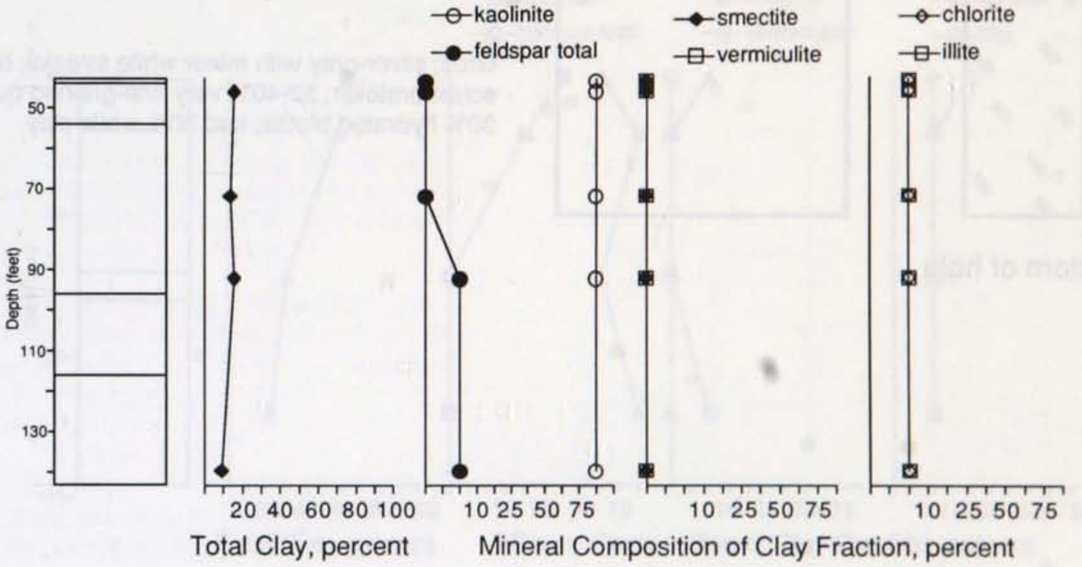
Grus, gray; darker than above; staurolite-biotite schist protolith; 10-20% white kaolinitic clay, 25% fine residual quartz grains, 45-50% hydrated biotite or green chloritic clay after biotite, 5-6% staurolite grains

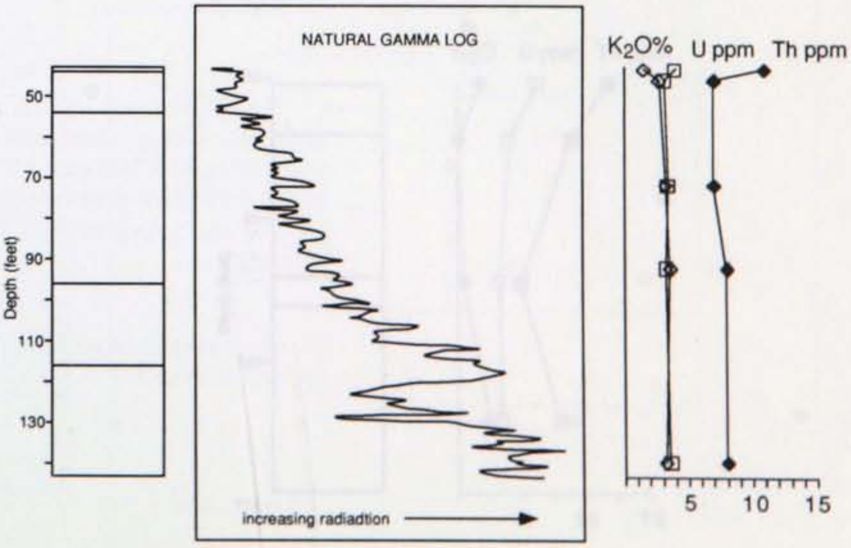
Staurolite-biotite schist, soft, punky

Staurolite-biotite schist, hard and fresh; 50% biotite, 6-8% staurolite porphyroblasts, minor garnet and muscovite, remainder is fine-grained quartz and feldspar; strongly foliated (near vertical), weakly crenulated

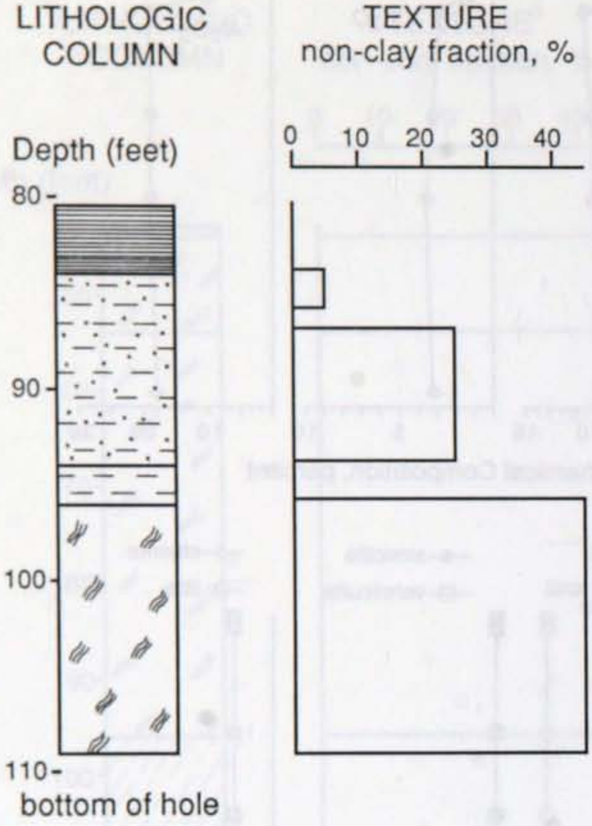
Royalton #1 (RY–1) continued







Royalton #2 (RY–2)



DESCRIPTION

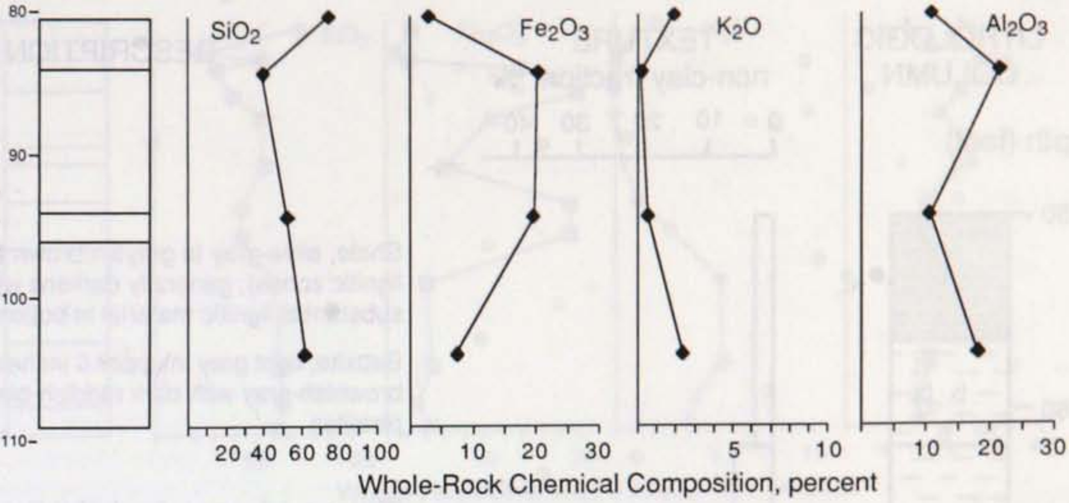
Shale, light to medium grayish-brown; contains scraps of black organic material

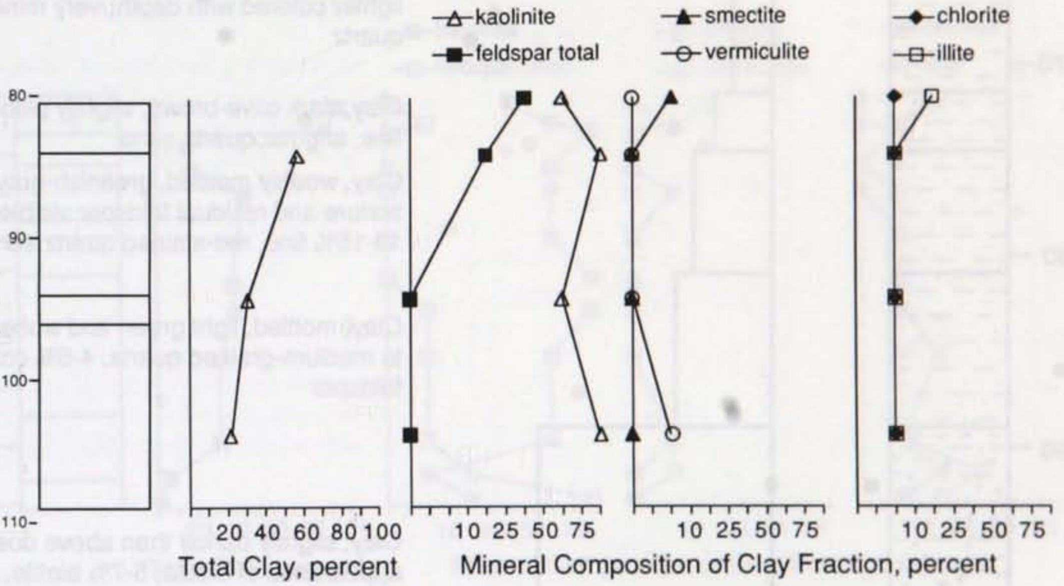
Clay; white with irregular light reddish-brown streaks; contains 1-3% coarse residual staurolite grains and 25% fine to medium residual quartz grains; very poor recovery 87-94'

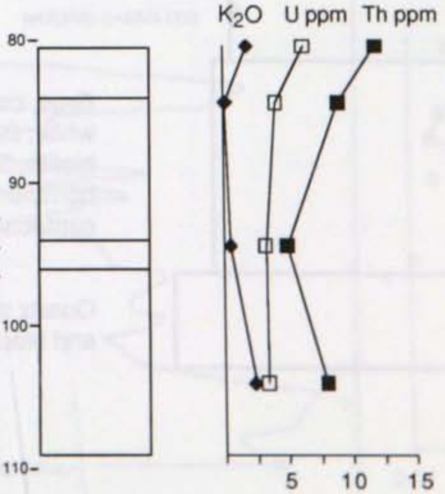
Clay, gray, very sticky; 10% fine residual grains of quartz, staurolite, and feldspar

Grus; silver-gray with minor white streaks; biotite schist protolith; 30-40% very fine-grained quartz, 30% hydrated biotite, and 30% white clay

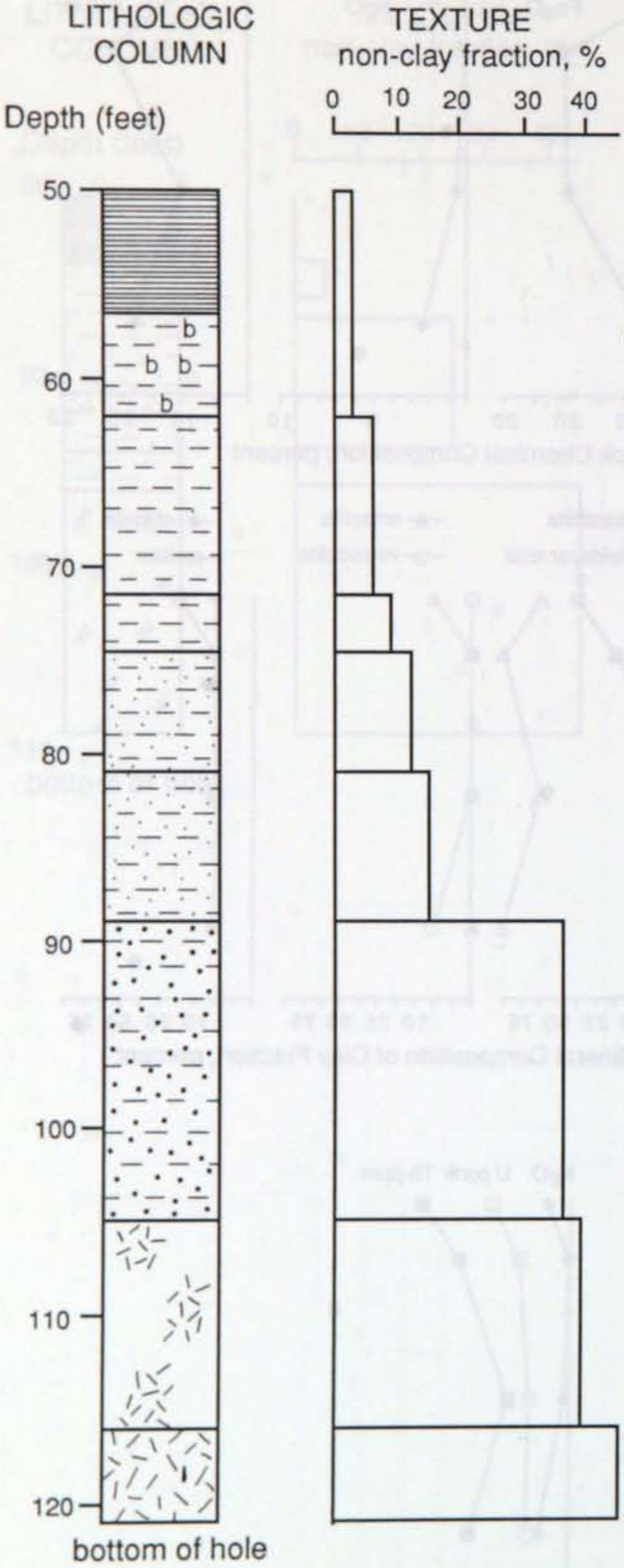
Royalton #2 (RY-2) continued







St. Augusta #1 (SA–1)



DESCRIPTION

Shale, olive-gray to grayish-brown to black (in lignitic zones); generally darkens with depth; substantial lignitic material in bottom foot

Bauxite; light gray in upper 6 inches, then brownish-gray with dark reddish-black pisolites

Clay, grayish-green, hard, slightly pisolitic; lighter colored with depth; very minor angular quartz

Clay, dark olive-brown, slightly pisolitic; 10-15% fine, angular quartz sand

Clay, weakly mottled, greenish-gray; igneous texture and residual feldspar visible below 76'; 10-15% fine, red-stained quartz sand

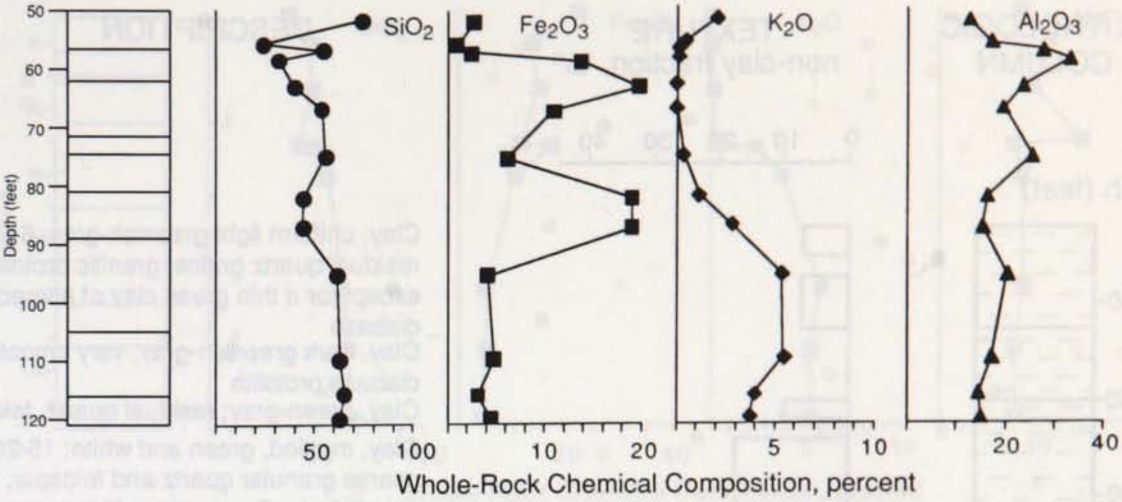
Clay, mottled, light green and white; 8-10% fine- to medium-grained quartz, 4-5% coarse-grained feldspar

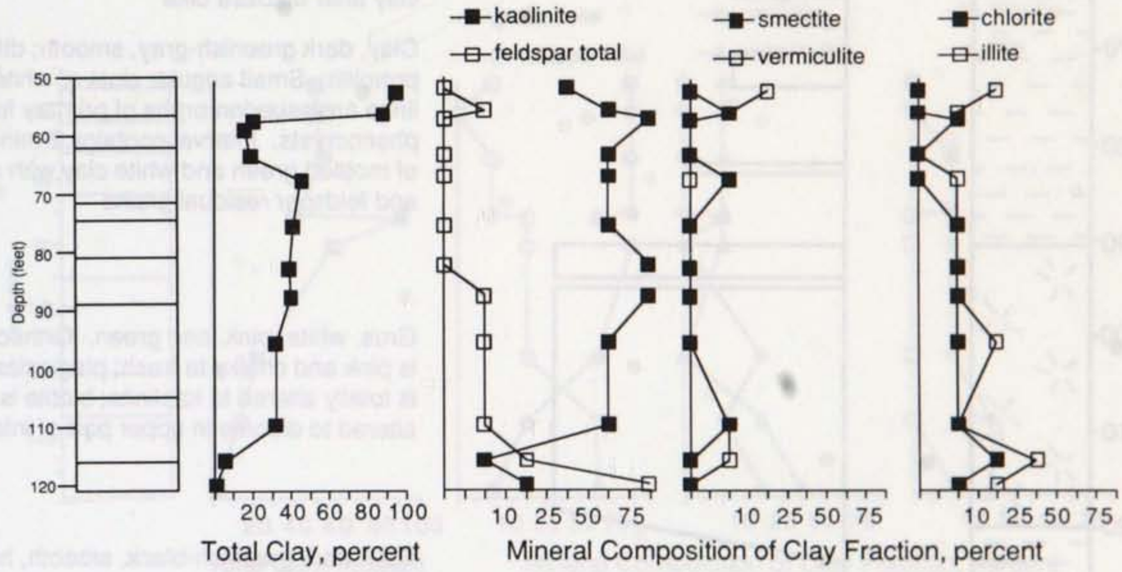
Clay; slightly darker than above due to the appearance of biotite; 5-7% biotite, 10-15% quartz, 15-20% medium- to coarse-grained feldspar

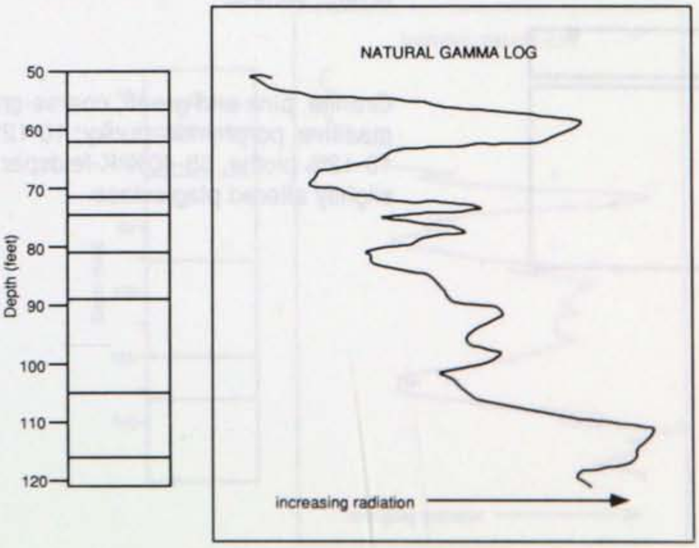
Grus, clay-rich, mottled, dark green and white; 20% pink feldspar; 15% quartz; 6% biotite; 30% dark green clay (weathered hornblende ?) near bottom, transitional contacts

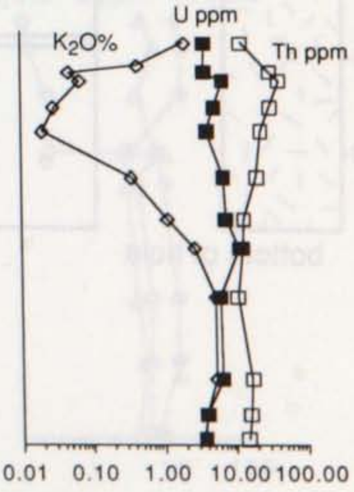
Quartz monzonite/adamellite, fresh, pink and black, massive

St. Augusta #1 (SA-1) continued

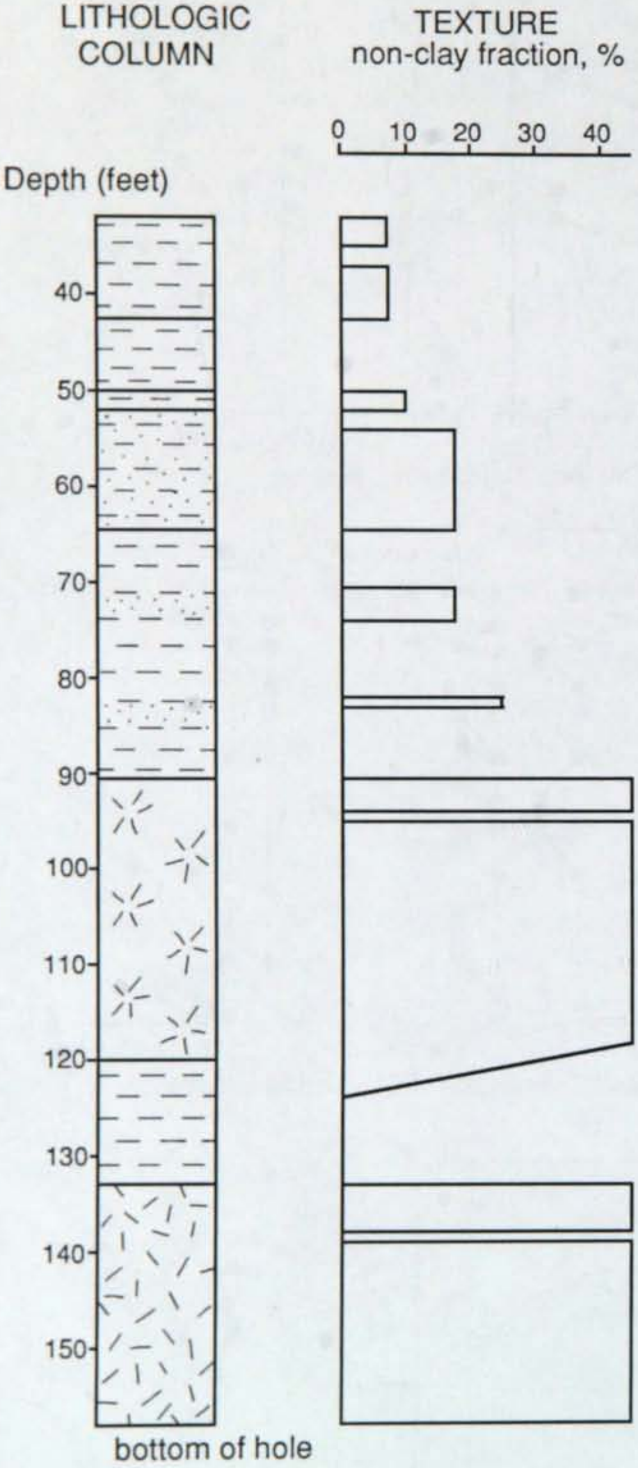








St. Joseph #1 (SJ–1)



DESCRIPTION

Clay, uniform light greenish-gray; 6-8% residual quartz grains; granitic protolith except for a thin green clay of altered diabase

Clay, dark greenish-gray, very smooth; diabase protolith

Clay, green-gray; residual quartz, feldspar

Clay, mottled, green and white; 15-20% coarse granular quartz and feldspar, chloritic near base; upper 2' is green clay after diabase dike

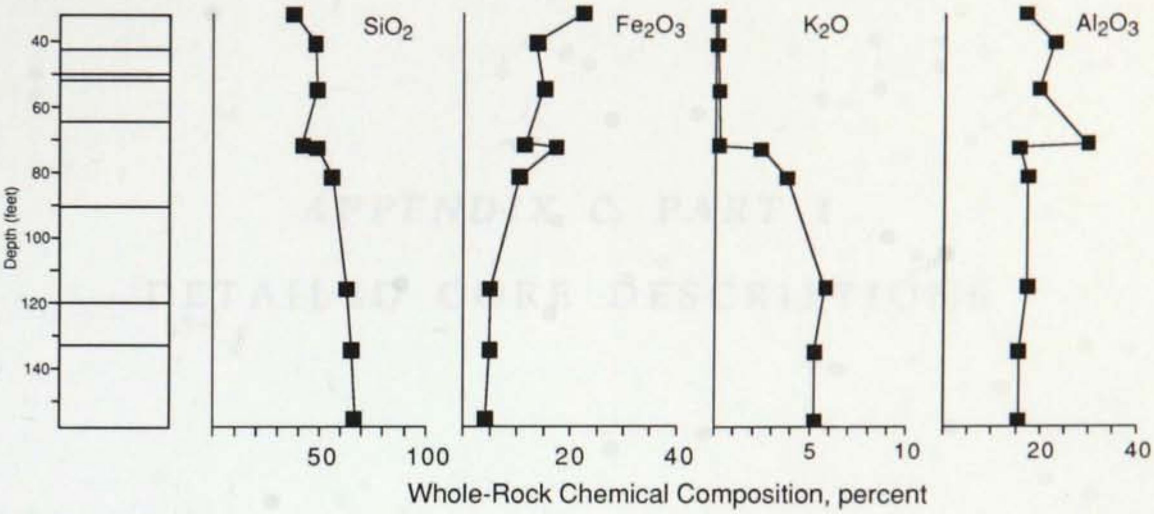
Clay, dark greenish-gray, smooth; diabase protolith. Small angular clots of white kaolinite are psuedomorphs of primary feldspar phenocrysts. Interval contains 2 minor layers of mottled green and white clay with quartz and feldspar residual grains

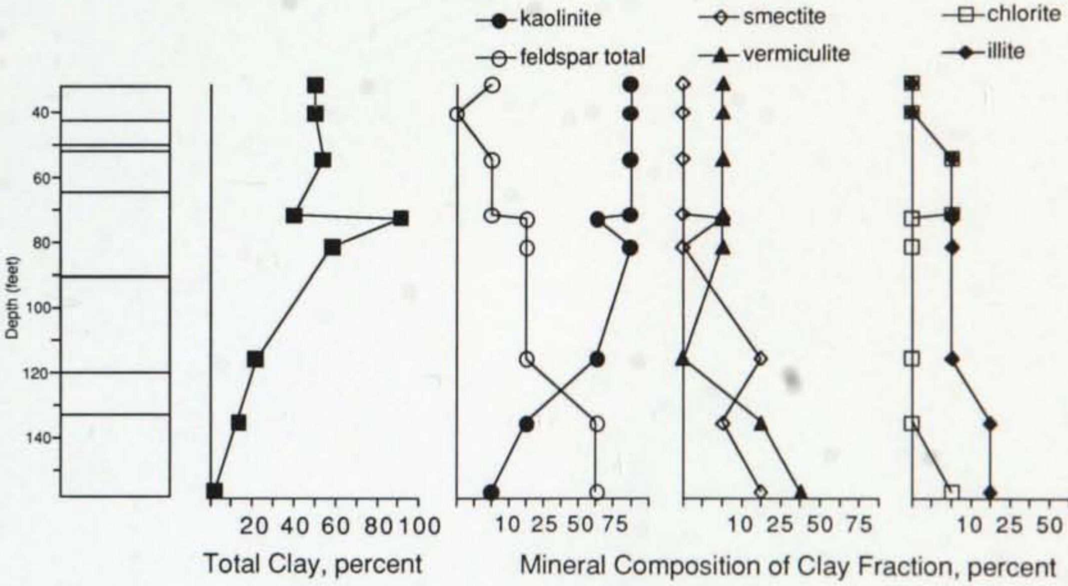
Grus, white, pink, and green. Orthoclase is pink and chalky to fresh; plagioclase is totally altered to kaolinite; biotite is altered to chlorite in upper part of interval

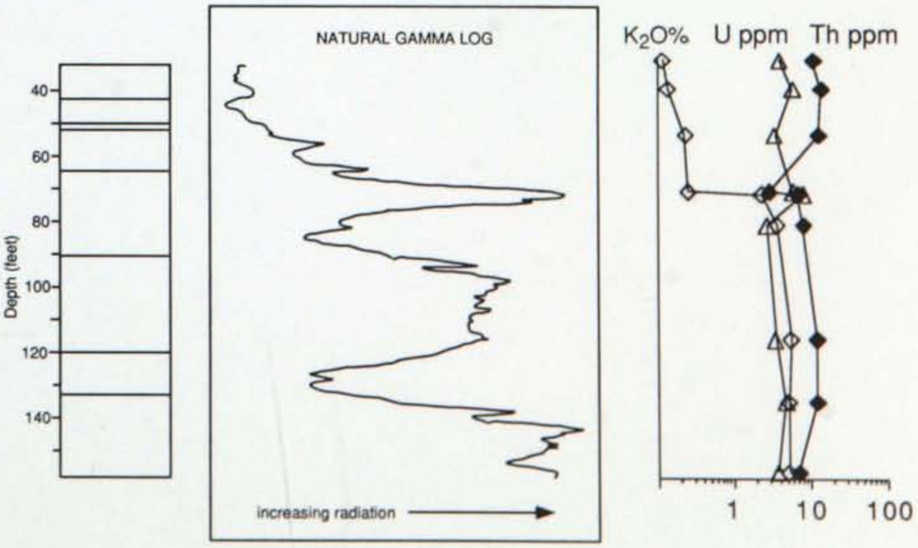
Clay, dark greenish-black, smooth, hard; protolith of microdiabase. Contact with grus is near vertical

Granite, pink and green, coarse-grained, massive, porphyritic, punky; 10-12% quartz, 10-12% biotite, 38-40% K-feldspar, 40% slightly altered plagioclase

St. Joseph #1 (SJ–1) continued







APPENDIX C, PART 1

DETAILED CORE DESCRIPTIONS

Morgan NE #1 (MNE-1)

30% recovery, 150–162 ft; most of sample loss probably from 152–161 ft interval.

Depth (feet)	Description
150–151	Grayish-brown pebbly till; abundant granule- to pebble-sized clasts, dominantly of carbonate but also minor quartz and mafic gneiss.
151–151.5	Dark grayish-brown pebbly till in abrupt, sharp contact with above till. Pebble lithology similar to above. Small chips of black organic material.
151.5–161	Coarse gravel. Only 6" sample recovered, the rest of sample from this interval probably lost.
161–161.5	Fine grayish-brown silty sand. Thin bands of heavy mineral concentrate highlight bedding. Probable Quaternary basal sand deposit.
161.5–162	Medium-grained, poorly sorted, white clayey sand and black organic material. Top 2–3", black organic material; next 2–3", white sand; thin layer of black organic material at the bottom of interval.
162–171	Interval represents unit of white shale, grading down into interlayered shale and sand, to sand.
	162–167 Slightly sandy white kaolinitic shale. Contains up to 2% quartz sand, as fine-grained angular grains and medium-grained rounded grains. Also contains 1–2% or more medium- to coarse-grained reddish grains of questionable mineralogy (possibly siderite), which vary in shape from round granules to wheat-shaped. These are of apparent authigenic origin.
	167–169 Dominantly sandy shale, with 0.5-to-2-inch-thick beds rich in poorly sorted, angular coarse-grained sand (up to 60% sand). Shale portions are similar to 162–167 ft, sand portions similar to below.
	169–171 Very coarse-grained white, angular sand (70–80% sand), with 20–30% white clay matrix. An inch-thick bed of shale is near the bottom of this subunit.
171–171.7	Slightly gray, very sandy shale, containing 0.2-to-4-cm rip-up clasts of nearly pure white shale in top 4"; the rip-up clasts are either imbricated or flattened into the bedding plane. This is underlain by an inch-thick (shaly) coarse angular sand with brownish-green earthy clots, possibly of organic origin; a 2"-thick bed of sandy shale; and an inch-thick coarse sand with abundant reddish-brown clots similar to those just above.
171.7–180.3	Fining-upward sequence consisting dominantly of white shale with a thin unit of coarse-grained shaly sand at the base.
	171.7–173 White shale; contains 1% fine-grained angular sand, 3–4% fine-grained gray minerals equivalent to the reddish-brown wheat-shaped minerals described as authigenic in the 162–167 ft interval above. Becomes an oxidized reddish color near bottom.
	173–176 Oxidized reddish-brown and white sandy shale. Top 6" is texturally the same as above, but sand content increases with depth to 20–30% medium- to coarse-grained, slightly rounded quartz sand. The red and white color patterns are irregular but locally (as near bottom) highlight bedding planes. Color variations also suggest that the rock may contain a high content of intraformational clasts that are texturally the same as the matrix.
	176–180.3 Top is texturally similar to the red-stained unit above; contains 10–12% medium-grained quartz sand to grit-sized subangular grains of quartz sand in a white shaly matrix. Amount of sand increases gradationally but changes abruptly at 179.5 ft to a dirty coarse-grained sandstone (70–80% sand).

Morgan NE #1 (MNE–1) continued

Depth (feet)	Description	
180.3–182	Fining-upward sequence of slightly sandy, pale greenish-gray shale (to 181.2 ft); transitional downward over 3" into a dirty sandstone, which increases in sand content and grain size to bottom of interval. A 3-cm-long chip of shale is present approximately 8" from bottom of unit, in coarse sand.	
182–183	Top 9", sandy, pale greenish-gray shale containing 8–10% medium-grained quartz sand; lower 3", coarse-grained sand. The high angle of the contact with the sandy shale below indicates the sand may have been deposited on a scoured surface.	
183–188	Fining upward sequence of relatively uniform sand/clay ratios. Top 2", reddish sandy shale with 20–25% medium-coarse sand and 1–2% red authigenic mineral similar to that described at 162 ft. Near 185 ft becomes abruptly more sandy; contains 60–65% medium-grained to grit-sized sand in a white clay matrix. Uniform from 185 to 187 ft; more shaly from 187 to 188 ft but still with 25–30% sand.	
188–199.5	Predominantly shale with thin beds of silty shale, coarsens to gritty sand at base of unit.	
	188–189	Slightly sandy, pale grayish-green shale. Contains 5–7% medium-grained quartz sand, 1–3% sand-like grains of red authigenic siderite.
	189–192.5	Reddish-brown, very smooth oxidized shale; variably mottled by unoxidized grayish-white shale.
	192.5–193.5	Unoxidized zone of shale, silty shale
	193.5–195.5	Red oxidized shale, similar to 189–192.5 ft interval, mottled white.
	195.5–198	Dominantly light gray shale, with local areas of red oxidation along finely laminated bedding planes (as at 196–196.5 ft). Silty from 197 to 197.5 ft.
	198–199.5	Abrupt 6" bed of medium-grained shaly sand, underlain by 5" of light gray silty shale, a 1/2" bed of sandy shale, and a 6" bed of gritty, angular, well-cemented sandstone, which is very clean relative to other sample units in this hole.
199.5–206	Two fining upward sequences of variable thickness.	
	199.5–200.2	2" bed of smooth shale underlain by a clean, partially cemented, medium-grained, well-sorted sand.
	200.2–206	Smooth shale to 202 ft, oxidized red with some gray mottling. Bedding laminae are accentuated because of preferential oxidation. 202–203 ft is silty shale grading to fine sand; 203–206 ft is grayish-white, poorly cemented, well-sorted, angular, fine-grained sand. Thin beds of black heavy mineral concentrates consisting of magnetite (± ilmenite), zircon, hornblende and/or augite, apatite, and possible tourmaline are present, especially towards bottom of interval. Within 1 ft of lower contact with regolith pieces of green and white clay begin to appear in the sand. Just above 206 ft is a thin band of yellow-stained sand, which gives a very large spike on the gamma log, and which also registers as slightly radioactive on a scintillometer; this is likely a uranium concentration in the basal-most sand.

Morgan NE #1(MNE–1) continued

Depth (feet)	**Description**
206–238	Pinkish-green crumbly grus developed on granitic bedrock. Entire interval is homogeneous; slight variations in pink to green color due to variable hornblende/feldspar ratios. An example of a darker colored zone is 230–237 ft; the zone below is lighter and pinker. At very top of saprolite is a 1–2" vein of white quartz. The saprolite/grus near the top consists of approximately 10–15% quartz, 4–6% 1–3-mm pieces of pink K-feldspar; 40–45% green clay plus flaky chlorite (?), and 40% white clay. The amount and grain size of K-feldspar increases with depth to 238 ft, where it is nearly all fresh, as angular cleaved pieces up to 1 cm across. Plagioclase is altered to kaolin throughout this interval. Transition to fresher rock below is fairly abrupt.
238–257	Moderately fresh, coarse-grained, greenish-pink hornblende granite. Contains 10–15% gray quartz up to 5 mm across; 35–45% heavily altered plagioclase up to 5 mm across (most 3–4 mm); 35–45% fresh pink K-feldspar of variable size, from 3 mm to 1.5 cm phenocrysts or porphyroclasts; and 5–20% hornblende totally altered to chlorite and/or green clay. The texture is variable, somewhat seriate, and at 242 ft is suggestive of possible mild cataclastic deformation and subsequent recrystallization, although there is no cleavage or foliation to the rock. *Thin-section description, 256.5 ft depth:* Coarse-grained granitic gneiss. Orthoclase grains (up to 1.5 cm) poikilitically enclose plagioclase and quartz. Plagioclase is moderately altered to sericite and stained brownish-red by dusty Fe oxides. Quartz is recrystallized granoblastic to mortar textured; biotite is brown to green pleochroic, slightly weathered, and associated with apatite and zircon. Approximate mode: 39% microcline, 32% plagioclase, 27% quartz, 2% biotite, and trace of apatite and zircon.

Morgan NE #2 (MNE–2)

Core recovery:			
	89.5–91	2 ft	recovered
	93–94	4"	recovered
	94–104	5 ft	recovered
	104–114	5 ft	recovered
	114–124	5 ft	recovered
	134–141.75	5 ft	recovered
	224–234	6 ft	recovered

All other intervals, 100% recovery.

Depth (feet)	**Description**
82.5–89.5	Cretaceous deposits of reworked kaolin and shale.
	82.5–83.9 White, secondary, redeposited kaolinite-rich sediment. Contains about 1% fine- to medium-grained red granular siderite and 4–6% fine- to coarse-grained angular quartz. Very sharp contact with brown shale below. Top is sticky and loose; 1.5 ft missing from top.
	83.9–89.5 Dark brown, very smooth shale, mottled by minor semicontinuous beds of grayish-brown shale 5 mm thick. These lighter colored streaks are slightly more silty than the dark brown shale and near the bottom of the interval contain a low volume of fine sand. Within 3" of the bottom are tiny white clay chips, probably reworked kaolin from below. Shale has a weak parting perpendicular to core axis.
89.5–97	(97 ft measured down from 94 ft marker) White to pale grayish-white clay-rich regolith with 2–4-cm-wide red iron-stained streaks. 89.5–92.5 ft and 94–95 ft contain only 5–7% medium-grained, angular sandy quartz and a trace of reddish-brown sandy feldspar. The other portions of this interval contain 14–18% angular, medium-grained quartz sand and 4–6% medium-grained to very coarse-grained feldspar grains that appear to be heavily etched by chemical weathering. See above for quantity recovered.
97–104.5	Similar to interval above but not stained red. Interval at top contains 20% medium-grained angular quartz; quartz content decreases slightly with depth, grading into next unit below. 1–2% medium coarse-grained orangish-red feldspar throughout. Poor recovery (see table above). Vague igneous texture visible similar to better preserved samples at bottom of hole.
104.5–106	(106 ft measured down from 104 ft; poor recovery [see table above]) Light gray clay-rich regolith. Contains approximately 10% medium-grained angular quartz (less than above), 1–2% feldspar (as above), and local patches of higher feldspar concentrations.
106–115.1	White to very pale gray, clayey regolith with approximately 20% quartz, 2–4% medium-grained, sandy, orangish-red feldspar. Very poor recovery this interval (20%).
115.1–124	(80% recovery) Pale gray to grayish-green; very similar to 104.5–106 ft interval above. Medium-coarse, sand-size chunks of heavily kaolinized (white and green) plagioclase now visible in washed and disaggregated sample.
124–141.75	Slightly lighter colored than above, more quartz rich (18–20%). Lithology consistent with depth; quartz content fluctuates slightly; K-feldspar content also varies slightly, from 20%. Color becomes increasingly darker with depth. At 133.9 ft, a 3-cm corestone of quartz-epidote vein containing minor disseminated marcasite.
141.75–142	(poor recovery; gamma log indicates 4-ft thickness) White to very pale grayish-green, clay-rich regolith with 10–12% coarse-grained quartz and 2–3% pink feldspar. Texture indicates this section may have had coarser grained protolith.

Morgan NE #2 (MNE-2) continued

Depth (feet)	Description
142–161	Very similar to 124–141.75 ft interval; igneous texture is more apparent here. Quartz content fluctuates slightly, from 15–20%. In general, the bottom 3–4 ft of this interval has a slightly lower quartz content than the top part; this may explain the gradually increasing values on the gamma log. Very little remnant feldspar, except at 153–153.5 ft; pieces of greenish-white, heavily kaolinized plagioclase noted in disaggregated and washed sample. At 157–157.5 ft, only 10–12% quartz and a slightly higher clay content.
161–162.5	Abruptly lighter colored interval with vague medium- to coarse-grained igneous texture. Contains 15–20% very coarse-grained sandy quartz; 1% orangish-red, medium- to coarse-grained, sandy K-feldspar; 6–8% white clay; remainder is greenish-gray clay. Good core recovery. Very little kaolinized plagioclase noted in washed samples; moderately abundant flakes of chlorite noted.
162.5–170	Same as 142–161 ft; contains 20% or more coarse-grained, sand-sized quartz grains; also a minor amount of white to green kaolinized plagioclase; minor orangish-red K-feldspar; moderately abundant flakes of chlorite.
170–177.5	Clay; light greenish-gray with minor white mottling. 25–28% very coarse, sand-size gray quartz; no significant feldspar. Primary igneous texture is well preserved.
177.5–180.5	Slightly darker, greenish-gray clay. Contains 20–22% quartz; moderately abundant chlorite. Kaolinized plagioclase noted in washed sample. This interval corresponds to a sharp gamma spike. Gradational above and below.
180.5–202	Grades from above to this interval, which is identical to the 170–177.5 ft interval in both color and mineralogy. Contains a low amount of very heavily sericitized plagioclase in washed sample. 0–1% red K-feldspar, partly weathered along cleavage planes.
202–205	Darker green and slightly lower in quartz than above and below. Top and bottom foot are gradational in color. These intervals represent slightly more mafic variants of the same rock.
205–210	Same as 170–177.5, 180.5–202 ft intervals.
210–214	Dark green, hard, clayey regolith, locally light bluish-green on fresh surface. Up to 1% fine-grained, shiny, fresh oxides visible; fine-grained white clay spots—relicts of primary fine-grained schistose texture. Inclusion of mafic schist is probable protolith. Coarse chlorite folia present near bottom of unit. Washed sample completely disaggregates, except for fine-grained fresh oxides.
214–242	Green clay (after hornblende), white clay (after plagioclase), and gray quartz; well-preserved igneous texture of a massive tonalite. The three major mineral ratios are quartz (30%), hornblende (green clay) (5 to 25%; average 10–12%), and plagioclase (white clay) (45–65%). Core lightens slightly in color with depth, because of decreasing hornblende, but darkens again in last 1.5 ft. Overall, very homogeneous rock with slightly variable amounts of hornblende. The sharp contrast in degree of weathering on either side of the amphibolite raft suggests that it—the raft—may have affected the weathering profile. Near 219.5 ft are some thin, dark green veinlets that are probably the result of brittle fracture in the rock; these veinlets may also have played a role in the weathering patterns. In general, however, it seems that the slight variations in white to light greenish-gray in the upper part of this core are probably the result of subtle variations in the hornblende content of the protolith. A small gamma spike at 220–222 ft corresponds to a slight kaolinite enrichment, but the correlation is weak. Near 227 ft, an 8" dark green zone is equivalent to the more heavily weathered rock near 170 ft. This closely corresponds to a negative gamma spike.

Redwood Falls #1 (RF–1)

Main intervals broken down by color, subintervals by quartz content. Quartz content generally increases with amount of white clay.

90–101 ft interval, 91% recovery; 110–120.5 ft interval, 95% recovery.

Depth (feet)		Description
90–99		Pale green clay-rich regolith. In general, moderately sandy (15–30% quartz), abundant, rosette-shaped, granule-sized siderite (1%); variable but minor zircon (washed sample).
	90–92	Pale grayish-green and white clay regolith, streakily mottled on fresh face. 1% siderite nodules, 10–15% very fine, sand-sized, angular quartz. Green clay/white clay ratio, 60:40. Vague primary gneissic layering visible; original grain size: fine- to medium-grained .
	92–99	Same as 90–92 ft, but with 25–30% fine- to medium-grained quartz, some in sugary-textured clots. Yellow stain from oxidized pyrite at 94 ft. Note: depth measured down from 90 to 94 ft; below 94 ft measured back up from 100 ft.
99–118.5		Clay regolith, medium green to light greenish-gray, weakly mottled white. Interval similar to 90–99 ft in quartz content and texture but darker green.
	99–108	10–25% medium-grained angular quartz; variable but minor rounded white kaolinized feldspar; variable rosette siderite; minor zircon.
	108–114	25–30% coarse- to very coarse-grained, angular, sandy quartz. Recrystallized elliptical quartz segregations up to 0.8 cm long. Primary texture is poorly preserved; green clay/white clay ratio, 95:5. Thin 6" interval at 110 ft of light gray regolith.
	114–117	10–25% fine-grained angular quartz sand, otherwise smooth and clay rich. Powder is gray to light olive-gray; fresh face is greenish-gray, with slight white mottling.
	117–118.5	20–35% medium-grained to very coarse-grained quartz sand. Fresh surface mottled green and white clay; green clay/white clay ratio, 90:10.
118.5–128		Clay-rich regolith, green with white mottling, contains 15–20% very coarse-grained, gritty, angular quartz sand. Texturally similar to above; darker colored. Green clay/white clay ratio, 70:30. Lighter colored, more quartzose with depth. Bottom 6", fine-grained, more homogeneous green clay with 15–20% quartz.
128–132		25–30% very coarse-grained angular quartz, 45% greenish-gray clay, 25% white clay. Mottled white on green; weakly foliated primary gneissic texture visible. Grades down to darker, less quartzose material with same texture.
132–140		Same as above, but lighter in color, 20–25% quartz. White chalky zones at 135 and 138.5 ft contain abundant granular quartz corestones.
140–146		Generally darker and greener than above. Bulk of interval is medium green clay mottled by white clay; homogeneous; local patches and zones of lighter colored, more coarse-grained and quartz-rich material.
146–156		15% fine-grained angular quartz sand, 75% green clay, 10% white clay, abundant siderite nodules present.
156–224		Regolith and grus developed on and grading into fresh granitic gneiss. The fresh rock consists of medium-grained, greenish-gray and white, homogeneous gneiss (25% quartz, 30% K-feldspar, 20% plagioclase, 25% hornblende and biotite [variable]); coarse-grained pink quartz and orthoclase pegmatite segregations, and an inequigranular hybrid gneiss with coarse, pink, orthoclase porphyroclasts and an increased granitic component. All of these three major rock types are gradational into one another. Foliation is of highly variable orientation.

Redwood Falls #2A (RF–2A)

Depth (feet)	**Description**
116–145	(100% recovery) Greenish-gray to gray, clayey regolith containing abundant quartz sand. Entire interval is very homogeneous in color, texture, and amount of sandy material. Fresh surfaces are mottled dark and light green clay, with variable but minor amounts of white clay. A relict, foliated gneissic texture is barely visible in the darker colored portions of the core. Medium- to coarse-grained, angular sandy quartz comprises 20–30% of volume; minor amount of medium- to coarse-grained, white, kaolinized feldspar is also present, as are rosette-form siderite nodules (up to 1%) and minor black euhedral zircon. At 133 ft, a local concentration of coarse granular quartz.
145–150	Transitional zone with arbitrary boundaries between the above unit, which has vague primary texture, to the unit below, which has a well-defined relict gneissic texture. The color gradually and irregularly changes to a slightly more grayish tint with depth because of increasing biotite content, which first appears in this interval. Amount and proportion of sandy material in regolith does not vary significantly from the above unit, except for the addition of biotite.
150–264	(General description) Regolith and grus developed from a layered biotite- and hornblende-rich granite to granodiorite gneiss. This interval begins very soft and clay-rich and progresses smoothly with depth to hard and fresh rock. Since quartz and K-feldspar persist high in the weathering profile, those intervals rich in granitic components are typically fresher than adjacent, more mafic rocks. Three basic types of protolith for the regolith exist: 1. Medium-grained, greenish-gray and white to pink, granitic gneiss (approximately 25% quartz, 30–35% K-feldspar, 20% plagioclase, 5% biotite, and 20% hornblende). Best example of this is 230–235 ft interval. 2. Darker greenish-gray, slightly inhomogeneous, medium- to coarse-grained, well-foliated granodiorite (?) (approximately 10–12% quartz, 40% biotite plus variable hornblende, and 50% feldspar of undeterminable proportions). Best example is 166–170 ft interval. 3. Coarse-grained, granitic pegmatite segregations (50% coarse pink K-feldspar, 25% plagioclase, 25% quartz). Best example is 228–230 ft interval. All three major rock types are gradational into one another and intermixed on all scales. Foliation is consistent throughout the core at 65–75° to core axis (in contrast to the variable foliation of RF-1). The following subintervals are based on mineralogical and textural variations, like color and grain size.
	150–154.5 Mottled greenish-gray and white sandy regolith with well-preserved medium-grained, homogeneous, foliated gneissic texture. Contains 15% quartz, 5–7% weathered biotite, 2–5% white kaolinized feldspar, 35–40% white clay, 40% green clay, and trace of black zircon and siderite. Becomes slightly grayer toward bottom of interval.
	154.5–161 Medium- to coarse-grained interval of pinkish-white and green, granite-rich layers and dark grayish-green and white regolith (foliated); similar to above interval but more biotite rich. 5–10% pink K-feldspar granules in the clayey matrix now noted. This interval and the next are similar to the type 2 gneiss described above with granitic stringers, i.e., migmatitic.
	161–170 Texturally similar to above but greener (vs. gray) and softer, because of more primary hornblende now weathered to green clay. At 169.5 ft, 6" layer of coarse biotite associated with a thin pegmatite vein. Interval contains 5–10% coarse-grained sandy feldspar, 15–20% medium-grained sandy quartz, 5% biotite, 40% green clay, and 30% white clay.

Redwood Falls #2A (RF-2A) continued

Depth (feet) **Description**

150–264 continued

170–172	Mottled green and white clay with good relict medium- to fine-grained gneissic texture; most similar to type 1, as described above. Proportions of minerals are similar to 150–154.5 ft, but with a higher granite component.
172–220	Interlayered interval consisting of 3–30-cm-thick, pink, pegmatitic granite segregations (10% of thickness) in a well-foliated coarse-grained, pink and green to medium-grained green and white grus (refer to types 2 and 3, described above).
220–264	Near 220 ft depth, the rock becomes noticeably harder and fresher; still somewhat punky and grus-like. This rather abrupt transition marks the depth at which all of the K-feldspar is fresh; plagioclase is still altered to white clay. Near 254 ft, no white patches of kaolin found, an indication that the plagioclase is probably fresh and relatively unaltered. Plagioclase is difficult to distinguish from K-feldspar; both are white and similar in texture. Below 254 ft the rock is much lighter in color because of its freshness; hornblende is altered to green clay to the bottom of the hole.

The granite segregations in this inhomogeneous gneiss vary in thickness to a point at which they become inseparable from the gneiss. Although modal volumes fluctuate considerably, this coarse, granite-rich gneiss makes up approximately 45% of the total thickness. In contrast, the darker and finer grained homogeneous gneiss (type 2) is relatively free of granitic segregations. Because of its higher biotite content, the homogeneous gneiss variety tends to be more grayish-black.

Thin-section description, 262.5 ft depth:

Medium-grained and weakly foliated granodiorite gneiss cut by 3-mm-wide granitic vein. Foliation defined by biotite and chlorite, which are concentrated along zones of crushed quartz and feldspar. Microcline generally fresh, typically with myrmekitic borders. Plagioclase weakly to moderately sericitized. Approximate mode: 45% plagioclase, 35% quartz, 12% microcline, 6% biotite, 1% chlorite, 1% opaque oxides, and trace of apatite.

Redwood Falls #3 (RF–3)

The four basic rock types referred to in the descriptive logs below are (1) well-foliated, pink and green, medium- to coarse-grained tonalite with large porphyroblasts of pink K-feldspar up to 3 cm across; variable amounts of mafic minerals from 15–75%; (2) pink, equigranular, medium- to coarse-grained, weakly foliated granite; (3) dark greenish-black mafic phase with fine white mottling and possible micro-diabasic texture; chlorite folia not visible; and (4) dark greenish-black altered amphibolitic enclaves, now very rich in foliated altered biotite; possibly the same as type 3 but micaceous and unmottled.

Depth (feet)	**Description**
153–164.5	Green, white, and pink grus/regolith developed on type 1 gneiss. Primary, coarse-grained, foliated, porphyroblastic texture well preserved. Contains 20–30% quartz, 7–10% pale pinkish-orange K-feldspar (commonly as porphyroblasts), 35% white clay, 35% green clay, chlorite, and minor biotite. Plagioclase is completely altered to white kaolinitic clay. Outer core surface has a characteristic green-spotted appearance; possible thin 4–5" intervals of type 2 granite at 157 and 160 ft. Large K-feldspar megacrysts abundant, 160–162 ft. From 159.5 to 160 ft, small disseminated crystals of galena are abundant *in* the rock and *lining* fracture faces.
164.5–166	Zone rich in dark green clay or chlorite after biotite. Probable protolith is a more amphibole-rich segregation. Thin layers of green and white, relict granitic gneiss are also present. No orthoclase porphyroblasts.
166–170	Dark green and white crumbly grus; a more mafic portion of type 1 gneiss. Similar to 153–164.5 ft interval, but with a higher content of mafic minerals. Contains orthoclase megacrysts.
170–171.5	Greenish-gray, weathered amphibolite (type 4); contains abundant, fine-grained, green chlorite and white, altered, quartzofeldspathic clots. Dark greenish-black locally. Abrupt upper and lower contacts.
171.5–175	Hybrid of types 1 and 2: a coarse-grained granite with orthoclase megacrysts as large as 5 cm across. Light pink; low in mafic minerals. Quartz/plagioclase/microcline ratio, 1:1:1.
175–175.5	Dark green clayey regolith developed on type 3 rock, mottled white (fine-grained plagioclase). No chlorite folia visible.
175.5–177	Same as 171.5–175 ft, but contains a slight volume of mafic clots.
177–177.5	Same as 175–175.5 ft, only more yellowish-green.
177.5–178	Dark-colored, coarse-grained, type 1 grus; same as 166–170 ft.
178–180	Type 3 rock (regolith); same as 175–175.5 ft. Fine-grained, weakly foliated fabric visible. Sharp upper and lower contacts.
180–180.9	Coarse-grained, dark, and very mafic type 1 gneiss. Possibly a hybrid with type 4 amphibolite.
180.9–184.5	Dark greenish-black regolith rich in coarse chlorite folia; developed on type 4 amphibolite. No obvious fabric visible.
184.5–184.8	Layer of pink granite.
184.8–185.5	Dark green type 3 regolith; same as 178–180 ft.

Redwood Falls #3 (RF-3) continued

Depth (feet)	Description
185.5–202.5	Granodiorite to tonalite gneiss (type 1); coarse-grained, dark green and white ± pink. Plagioclase is altered to kaolinite in upper part; by 189 ft, mostly fresh and hard. Layer of equigranular pink granite, 188.5 to 189 ft. K-feldspar content variable: from 5% at top to 15% near 192 ft, and from 5% or less near 200 ft to 20% by 202.5 ft (assuming all K-feldspar is pink and plagioclase is white). The K-feldspar typically occurs as large porphyroblasts and thin pegmatitic stringers. 20–40% mafic component of dominantly green biotite; most abundant in areas low in K-feldspar; tends to form cm-sized clots. Thin layers of biotite-rich mafic inclusions or schleiren at 194, 196 ft; small cm-scale inclusions near 201 ft.
202.5–204	Zone consisting of type 2, light pink, equigranular granite.
204–219	Fairly homogeneous zone of coarse-grained, medium pinkish-green, well-foliated granitic gneiss; akin to a hybrid of types 1 and 2. Generally more felsic than 185.5 to 202.5 ft interval; outer core surface has the characteristic mottling of 153–164.5 ft interval and is probably very similar to that interval. All feldspar is fresh; general mineral ratios are 25% quartz, 30% K-feldspar, 30% plagioclase, 15% biotite and green clay; K-feldspar content is quite variable. 6" zone of massive, equigranular, coarse-grained, K-feldspar-rich granite, 204.5–205 ft; 6" inclusions of weathered amphibolite at 212, and 216.5 ft.
219–223	Zone of fine-grained, type 3, mafic rock. Contains 35% fine-grained, fresh, greenish plagioclase and abundant fine-grained chlorite in dark green clay matrix. Rock also contains scattered 4–6-mm, blocky, subhedral, plagioclase phenocrysts or porphyroblasts. Lower contact is conformable with foliation.
223–224	Intermediate porphyroblastic granite gneiss; similar to 204–219 ft interval.

Thin-section description, 204.5 ft depth:

Medium- to coarse-grained granitic gneiss, moderately crushed. Both feldspars are fresh; plagioclase appears antiperthitic in part and is of probable sodic composition. Rock is very leucocratic. Approximate mode: 50% orthoclase, 25% plagioclase, 24% quartz, 1% biotite, and trace of sphene and zircon.

Thin-section description, 224 ft depth:

Coarse-grained granodioritic gneiss showing good crush texture. Fabric defined by concentration of biotite along zones of deformation, by elongate masses of quartz, and by rotation of inequant feldspars into the foliation. Plagioclase weakly to moderately sericitized, poorly twinned and possibly sodic in composition. Approximate mode: 44% plagioclase, 31% quartz, 15% orthoclase, 10% biotite, and trace of hornblende, apatite, and zircon.

Cold Spring #1 (CS–1)

Depth (feet)	Description
64–85.5	Dark gray and white gritty regolith developed on a homogeneous and porphyritic rapakivi granite (see description of bedrock below). Primary, coarse-grained, weakly foliated texture is obvious. Rock contains 5–10% medium-grained to grit-sized sandy quartz and 3–5% pinkish-orange, medium-grained K-feldspar. Dark gray portion contains large proportion of dark green to black hydrated biotite and chlorite; white clay from plagioclase ± K-feldspar alteration. Ratios of dark "clay" to white clay approximately 50:50. Most of biotite disaggregates readily to clay. At 71.5 ft, small inclusion of fine-grained quartzofeldspathic biotite schist. The schist contains rare K-feldspar porphyroblasts and is weakly foliated parallel to the contacts with the surrounding granitic rock. Streaks of green clay in the schist suggest it may have originally had a low content of hornblende. Host rock possibly enriched in quartz near inclusion. 64–74 ft, 80% recovery; core probably lost near 72 ft (measured up from 74 ft mark), where there is a zone of green clay that has either developed in a shear zone or is from a mafic amphibolitic inclusion. Amount of pink K-feldspar increases steadily with depth to about 76 ft, where it increases rapidly. By 84 ft the rock contains approximately 18% quartz, 22% K-feldspar, 30% biotite and green clay (after hornblende or augite), 30% white clay after plagioclase.
85.5–94	Dark greenish-black and white regolith; poor in K-feldspar and quartz; developed on a more mafic protolith than that above. Protolith similar to 107–110 ft interval below. Contains 2–5% rounded medium-grained quartz and 2–5% pink K-feldspar; dark greenish-black clay/white clay ratio, 60:40. About 50% of the dark portion is hydrated biotite that crumbles when disaggregated. Coarse-grained primary texture is well preserved; weak foliation parallel to core axis is present.
94–96	Pink, green, and white mottled clayey grus (very similar protolith to 64–85 ft interval); large pink K-feldspar phenocrysts up to 2 cm across disaggregate easily into angular granules. Plagioclase is still totally altered to kaolinite.
96–107	(70% recovery) Very crumbly, dark greenish-pink and white mottled, clayey grus. Contains 25–30% pink K-feldspar, which crumbles to angular gritty chunks; 10% quartz; 55% dark green clay and biotite (less biotite than most of core); and 10–15% white kaolinite after plagioclase. Probable green clay after hornblende. More mafic than 94–96 and 107–112 ft intervals.
107–112	Coherent, relatively fresh and hard, gneissic(?), rapakivi granite grus. Color varies from dominantly pink to dominantly green, owing to variations in the ratios of feldspar to mafic minerals. Tabular blocky phenocrysts of pink K-feldspar, commonly rimmed by plagioclase (white kaolinite), are up to 5 cm long and aligned parallel to the core axis. Rock contains 20–35% K-feldspar, 12–13% quartz, 15–35% plagioclase, 40–50% mafic minerals (biotite, clay after hornblende). Plagioclase becomes relatively fresh and waxy green at 107 ft. A 6" segregation of pegmatitic K-feldspar with coarse, irregular quartz inclusions is present at 110–110.5 ft. A pervasive, closely spaced, subhorizontal brittle-fracture set cuts the core; other steeply dipping, more irregular brittle fractures are lined with green chlorite or clay.

Cold Spring #1 (CS–1) continued

Depth (feet) **Description**

Thin-section description, 111 ft depth:

Coarse-grained, massive, porphyritic granodiorite (Streckeisen classification[1]) with rapakivi texture. Relatively fresh and unaltered microcline occurs almost exclusively as phenocrysts and is locally myrmekitic along grain boundaries. Plagioclase moderately to heavily altered to sericite; zoned. Biotite altered to chlorite; chlorite pseudomorphs hornblende. Approximate mineralogy: 40% plagioclase, 28% quartz, 12% microcline, 12% chlorite, 6% biotite, 1% apatite, and trace of opaque oxides, zircon, calcite.

1. Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 10-34

Royalton #1 (RY–1)

Depth (feet)	**Description**
40–43.3	Dark brown material that settled into hole before coring began; not representative of any sample (appearance is similar to brown till).
43.3–44	Light brownish-gray, non-calcareous, Cretaceous shale. Very smooth with minor silt and no sand. Scattered flakes of fine-grained muscovite (gypsum ?) are disseminated throughout the clay. A vague lamination is visible, especially at 43.5 ft. Shale contains a few scattered chips of sooty black organic material. Sharp contact with regolith below.
44–54	Silvery-gray, soft, clayey regolith developed on staurolite schist. Silvery sheen on fresh faces due to hydrated biotite or chlorite after biotite. Distinctive original texture of fine-grained, well-foliated, staurolite-biotite schist. Staurolite porphyroblasts disaggregate easily to a reddish-brown, very coarse-grained, staurolite sand. Regolith appears to contain 15–25% white clayey matrix between the biotite and staurolite grains. Quartz is present but volume is difficult to ascertain.
54–100	Dark gray regolith, in contrast to the light gray above. Appears to contain more sandy quartz (25–30%) than the above interval but may simply be more visible because of the higher biotite content and darker color. The regolith contains approximately 50% fine-grained, dark green and black biotite. Regolith becomes progressively lighter in color to 64 ft, dark gray to 72 ft, medium gray below 72 ft. These color variations are apparently a function of the biotite content of the parent rock. The regolith progresses smoothly to sound fresh bedrock with depth; 100 ft depth is an arbitrary pick as to where fresh bedrock begins.
100–143	Fine-grained, strongly foliated, garnet-staurolite-biotite schist (metamorphosed pelitic sediment, Little Falls Formation). The dominant foliation, defined by biotite, is nearly parallel to the core axis and weaves around euhedral staurolite porphyroblasts. A weak crenulation is present and most obvious at 102 ft. Staurolite porphyroblasts up to 2 cm long are slightly broken, stretched, and/or rotated by a second deformation, which caused the crenulation; the staurolite porphyroblasts underwent variable retrograde metamorphism to a muscovite-bearing assemblage—most notable at 116–118 ft depth. Rock contains approximately 35% biotite, 6–8% staurolite, and minor garnet. The remaining amount is dominantly quartz and plagioclase but also likely contains muscovite and possibly other aluminosilicate minerals, like kyanite, andalusite, or sillimanite. Garnet is locally concentrated near the borders of the staurolite crystals. *Thin-section description, 132 ft depth:* Fine-grained, crystalline, quartzfeldspathic biotite schist containing rotated staurolite and garnet porphyroblasts. Fibrous brown sillimanite occurs in clots that apparently pseudomorph garnet. Quartz and feldspar form a granoblastic matrix to biotite; feldspar is weakly sericitized. Approximate mode: 33% biotite, 32% quartz, 31% feldspar, 1% staurolite, 1% garnet, 1% sillimanite, and trace of chlorite, apatite, opaques, tourmaline.

Royalton #2 (RY-2)

Depth (feet)	Description
50–80.5	Not sampled; material that settled back into hole prior to coring; only 2.5 ft of core recovered.
80.5–84	Light to medium grayish-brown Cretaceous shale. Color darkens with depth; rock is comprised of clay, minor silt, and no sand. Contains chips of black organic material, especially towards top of interval. This rock is quite solid and recovery is probably 100% on this interval.
84–94	Clay-rich regolith interval, which is dominantly white in color, but which ranges from white to very pale grayish-green to olive-yellow to reddish-brown to gray. Color variations are streaky and irregular. Gray portion at top contains a low percentage of coarse-grained muscovite flakes; 15–20% quartz, which ranges from fine-grained and angular to granule-sized and rounded. A thin yellow layer within the gray clay is very smooth and contains minor fine-grained quartz and mica and smells weakly of sulfur. From 84.5 to 94 ft, the regolith is very white with local grayish zones and irregular reddish-brown patches. Contains 1–3% fine-grained, round, sandy staurolite. 86 to 87 ft interval (measured from 84 ft marker) is very smooth and clay-rich, contains only a trace of quartz and staurolite. Below 87 ft the regolith becomes very sandy-textured and contains 25% or more fine- to medium-grained angular quartz, 25% medium-grained round staurolite, possibly feldspar. The recovery in this interval (from approximately 87 to 94 ft) is very poor, with only 6" or less of sample for 7 ft of actual drilling depth.
94–96	Abrupt change to sticky, sandy, gray clayey regolith. Contains 50–60% fine- to medium-grained sand, which is dominantly quartz but also contains yellowish-red staurolite or possibly feldspar. At least 2 ft of core missing from the 94–100-ft interval, probably washed out from around the 95 ft depth.
96–109	Near 96 ft changes from slightly greenish-gray to dark silvery gray. The silver color may result from graphite but is more likely because of weathering and hydration of the micas. At approximately 98.5 ft (measured backwards from 104 ft marker) there is a swirled 3" patch of white, soft, clay-rich regolith, which is similar to the 84–94 ft interval and may represent a narrow zone of increased permeability. By 99 ft the regolith is a dark greenish-gray color mottled with 2–3% foliated clots of white clay, which may represent feldspar segregations in the original rock. The relict foliation is at about 30° to the core axis (compared to RY-1, which was nearly parallel to the core axis). Texturally this interval contains 30–40% or more fine to medium-grained sand composed dominantly of quartz and feldspar (or staurolite?)—the latter yellowish-green in color. At 101 ft depth, a 6" light-colored zone, consisting of white clay and light green to olive green clay with minor fine-grained quartz and feldspar, shows a crude relict medium-grained igneous texture, suggesting it may have had a granitic dike as a protolith. The regolith on either side of this layer is solid gray and has a schist protolith. From 101 ft and below the regolith is essentially the same (dark gray, foliated, micaceous, fine- to medium-grained, biotite schist protolith), with the exception of lighter-colored zones at 103 ft and 108–109 ft depth. At 108 ft a few 2–3-mm staurolite crystals are locally present.

St. Augusta #1 (SA–1)

Depth (feet)	**Description**
50–56.5	Olive gray to grayish-brown to black (lignitic) Cretaceous shale. Becomes generally darker with depth; near 55.5 ft substantial, black, lignitic, woody material begins to appear. Contact with underlying regolith is abrupt; lignite is directly on top of/against the bauxitic regolith. 50–61 ft, only 95% core recovery.
56.5–62	Bauxite (first 1–2"), gray on powdered face. Brownish-gray on fresh face, with wisps of black organic material and 2–4 cm, irregularly shaped nodules consisting of a reddish-brown core of weathered pyrite rimmed by a thin white chalky rind. Very fine pyrite visible; rock smells weakly of sulfur. Next 5–6", pisolitic bauxite, white (powder is light gray) . Pisolites are 1 cm, have vuggy cores of fine-grained pyrite, which form crusty botryoidal masses—again rimmed by white clay. Internodule areas (nodules comprise 20% of volume) contain abundant (up to 50% or more) fine-grained, angular, sandy quartz in a chalky white matrix. At 57.2 ft an abrupt transition from the chalky white clay matrix to a waxy green matrix. This greener material is much harder to disaggregate than the above white material. Coincident with the change to the green color, the pisolites become larger (to 1.5 cm maximum), rounder, more deeply red or dark gray, and better defined. The pisolites are not hollow as above; they vary from white to earthy reddish-brown to dark greenish-black, and become darker with depth. Most have a thin reddish-brown rind. The fine-grained quartz has apparently been dissolved and replaced by white chalky material (see example at 58 ft depth); not all quartz is gone. Contains a small amount of disseminated pyrite cubes. The green color (between pisolites) darkens with depth; the pisolites also become blacker. Thin, flat, radial discs of calcite line the surfaces along which the core breaks.
62–71.5	Hard, grayish-green, waxy, opaline-like clay material. Massive, scattered small white 2–3-mm pisolites; small white angular clots that pseudomorph quartz grains. Near 64 ft, tiny white worm-like masses noted that apparently fill small contraction fractures in the greenish-gray host material. At 64 ft a 1" zone of very smooth, slightly silty, dark brownish-gray clay that contains small chunks of black organic material or black clay; this is not in place, but "left over" in core tube from Cretaceous shale above. Below 64 ft clay is locally variegated. 66–67, 68–69 — Soft zones of variegated grayish-green and brownish-reddish-gray, similar in color to rest of interval. Interval becomes slightly lighter in color with depth, to light olive-gray at 71 ft; also becomes less waxy with depth as the color lightens. Interval contains a small amount of fine-grained angular quartz (visible in disaggregated and washed samples).
71.5–74.6	Abrupt change to darker olive-gray, smooth clay regolith. Contains 10–15% fine-grained angular sandy quartz. Becomes pisolitic near 72.5 ft; number of pisolites increases to 74 ft depth (pisolites are deep reddish-brown color, less than one cm, and of similar texture and competence as matrix). Rock becomes increasingly soft as 74 ft is approached. At 74 ft a 6" zone of very soft, doughy greenish-black mottled clay; also clots of bluish-gray clay; pisolites are altered to deep brownish-black material. A fracture system or zone of higher permeability is apparently responsible for this more intense weathering.
74.6–81	Start of visible igneous texture. 74.6–75.5 ft, greenish-gray with wispy reddish-colored strings. By 75.5 ft rock is fairly homogeneous; visible igneous texture due to very subtle variations in darkness of green. Medium soft; disaggregates easily in the hand. Contains 5–8% fine-grained angular quartz sand. First remnant feldspar appears at 76 ft as fine-grained, orangish-red, angular sand; abundant by 78 ft.

St. Augusta #1 (SA-1) continued

Depth (feet)	Description
81–89	Fairly abrupt transition to medium coarse-grained (relict texture), green and white mottled, clayey regolith. Green clay/white clay ratio, 60:40. 4–5% orangish-red, coarse, granular, sandy feldspar and 8–10% medium fine-grained, angular quartz sand is visible; rest is clay. At 82 ft, thin layer of reddish-brown clay slickensides at 45° to the core axis. Clay regolith shows a weak relict foliation from 85–88 ft; the foliation is defined by elongate patches of yellowish-green clay (5–6%), which are possibly after epidote. First appearance of biotite just above 89 ft. Washed sample at 88 ft yields coarse, granule-sized yellow feldspar.
89–105	(Only 65% recovery, 89.5–105 ft) Slightly finer grained interval (medium-grained); grayer and more massive with much black biotite. 5–7% biotite, 10–15% medium-grained quartz (hard to distinguish), 15–20% white feldspar (medium- to coarse-grained [washed sample]). This interval has coarser grained portions, subtle changes in grain size from medium to medium-coarse. Similar to above interval but with more feldspar and marked by appearance of biotite. 93.5–94 ft is finer grained, lighter colored, and contains less biotite.
105–116	Grus, transitional from above to darker green and white (higher contrast) rock, fresher but still crumbly. Rock may have been more hornblende-rich below 105 ft. Contains (visible with hand lens) 5–6% biotite, 30–40% dark green clay, 15–20% pink feldspar, and 8–10% white clay. Rock progressively hardens with depth (less clay, more fresh minerals) to 116 ft, where it is essentially sound bedrock. Hardens most abruptly in the last 2 ft of interval.
116–121	Massive, pink and black, medium- to coarse-grained quartz monzonite; local greenish alteration patches. Rock is moderately broken by brittle shear near 116 ft, where chlorite-lined lineated slickenside surfaces are at approximately 65° to core axis. Fractures are cm-spaced, 115–116 ft; in the rest of core, spaced more widely and variably. Last 1.5 ft is slightly more weathered because of abundance of brittle fractures. *Thin-section description, 119 ft depth:* Medium coarse-grained, equigranular quartz monzonite/adamellite (Streckeisen classification[1]). Plagioclase is stained red by submicroscopic Fe oxide; variably saussuritized; weakly zoned. Microcline is fresh. Quartz, biotite, and hornblende are late anhedral-interstitial in habit. Thin section is cut by quartz-epidote vein and thin, irregular, chlorite- or calcite-filled brittle fractures. Approximate mode: 44% plagioclase, 40% microcline, 10% quartz, 3% chlorite (after biotite), 1% biotite, 1% hornblende, and trace of apatite, zircon, sphene, epidote, and calcite.

[1] Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 10-34

St. Joseph #1 (SJ–1)

Depth (feet)	**Description**
30–32	Slightly sandy, smooth gray clay (not representative sample). Pebble lithology and presence of mica suggest this sample backsettled into hole prior to coring. Very poor recovery.
32–33.5	Light gray, sandy-textured, clayey regolith. Contains 6–8% feldspar as lumpy reddish-brown, coarse-grained gritty sand. This "feldspar" may be altered quartz (it appears to grade with depth to gray quartz, which has a reddish-brown stain along rims and fracture planes). Abundant pale grayish-green mica and light color indicate granitic regolith.
33.5–34	Light to medium-gray, very smooth and pure clay, developed from a diabase protolith. Nonmicaceous.
34–35	Similar to 32–33.5 ft interval. The reddish-brown sandy grains here begin to show quartz.
35–37	Same as 33.5–34 ft, except slightly darker greenish-gray. Very pure and smooth; diabase protolith.
37–42.5	Same as 34–35 ft, abundant greenish-gray mica.
42.5–50	Dark greenish-gray to dark bluish-gray (on fresh unoxidized surface), very smooth pure clay from a diabase protolith. Lower contact (measured back up from 54 ft marker) tapers gradually and nearly parallel to core axis. Only 60% recovery, 44 to 54 ft interval; most of loss is from 44 to 48 ft interval, where the gray clay is very loose and watery.
50–52	Greenish-gray gritty regolith similar to 37–42.5 ft. Contains 8–9% coarse-grained to granule-sized quartz and feldspar, similar to the sandy grains in the other intervals of the same lithology. Irregular contact with below.
52–54	Smooth greenish-gray pure clay; protolith of diabase dike.
54–64	Greenish-gray gritty clay; same as 50–52 ft interval. Near 55.5 ft a coarse, relict igneous texture begins to show up well, because of the mottling of various shades of green. Contains 15–20% very coarse-grained to granular feldspar.
64–64..5	Abrupt change to high-contrast green and white clay (vs. the more subtle, pale to medium greenish-gray color variations above). This darker green color results from fresh chlorite after biotite—in contrast to above, where the chlorite has been strongly altered to other secondary clays, homogenizing the color.
64.5–70.6	Dark greenish-gray, smooth clay after diabase; subtle fine- to medium-grained white mottling mimics original texture of feldspar (lower depth measured up from bottom of box).
70.6–72	Greenish-gray, gritty, clayey regolith with minor white mottling. Similar to 54–64 ft interval. Contains 15–20% coarse-grained to granular quartz. Chlorite altered to greenish-gray clay; folia still visible.
72–73	Dark greenish-gray, smooth, pure clay developed from diabase. Only 50% recovery, 64–74 ft; this interval is probably 5 ft thicker.
73–74	Dark green and white, gritty, clay regolith.
74–82	Very smooth and slippery, dark greenish-gray, clayey regolith developed from a diabase protolith. Primary microdiabase texture of 1-mm-long plagioclase phenocrysts in an aphanitic groundmass shows up clearly (the feldspars are replaced by white kaolin. Upper contact is somewhat irregular; bottom is sharp, at approximately 50° to the core axis.

St. Joseph #1 (SJ–1) continued

Depth (feet)	Description
82–83	Pink, dark green, and white grus-like regolith developed on a granitic protolith. Pale pink K-feldspar is still somewhat chalky, plagioclase is completely altered to white kaolinite; dark green chlorite is partially altered to dark green clay (clay possibly from hornblende?).
83–90.6	Dark grayish-green, smooth, clay regolith from diabase; identical to 74–82 ft interval. Contact is nearly parallel to core axis.
90.6–94	Same as 82–83 ft. See fresh bedrock description (139-158 ft interval) for proportions of primary minerals. Plagioclase is totally altered to kaolinite; biotite is mostly altered to chlorite or dark green clay.
94–94.8	Same as 82–83 ft; dark greenish-gray clay from diabase protolith.
94.8–118	Entirely homogeneous interval of grus-like regolith developed on uniform granite. Biotite becomes fresh and black near 104–105 ft, otherwise entirely homogeneous. Plagioclase altered to kaolinite.
118–124	Core is partly granite and partly diabase protolith along near vertical contact that extends the entire length of this interval. Diabase gradually becomes dominant rock with depth.
124–133	Dark kelly-green, smooth, hard, clayey regolith developed from microdiabase. Texture is well preserved (see 82–83 ft). Thin, irregular, slickenside-lined fractures cut diabase core; may be post-weathering.
133–138	Nearly fresh granite. Plagioclase is still totally altered, but rock has a sound ring when tapped with hammer. All other minerals except plagioclase fresh.
138–139	Zone of green clay; from diabase dike.
139–158	Uniform and massive, pink and green, coarse-grained porphyritic granite. 10–12% quartz, 10–12% biotite, 38–40% pink K-feldspar, and 40–42% yellowish, slightly altered plagioclase. Core is transected by a few random brittle fractures but otherwise massive. *Thin-section description, 154 ft depth:* Coarse-grained, equigranular quartz monzonite (Streckeisen classification[1]). Plagioclase is patchily stained red by submicroscopic material, but overall both feldspars are quite fresh. Biotite and hornblende are moderately altered to chlorite and a dark brown clay mineral. Rock is transected by numerous thin biotite-lined fractures filled with calcite. Approximate mode: 46% microcline, 37% plagioclase, 10% quartz, 2% biotite, 2% calcite, 1% hornblende, 1% chlorite, 1% clay minerals, trace of apatite, opaque oxides, zircon.

---

[1] Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 10-34

APPENDIX C, PART 2

DESCRIPTIONS OF CORE SAMPLES USED IN CHEMICAL AND MINERALOGICAL ANALYSES

Morgan NE #1 (MNE–1)

Depth (ft)	Description
163–163.5	White shale with 1–2% quartz sand, 1% red nodules of siderite (?).
181–181.5	White, medium-grained, subangular quartz sandstone with 10–15% white kaolinite matrix.
194–194.5	Very smooth kaolinitic shale, dominantly orangish-red (oxidized Fe), mottled pale grayish-white to white.
205.9–206	Very poorly consolidated, medium- to fine-grained, clean quartz sand from bottom of Cretaceous section; contains a yellow U-bearing clay that gives a large gamma spike.
214–214.5	Crumbly green, white, and pink grus. Pink K-feldspar grains are still intact but crumble easily; clays are smooth, light green to grayish-green, or white; quartz is not as abundant as in lower samples. Pink K-feldspar, 30–35%; green clay, 35%; white clay, 25–30%; quartz, 5%. Possibly slightly more mafic than lower samples; color is more homogeneous than below because of more extensive weathering. This sample is representative of most heavily weathered interval.
242–256.5	Moderately weathered granite. Pink K-feldspar and quartz still intact; plagioclase altered to white kaolin clay; hornblende altered to green clay. Contains 15% quartz, 5% green clay, 40% pink K-feldspar, and 40% white clay after plagioclase.
256–256.5	Moderately fresh granite; similar to 242 ft, except plagioclase is slightly fresher (but still heavily weathered) and quartz content slightly higher. This is the least weathered sample of the core.

Morgan NE #2 (MNE–2)

Depth (ft)	Description
84.3–84.5	White, silty and slightly sandy shale of Cretaceous age.
94.5–95	White, kaolin-rich regolith with 3–8% coarse sandy quartz grains. Small mica faces (white) are visible.
124–124.5	White kaolin-rich regolith with 18–23% coarse, angular, sandy quartz grains. Similar to 94.5–95 ft, only more sandy. Primary igneous texture visible, but very vague. Possibly contains a low amount of K-feldspar.
136–136.5	Very pale greenish-white and white mottled, clay-rich regolith. The different color shades result from primary mineralogy—perhaps different feldspars. Contains 20% or more gritty quartz and a small amount of slightly pink, moderately fresh, K-feldspar granules.
170–170.5	Similar to 136 ft, except slightly fresher. Quartz grains very well-preserved as medium- to coarse-grained, angular sand grains (25–30%). Colors of clays and amount of feldspar similar to 136 ft, but rock slightly harder and fresher.
182.5–183	Similar to 170 ft. First (top) of 3 samples taken to investigate a steadily increasing gamma response.
186–186.5	Similar to 182.5 ft sample. Very pale greenish-white and white clay, 20–22% relict quartz, low volume of feldspar. Overall, very white in color.
201.5–202	Essentially the same as 186 ft; last (lowest) of 3 samples taken to investigate steadily increasing gamma response.
213.5–214	White and medium greenish-gray clayey regolith with 25% quartz, very little or no feldspar. Contains 10–12% green clay, including chlorite.
234–234.5	Similar to 213.5. 3–4% green clay (probably after hornblende); white clay breaks into squarish pieces, begins to show a hint of heavily altered chalky feldspar precursor. Sample from lowest portion of core available.

Redwood Falls #1 (RF–1)

Depth (ft).	Description
92–93	Light greenish-white and light green mottled, clay-rich regolith with a vague primary gneissic texture. Contains 20% quartz grit and 1% round, gritty, reddish-brown feldspar or siderite. Minor yellow stain from oxidized pyrite.
110–111	Homogenous, light grayish-green, quartz-rich clay regolith. Similar to 92–93 ft, but slightly darker with a more clear distinction between the green and white mottled clays (white clay is subordinate to green). Vague primary layering is visible.
122	Quartz vein—gray, recrystallized, clean. Sampled to check out large gamma spike on gamma log.
±122	Saprolite from either side of quartz vein at 122 ft..
140–141	Very similar to 110–111 ft, but with a small amount of altered white feldspar; primary grains more distinct. Homogeneous in texture.
153–154	Light green clay (50%) mottled with white clay (20%), 30% gray quartz. The presence of relict feldspar is questionable. Less color than 140–141 ft sample.
167–168	Green and white saprolite from layered gneiss. Green layers (30% of volume) contain relatively abundant coarse chlorite after biotite, possibly some biotite. Feldspars are altered to white clay. Sample contains at least 30% quartz. Primary texture is very well preserved color very inhomogeneous.
186.5–187.5	Dark green and white, clay-rich weathered gneiss. Pinkish-yellow, chalky, relict feldspar is becoming relatively abundant by this depth, and biotite is fresher, darker, and less altered to chlorite. Green clay ± chlorite ± biotite, 35%; white clay ± feldspar, 35%,\; quartz, 30%.
219–220	Freshest sample of drill core. Pinkish-white and green, biotite (± hornblende?)-rich augen gneiss. Pink K-feldspar is slightly altered on edges, other feldspar grains (plagioclase?) completely altered to white clay. Biotite (± hornblende?) altered to dark green chlorite. 30% chlorite, 25% quartz, 25% pink feldspar, 20% white clay.

Redwood Falls #2A (RF–2A)

Depth (ft)	Description
124–125	Homogeneous, light grayish-green, quartz-rich clay regolith. 25% gray quartz shows primary texture, otherwise completely homogeneous.
151–152	Layered, green and white, quartzose, clay-rich regolith. Primary layered gneissic texture is well preserved. Feldspars retain a somewhat blocky cleavage face, but are heavily altered to kaolinite. Dark green chlorite after biotite, 5%; green clay, 20%; white clay/feldspar, 45%; quartz, 30%.
158–159	Green and white mottled, clay-rich regolith. Smooth green clay, 30–35%; white clay, 20%; quartz, 25%; chalky white feldspar, 15%; dark grayish-green chlorite after biotite, 5–10%. Primary texture well preserved.
189.5–190.5	Pink, green, and white clay-rich grus. Most K-feldspar is pink and relatively fresh; primary gneissic layering is very well preserved via layers alternating in feldspar and green clay plus chlorite. Plagioclase is totally altered to chlorite. Quartz, 27%; white clay, 25%; green clay, 30%; pink K-feldspar, 10%; biotite/chlorite, 8%.
229–229.5	Pegmatitic segregation in granite gneiss.
261–262	Greenish-pink biotite granite gneiss with cm-wide segregations of coarse pink granite. Granitic segregations vary from discrete units to an inseparable part of the schist. Plagioclase is moderately fresh, but still altered to kaolinite; biotite is extensively altered to chlorite. Quartz, 30%; pink K-feldspar, 30%; plagioclase, 30%; biotite altered to chlorite, 10%.

Redwood Falls #3 (RF-3)

Depth (ft)	Description
155–156	Pink, green, and white grus. 35% fresh pink K-feldspar, 20% biotite that is partially altered to chlorite, 20% quartz, 25% white kaolin (presumably after plagioclase).
159.5–160	Pink, K-feldspar-rich, equigranular granite with small galena crystals lining brecciated fracture faces.
192–192.5	A less weathered equivalent to 155–160 ft sample. Pink, white, and green augen gneiss: 30% pink K-feldspar; 30% altered, chalky feldspar (plagioclase); 20% quartz; 20% biotite partially altered to chlorite.

Cold Spring #1 (CS–1)

Depth (ft)	Description
70–70.5	Primary, coarse-grained, igneous texture is well preserved. Rock consists of 45% white clay after plagioclase (± K-feldspar), 45% dark green clay ± chlorite ± biotite (dominantly the latter), 7% gray quartz, 3% chalky pink K-feldspar.
79–80	Pink, green, and white grus/saprolite with well-preserved primary igneous texture. 25% gray quartz, 20% chalky pink K-feldspar, 35% white clay after plagioclase, 20% biotite and dark green clay or chlorite. This sample is more felsic than the other four from this hole.
88.5–89	Dark green and white mottled saprolite. 15% gray quartz, 5–6% chalky pink orthoclase, 30% white clay after plagioclase, 50% dark green clay and biotite. Dark green clay/biotite ratio approximately 50:50. Primary texture well preserved.
106–106.5	Similar to 88.5–89 ft; K-feldspar content is much higher—to 30% or more, because more K-feldspar was left unweathered and the K-feldspar content was initially higher. Also, the amount of biotite relative to green clay is less, possibly because of higher initial amount of hornblende.
111–112	Dark green and pink, soft, weathered granite. Plagioclase is very chalky but still forms coherent grains, unlike above, where it is completely altered to clay. 30% pink K-feldspar, 10–15% gray quartz, 30% chalky plagioclase, 30% dark green chlorite and weathered biotite.

Royalton #1 (RY–1)

Depth (ft)	Description
43.3–44	Light brownish-gray shale; Cretaceous.
46–47	Silvery-gray staurolite-biotite schist saprolite. Biotite grains are altered to greenish-gray chlorite; feldspar (originally intermediate to sodic plagioclase?) completely altered to white kaolinitic clay; fine-grained quartz has not been affected. Staurolite is partially altered, consists of sandy staurolite in a white kaolinitic matrix. Quartz/altered biotite/white clay ratios are approximately equal. Original rock contained 6–10% staurolite.
72–73	Same as 46–47 ft, but biotite is fresh, black in this sample.
92.5–93	Similar to above 2 samples, but staurolite crystals are fresh. Note scattered clots of chlorite. Core is harder, more brittle and coherent than in the above more clay-rich samples.
139.5–140.5	Fresh equivalent to above 3 samples. Biotite is very fresh, dark brown in color. Modes of all 4 schist samples are very similar.

Royalton #2 (RY–2)

Depth (ft)	Description
81–82	Smooth, grayish-brown Cretaceous shale with a minor amount of black organic material and rare fossils. Fine-grained white mica visible with hand lens; probably reworked from the underlying saprolite.
84.5–85.5	Cream-colored, clay-rich regolith with wispy streaks of light orangish-brown clay. Contains 1–3% fine- to coarse-grained sandy quartz and 1–2% coarse-grained, reddish-brown, granular staurolite. This material is possibly reworked, but the lack of stratification and the random distribution of coarse sand granules suggest that it is in place.
94.5–95.5	Medium greenish-gray sandy regolith. Contains 50% or more medium-grained angular quartz sand, minor reddish-brown staurolite, and a matrix of gray clay. Small (2 mm) clots of white clay mottled throughout are less than 3% of total volume. Primary texture not visible.
104–105	Gray, moderately weathered, fine-grained biotite schist. Original well-foliated texture is obvious. Biotite is altered to a dark greenish-black chlorite; fine-grained sandy quartz is abundant; and white clay occurs as a matrix and as a wispy foliation of parallel streaks.

St. Augusta #1 (SA–1)

Depth (ft)	Description
52–53	Olive-gray Cretaceous shale. Contains abundant fine-grained flakes of micaceous material.
55.9–56	Black, very organic-rich shale.
57–57.5	White pisolitic bauxite. Contains up to 50% fine-grained angular quartz, minor black organic material in grayish-green waxy matrix.
58.5–59.5	Brown pisolitic bauxite with abundant reddish-brown to black pisolites. Similar to the sample at 57 ft, but here the angular sandy quartz is altered to a white clayey material (in the same waxy green matrix).
63–64	Hard, grayish-green, waxy, clay-rich regolith. Contains minor, tiny, white clay clot; 1–5% fine-grained, reddish-brown, translucent grains (of secondary origin); and a small amount of 2–7 mm white clay pisolites.
67–68	Light grayish-green regolith, which has pink patches in it. Contains abundant, fine-grained, angular quartz (6–8%); also abundant (5–6%), fine-grained, secondary red mineral, similar to 63 ft sample. More clay-rich and lighter colored than 63 ft sample.
75–76	Soft, green, clay-rich regolith. Very homogeneous in color; igneous texture vaguely visible. Contains 15–20% quartz, possibly a low amount of feldspar. Green clay is mottled with a minor amount of pink stain.
82–83	Green and greenish-white mottled regolith. Contains 5–15% Fe-stained quartz; good chlorite (?) folia now visible.
87–88	More distinctly green and white than 82 ft sample. Contains the first distinct feldspar, as very heavily altered, chalky, and squarish chunks. Quartz still hard to see; abundant fine-grained mica faces.
95–96	Green and white kaolinite and chlorite-rich regolith with very well-preserved igneous texture. Chlorite plus green clay, 33%; quartz, 25%; white clay, 32%; chalky white feldspar, 6–10%.
109–110	Saprolite; dark green, white, and pink chlorite, kaolinite, feldspar, and quartz; igneous texture well preserved. Contains 15% pink K-feldspar, an indeterminable amount of quartz, 40% green clay plus chlorite after biotite, 45% white kaolinitic clay.
115–116	Green, white and pink, moderately weathered, granitic rock. Contains 40% white kaolinitic clay after plagioclase, 10% pink K-feldspar, 10% quartz, 40% chlorite after biotite, plus green clay after hornblende. A minor amount of hornblende may be present.
119–120	Fresh, medium-grained, equigranular, pink and black granite. Plagioclase is slightly waxy and saussuritized to a greenish color; biotite and hornblende fresh and black. Contains 37% pink orthoclase, 33% plagioclase, 8% biotite, 12% hornblende, 10% quartz.

St. Joseph # 1 (SJ–1)

Depth (ft)	Description
32–33	Light greenish-gray, homogeneous, clayey regolith. Contains abundant flakes of light greenish-gray mica, 6–7% gritty, reddish-brown grains that appear to be quartz.
41–42	Similar to 32–33 ft, but slightly darker green; contains more of the grayish-green mica; vague igneous texture now visible.
55–56	Similar to 41–42 ft, but lighter color similar to the 32–33 ft sample. This and the above two samples are very similar in texture, color, and clay content, but subtle changes in relict texture and color suggest variable weathering.
72–73	Very smooth, medium greenish-gray clay. Weak layering of darker and lighter color banding on a cm-thick scale. Protolith of diabase or possibly a quartz-free mafic schist.
73–74	Dark green and white mottled, clayey regolith; sandwiched between diabase. Contains no relict feldspar; green portion consists of chlorite plus clay. Quartz, 15%; green clay, 45%; white clay, 45%. Coarse-grained igneous texture well preserved.
82–83	Green, white, and pale pink grus/regolith. K-feldspar is soft and chalky, but remains coherent. K-feldspar, 15%; green clay plus chlorite, 35–40%; white clay, 35–40%; quartz 10%.
116–117	White, pink, and green grus developed from coarse-grained granite. K-feldspar is pink and quite fresh; chlorite is dark green and forms distinct flakes. White clay (after plagioclase), 35%; green clay (after hornblende?) plus chlorite, 25%; pink K-feldspar, 25%; quartz, 15%.
135–136	Pink, green, and white weathered granite. Possibly a low amount of remnant plagioclase, and possibly some remnant biotite in with altered chlorite. Original grain boundaries sharp and distinct. Microcline, 30%; chlorite and green clay, 30%; white clay, 30%; quartz, 10%.
156–157	Fresh and sound, greenish-pink, coarse-grained, slightly porphyritic, massive granite. Plagioclase saussuritized to a greasy greenish color; biotite is fresh and greenish-black; hornblende is slightly altered to green clay. Microcline, 40%; plagioclase, 30%; biotite, 15%; hornblende, 5%; quartz, 10%.

APPENDIX D

X-RAY MINERALOGY OF CLAY SEPARATES

(0, not present; 1, trace [less than 10%]; 2, small [10–25%]; 3, moderate [26–50%]; 4, abundant [51–75%]; 5, dominant [more than 75%] Analyses by the Soil Survey Laboratory, University of Minnesota, St. Paul)

Under **Sm** (smectite): HISm (hydroxy interlayered smectite)
Under **Ve** (vermiculite): HIV (hydroxy interlayered vermiculite)
Ch (chlorite); **Il** (illite); **Kao** (kaolinite); **Qu** (quartz)
Under **Fel** (feldspars): KNa (alkali feldspar); NaCa (plagioclase); Ca (anorthite). Albite and othoclase not present
Under **Ox** (Oxides): hem (hematite); goe (goethite); ana (anatase). Boehmite, cristobalite, gibbsite, lepidocrocite, maghemite, and rutile not present
Under **Carb** (carbonates): sid (siderite—$FeCO_3$). Calcite, dolomite, magnesite ($MgCO_3$), and rhodochrosite ($MnCO_3$) not present
Under **Inter-/strat** (mixture of minerals): mineral abbreviations as indicated above
Under **Other**: amph (amphibolite); pyr (pyrite); other mineral abbreviations as indicated above

Depth (feet)	Sm	Ve	Ch	Il	Kao	Qu	Fel	Ox	Carb	Inter-strat	Other
SOUTHWESTERN MINNESOTA											
Morgan NE #1 (MNE–1)											
163–163.5	0	0	0	1	5	0	0	goe-1, ana-1	0	0	talc-1
181–181.5	3	0	0	1	4	0	KNa-1	0	0	0	0
194-194.5	0	0	0	0	4	0	0	hem-3, goe-1	0	0	0
205.5–206	4	2	1	2	2	0	0	0	0	0	amph-1
214–214.5	2	0	1	3	4	0	0	0	0	ChIl-1	amph-1
242–242.5	2	1	0	1	4	1	2	goe-1, ana-1	0	0	0
256–256.5	0	2	1	1	2	1	KNa-2, NaCa-2	ana-1	0	ChVe-1	talc/pyr-1
Morgan NE #2 (MNE–2)											
84–84.5	1	0	1	1	5	1	0	goe-1	0	0	0
94.5–95	0	0	1	1	5	1	0	goe-1	0	SmIl-1	0
124–124.5	1	0	1	1	5	1	1	goe-1	sid-1	0	0
136–136.5	1	HIV-1	1	1	5	1	0	0	0	0	0
170–170.5	0	HIV-1	1	1	5	1	0	0	0	ChIl-1	pyr-1
182.5–183	1	HIV-1	0	1	5	1	1	goe-1	0	VeIl-1	0
186–186.5	1	HIV-1	1	1	5	1	0	goe-1	0	0	0
201.5–202	0	HIV-1	1	1	5	1	0	0	0	0	0
213.5–214	1	HIV-1	1	1	5	1	0	goe-1	0	SmIl-1	0
234–234.5	0	0	1	1	5	1	KNa-1	0	0	0	0
Redwood Falls #1 (RF–1)											
92–93	1	0	1	1	5	1	0	0	0	ChIl-1, SmKao-1	0
110–111	0	0	1	1	4	1	KNa-1	0	0	ChIl-1, SmKao-1	talc-2

Depth (feet)	Sm	Ve	Ch	Il	Kao	Qu	Fel	Ox	Carb	Interstrat	Other
Redwood Falls #1 (RF–1) continued											
121–122	1	HIV-1	0	1	5	1	0	ana-1	0	SmKao-1	talc-2, amph-1
140–141	1	1	0	1	5	1	0	goe-1	0	SmKao-1	talc-1
153–154	0	HIV-1	1	1	5	1	0	goe-1	0	0	talc-1
167–168	1	HIV-1	1	1	5	1	0	ana-1	0	ChIl-1	0
186.5–187.5	0	HIV-1	1	1	5	1	KNa-1	goe-1	0	ChIl-1	amph-1
219–220	3	0	1	1	2	1	KNa-2	goe-1	0	0	amph-1
Redwood Falls #2A (RF–2A)											
124-125	0	HIV-1	1	1	5	1	0	goe-1	0	ChIl-1, SmKao-1	talc-1
151-152	0	HIV-1	1	2	5	1	0	goe-1	0	0	0
158-159	0	HIV-1	1	2	5	1	0	goe-1	0	ChIl-1	0
189.5-190.5	0	0	0	1	5	1	0	goe-1	0	0	0
229-229.5	0	0	0	2	5	1	KNa-1	0	0	0	0
261-262	1	0	1	1	4	1	KNa-1, NaCa-2	ana-1	0	ChIl-1	HISm-1
Redwood Falls #3 (RF–3)											
155-156	3	0	0	1	4	1	KNa-1, NaCa-1	0	0	0	0
159.5-160	3	0	0	1	3	1	KNa-2, NaCa-2	0	0	0	0
192-192.5	4	0	0	1	2	1	KNa-2, NaCa-2	0	0	0	0
EAST-CENTRAL MINNESOTA											
Cold Spring #1 (CS–1)											
70–70.5	0	HIV-1	1	1	5	1	KNa-1	goe-1	0	0	talc-1, amph-1
79–80	2	HIV-1	1	1	5	1	KNa-1	0	0	ChIl-1	amph-1
88.5–89	0	0	1	1	5	1	KNa-1	goe-1	0	ChIl-1	HISm-1, amph-1
106–106.5	0	0	0	1	3	1	KNa-2, NaCa-1	0	0	0	0
111–112	4	0	0	1	2	1	KNa-2, NaCa-2	0	0	0	0
Royalton #1 (RY–1)											
42–43	0	0	1	1	5	1	0	0	0	0	0
46–47	0	0	1	1	5	1	0	goe-1	0	KaoSm-1	0
72–73	0	0	1	1	5	1	0	goe-1	0	0	0
92.5–93.5	0	0	1	1	5	1	KNa-1	0	0	0	0
139.5–140.5	0	0	1	1	5	1	KNa-1	goe-1	0	SmIl-1	0

Depth (feet)	Sm	Ve	Ch	Il	Kao	Qu	Fel	Ox	Carb	Inter-strat	Other
Royalton #2 (RY–2)											
80–81	HISm-1	0	1	2	4	1	KNa-2, NaCa-1	hem-1	0	ChIl-1	0
84.5–85.5	0	0	1	1	5	1	KNa-1, NaCa-1	0	0	0	0
94.5–95.5	0	0	1	1	4	1	0	hem-1	0	0	0
104–105	0	HIV-1	1	1	5	1	0	0	0	0	0
St. Augusta #1 (SA–1)											
52–53	0	2	0	2	3	1	0	ana-2	0	SmCh-2	0
55.5–56	1	1	0	1	4	1	1	gib-2, ana-1	0	0	0
57–57.5	0	0	1	1	5	1	0	gib-2, goe-1, ana-1	0	0	talc/ pyr-1
58.5–59	0	0	1	0	4	1	0	ana-1, goe-1, gib-2	sid-1	0	amph-1
63–64	0	0	0	0	4	1	0	goe-1, ana-1	sid-1	0	amph-1
67–68	1	0	0	1	4	1	0	goe-1, ana-1	sid-1	ChIl-1	talc/ pyr-1
75–76	0	0	1	1	4	1	0	goe-1, ana-1	0	ChIl-1	talc/ pyr-1
82–83	0	0	1	1	5	1	0	goe-1, hem-1	sid-1	ChIl-1	talc/ pyr-1
87–88	0	0	1	1	5	1	Ca-1	goe-1	sid-1	0	talc/ pyr-1
95–96	0	0	1	2	4	1	Ca-1	goe-1, ana-1	0	ChIl-1	talc/ pyr-1
109–110	1	1	1	1	4	1	1	goe-1, ana-1	0	SmKao-1	0
115–116	0	1	2	3	1	1	NaCa-2	0	0	ChVe-2	0
119–120	0	0	1	2	2	1	NaCa-3, KNa-2	0	0	VeIl-1	0
St. Joseph #1 (SJ–1)											
32–33	0	HIV-1	0	1	5	0	NaCa-1	goe-1	0	0	amph-1
41–42	0	HIV-1	0	0	5	1	0	goe-1	0	0	amph-1
55–56	0	HIV-1	1	1	5	1	1	goe-1	0	0	amph-1
72–73	0	HIV-1	1	1	5	1	NaCa-1	goe-1	0	ChIl-1	0
73–74	1	HIV-1	0	1	4	1	KNa-1, NaCa-1	goe-1	0	SmKao-1	amph-1
82–83	0	HIV-1	0	1	5	1	NaCa-1, KNa-1	0	0	0	amph-1
116–117	2	0	1	1	4	1	KNa-1, NaCa-1	goe-1	0	SmKao-1	HISm-1
135–136	1	2	0	2	2	1	KNa-2, NaCa-2	0	0	SmKao-1	HISm-1
156–157	2	3	1	2	1	1	KNa-2, NaCa-2	goe-1	0	0	amph-1

APPENDIX E

CHEMICAL ANALYSES

[The trace-element constituents and detection limits are measured in parts per million (ppm); the whole-rock major elements (WRMAJ) and whole-rock minor elements (WRMIN) are in percent (%), as are their detection limits. 0, the result was below the detection limit; n.a., not available. Results missing from the MnO % column are reported in the Mn ppm column, and the converse. Mol prop, molecular proportions used in the calculation of CIA values. The analyses were performed by X-ray Assay Laboratories (XRAL) of Don Mills, Ontario, Canada.]

Constituent	Method of Analysis	Detection Limit
Ag	direct current plasma spectrometry	0.5
As	flameless atomic absorption spectrophotometry	1
Au	fire assay with direct current plasma emiss. spec.	1
B	direct current plasma emission spectrometry	10
Be	direct current plasma emission spectrometry	5
Bi	inductively coupled plasma mass spectrometry	0.5
Cd	direct current plasma emission spectrometry	1
Ce	inductively coupled plasma mass spectrometry	1
Co	inductively coupled plasma spectrophotometry	1
Cr	direct current plasma emission spectrometry	2
Cs	neutron activation analysis	1
Cu	direct current plasma emission spectrometry	0.5
Dy	inductively coupled plasma mass spectrometry	0.5
Er	inductively coupled plasma mass spectrometry	0.5
Eu	inductively coupled plasma mass spectrometry	0.1
Ga	inductively coupled plasma spectrophotometry	1
Gd	inductively coupled plasma mass spectrometry	0.5
Ge	direct current plasma emission spectrometry	10
Hf	neutron activation analysis	1
In	inductively coupled plasma spectrophotometry	1
La	inductively coupled plasma mass spectrometry	2
Li	atomic absorption spectrophotometry	10
Lu	inductively coupled plasma mass spectrometry	0.1
Mn	direct current plasma emission spectrometry	2
Mo	inductively coupled plasma spectrophotometry	2
Nd	inductively coupled plasma mass spectrometry	0.5
Ni	direct current plasma emission spectrometry	1
Pb	direct current plasma emission spectrometry	2
S	x-ray fluorescence spectrometry	100
Sb	flameless atomic absorption spectrophotometry	0.2
Se	graphite furnace atomic absorption spectrophoto.	3
Sm	inductively coupled plasma mass spectrometry	0.5
Sn	x-ray fluorescence spectrometry	10
Ta	neutron activation analysis	1
Th	neutron activation analysis	1
Tl	inductively coupled plasma mass spectrometry	1
U	neutron activation analysis	0.5
V	direct current plasma emission spectrometry	10
W	neutron activation analysis	3
WRMAJ	x-ray fluorescence spectrometry	0.01
WRMIN	x-ray fluorescence spectrometry	10
Zn	direct current plasma emission spectrometry	0.5

Southwestern Minnesota

sample ident.	lithology	sample depth	sample elev.	clay fraction %	CIA	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 tot %	MnO %	MgO %
MNE-1-163	shale	163.0	842	79	98.6	45.1	0.94	34.7	3.84		0.14
MNE-1-181	sandstone	181.0	824	19	94.9	88.6	0.15	6.2	0.88		0.06
MNE-1-194	shale	194.0	811	88	97.2	43.0	0.97	32.2	9.05		0.27
MNE-1-206	sandstone	206.0	799	8	74.9	90.0	1.24	3.5	1.11		0.07
MNE-1-214	grus	214.0	791	23	63.0	69.5	0.22	14.5	3.39		0.46
MNE-1-242	weath. gneiss	242.0	763	5	55.4	72.4	0.24	15.0	1.54		0.33
MNE-1-256	granitic gneiss	256.0	749	2	53.0	73.5	0.35	13.7	1.78		0.39
MNE-2-84.3	shale	84.3	891	51	95.5	59.6	0.16	25.6	3.16	0.10	0.14
MNE-2-94.5	saprolith	94.5	880	46	96.9	55.1	0.47	24.4	6.59		0.27
MNE-2-124	saprolith	124.0	851	31	94.8	66.0	0.43	19.7	3.70		0.20
MNE-2-136	saprolith	136.0	839	33	95.0	63.5	0.42	21.1	3.79		0.22
MNE-2-170	saprolith	170.0	805	36	98.4	69.2	0.35	20.2	1.96		0.10
MNE-2-182.5	saprolith	182.5	792	45	98.2	70.3	0.21	20.6	0.77		0.07
MNE-2-186	saprolith	186.0	789	42	98.5	67.6	0.24	21.6	1.47		0.10
MNE-2-201.5	saprolith	201.5	773	44	98.1	67.7	0.21	21.4	1.49		0.11
MNE-2-213.5	saprolith	213.5	761	44	95.2	67.7	0.19	19.6	2.91		0.27
MNE-2-234	saprolith	234.0	741	32	79.3	71.5	0.14	17.8	0.67		0.13
RF-1-92	saprolith	92.0	928	47	97.9	61.0	0.57	25.1	2.43		0.16
RF-1-110	saprolith	110.0	910	29	97.5	66.1	0.62	21.3	3.10		0.17
RF-1-121	quartz vein	121.0	898	32	97.0	66.7	0.48	21.4	3.06		0.17
RF-1-122	saprolith	122.0	899	32	63.3	97.0	0.08	0.7	0.32		0.04
RF-1-140	saprolith	140.0	880	35	97.1	62.9	0.55	21.3	4.70	0.12	0.26
RF-1-153	saprolith	153.0	867	45	96.7	68.1	0.35	20.5	2.60		0.20
RF-1-167	saprolith	167.0	853	38	90.4	70.0	0.31	18.7	2.23		0.44
RF-1-186.5	weath. gneiss	186.5	833	47	82.6	68.8	0.41	17.3	3.39	0.09	0.53
RF-1-219	weath. gneiss	219.0	801	24	65.4	67.9	0.50	16.9	3.45		0.90
RF-2A-124	saprolith	124.0	886	47	96.9	64.3	0.57	21.8	3.36		0.20
RF-2A-151	saprolith	151.0	859	40	82.5	65.1	0.60	18.4	3.95		0.61
RF-2A-158	saprolith	158.0	852	33	87.0	65.8	0.49	18.9	4.33		0.83
RF-2A-189.5	grus	189.5	820	n.a.	70.5	69.7	0.26	15.6	2.92		0.48
RF-2A-229	granod. gneiss	229.0	781	24	60.5	74.1	0.12	13.9	0.71		0.17
RF-2A-261	granod. gneiss	261.0	749	13	53.1	74.6	0.21	13.7	1.28		0.46
RF-3-155	grus	155.0	848	13	60.9	71.0	0.15	15.0	2.48	0.12	0.71
RF-3-159.5	grus	159.5	843	6	55.5	72.4	0.08	15.0	1.33		0.53
RF-3-192	granod. gneiss	192.0	811	5	51.1	73.5	0.10	14.0	1.05		0.34

Southwestern Minnesota continued

sample ident.	CaO %	Na2O %	K2O %	P2O5 %	LOI %	Sum.	H2O+ %	H2O- %	CO2 %	Cl ppm	FeO %
MNE-1-163	0.17	0.06	0.07	0.03	14.20	99.3	12.4	0.0	1.95	0	2.6
MNE-1-181	0.10	0.06	0.05	0.03	3.31	99.5	2.2	0.0	0.42	0	0.4
MNE-1-194	0.26	0.09	0.28	0.06	12.90	99.2	11.8	0.0	0.78	0	1.4
MNE-1-206	0.19	0.05	0.69	0.23	1.54	98.9	1.2	0.0	0.03	100	0.3
MNE-1-214	0.28	0.99	5.90	0.07	3.77	99.2	2.4	0.0	1.26	0	2.0
MNE-1-242	0.51	3.16	5.50	0.08	1.54	100.4	1.3	0.0	0.32	50	0.5
MNE-1-256	0.52	3.68	4.77	0.10	0.93	99.9	1.0	0.0	0.06	50	0.6
MNE-2-84.3	0.15	0.32	0.38	0.02	10.20	99.9	9.0	0.0	1.23	0	1.9
MNE-2-94.5	0.20	0.19	0.09	0.02	12.00	99.4	8.8	0.0	3.47	0	5.3
MNE-2-124	0.20	0.37	0.10	0.04	8.70	99.5	7.2	0.0	1.64	0	3.3
MNE-2-136	0.20	0.30	0.23	0.05	9.16	99.0	7.6	0.0	1.52	0	3.0
MNE-2-170	0.12	0.02	0.08	0.02	7.93	100.0	7.3	0.0	0.29	0	0.8
MNE-2-182.5	0.13	0.03	0.08	0.02	7.77	100.0	7.4	0.0	0.10	0	0.2
MNE-2-186	0.12	0.03	0.06	0.02	8.16	99.4	7.8	0.0	0.54	0	0.6
MNE-2-201.5	0.12	0.05	0.11	0.03	8.31	99.6	7.7	0.0	0.19	0	0.4
MNE-2-213.5	0.20	0.00	0.57	0.03	7.62	99.1	6.9	0.0	0.98	50	1.8
MNE-2-234	0.11	0.10	3.95	0.02	4.85	99.4	4.7	0.0	0.06	0	0.2
RF-1-92	0.22	0.00	0.13	0.04	9.70	99.4	8.9	0.3	0.50	50	1.4
RF-1-110	0.22	0.02	0.10	0.02	8.31	100.0	7.7	0.3	0.11	50	1.6
RF-1-121	0.23	0.06	0.13	0.05	8.00	100.4	7.6	0.3	0.14	50	1.9
RF-1-122	0.20	0.02	0.03	0.02	0.85	99.3	n.a.	n.a.	n.a.	50	0.1
RF-1-140	0.27	0.04	0.08	0.06	9.31	99.6	7.7	0.3	1.41	50	3.0
RF-1-153	0.24	0.02	0.22	0.03	7.77	100.1	7.2	0.3	0.35	50	1.3
RF-1-167	0.21	0.03	1.43	0.03	6.47	100.0	6.1	0.2	0.38	150	1.1
RF-1-186.5	0.24	0.09	2.82	0.05	5.93	99.8	5.0	0.2	0.67	150	1.8
RF-1-219	0.68	2.45	3.38	0.03	3.77	100.2	3.5	0.5	0.02	50	1.5
RF-2A-124	0.20	0.03	0.26	0.02	8.39	99.2	7.9	0.0	0.40	0	1.8
RF-2A-151	0.16	0.09	3.20	0.04	6.85	99.2	5.7	0.0	0.87	0	2.4
RF-2A-158	0.14	0.07	2.27	0.03	6.77	99.7	6.4	0.0	0.67	100	2.8
RF-2A-189.5	0.16	0.22	5.44	0.02	4.54	99.6	3.6	0.0	0.89	50	2.1
RF-2A-229	0.09	0.58	7.34	0.02	2.54	99.8	2.1	0.0	0.10	0	0.1
RF-2A-261	1.22	3.07	4.48	0.07	0.93	100.2	0.9	0.0	0.03	100	0.4
RF-3-155	0.99	2.41	3.59	0.03	3.08	99.7	2.6	0.0	0.60	150	1.4
RF-3-159.5	0.75	3.32	4.79	0.02	1.85	100.2	1.0	0.2	0.09	0	0.4
RF-3-192	1.43	3.67	4.39	0.04	0.93	99.6	0.3	0.1	0.08	0	0.4

Southwestern Minnesota continued

sample ident.	U ppm	Th ppm	Au ppb	Li ppm	Be ppm	B ppm	S ppm	V ppm	Cr ppm	Mn ppm	Co ppm
MNE-1-163	3.4	26	42	40	0	50	160	110	97	120	17
MNE-1-181	1.1	8	3	0	0	20	340	30	47	60	2
MNE-1-194	5.0	35	21	0	0	50	140	150	162	200	17
MNE-1-206	20.5	440	11	0	0	30	300	90	128	330	27
MNE-1-214	1.8	19	65	0	0	20	160	30	21	180	5
MNE-1-242	2.3	17	21	0	0	30	120	20	24	100	5
MNE-1-256	2.7	18	9	0	0	20	240	30	30	58	5
MNE-2-84.3	1.1	31	2	0	0	50	180	20	42		5
MNE-2-94.5	1.5	45	0	0	0	40	160	40	54	350	3
MNE-2-124	2.2	42	17	0	0	40	100	30	42	480	3
MNE-2-136	2.7	51	23	0	0	40	120	30	40	430	3
MNE-2-170	2.2	7	25	0	0	30	120	20	31	250	3
MNE-2-182.5	1.9	5	14	0	0	40	0	20	34	86	5
MNE-2-186	2.0	9	6	0	0	40	0	20	31	360	4
MNE-2-201.5	2.7	40	9	0	0	30	100	20	35	66	3
MNE-2-213.5	1.9	22	3	0	0	40	100	20	47	360	5
MNE-2-234	1.4	7	3	0	0	30	100	10	29	42	4
RF-1-92	2.7	15	0	0	0	20	100	20	10	160	23
RF-1-110	3.3	29	0	0	0	30	200	30	4	80	1
RF-1-121	4.8	100	0	0	0	30	200	40	14	92	12
RF-1-122	n.a.	n.a.	0	0	0	20	0	0	6	100	n.a.
RF-1-140	4.8	13	0	0	0	20	100	30	4		9
RF-1-153	2.0	36	0	0	0	20	100	20	8	180	3
RF-1-167	2.3	35	0	0	0	20	200	10	4	190	10
RF-1-186.5	4.0	76	0	0	5	30	100	30	4		6
RF-1-219	7.2	17	0	0	5	60	100	30	14	130	8
RF-2A-124	11.8	30	2	0	0	60	120	50	22	260	5
RF-2A-151	9.7	20	0	20	0	40	120	40	10	360	12
RF-2A-158	7.3	16	0	0	0	40	100	50	20	180	16
RF-2A-189.5	2.7	8	0	0	0	40	0	30	10	470	8
RF-2A-229	4.1	59	10	0	0	30	120	20	8	74	5
RF-2A-261	3.3	12	1	0	0	30	0	30	8	98	6
RF-3-155	1.9	10	0	0	0	40	240	20	30		11
RF-3-159.5	2.3	14	0	0	0	50	0	20	20	150	5
RF-3-192	2.3	12	0	0	0	40	0	10	34	110	5

Southwestern Minnesota continued

sample ident.	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Ge ppm	As ppm	Se ppm	Mo ppm	Ag ppm	Cd ppm	In ppm
MNE-1-163	30	16.0	15.0	41	0	2	0	5	0.0	0	0
MNE-1-181	5	5.0	8.0	8	0	1	0	0	0.0	0	0
MNE-1-194	43	27.0	38.0	47	0	4	0	0	0.0	0	1
MNE-1-206	37	30.0	110.0	12	0	19	0	0	0.0	0	0
MNE-1-214	6	5.5	47.0	19	0	1	0	0	0.0	0	0
MNE-1-242	6	4.5	32.0	19	0	2	0	0	0.0	0	0
MNE-1-256	5	3.0	29.0	19	0	3	0	0	0.0	0	0
MNE-2-84.3	6	6.0	22.0	29	0	3	0	0	0.0	0	0
MNE-2-94.5	6	5.0	20.0	33	0	0	0	0	0.0	0	0
MNE-2-124	8	5.5	26.0	26	0	3	0	0	0.0	0	0
MNE-2-136	7	14.0	26.0	28	0	5	0	0	0.0	0	0
MNE-2-170	9	5.0	29.0	27	0	1	0	0	0.0	0	1
MNE-2-182.5	5	5.0	21.0	26	0	1	0	0	0.0	0	0
MNE-2-186	7	8.0	29.0	29	0	2	0	0	0.0	0	0
MNE-2-201.5	9	6.0	26.0	27	0	3	0	0	0.0	0	0
MNE-2-213.5	21	11.0	98.0	25	0	2	0	0	0.0	0	0
MNE-2-234	8	4.0	39.0	23	0	1	0	0	0.0	0	0
RF-1-92	16	20.0	51.0	30	0	1	0	0	0.0	0	1
RF-1-110	9	11.0	28.0	29	0	0	0	0	0.0	0	0
RF-1-121	14	13.0	19.0	29	0	2	0	0	0.0	0	0
RF-1-122	2	2.0	2.5	n.a.	0	1	n.a.	n.a.	0.0	0	n.a.
RF-1-140	12	13.0	27.0	30	0	0	0	0	0.0	0	0
RF-1-153	6	12.0	24.0	26	0	2	0	0	0.0	0	0
RF-1-167	7	11.0	160.0	22	0	1	0	0	0.0	0	0
RF-1-186.5	8	10.0	100.0	24	0	0	0	0	0.0	0	0
RF-1-219	15	13.0	130.0	18	0	0	0	0	0.0	0	0
RF-2A-124	16	9.0	44.0	26	0	1	0	0	0.0	0	0
RF-2A-151	16	10.0	91.0	26	0	0	0	0	0.0	0	0
RF-2A-158	17	15.0	48.0	29	0	1	0	0	0.0	0	0
RF-2A-189.5	14	8.5	90.0	17	0	1	0	0	0.0	0	0
RF-2A-229	6	10.0	32.0	17	0	0	0	0	0.0	0	0
RF-2A-261	7	3.5	44.0	15	10	1	0	0	0.0	0	0
RF-3-155	33	15.0	63.0	20	0	1	0	0	0.0	0	0
RF-3-159.5	29	13.0	35.0	18	10	1	0	0	0.0	0	0
RF-3-192	13	26.0	27.0	17	0	1	0	0	0.0	0	0

Southwestern Minnesota continued

sample ident	Sn ppm	Sb ppm	Cs ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Dy ppm	Er ppm
MNE-1-163	11	0.4	1	47	104	35.8	5.9	0.9	4.2	3.4	1.9
MNE-1-181	0	0.3	0	38	130	22.0	3.0	0.5	2.1	1.8	1.0
MNE-1-194	0	0.2	1	35	429	30.0	4.9	1.3	5.1	4.7	2.5
MNE-1-206	0	0.4	0	1220	2200	764.0	85.6	2.1	59.2	23.5	6.6
MNE-1-214	17	0.0	1	41	71	22.4	2.7	0.9	2.0	0.9	0.5
MNE-1-242	0	0.0	0	43	69	22.5	2.6	1.0	1.9	0.7	0.0
MNE-1-256	0	0.0	0	58	94	29.9	3.8	0.9	2.1	1.5	0.7
MNE-2-84.3	0	0.0	0	19	63	9.5	1.4	0.3	1.0	1.0	0.5
MNE-2-94.5	18	0.0	0	10	55	8.6	1.5	0.2	1.4	1.3	0.6
MNE-2-124	0	0.0	0	35	95	27.5	4.4	0.4	2.8	1.6	0.6
MNE-2-136	0	0.0	0	67	157	50.0	7.3	0.9	4.7	2.6	1.0
MNE-2-170	10	0.0	0	21	38	12.5	1.9	0.6	1.8	1.2	0.7
MNE-2-182.	0	0.0	0	27	40	14.8	2.4	0.6	2.4	1.3	0.6
MNE-2-186	0	0.0	0	25	41	14.3	2.4	0.6	2.4	1.6	0.8
MNE-2-201.	0	0.0	0	40	62	25.4	3.1	0.5	2.1	1.4	0.6
MNE-2-213.	0	0.0	4	43	59	27.6	3.6	0.5	2.3	1.5	0.5
MNE-2-234	0	0.0	1	26	25	13.6	1.9	0.9	1.3	0.8	0.0
RF-1-92	0	0.0	0	172	315	76.1	8.7	1.5	6.0	3.0	1.3
RF-1-110	0	0.0	0	11	41	7.0	1.0	0.2	0.8	0.8	0.0
RF-1-121	0	0.0	0	312	143	150.0	11.5	1.0	4.2	2.0	0.8
RF-1-122	16	0.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RF-1-140	0	0.0	0	27	930	20.2	3.6	0.7	2.6	1.9	0.8
RF-1-153	0	0.0	0	96	152	52.1	5.7	0.9	2.9	1.6	0.7
RF-1-167	0	0.2	4	209	146	111.0	11.3	2.0	5.5	2.9	1.4
RF-1-186.5	0	0.0	1	362	730	189.0	18.7	2.8	9.8	6.3	2.7
RF-1-219	0	0.0	1	95	156	45.3	5.1	1.0	4.1	3.2	1.9
RF-2A-124	12	0.0	0	18	58	15.3	2.3	0.5	2.0	2.6	1.5
RF-2A-151	0	0.0	3	237	236	141.0	18.2	3.7	13.0	7.7	3.7
RF-2A-158	0	0.0	5	178	148	111.0	15.3	3.0	11.0	6.8	3.0
RF-2A-189.5	0	0.0	1	48	52	22.8	3.0	0.8	2.8	1.8	1.0
RF-2A-229	0	0.0	2	26	66	16.8	2.4	0.7	1.5	1.3	0.7
RF-2A-261	0	0.0	2	38	74	20.6	2.4	0.7	1.9	1.3	0.7
RF-3-155	0	0.0	1	49	80	24.7	2.9	0.8	2.2	1.8	0.9
RF-3-159.5	0	0.0	1	16	27	8.8	1.3	0.7	1.1	0.9	0.6
RF-3-192	0	0.0	1	9	19	8.9	1.8	0.6	1.6	1.4	0.8

Southwestern Minnesota continued

sample ident.	Lu ppm	Hf ppm	Ta ppm	W ppm	Tl ppm	Pb ppm	Bi ppm	Cr ppm	Rb ppm	Sr ppm	Y ppm
MNE-1-163	0.1	11	2	0	0	10	0.6	97	11	0	29
MNE-1-181	0.1	2	0	0	0	12	0.0	47	16	0	0
MNE-1-194	0.3	8	1	0	0	24	0.0	162	34	0	34
MNE-1-206	0.4	45	0	7	0	84	0.0	128	18	0	169
MNE-1-214	0.0	5	0	0	1	10	0.0	21	216	55	0
MNE-1-242	0.0	3	0	0	1	6	0.0	24	191	157	0
MNE-1-256	0.0	6	0	0	0	8	0.0	30	201	160	0
MNE-2-84.3	0.0	6	0	0	0	12	0.0	42	46	0	0
MNE-2-94.5	0.1	9	0	0	0	16	0.0	54	12	0	14
MNE-2-124	0.1	8	0	0	0	26	0.0	42	20	0	0
MNE-2-136	0.1	9	0	0	0	26	0.0	40	33	0	19
MNE-2-170	0.0	7	0	0	0	46	0.0	31	11	0	0
MNE-2-182.5	0.0	6	0	0	0	44	0.0	34	24	0	12
MNE-2-186	0.0	5	0	0	0	54	0.0	31	0	0	0
MNE-2-201.5	0.0	5	0	0	0	36	0.0	35	0	0	0
MNE-2-213.5	0.0	4	0	8	1	20	0.0	47	111	0	14
MNE-2-234	0.0	3	0	0	1	22	0.0	29	135	67	0
RF-1-92	0.1	8	0	0	0	28	0.0	10	18	0	35
RF-1-110	0.0	8	0	0	0	40	0.0	4	18	0	0
RF-1-121	0.0	12	0	0	0	38	0.0	14	0	0	17
RF-1-122	n.a.	n.a.	n.a.	n.a.	n.a.	4	n.a.	6	0	0	0
RF-1-140	0.0	8	1	0	0	48	0.0	4	13	0	0
RF-1-153	0.0	8	0	0	0	20	0.0	8	32	0	0
RF-1-167	0.1	11	0	0	1	16	0.0	4	162	38	0
RF-1-186.5	0.2	7	0	0	1	34	0.0	4	216	47	36
RF-1-219	0.2	6	0	0	1	24	0.0	14	257	251	34
RF-2A-124	0.3	8	1	0	0	36	0.0	49	23	0	0
RF-2A-151	0.4	8	0	0	2	22	0.0	30	161	39	29
RF-2A-158	0.3	6	0	0	2	36	0.0	44	187	20	25
RF-2A-189.5	0.1	3	0	0	1	14	0.0	30	199	129	18
RF-2A-229	0.1	7	0	0	2	14	0.0	21	238	109	0
RF-2A-261	0.0	4	0	0	1	16	0.0	26	171	358	0
RF-3-155	0.1	5	0	0	0	16	0.0	55	119	172	0
RF-3-159.5	0.0	4	0	0	0	200	0.0	20	142	199	0
RF-3-192	0.0	3	1	0	0	16	0.0	34	114	280	16

Southwestern Minnesota continued

sample ident.	Zr ppm	Nb ppm	Ba ppm	Al2O3 mol pro	CaO mol prop.	Na2O mol prop	K2O mol prop.
MNE-1-163	414	30	74	0.340	0.003	0.001	0.001
MNE-1-181	55	11	70	0.061	0.002	0.001	0.001
MNE-1-194	303	32	126	0.316	0.005	0.001	0.003
MNE-1-206	1730	0	147	0.034	0.003	0.001	0.007
MNE-1-214	145	0	725	0.142	0.005	0.016	0.063
MNE-1-242	128	15	742	0.147	0.009	0.051	0.058
MNE-1-256	200	17	622	0.134	0.009	0.059	0.051
MNE-2-84.3	186	0	94	0.251	0.003	0.005	0.004
MNE-2-94.5	273	0	101	0.239	0.004	0.003	0.001
MNE-2-124	257	0	43	0.193	0.004	0.006	0.001
MNE-2-136	329	0	66	0.207	0.004	0.005	0.002
MNE-2-170	210	17	47	0.198	0.002	0.000	0.001
MNE-2-182.	160	16	84	0.202	0.002	0.000	0.001
MNE-2-186	151	14	71	0.212	0.002	0.000	0.001
MNE-2-201.	157	0	64	0.210	0.002	0.001	0.001
MNE-2-213.	118	0	116	0.192	0.004	0.000	0.006
MNE-2-234	97	0	525	0.175	0.002	0.002	0.042
RF-1-92	314	0	109	0.246	0.004	0.000	0.001
RF-1-110	290	30	93	0.209	0.004	0.000	0.001
RF-1-121	421	0	106	0.210	0.004	0.001	0.001
RF-1-122	30	0	54	0.007	0.004	0.000	0.000
RF-1-140	272	0	102	0.209	0.005	0.001	0.001
RF-1-153	262	23	89	0.201	0.004	0.000	0.002
RF-1-167	427	0	367	0.183	0.004	0.000	0.015
RF-1-186.5	327	0	680	0.170	0.004	0.001	0.030
RF-1-219	242	0	986	0.166	0.012	0.040	0.036
RF-2A-124	262	14	72	0.214	0.004	0.000	0.003
RF-2A-151	371	14	749	0.180	0.003	0.001	0.034
RF-2A-158	248	29	420	0.185	0.002	0.001	0.024
RF-2A-189.5	114	0	1510	0.153	0.003	0.004	0.058
RF-2A-229	164	0	1310	0.136	0.002	0.009	0.078
RF-2A-261	91	0	1250	0.134	0.022	0.050	0.048
RF-3-155	152	13	659	0.147	0.018	0.039	0.038
RF-3-159.5	137	19	926	0.147	0.013	0.054	0.051
RF-3-192	72	0	882	0.137	0.025	0.059	0.047

East-central Minnesota

sample ident.	lithology	sample depth	sample elev.	clay fraction %	CIA	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 tot %	MnO %	MgO %
CS-1-70	saprolith	70.0	1041	40	81.2	51.2	1.56	23.1	9.16	0.15	1.07
CS-1-79	saprolith	79.0	1032	20	64.7	68.6	0.42	15.7	2.74		0.41
CS-1-88.5	saprolith	88.5	1022	n.a.	68.6	59.1	0.89	18.6	7.44	0.10	0.98
CS-1-106	saprolith	106.0	1005	16	59.8	61.0	0.86	15.9	7.64	0.08	1.19
CS-1-111	weath.granod.	111.0	1000	9	53.7	62.3	1.04	16.3	6.29		1.03
SJ-1-32	saprolith	32.0	1034	50	79.2	37.7	0.74	17.0	22.50	0.63	1.15
SJ-1-41	saprolith	41.0	1025	50	91.9	48.0	0.81	22.6	13.50	0.19	0.76
SJ-1-55	saprolith	55.0	1011	54	91.4	49.0	0.80	19.6	14.80	0.24	1.05
SJ-1-72	saprolith	72.0	994	40	96.5	42.1	2.07	29.5	11.50	0.13	0.60
SJ-1-73	saprolith	73.0	993	91	76.6	48.6	0.69	15.7	17.30	0.37	1.27
SJ-1-82	saprolith	82.0	984	58	76.2	56.3	0.65	17.3	10.40	0.17	1.07
SJ-1-116	grus	116.0	950	22	58.1	63.1	0.62	17.3	5.12		0.73
SJ-1-135	weath. granite	135.0	931	13	54.1	65.3	0.56	15.7	4.75		0.68
SJ-1-156	qtz monzonite	156.0	910	2	50.7	66.7	0.54	15.7	4.21		0.69
SA-1-52	shale	52.0	955	95	78.9	73.7	1.26	12.6	2.75		0.81
SA-1-55.8	shale	55.8	951	88	81.9	24.1	0.80	17.3	0.96		0.56
SA-1-57	bauxite	57.0	950	20	97.7	55.1	0.59	27.9	2.41		0.18
SA-1-58.5	bauxite	58.5	948	16	96.9	32.1	1.02	33.4	13.80	0.15	0.42
SA-1-63	saprolith	63.0	944	19	96.6	39.6	1.08	23.7	19.70	0.12	0.50
SA-1-67	saprolith	67.0	940	45	95.5	54.0	0.79	19.8	10.90	0.15	0.38
SA-1-75	saprolith	75.0	932	41	96.3	55.5	1.00	25.7	6.13		0.39
SA-1-82	saprolith	82.0	925	39	82.7	44.5	0.72	16.4	19.00	0.20	1.47
SA-1-87	saprolith	87.0	920	40	74.0	44.2	0.68	15.4	19.00	0.72	1.55
SA-1-95	saprolith	95.0	912	32	75.2	61.7	0.78	20.4	4.13		1.07
SA-1-109	saprolith	109.0	898	32	67.4	63.0	0.71	17.3	4.84		1.44
SA-1-115	weath qtz monz	115.0	892	6	47.4	65.4	0.57	14.6	3.17		1.14
SA-1-119	quartz monzon	119.0	888	1	47.4	63.0	0.61	15.1	4.48	0.09	2.17
RY-1-43.3	shale	43.3	1007	n.a.	78.3	78.5	1.29	10.0	1.89		0.49
RY-1-46	saprolith	46.0	1005	16	83.5	57.0	0.94	19.1	10.30	0.11	2.61
RY-1-72	saprolith	72.0	979	14	78.4	56.4	0.96	18.9	9.72		3.20
RY-1-92.5	saprolith	92.5	958	16	79.7	57.9	0.96	19.0	9.57		3.12
RY-1-139.5	biotite schist	139.5	911	9	69.7	59.6	0.89	18.1	8.83		3.34
RY-2-80	shale	80.0	1057	n.a.	78.3	73.7	1.38	11.0	3.16	0.09	0.69
RY-2-84.5	saprolith	84.5	1053	57	95.6	39.5	1.11	21.5	20.10	0.14	0.35
RY-2-94.5	saprolith	94.5	1043	31	78.8	52.3	0.61	10.7	19.70	0.47	1.03
RY-2-104	weath. schist	104.0	1034	22	85.3	61.9	0.94	18.1	7.33		2.12

East-central Minnesota continued

sample ident.	CaO %	Na_2O %	K_2O %	P_2O_5 %	LOI %	Sum.	H_2O+ %	H_2O- %	CO_2 %	Cl ppm	FeO %
CS-1-70	0.38	0.15	4.09	0.08	8.93	100.2	7.3	0.3	1.63	150	5.5
CS-1-79	0.26	0.24	7.12	0.03	3.31	99.1	2.8	0.1	0.60	150	1.8
CS-1-88.5	0.41	0.40	6.56	0.05	5.77	100.6	4.2	0.2	1.67	200	5.1
CS-1-106	1.16	1.85	5.10	0.20	5.23	100.5	3.2	0.4	2.33	100	5.0
CS-1-111	1.98	3.58	4.20	0.38	2.39	99.8	2.2	0.4	0.36	100	3.6
SJ-1-32	2.38	0.01	0.12	0.87	17.50	100.7	6.2	0.2	12.80	50	18.1
SJ-1-41	0.98	0.04	0.14	0.23	13.00	100.4	8.4	0.4	5.09	50	9.6
SJ-1-55	0.85	0.03	0.23	0.07	13.80	100.6	7.1	0.3	7.50	50	11.1
SJ-1-72	0.40	0.05	0.25	0.07	12.90	99.7	11.3	0.6	1.27	50	5.9
SJ-1-73	1.12	0.11	2.39	0.10	12.20	100.0	5.1	0.2	8.49	50	13.0
SJ-1-82	0.61	0.10	3.81	0.07	9.08	99.8	5.0	0.2	4.52	50	7.3
SJ-1-116	1.26	2.40	5.77	0.16	3.23	100.1	2.7	0.2	0.54	100	2.7
SJ-1-135	1.47	3.04	5.24	0.15	2.39	99.6	1.9	0.2	0.55	100	2.4
SJ-1-156	1.90	3.71	5.25	0.15	1.08	100.3	0.9	0.1	0.28	100	2.5
SA-1-52	0.40	0.26	2.04	0.06	5.54	99.5	3.4	0.6	0.01	0	1.1
SA-1-55.8	1.62	0.24	0.44	0.04	54.60	100.7	n.a.	n.a.	0.08	100	n.a.
SA-1-57	0.29	0.04	0.05	0.03	13.00	99.7	9.5	0.8	0.02	0	0.6
SA-1-58.5	0.48	0.07	0.07	0.11	18.70	100.5	11.3	1.5	5.28	0	9.4
SA-1-63	0.38	0.07	0.03	0.04	14.10	99.4	8.5	0.6	5.03	0	15.7
SA-1-67	0.48	0.02	0.02	0.04	12.50	99.2	7.0	0.4	5.12	0	8.7
SA-1-75	0.33	0.00	0.36	0.07	10.80	100.4	8.4	0.5	0.84	0	2.9
SA-1-82	1.18	0.02	1.16	0.17	14.90	99.8	5.1	0.2	10.20	0	14.8
SA-1-87	1.26	0.05	2.81	0.33	14.20	100.3	n.a.	n.a.	10.60	0	n.a.
SA-1-95	0.36	0.15	5.37	0.22	5.93	100.5	5.0	0.3	0.18	0	1.9
SA-1-109	0.61	0.85	5.43	0.21	4.85	99.5	3.6	0.3	0.34	0	2.3
SA-1-115	3.57	3.30	3.93	0.23	4.16	100.3	1.1	0.1	2.40	0	1.5
SA-1-119	3.77	3.57	3.72	0.24	3.23	100.2	1.1	0.0	1.90	0	2.7
RY-1-43.3	0.41	0.23	1.52	0.04	4.00	98.5	1.9	0.2	0.28	0	0.5
RY-1-46	0.30	0.14	2.78	0.04	7.00	100.4	5.1	0.3	1.40	0	6.4
RY-1-72	0.87	0.08	3.22	0.42	5.62	99.5	4.2	0.3	0.38	0	5.5
RY-1-92.5	0.47	0.06	3.58	0.18	5.08	100.0	3.9	0.4	0.14	0	5.3
RY-1-139.5	1.29	1.23	3.23	0.17	3.47	100.3	1.9	0.6	0.10	0	5.8
RY-2-80	0.46	0.11	1.87	0.04	6.39	99.0	2.8	0.5	0.66	0	1.7
RY-2-84.5	0.44	0.02	0.15	0.04	17.10	100.5	6.8	0.3	10.50	0	16.0
RY-2-94.5	1.00	0.31	0.51	0.19	13.60	100.5	3.4	0.1	10.90	100	15.7
RY-2-104	0.24	0.04	2.41	0.05	6.31	99.6	5.4	0.2	0.28	0	4.1

East-central Minnesota continued

sample ident.	U ppm	Th ppm	Au ppb	Li ppm	Be ppm	B ppm	S ppm	V ppm	Cr ppm	Mn ppm	Co ppm
CS-1-70	n.a.	n.a.	0	0	5	30	100	60	26		16
CS-1-79	1.1	2	0	0	0	20	100	20	12	280	7
CS-1-88.5	2.3	8	0	0	5	20	300	40	22		23
CS-1-106	1.9	3	0	0	0	30	0	40	16		12
CS-1-111	1.1	2	0	0	0	30	100	50	12	380	12
SJ-1-32	4.1	11	2	0	5	50	200	70	14		18
SJ-1-41	5.9	14	1	0	0	30	100	70	8		15
SJ-1-55	3.6	13	1	0	0	30	100	50	10		19
SJ-1-72	6.0	3	5	0	0	40	300	160	130		32
SJ-1-73	8.0	7	0	0	5	30	100	60	18		16
SJ-1-82	2.8	8	0	0	0	30	0	50	22		19
SJ-1-116	3.6	12	0	0	0	20	100	30	22	290	15
SJ-1-135	4.7	12	0	0	0	20	100	30	18	360	15
SJ-1-156	3.7	7	2	0	0	20	100	40	18	480	13
SA-1-52	4.1	13	0	0	0	140	100	100	98	190	17
SA-1-55.8	n.a.	n.a.	0	0	0	290	7400	150	64	26	7
SA-1-57	3.9	32	0	20	0	90	8200	120	110	22	5
SA-1-58.5	7.2	45	0	20	0	110	500	210	100		3
SA-1-63	5.4	32	0	30	5	60	200	300	110		5
SA-1-67	4.2	24	0	0	0	70	100	220	76		9
SA-1-75	7.1	21	0	0	5	40	0	160	66	150	11
SA-1-82	7.9	14	0	0	10	50	100	250	52		23
SA-1-87	11.5	13	0	0	10	30	0	240	66		25
SA-1-95	6.3	11	0	0	5	60	200	120	50	390	19
SA-1-109	6.7	17	0	0	5	70	100	80	68	300	16
SA-1-115	3.9	16	0	0	0	40	100	70	62	380	12
SA-1-119	3.6	15	0	0	0	30	0	80	40		13
RY-1-43.3	4.0	11	0	0	0	130	100	70	52	240	13
RY-1-46	3.1	7	3	110	0	80	0	170	130		30
RY-1-72	3.4	7	0	100	0	60	0	160	150	310	30
RY-1-92.5	3.2	8	0	70	0	90	0	180	150	280	29
RY-1-139.5	3.5	8	0	0	0	80	0	160	130	460	27
RY-2-80	6.4	12	0	0	0	120	100	90	56		17
RY-2-84.5	4.1	9	0	0	5	80	100	200	190		9
RY-2-94.5	3.3	5	0	0	5	60	0	140	110		23
RY-2-104	3.4	8	0	0	0	50	0	130	140	220	29

East-central Minnesota continued

sample ident	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Ge ppm	As ppm	Se ppm	Mo ppm	Ag ppm	Cd ppm	In ppm
CS-1-70	14	19.0	250.0	38	20	0	0	0	0.0	0	1
CS-1-79	6	5.0	71.0	20	0	0	0	0	0.0	0	0
CS-1-88.5	15	23.0	120.0	29	0	0	0	0	0.0	0	0
CS-1-106	10	12.0	100.0	25	10	1	0	0	0.0	1	0
CS-1-111	11	28.0	79.0	27	10	0	0	0	0.0	1	0
SJ-1-32	79	24.0	53.0	33	0	2	0	0	0.0	1	0
SJ-1-41	17	24.0	43.0	36	0	0	0	0	0.0	0	0
SJ-1-55	19	29.0	39.0	33	0	0	0	0	0.0	0	0
SJ-1-72	44	92.0	220.0	37	0	2	0	0	0.0	1	1
SJ-1-73	20	24.0	250.0	30	0	1	0	0	0.0	0	0
SJ-1-82	18	23.0	130.0	28	0	0	0	0	0.0	0	0
SJ-1-116	20	16.0	110.0	23	0	0	0	0	0.0	0	0
SJ-1-135	20	32.0	86.0	20	0	2	0	0	0.0	1	0
SJ-1-156	16	10.0	79.0	20	0	2	0	0	0.0	0	0
SA-1-52	31	22.0	74.0	17	0	8	0	0	0.0	0	0
SA-1-55.8	21	19.0	20.0	45	0	8	0	8	0.0	0	0
SA-1-57	14	3.5	12.0	32	0	71	0	16	0.0	0	0
SA-1-58.5	8	7.0	20.0	59	0	12	0	0	0.0	0	0
SA-1-63	14	7.5	18.0	55	0	11	0	20	0.0	0	0
SA-1-67	29	6.0	17.0	31	0	3	0	0	0.0	0	0
SA-1-75	21	18.0	49.0	36	0	5	0	0	0.0	0	0
SA-1-82	17	20.0	140.0	32	10	3	0	0	0.0	0	0
SA-1-87	17	31.0	140.0	28	10	3	0	0	0.0	0	0
SA-1-95	26	7.0	190.0	26	10	3	0	0	0.0	0	0
SA-1-109	20	14.0	120.0	24	20	2	0	0	0.0	2	0
SA-1-115	19	12.0	84.0	21	0	2	0	0	0.0	0	0
SA-1-119	16	10.0	91.0	20	0	3	0	0	0.0	0	0
RY-1-43.3	23	16.0	53.0	16	0	5	0	0	0.0	0	2
RY-1-46	94	84.0	75.0	27	0	2	0	0	0.0	0	0
RY-1-72	110	40.0	69.0	21	10	2	0	0	0.0	0	0
RY-1-92.5	90	62.0	62.0	23	0	2	0	0	0.0	0	0
RY-1-139.5	83	58.0	69.0	22	0	2	0	0	0.0	0	0
RY-2-80	33	18.0	54.0	18	0	6	0	2	0.0	0	0
RY-2-84.5	43	21.0	18.0	38	0	8	0	0	0.0	0	0
RY-2-94.5	39	45.0	57.0	25	10	1	0	3	0.0	0	1
RY-2-104	93	53.0	170.0	27	0	2	0	0	0.0	0	0

East-central Minnesota continued

sample ident.	Sn ppm	Sb ppm	Cs ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Dy ppm	Er ppm
CS-1-70	0	0.0	n.a.	133	180	90.4	12.1	3.2	8.9	6.5	3.4
CS-1-79	0	0.4	1	26	49	17.1	2.4	1.4	1.8	1.8	1.0
CS-1-88.5	0	0.0	1	71	136	65.1	10.2	2.7	8.1	6.2	3.4
CS-1-106	0	0.0	0	40	98	43.0	7.5	1.8	5.7	5.2	2.8
CS-1-111	0	0.0	0	56	127	71.7	12.5	2.0	9.9	8.4	4.2
SJ-1-32	0	0.0	0	122	101	46.8	5.8	1.2	4.3	3.3	1.7
SJ-1-41	0	0.0	0	153	234	140.0	22.2	4.8	14.8	10.4	5.1
SJ-1-55	17	0.0	0	83	133	104.0	17.4	3.5	11.8	8.3	4.6
SJ-1-72	13	0.0	1	72	76	139.0	28.6	6.9	28.1	24.6	15.3
SJ-1-73	11	0.3	6	89	126	160.0	32.5	7.9	29.5	22.7	13.2
SJ-1-82	0	0.0	2	45	84	39.1	6.6	1.6	5.3	4.0	2.3
SJ-1-116	0	0.0	4	68	134	58.2	10.0	1.9	7.0	5.3	3.0
SJ-1-135	0	0.0	3	73	125	56.5	7.9	1.9	5.8	4.3	2.6
SJ-1-156	0	0.0	4	53	103	43.3	7.2	1.7	5.4	4.3	2.4
SA-1-52	19	0.5	3	47	99	44.6	7.9	1.4	6.1	4.8	2.8
SA-1-55.8	0	1.3	n.a.	65	136	40.6	7.0	1.2	6.3	5.1	3.0
SA-1-57	0	0.7	1	15	39	13.3	2.3	0.3	1.9	1.1	0.0
SA-1-58.5	14	0.6	0	3	10	3.0	0.7	0.0	0.0	0.0	0.0
SA-1-63	22	1.8	1	13	26	10.0	1.7	0.3	1.1	0.5	0.0
SA-1-67	17	0.3	0	30	51	20.2	2.8	0.5	1.5	0.9	0.0
SA-1-75	0	0.2	0	78	122	39.7	5.3	1.2	4.6	2.6	1.2
SA-1-82	0	0.0	1	33	132	42.5	7.8	1.8	6.9	5.7	3.3
SA-1-87	0	0.2	2	53	239	66.3	12.7	3.3	11.7	10.5	6.7
SA-1-95	0	0.0	7	112	195	99.4	14.8	3.7	11.5	6.8	3.1
SA-1-109	0	0.0	4	48	105	45.3	7.0	1.8	5.4	3.6	1.8
SA-1-115	0	0.0	2	60	114	49.9	7.6	1.8	5.5	3.3	1.6
SA-1-119	0	0.0	2	58	113	47.5	7.0	1.7	5.4	3.2	1.5
RY-1-43.3	22	0.4	2	38	91	37.9	6.4	1.2	5.0	3.5	2.1
RY-1-46	12	0.0	11	41	61	50.1	8.6	1.5	6.4	3.2	1.4
RY-1-72	13	0.0	7	51	83	59.9	10.7	2.5	9.9	4.8	2.2
RY-1-92.5	0	0.0	6	33	71	34.9	6.0	1.5	5.4	2.9	1.3
RY-1-139.5	0	0.0	6	32	69	32.6	5.7	1.5	4.7	2.3	1.0
RY-2-80	0	0.0	3	45	103	41.1	6.9	1.4	6.0	4.5	2.5
RY-2-84.5	21	0.0	0	19	8	5.7	1.0	0.5	1.0	1.0	0.7
RY-2-94.5	0	0.0	3	50	116	52.6	8.9	2.2	7.1	4.9	2.5
RY-2-104	0	0.0	7	86	66	93.3	16.8	4.0	15.9	10.1	4.3

East-central Minnesota continued

sample ident.	Lu ppm	Hf ppm	Ta ppm	W ppm	Tl ppm	Pb ppm	Bi ppm	Cr ppm	Rb ppm	Sr ppm	Y ppm
CS-1-70	0.3	n.a.	n.a.	n.a.	3	22	0.0	26	478	119	35
CS-1-79	0.1	7	0	0	1	20	0.0	12	238	80	20
CS-1-88.5	0.4	10	1	0	1	22	0.0	22	287	117	44
CS-1-106	0.3	13	1	0	0	10	0.0	16	135	187	30
CS-1-111	0.4	13	1	0	0	10	0.0	12	102	299	48
SJ-1-32	0.2	14	1	12	0	20	0.0	14	11	43	0
SJ-1-41	0.6	14	0	0	0	14	0.0	8	36	39	25
SJ-1-55	0.6	14	1	0	0	12	0.0	10	30	15	47
SJ-1-72	1.9	6	1	0	0	28	0.0	130	31	0	190
SJ-1-73	1.6	10	1	0	0	12	0.0	18	115	0	144
SJ-1-82	0.3	12	1	0	0	10	0.0	22	167	42	30
SJ-1-116	0.3	11	1	0	0	14	0.0	22	191	196	34
SJ-1-135	0.3	10	0	0	0	16	0.0	18	154	239	35
SJ-1-156	0.3	11	0	0	0	10	0.0	18	156	275	23
SA-1-52	0.4	10	2	3	0	14	0.0	98	97	51	49
SA-1-55.8	0.3	n.a.	n.a.	n.a.	0	26	0.6	64	37	214	31
SA-1-57	0.0	10	1	0	1	14	1.0	110	14	25	22
SA-1-58.5	0.0	15	2	0	0	16	1.8	100	18	152	0
SA-1-63	0.0	15	2	0	0	16	1.3	110	0	0	12
SA-1-67	0.0	11	1	0	0	34	0.9	76	18	0	11
SA-1-75	0.2	9	1	0	0	34	0.0	66	40	95	17
SA-1-82	0.5	6	1	0	0	18	0.0	52	69	18	29
SA-1-87	0.9	6	1	0	0	44	0.0	66	101	84	43
SA-1-95	0.3	6	1	0	3	40	0.0	50	342	538	24
SA-1-109	0.2	7	1	0	2	24	0.0	68	214	362	0
SA-1-115	0.1	5	0	0	1	18	0.0	62	162	525	49
SA-1-119	0.2	5	0	0	1	16	0.0	40	129	761	11
RY-1-43.3	0.3	13	1	5	0	12	0.0	52	62	23	49
RY-1-46	0.2	4	0	0	0	12	0.0	130	171	0	27
RY-1-72	0.3	5	0	0	1	26	0.0	150	204	0	40
RY-1-92.5	0.2	4	0	0	0	16	0.0	150	199	0	31
RY-1-139.5	0.1	5	0	0	0	10	0.0	130	138	140	24
RY-2-80	0.3	9	2	0	0	14	0.0	56	104	39	52
RY-2-84.5	0.0	4	1	3	0	6	0.5	190	16	0	21
RY-2-94.5	0.3	3	1	21	0	16	0.0	110	40	0	28
RY-2-104	0.5	3	1	0	1	12	0.0	140	179	0	67

East-central Minnesota continued

sample ident.	Zr ppm	Nb ppm	Ba ppm	Al_2O_3 mol pro	CaO mol prop.	Na_2O mol prop	K_2O mol prop.
CS-1-70	739	66	1340	0.227	0.007	0.002	0.043
CS-1-79	235	23	1610	0.154	0.005	0.004	0.076
CS-1-88.5	397	32	1980	0.182	0.007	0.006	0.070
CS-1-106	414	50	2080	0.156	0.021	0.030	0.054
CS-1-111	473	38	1800	0.160	0.035	0.058	0.045
SJ-1-32	610	42	237	0.167	0.042	0.000	0.001
SJ-1-41	651	21	209	0.222	0.017	0.001	0.001
SJ-1-55	598	28	225	0.192	0.015	0.000	0.002
SJ-1-72	313	31	146	0.289	0.007	0.001	0.003
SJ-1-73	510	23	696	0.154	0.020	0.002	0.025
SJ-1-82	446	34	1740	0.170	0.011	0.002	0.040
SJ-1-116	450	27	2430	0.170	0.022	0.039	0.061
SJ-1-135	375	17	2390	0.154	0.026	0.049	0.056
SJ-1-156	384	23	2230	0.154	0.034	0.060	0.056
SA-1-52	362	39	407	0.124	0.007	0.004	0.022
SA-1-55.8	168	26	205	0.170	0.029	0.004	0.005
SA-1-57	343	19	98	0.274	0.005	0.001	0.001
SA-1-58.5	659	43	225	0.328	0.009	0.001	0.001
SA-1-63	681	46	96	0.232	0.007	0.001	0.000
SA-1-67	484	41	88	0.194	0.009	0.000	0.000
SA-1-75	376	25	195	0.252	0.006	0.000	0.004
SA-1-82	276	33	301	0.161	0.021	0.000	0.012
SA-1-87	260	24	676	0.151	0.022	0.001	0.030
SA-1-95	231	11	1920	0.200	0.006	0.002	0.057
SA-1-109	248	24	1440	0.170	0.011	0.014	0.058
SA-1-115	165	0	1000	0.143	0.064	0.053	0.042
SA-1-119	194	13	991	0.148	0.067	0.058	0.039
RY-1-43.3	471	25	358	0.098	0.007	0.004	0.016
RY-1-46	178	21	542	0.187	0.005	0.002	0.030
RY-1-72	166	10	712	0.185	0.016	0.001	0.034
RY-1-92.5	146	0	725	0.186	0.008	0.001	0.038
RY-1-139.5	158	26	802	0.178	0.023	0.020	0.034
RY-2-80	342	26	461	0.108	0.008	0.002	0.020
RY-2-84.5	193	32	122	0.211	0.008	0.000	0.002
RY-2-94.5	112	25	217	0.105	0.018	0.005	0.005
RY-2-104	136	24	610	0.178	0.004	0.001	0.026

APPENDIX F

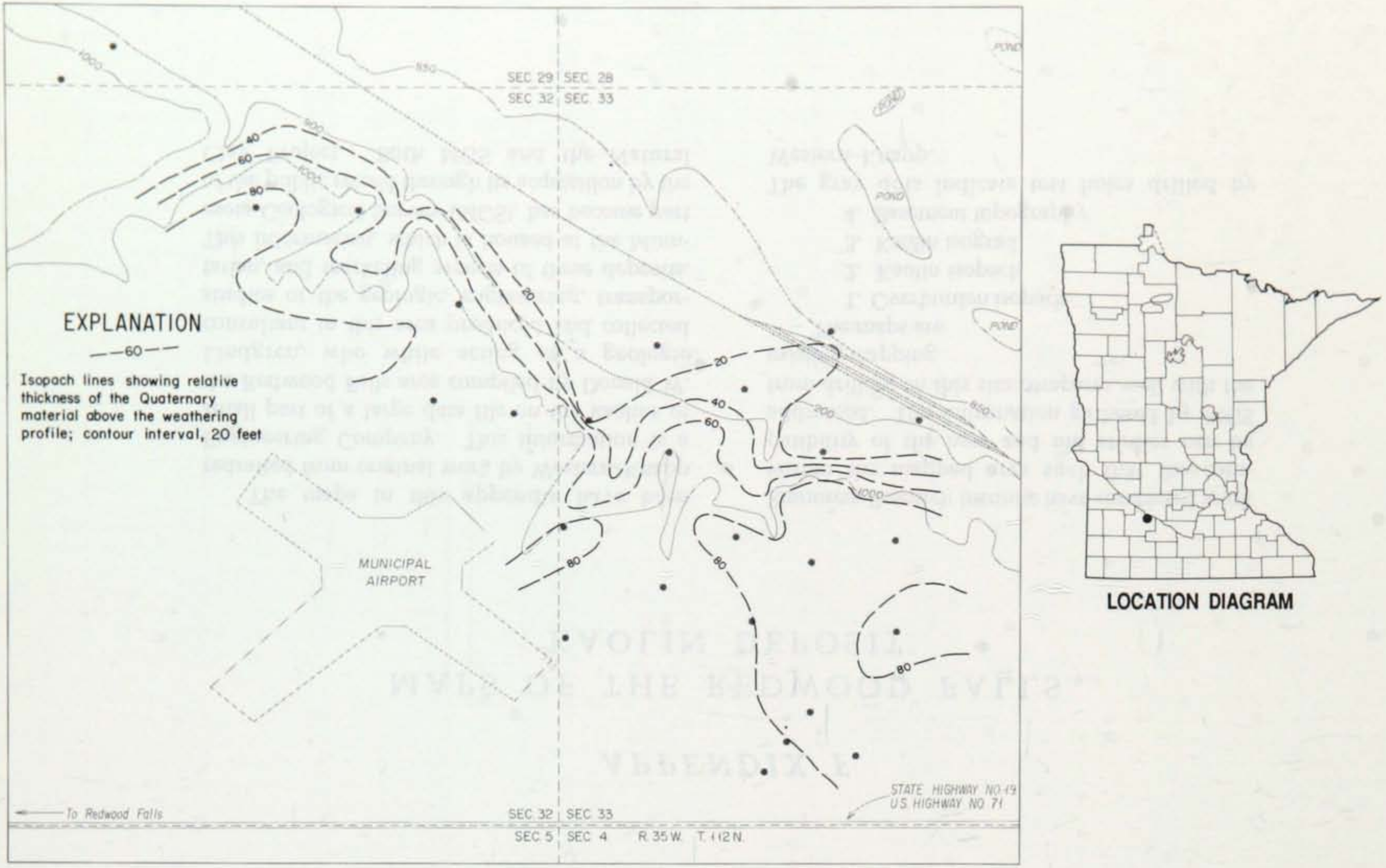
MAPS OF THE REDWOOD FALLS KAOLIN DEPOSIT

The maps in this appendix have been redrafted from original work by Western-Knapp Engineering Company. This information is a small part of a large data file on the kaolins of the Redwood Falls area compiled by Donald W. Lindgren, who while acting as a geologic consultant in this area produced and collected studies of the geologic, engineering, transportation, and marketing aspects of these deposits. This information, which is housed at the Minnesota Geological Survey (MGS), has become part of the public record through its acquisition by the Clay Project. Both MGS and the Natural Resources Research Institute have conducted work within the mapped area such that the compatibility of the new and old studies can be addressed. The information gathered by MGS from drilling on this site compares well with the existing mapping.

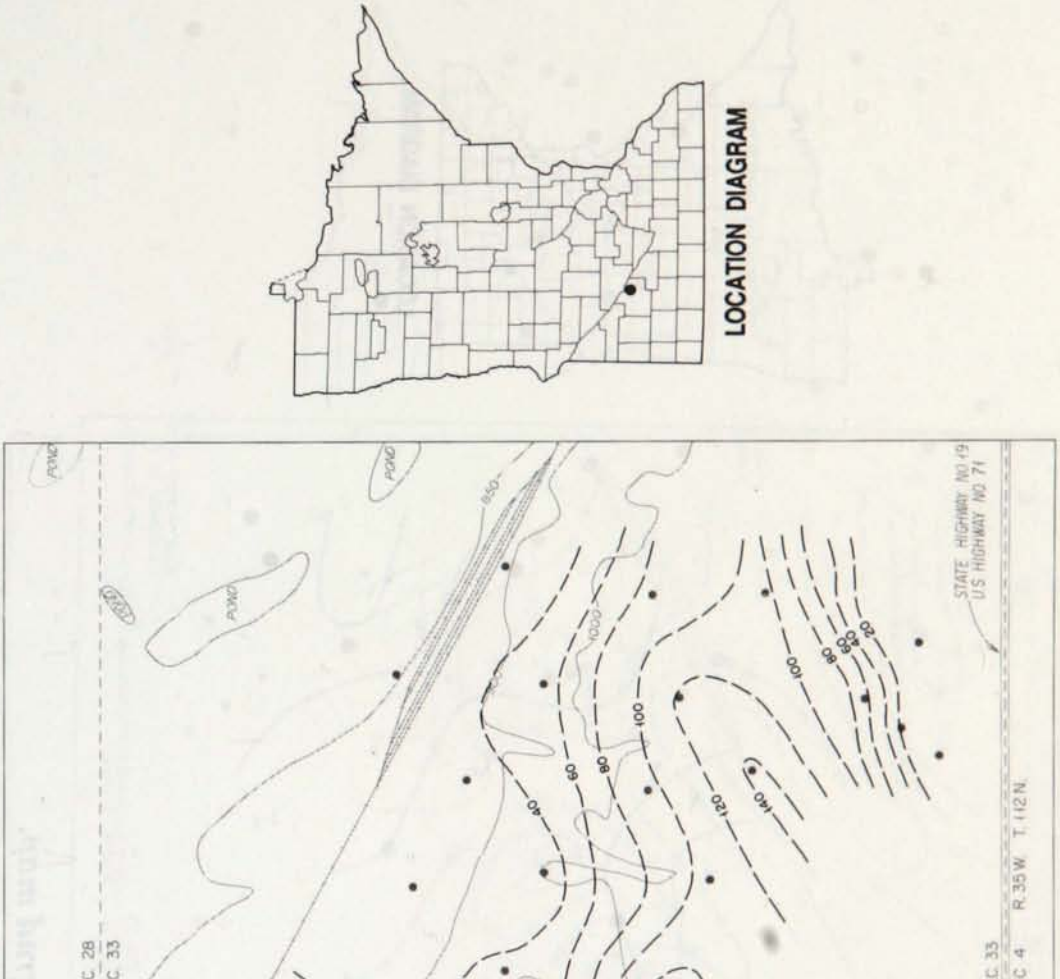
The maps are

1. Overburden isopach
2. Kaolin isopach
3. Kaolin isograd
4. Basement topography

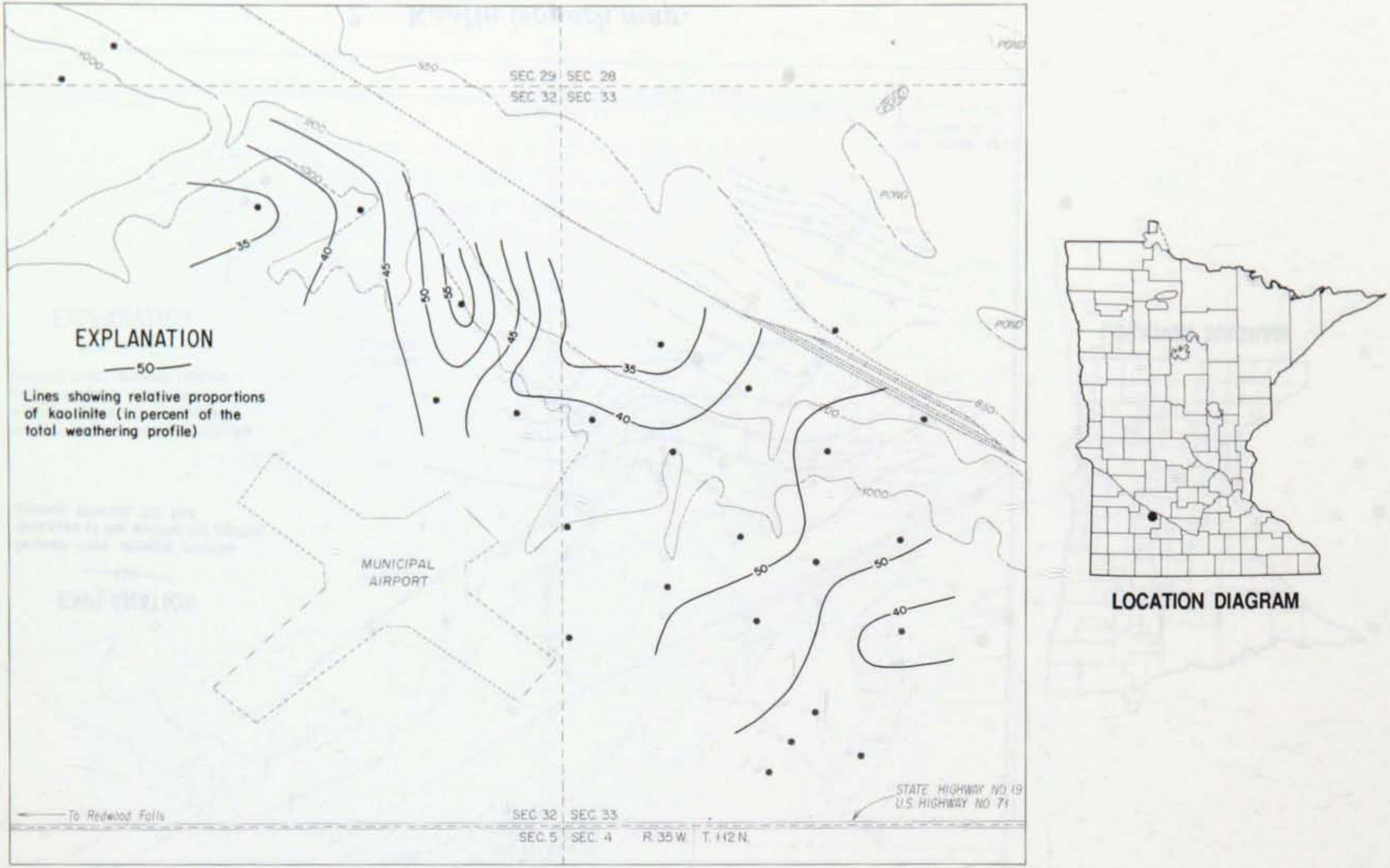
The gray dots indicate test holes drilled by Western-Knapp.



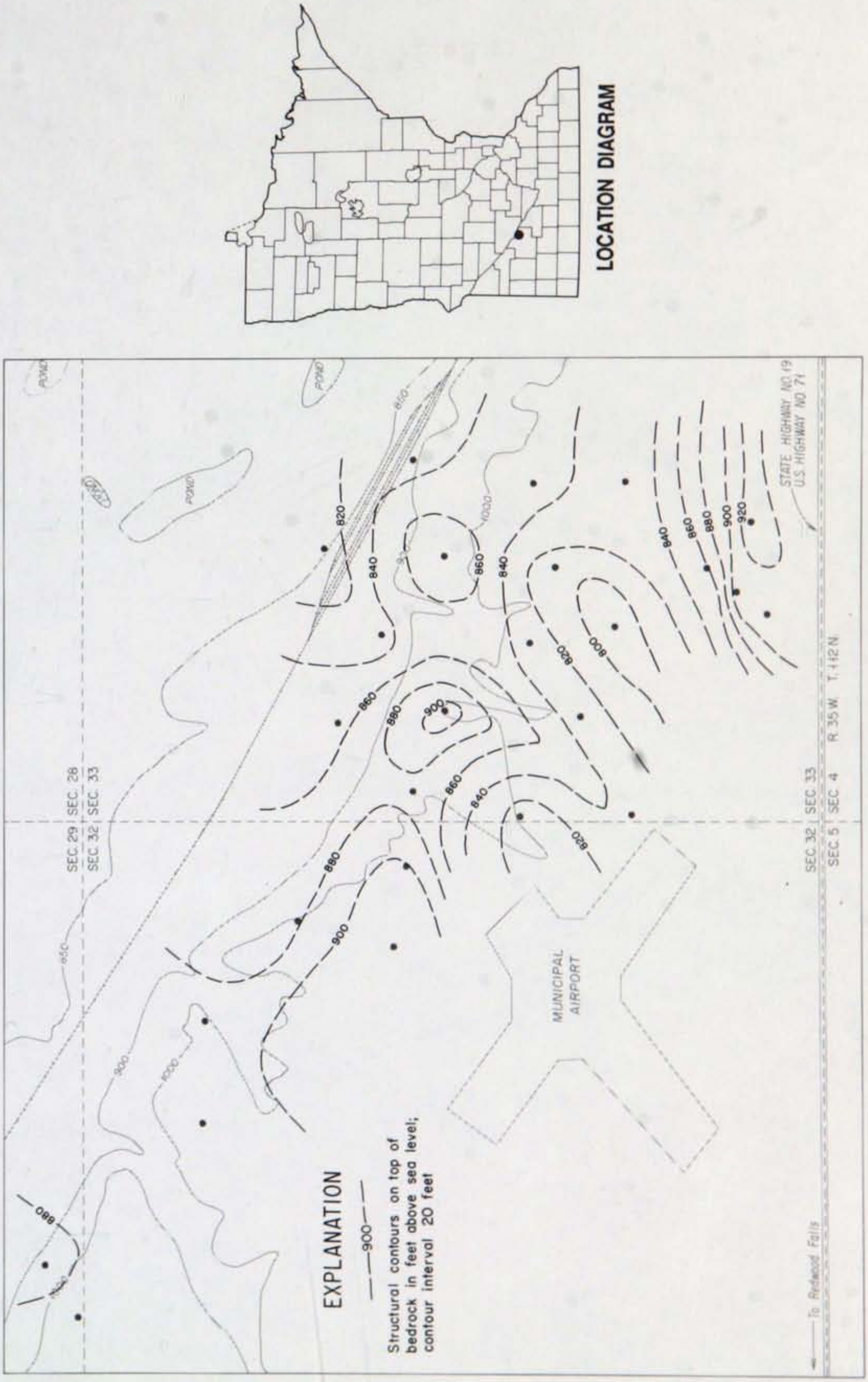
1. *Overburden isopach map.*



2. *Kaolin isopach map.*



3. *Kaolin isograd map.*



4. *Basement topography map.*