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BEDROCK AND GLACIAL DRIFT MAPPING FOR VOLCANOGENIC MASSIVE SULFIDE AND LODE GOLD ALTERATION IN THE VERMILION - BIG FORK GREENSTONE BELT

PART B: THE UTILITY OF GLACIAL DRIFT PROSPECTING IN THE VERMILION DISTRICT, MINNESOTA

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Preface

Glacial indicator tracing, that is the definition of dispersal trains of distinctive lithologies or geochemical signatures in glacial sediment, has proven to be a valuable tool in exploration for volcanogenic massive sulfide or lode gold deposits. This technique has been widely used in Canada and in Scandinavia. However, the usefulness of similar techniques for exploration in Minnesota has been questioned because of rather different glaciological and glacial geological settings. Several attempts have been made to define geochemical anomalies in till, lake sediment, and soils. Although some unusual concentrations of indicator minerals have been noted, no consistent anomalies or dispersal trains have been defined. Part of the reason for the lack of success is that the relation between bedrock and glacial sediment is complicated and there is little agreement on what constitutes a geochemical or lithologic anomaly.

This investigation consists of two parts; 1) a comprehensive study of lithology, alteration, and geochemistry at the Five Mile Lake, Eagles Nest, and Quartz Hill prospects, and 2) an investigation of the utility of glacial drift prospecting in the Vermilion District. This approach to glacial indicator tracing begins with a fundamentally different approach than previous studies. It begins at a known massive sulfide and lode gold prospect in the vicinity of Five Mile Lake. The unique lithologies are then traced in till from known sources. In this manner the lithologic relation between drift and bedrock can be assessed quantitatively. Length scales of dispersal of rock types of different resistance to erosion can be assessed and dilution and comminution coefficients can be calculated. From theses data sampling strategies can be developed that incorporate appropriate spacing for particular lithologic anomalies.

The results of this investigation indicate that the Vermilion District of northeastern Minnesota contains examples of deep water, flow dominated VMS systems (Noranda type), as well as shallow water, volcaniclastic-dominated (Mattabi type) VMS systems. In addition, glacial indicator tracing of lithologic anomalies in till provide an extremely valuable exploration tool.

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Conversations with George Hudak, Ron Morton, and Dean Peterson provided much information about the geology and mineralization in the Vermilion District, helping us design and focus our sampling program.

Dean Peterson provided us with an early digital copy of his bedrock geology map (Peterson and Jirsa, 1999) of the Vermilion District.

J. Munson, K. Hager, and J. Aronson assisted in processing glacial drift samples collected for this study.

ABSTRACT

Glacial till samples were collected in an area between Tower and Ely, Minnesota, in order to assess the utility of drift exploration techniques in the Vermilion District. In order to test the relationship between local bedrock and till compositions, till sample clast lithologies were quantified. The resulting data set was subjected to factor analysis. In addition, data from Lawler and Riihiluoma (1997), and a set of geochemical data from drill core and drift cobbles were also analyzed.

Three type of lithologic indicator dispersal trains were identified in the study area: Quartz-epidote altered basalts, magnetite-chert iron formation, and quartz-ankerite±sericite. The quartz-epidote altered basalts form a well-defined dispersal train extending in the down-ice direction of an alteration zone extending from Fivemile to Eagle's Nest Lake. Magnetite-chert iron formation forms well-defined dispersal trains extending in the down-ice direction from two east-west striking sequences of the Soudan Iron Formation. The dispersal patterns exhibited by the altered basalts and iron formation suggest dilution is the dominant process controlling their concentrations. In contrast, quartz-ankerite±sericite dispersal trains occur only in small, isolated locations. The soft nature of this alteration results in rapid comminution, consequently the dispersal trains persist only a short distance.

Factor analysis demonstrates that a large portion of the variance in till lithologic compositions is controlled by the relative amounts of rock types with local sources. A lesser component of variance is controlled by a 'regional' signature representing bedrock compositions along a larger portion of the glacial flow path. Factor analysis of geochemical data from Lawler and Riihiluoma (1997) showed 2 out of 18 of the Mineralized Clast Areas were distinguishable from the others. However, the apparent differences between the MCA's are not statistically significant. Factor analysis and student's test of geochemical data from drill core collected at the Fivemile Lake prospect, and glacially transported cobbles collected 2 km in the down-ice flow direction, showed the two data sets are statistically indistinguishable. This suggests lithologies identified in glacial till can be confidently correlated with bedrock lithologies.

Emprically, lithologic analyses indicate a close relationship between till clast composition and the composition of local bedrock. This conclusion is further reinforced by results of the factor analyses. This relationship suggests till exploration techniques promise to be an effective tool for exploration in the Vermilion District and other areas with similar glacial geologic settings in Minnesota. Likewise, the results suggest that application of multivariate analytical techniques are an extremely valuable tool for interpretation of extensive glacial drift lithologic (and geochemical) data sets.

INTRODUCTION

Glacial indicator tracing, that is the use of geochemical or lithologic signatures in glacial sediment, has been used effectively for exploration for volcanogenic massive sulfide (VMS) and lode gold deposits in Canada and northern Scandinavia (e.g. Kujansuu and Saarnisto, 1990; McClenaghan et al. 1997). The great success of drift prospecting in these areas can be attributed to several factors. The glacial deposits are typically thin (~10 m or less) with simple stratigraphies; therefore geochemical and lithologic signatures are readily traced to their sources. Existing comprehensive studies of glacial stratigraphy and ice flow directions facilitate source identification. But the primary reason that drift exploration has been so successful in these areas is the number and comprehensive nature of studies on glacial erosion, glacial dispersal trains, and the persistence of geochemical signatures in drift.

There has long been concern that the techniques of glacial indicator tracing that have been so successful in Canada and Scandinavia would be of little use in Minnesota because of the difference in the glacial geological setting. Although NE Minnesota is an area of thin drift, areas to the west, southwest, and south are covered with thick Pleistocene deposits. The complex stratigraphy and the potential for multiple cycles of glacial erosion and deposition make difficult the identification of the sources of geochemical and lithologic anomalies.

For glacial sediment to be valuable in the exploration of VMS and lode gold deposits, host rock lithologic and geochemical indicators must be identifiable and traceable to their sources. The indicators should be easy to sample and analyze, and the necessary analytical procedures must be cost effective. However, each geochemical and lithologic signature will behave differently. Host rocks of VMS and lode gold deposits are of several types. Each is eroded and entrained differently within the glacial geological system. Each mineral type or geochemical signature has unique weathering characteristics in the surface and subsurface environment. Shallow and deep soil water and groundwater chemistry controls the spatial and temporal variability of redox conditions, and redox in turn controls the stability of minerals in the surface environment. Therefore the use of lithologic and geochemical anomalies in glacial sediment is complicated, and effective exploration requires knowledge of which anomalies provide the best exploration tool and how that anomaly is distributed spatially relative to its source.

This study focuses on definition of the dispersal patterns of two distinctive rock types from known source areas in the vicinity of Fivemile and Eagles Nest Lakes and an evaluation of the utility of collection of mineralized clasts in stratified glacial sediment. The Fivemile Lake area was chosen because it contains reasonably well-defined VMS and lode gold prospects. The spatial distribution of the rocks that host the mineral deposits are well known, as the geology has recently been mapped in detail (Peterson and Jirsa, 1999). Numerous boreholes exist for detailed characterization of the bedrock petrography (Hudak and Morton, 1999). Glacial deposits are relatively thin and ice flow directions are well known.

The key to successful exploration for VMS and lode gold utilizing glacial indicator tracing is the development of a foundation that tests basic relations between drift and local bedrock. The present study was designed to test these basic relationships and address several questions required for successful drift prospecting:

1) Can local bedrock lithologic signatures be identified in drift?
2) What type of glacial sediment, till or stratified drift, best retains the local bedrock signature?
3) What is the fate of these lithologic signatures in various size fractions in relation to glacial processes of erosion and comminution?
4) What sampling densities and clast sizes are appropriate for identification of lithologic anomalies in glacial drift?

For lithologic anomalies to be useful there must be a well-defined set of criteria for their identification. VMS deposits are associated with submarine volcanic rocks with no strong correlation with age or rock chemistry (D. Peterson, unpublished manuscript). Quartz-epidote and chlorite alteration zones are commonly associated with VMS deposits. In the case of lode gold deposits, host rocks include a variety of lithologies.

PREVIOUS STUDIES

Studies involving the use of glacial indicator tracing in Minnesota are of several types. Numerous DNR-Minerals reports focus on the results of geochemical investigations of lake sediment, peat, gyttja, groundwater, and soils, (e.g. Beckwith and Clark, 1985, Meineke et al., 1976, Meineke et al., 1977a-b-c, Meineke, et al. 1978, MDNR 1977a-b-c-d-e-f, Morton and Ameel, 1985, Sellner, 1985, Vadis and Meineke, 1977, Vadis and Meineke, 1982). Although these types of geochemical studies can be quite useful, little background information is available on weathering and the fate of elements in the near surface environments and lakes in Minnesota. Even if information on elemental chemistry were available, there is a general lack of comprehensive studies on the genesis and origin of weathered sediments.

Several investigations have focused on coring of Quaternary stratigraphy and the sedimentological and geochemical analysis of these sediments (e.g. Martin et al., 1988, Martin et al., 1989, Martin et al., 1991). These investigations had essentially two objectives: to define Quaternary stratigraphy, which in these areas was essentially unknown, and to identify geochemical anomalies that might relate to ore deposits. The spacing of drill holes was rather large and arbitrary; however, there were no existing studies to suggest a more appropriate spatial distribution. Existing preliminary stratigraphic and geochemical studies have not been followed up by geostatistical analysis to determine spatial scales of correlation and evaluate optimum drill hole spacing.

Pilot studies have been conducted assessing the utility of glacial drift prospecting in Minnesota utilizing till (e.g. Buchheit et al., 1989) or glaciofluvial sediments (e.g. Martin and Eng, 1986, Nelson et al., 1992, Nelson et al., 1997, Lawler and Riihiluoma, 1997). Unfortunately, these studies have either focussed on areas of relatively thick, complex drift stratigraphy (in the case of studies utilizing tills), or have utilized sediments whose provenance is either poorly constrained, or constrained in only the most general fashion.

Most of the above mentioned studies have suffered from a lack of a satisfactory explanation of the spatial and compositional links between bedrock geology and the glacial sediments overlying them. A few studies have specifically addressed this issue (Green and Venzke, 1990; Everson, 1977), however they stand as the exception rather than the rule. In consequence of the paucity of background glacial geological studies and a lack of demonstrable results, glacial drift prospecting has been viewed as having relatively limited value as viable mineral exploration tool in Minnesota.

Similar studies in Canada (e.g. Bajc, 1991, and McClenaghan, 1994) have resulted in significant mineral deposit discoveries. These Canadian investigations differ from those in Minnesota by relying on a more extensive background glacial geological investigations, appropriate drill hole densities, and more comprehensive data analysis.

GLACIAL SETTING

Glacial sediments of the western Lake Superior region are assigned to three main ice lobes. During the late Wisconsinan (ca. 30 - 11 ka), the Rainy and Superior lobes advanced from the northeast from accumulation centers in the Hudson and James Bay lowlands, respectively, while the Itasca lobe advanced from the north-northeast and had a source in central or western Hudson Bay (Figure 1). The Superior lobe advanced along the trend of the deep Lake Superior basin, and the record of ice advance and retreat suggests numerous ice-marginal fluctuations that have been attributed to surges (Wright, 1973). The Rainy lobe advanced parallel to the Superior lobe, but over topographically higher terrain (~800 meters above the bottom of Lake Superior) underlain by either crystalline bedrock or thin gravelly drift. The Itasca lobe traversed topographically lower but geologically similar terrain to the west of the Rainy lobe.

The three primary morainic systems of the Rainy lobe in the western Lake Superior region are the Alexandria, St. Croix, and Vermilion moraines, associated with the Hewitt, St. Croix, and Vermilion - Highland phases of late Wisconsinan glaciation, respectively (Clayton and Moran, 1982; Wright and Ruhe, 1965; see Figure 1).

The Hewitt Phase

The first and most extensive Late Wisconsinan glacial advance of the Rainy lobe was the Hewitt phase (formerly the Wadena lobe, see Goldstein, 1989; Meyer, 1996, and Wright and Ruhe, 1965; see Figure 1). The associated Alexandria moraine is an ice marginal accumulation of debris that is 20-30 km broad, more than 300 km in length, and has local relief of 30-100 m. The Hewitt phase culminated after ca. 26 ka but before 20.7 ka., possibly 23-21 ka. (Figure 1). Relatively little is known about the recession of the Rainy lobe from the Alexandria moraine, but the ice-margin probably retreated into northern and northeastern Minnesota (Wright and Ruhe, 1965; see Figure 1).

The St. Croix - Itasca Phase

The next prominent late Wisconsinan ice glacial advance formed the St. Croix moraine of the Rainy and Superior lobes and the contemporaneous Itasca moraine of the Itasca lobe (Figure 1). Two components of flow are indicated; one from the north-northeast, supplying ice to the Itasca lobe, and the other from the northeast, to the Rainy and Superior lobes. The St. Croix - Itasca phase culminated at about 16 - 15.5 ka (Clayton and Moran, 1982) and the initial stages of retreat began ca. 15 ka (Figure 1).

The Vermilion - Highland Phase

The final prominent morainic system is the Vermilion - Highland moraine of the Rainy and Superior lobes (Figure 1). The Vermilion portion of the moraine system runs through the present study area, and although the most prominent Rainy lobe moraine in the area, it is not the only one. Several minor moraines also record the overall recession of the Rainy lobe. These include the Allen, Big Rice, Wahlsten, and Wampus Lake moraines (Lehr and Hobbs, 1992). The Wahlsten moraine trends east to west along the southern margin of the study area (Lehr and Hobbs, 1992) (Figure 2).

The age of the Vermilion moraine is constrained by several radiocarbon dates and correlations with other ice margins. The most accurate age estimate on the Vermilion moraine is ca. 13 ka Following the Vermilion - Highland phase, the ice retreated relatively rapidly, and by 11 ka the Lake Superior basin and surrounding highlands were free of ice.

GLACIAL PROCESSES

In order to understand and interpret the distribution, extent, and magnitude of glacial indicator dispersal trains, it is critical to understand the glaciological processes that controlled the development of these trains. The following section is a brief overview of glaciological processes. A longer treatment of the subject, and its implication for sediment erosion, entrainment, comminution, and deposition, is appended to this report as Appendix A.

Quarrying, abrasion, and block incorporation are the three means of subglacial erosion. Glacial erosion, entrainment, and deposition are controlled by a glacier's basal thermal regime and the distribution of velocities in the ice in contact with the glacier bed. The thermal regime and velocity, in turn, are determined by ice surface temperature, the accumulation pattern, and the geothermal heat flux (Paterson, 1994; Hooke, 1998).

Processes acting at the ice/bed interface control the spatial and temporal distribution of quarrying and abrasion. Abrasion is enhanced where velocities are higher and where particles are impinging on the bed. Quarrying is greatest where rocks are fractured or jointed where stresses are high, and where clasts can effectively be entrained into the ice. Although abrasion and quarrying can occur on all surfaces in the subglacial environment, certain areas favor erosion. Sliding effectively accommodates large protuberances such as large bedrock hills. Rapid deformation by enhanced creep leads to locally high sliding velocities and enhanced erosion by both abrasion and quarrying. Relatively level beds are not subject to the stress enhancements of large bumps; abrasion and quarrying occur but at lower rates. The relative contribution of abrasion to quarrying depends on a number of factors including bedrock type.

Once debris has been incorporated into the basal debris layer of a glacier, dilution and comminution will alter the concentration and distribution of indicator lithologies. Comminution will decrease the average particle size, and dilution will decrease the concentration of indicator clasts. Decreasing particle size increases susceptibility of elements of economic interest to chemical weathering and remobilization. The finer fractions of till tend to reflect the farthest transported material. Conversely, coarser fractions of till tend to reflect the shortest transported, or locally derived material.

METHODS

SELECTION OF STUDY AREA

Successful glacial indicator tracing and drift prospecting is contingent on correlating geochemical and lithological signatures in glacial sediment to specific bedrock localities. Correlation established between bedrock and drift characteristics is often qualitative, but ideally quantitative.

Only a few previous investigations in Minnesota have addressed this issue (Green and Venzke, 1990; Everson, 1977). Much of the bedrock geology of Minnesota is poorly constrained, including the areas examined by these previous studies. Therefore, most studies have not quantitatively assessed the relationships between glacial sediment composition and specific bedrock lithologies and compositions.

In light of these previous efforts, a study area was selected that has unique, well-defined bedrock characteristics. The suite of rocks present in the Vermilion District between Tower and Ely, Minnesota are relatively well known. In addition, numerous lode gold and VMS prospects and their associated halos of altered rocks occur in this area. The rocks of this belt thus promised produce a distinctive lithologic signal in glacial sediments. Location of the study area and sampling sites are shown in Figure 1 and Figure 3.

SAMPLING STRATEGY

Glacial sediments in the study area are relatively thin (0-10 meters) in the north, but thicken to 30-35 meters to the south and southwest of the Wahlsten Moraine. These sediments consist primarily of till and stratified sediments. The stratified sediments include outwash and ice contact deposits. Early field reconnaissance involved assessment of bedrock lithological associations and a survey of the glacial sediments. Since both types of glacial sediment, till and stratified drift, are abundant in the vicinity it was decided to develop a sampling strategy that focused on collection of both.

Initial fieldwork focused on examination of cobble-sized clasts in gravel pits, which mainly exposed stratified sediment. However, the diversity of sorting of the exposed glaciofluvial sediments, as well as the lack of vertical control in stratified sediment, made it difficult to design a consistent sampling strategy using these sediments.

Consequently, the decision was made to focus on sampling till, which, although thin, forms a consistent veneer over bedrock throughout the study area. Because of this, till provides excellent stratigraphic control. Although there is variability in the depositional environment of till, it provides the most consistent and spatially uniform medium for glacial sediment sampling in the study area.

Early in the study, the significance of silicified and quartz-epidote altered cobbles in drift in the down ice-flow direction of the Fivemile and Eagle's Nest VMS prospects was realized. Consequently, later portions of the sampling program focussed on ensuring adequate sample density to delineate the extent and magnitude of this dispersal train.

SAMPLING METHODOLOGY

Glacial drift samples were collected at 118 sites in a 15 by 40 km belt extending roughly from Tower to Ely (Figure 3, Table 1). Samples were collected either from shovel pits between 10 and 70 cm deep, or collected on road cuts or in gravel pits at least 1m below the soil surface. Sample size ranged from 1-2 kg of material. Coarser stones and cobbles (>30 mm) were hand cobbed and discarded at the site. Care was taken to collect samples below the depth of visible surface weathering and oxidation.

Of the 118 drift samples collected, 48 till samples were selected for further analysis. The 70 drift samples not analyzed further were either glaciofluvial, glaciolacustrine, or ice-contact material (e.g. stratified drift), or lay a significant distance from the core Fivemile-Eagle's Nest Lakes sampling area. Limiting analysis to the selected tills assured that comparable analyses were being conducted on a relatively uniform sampling media. Compositional differences due to normal, expected variations between adjacent drift materials of differing origin can thus be eliminated as a source of variability in the results.

The till samples were dried, disaggregated, and dry screened. The 4-16 mm pebble fraction was separated and washed for lithologic analysis. The 1-2 mm coarse sand fraction was separated, washed, split, and mounted in petrographic thin section for grain identification by microscope. Splits of both these fractions were archived. In addition, the coarse, middling, and fine fractions not considered by the present study have also been archived.

Lithologic analyses were conducted on the two separate pebble and coarse sand fractions in the manner outlined by Hirvas and Nenonen (1990). Stone counts were conducted on splits comprising 100-130 pebbles in the 4-16 mm fraction. Lithologies were assigned to one of 58 sub-categories in 9 broad categories (Table 2). Stones with unique and/or interesting lithologies, including visible alteration, were further noted. The data are tabulated in Appendix C.

Identifications of 70-100 thin section mounted 1-2 mm coarse sand size grains were conducted for each sample using a petrographic microscope. Grains were assigned to the same lithologic sub-categories and categories as the stone counts. The data are tabulated in Appendix B.

For one particular lithology of interest, quartz-epidote altered basalts, the proportion in both the sand and pebble size fractions was reevaluated on a mass basis. Pebble counts indicated a systematic variation of concentration of this lithology with transport distance. It was felt that separation of altered grains from the samples would give a more representative value for the content of this component. The results validated this approach; mass percentages of QEAB in both the sand and pebble fractions showed variations with transport distance with greater resolution than indicated by grain counts.

Twenty-two samples that the stone counts indicated contained either quartz-epidote altered basalt pebbles (QEAB), or were adjacent to samples with QEAB pebbles were selected. For these samples, the QEAB pebbles were hand separated from the entire pebble fraction, and from splits of the sand size fraction. The splits of QEAB clasts were weighed and compared to the weight of the bulk size fraction (or split thereof) as a whole (see Appendix G).

MULTIVARIATE ANALYSIS

Analytical results of drift petrography and drift geochemistry completed as part of this study, and results from DNR Report 318 were compared using factor analysis. Data were normalized and the number of factors retained was determined by the 75% variance rule (Gorsuch, 1983). The solutions were then rotated using a Varimax orthogonal transformation to maximize the variance of the loadings on the factors. The method of analysis can be summarized as follows. The general model for the factor analysis is:

$$Xj*p = Fn*k * Ak*p + En*p \quad (1)$$

where Fn*k is the factor score matrix, Ak*p is the factor loadings matrix, and En*p is the residual matrix. The general purpose of factor analysis is to reduce the number of variables and to determine the relative contributions of the variables to the overall sample variance.

Analysis of Drift Petrography

An important aspect of the investigation was multivariate analysis of the lithologic data. The lithologic counts for the pebble and sand fractions were combined into 11 categories, the 9 main rock groups listed in Table 2 and two additional categories that are direct indicators of mineralized host rocks. These two additional categories (which can be more appropriately considered sub-categories of the original 9) were quartz-epidote alteration as an indicator of the VMS host rocks and quartz-ankerite±sericite alteration indicative of lode gold deposits. Data from these 11 categories of clasts were combined for both sand and pebble fractions, and the data were normalized. The resultant 48 samples therefore each have 22 variables, 11 lithologic categories in both sand and pebble fractions. Factor loadings are tabulated in Table 3 and factor scores are tabulated in Appendix D.

Analysis of Mineralized Clast Areas defined in Report 318
DNR Minerals Report 318 (Lawler and Riihiluoma, 1997) reported geochemical analytical results for 153 samples. However, different labs were used for the analyses and the analytical results were not standardized. There were 20 elements from the ICP package analyzed by Bondar Clegg and 24 elements in the ICP package analyzed by ACTLABS. Fourteen of the variables were common to both groups. Factor analysis was performed on 153 samples and the 14 common variables. Following initial review of the data it was determined that two of the variables were of little use in discriminating the groups, and these were removed from the data set. In the end 153 samples and 12 variables were analyzed. In an effort to identify the validity of the Mineralized Clast Areas (MCA's) defined by Lawler and Riihiluoma (1997) factor scores of the samples were plotted by their MCA numbers. Factor scores for Project 318 analyses are tabulated in Appendix E.

Analysis of bedrock in Five Mile and Eagles Nest areas
The correlation of specific drift lithologies with specific bedrock units was deemed an important goal of this project. Twenty-two samples of rock associated with the Fivemile VMS prospect were collected from drill core and submitted for whole rock geochemical analysis (Hudak and Morton, 1999). Eight additional samples, comprised of glacially transported cobbles, were collected from an exposure of glacial drift approximately 2 km in the down ice-flow direction of the Fivemile prospect.

Four of the cobble samples were unaltered basaltic volcanic rocks. The other four cobble samples were selected because of visual resemblance to altered volcanic rocks identified at the Fivemile prospect.

The eight cobble samples were submitted to Actlabs Inc. of Wheat Ridge, CO, for whole rock geochemical analysis of 51 major and trace elements. Major element concentrations were determined by fusion and ICP-AES analysis. Trace elements were determined by fusion and ICP-MS. The same methods were used for both the drill core and cobble samples.

The data set for rock geochemistry consists of 22 samples from drill core and the 8 samples of drift cobbles, both with 51 variables. These were combined into a group of 30 samples with 51 variables. The analytical results were compared in two ways. First, factor analysis was used to determine the number of groups of independent variables and the variable in each group with the highest variance. These variables are Dy, V, Sr, Ni, Cs, Sb, Zn, Cu, and W. Numerical results of the factor analysis of the relations among drift and bedrock are tabulated in Appendix F.

RESULTS

Results indicate that Rainy lobe tills in the Vermilion District are characterized by distinctive compositional variability in the coarse sand and pebble fractions. The clast composition reflects the bedrock traversed by the glacial ice. Lithologies present in till record both a regional signal that integrates the entire flow path of the Rainy lobe and distinctive signals related to unique, local rock types. These local rock types can be readily identified but their signal is diluted in the down glacier direction by dilution from further erosion and comminution into finer clast sizes. Three distinct types of dispersal trains were identified in the study area and are outlined below.

LITHOLOGIC INDICATOR DISPERSAL TRAINS

Quartz-Epidote Altered Basalts

A quartz-epidote altered basalt clast dispersal train occurs as a broad, well-defined dispersal train extending in the down ice-flow direction from a zone of quartz-epidote altered basalt extending at least 8 km along a strike length between Fivemile and Eagle's Nest Lakes (Figures 4, 5). This alteration zone is oriented roughly normal to ice flow direction

This quartz-epidote dispersal train was first noted in pebble counts. A weak, logarithmically decaying trend in the concentration occurred in the down ice-flow direction as much as 9 km from the outcrop area (Figure 6). These samples were subsequently reanalyzed by separating quartz-epidote altered clasts, and measuring their concentration as a mass proportion. The same logarithmic decay in the signal is evident, however the signal is considerably stronger (Figure 7).

The persistence of the dispersal train in the down ice-flow direction, as well as the logarithmic nature of the decaying signal, suggests dilution is the dominant process affecting the concentration of quartz-epidote altered clasts in the pebble fraction. This is likely a reflection of the relative resistance of the quartz-epidote altered clasts to comminution.

The same mass proportion analysis of quartz-epidote altered clast dispersion was conducted on the sand size fraction. In contrast to the pebbles, the sand fraction showed a relatively low concentration along the length of the dispersal train (Figure 8). A distinct slightly concave-downward pattern in the concentration is, however, apparent.

This may be the result of either (i) the concentration of quartz-epidote altered sand grains derived from the Fivemile-Eagle's Nest area not rising above some background level, or (ii) addition to the sand fraction by comminution of coarser particles approximately equaling the dilution rate. In the pebble sized and coarser fractions, the indicator perists in concentrations well above background for at least 10 km of transport distance. In light of this, it seems unlikely that no signal of the indicator would be present in the coarse sand fraction, suggesting that the second scenario is the most likely.

The low concentrations in the sand fraction do indicate that for this particular lithology (quartz-epidote altered clasts), as well as lithologies of similar material strength, consideration of the concentration in the pebble fraction provides the strongest signal to background ratio.

It is interesting to note that the strongest, most discrete dispersal train of quartz-epidote altered basalt clasts appears to originate directly in the Fivemile Lake basin. The Fivemile Lake basin may represent an area where subglacial erosion has extensively quarried out intensely altered mafic volcanic rocks. In that case, it is not surprising that the strongest dispersal trend appears to originate in the Fivemile Lake basin.

Iron Formation

Magnetite-chert iron formation occurs in well-constrained areas of outcrop of limited aerial extent within the study area. Iron formation clasts are easily and unambiguously identifiable in all size fractions.

Iron formation associated with the Soudan Iron Formation outcrops in two prominent east-west trending belts in the study area. Prominent dispersal trains of iron formation lithologies extend in the down ice-flow direction of both these outcrop areas (Figures 9).

Iron formation clasts in the pebble fraction show a logarithmic decrease in concentration with increasing distance from the nearest up ice-flow iron formation outcrop (Figure 10). Sand-sized clasts, in contrast, show a significantly weaker trend, however concentrations do generally decrease with distance from iron formation outcrop (Figure 11).

The logarithmic decay in the concentration of the pebble fraction dispersal trains suggests the signal is the result of dilution by continued bedrock erosion. In contrast, the much weaker signal decay in the sand size fraction suggests the effects of dilution are somewhat buffered by the addition of particles to the sand size fraction due to comminution of larger clasts. Although the regression coefficients are low, the overall trend of the lines are similar to that predicted by theory (Figure 27).

Quartz-Ankerite±Sericite Alteration
Phyllitic clasts containing quartz, weathered ankerite, and sericite were noted in the pebble and cobble fractions of till at a number of locations in the study area generally south of the Murray Shear Zone. These quartz-ankerite±sericite dispersal trains appear to be small, localized, and to rapidly decay. Their occurrence stands in marked contrast to the longer, farther traveled quartz-epidote alteration and iron formation dispersal trains (Figure 12).

The pattern of quartz-ankerite±sericite dispersal trains suggests that altered clasts were quarried from numerous sources, and that comminution rapidly destroyed clasts in the coarser size fractions (>1 mm) in the down ice flow direction.

Consequently, the sample density of the present study is too wide-spaced to accurately define the extent of these dispersal trains.

The limited aerial extent of the quartz-ankerite dispersal trains, as well as the fact that identified clasts were in only the pebble and cobble size fractions suggests comminution is the dominant process controlling the strength and persistence of these dispersal trains.

MULTIVARIATE ANALYSIS

Analysis of drift petrography
Results of the factor analysis of petrographic data reduce the data set from 22 lithologic variables to seven factors. These seven factors account for 75% of the total sample variance (Table 3). Factor 1 accounts for 16% of the variance, and is loaded mainly by chemical sedimentary rocks (Table 3). This relation is not surprising considering the predominance and unique characteristics of iron formation throughout the region.

An inverse relation between mafic volcanic rocks and the combination of high-grade metamorphic, clastic sedimentary, and "other" clasts loads factor 2, which accounts for 13% of the variance (Table 3). The "other" category includes monomineralic grains such as quartz and feldspar, which are likely derived from gneisses and other granitic rocks of the Vermilion Massif. Essentially, there seems to be a tendency for samples to either have mafic volcanics, or the combination of high-grade metamorphic, clastic sedimentary, and "other" clasts.

Factor 3, accounting for 11% of the variance, is loaded by felsic intrusive rocks (Table 3), again reflecting the predominance of granite along the erosional flow path of the Rainy lobe.

Factor 4 is rather interesting and accounts for 12% of the variance (Table 3). An inverse relation between felsic volcanic clasts and mafic intrusive and high-grade metamorphic clasts loads this factor. Such a relation indicates that samples that have mafic intrusive and high-grade metamorphic clasts do not have felsic volcanics and vice versa. The importance of this relation is that these rock types are regional in extent. One might expect that a regional signal would be fully mixed within the glacial transportation and depositional process. Rather, this relation suggests that even regional signals are distinctly identifiable.

Sheared rocks and quartz-ankerite±sericite alteration control the variance on factor 5 (Table 3). This is an interesting relation in that sheared rocks account for only a small proportion of the bedrock. However, these clasts are distinctive and are found only in a few samples, thereby making them useful in discriminating certain samples.

An inverse relation between sheared rocks and "other" clasts loads factor 6, and clastic sedimentary rocks (Table 3) control the variance on factor 7. These factors account for 9 and 6% of the total variance, and the usefulness of these relations in determining regional relations is elusive.

The factor scores (Appendix D) for each sample can be plotted spatially and contoured to provide an image of the variance structure of the drift lithology in relation to bedrock types that control the variance on each factor. Two of the factors reflect local bedrock types that are of particular interest, iron formation and quartz-ankerite±sericite alteration. Figure 13 is a contour map of the factor 1 scores (predominantly reflecting the distribution of iron formation in the drift) in relation to the distribution of iron formation in the bedrock. Note that negative factor scores reflect the abundance of iron formation (Table 3), and the negative scores (red contours on Figure 13) are distributed to the SSW of a large knob of iron formation. This distribution clearly reflects the contribution of the positive relief of the iron formation to glacial quarrying and abrasion on the knob. The flow direction of the Rainy lobe is clearly imprinted in the multivariate analysis as the boundary between positive and negative factor scores trends about 190 degrees.

Similarly, the factor 5 scores (positive factor 5 scores indicate abundant quartz-ankerite±sericite) indicate the maximum abundance of quartz-ankerite-sericite alteration is found a short distance down glacier from the outcrops (Figure 14).

The most predominant signal in the drift petrography elucidated by the multivariate analysis is the distribution of iron formation (Factor 1) (Table 3). Other important signatures are regional in extent such as the apparent influence of the Vermilion Massif (Factor 2) and the inverse relation between volcanic clasts and mafic intrusive and high-grade metamorphic clasts (Factor 3). These relations suggest that regional signals are apparent, but that mixing is insufficient to overwhelm local bedrock signatures. (e.g. the relations described by Factor 3). The presence of local bedrock signatures is encouraging and is supported by the importance of sheared rocks and quartz-ankerite±sericite altered clasts.

What is missing, however, is any signature in the factor scores of the quartz-epidote altered clasts indicative of the Fivemile / Eagles Nest rock suite. Although these clasts produce a well-defined dispersal train from the Fivemile Lake area, the relatively low concentrtion of QEAB clasts results in their not influencing the overall variance among the glacial sediments.

These results suggest that multivariate analysis is an extremely valuable tool in the interpretation of extensive petrographic (and geochemical) data sets. The analyses reduce a large volume of data to a small number of factors, and the variables that control the largest proportion of the variance can be determined. In this case iron formation, a local signal is most important. Next a series of regional lithologies are important in sample discrimination. Another local signal, the quartz-ankerite±sericite altered clasts, is readily identifiable. Multivariate imaging of the relationship between drift and local bedrock, by overlaying contoured factor scores with controlling bedrock elements, also proves to be a useful tool. However, caution should be entertained when using multivariate analysis of lithologic and geochemical data, as some important local rock signatures may be of little importance in determining the variance among samples, as is the case with the quartz-epidote altered clasts. These clasts are an indicator of VMS associated alteration but are insignificant in controlling the sample variance.

Analysis of Mineralized Clast Areas defined in Report 318

Analysis of lithologic and geochemical data from Lawler and Riihiluoma (1997) identified five significant factors. The factor loadings are tabulated in Table 3. A direct relation between Cu and Co (Table 4) loads factor 1, which accounts for 14% of the total variance, therefore these two elements are commonly found together in samples. Factor 2 is loaded primarily by the concentration of Au, factor 3 by Cd, factor 4 by Mn, and factor 5 by Ni. Therefore the 12 common variables from the analytical procedure were reduced to 5 factors that suggest 6 elements control most of the variance. The factor scores for these 153 samples are tabulated in Appendix D. The individual sample factor scores were grouped by MCA number and the scores plotted on Figure 14.

Figure 15a is a plot of the factor 1 scores. There is considerable overlap of samples from all MCA's and there is no statistically significant difference among any of the MCA's. However, the average factor 1 score of MCA 1 is higher than all others, indicating that Cu and Co are slightly more abundant. The geological implications of this result are unclear. All other MCA's are similar with respect to factor 1.

Factor 2 scores, loaded primarily by gold, are plotted on Figure 15b. MCA 2 has the highest average gold values, and although not statistically significant, this is the only MCA that appears different from the others. As can be determined from Figures 15a, b, c, and d, MCA's 3-18 are indistinguishable.

Therefore the only MCA's that stand out, and again none of the differences are significant, are MCA's 1 and 2. MCA 1 because of its slightly elevated Cu and Co values and MCA 2 because of is gold signature. On the basis of these results one could define 3 MCA's: MCA 1, MCA 2, and all others (3-18), but with little confidence.

Analysis of geochemical relationship between bedrock and glacially-transported clasts, Fivemile Lake area

Nine factors accounting for 64% of the variance were defined. Factors 1 and 2 account for nearly 60% of the total variance. Factor 1 (41% of the variance) is loaded by the rare earth elements Nd, Sm, Gd, Tb, Dy, Ho, Er, Yb, Lu, as well as Y and Tm (Appendix E). The systematic variance of the rare earth elements in igneous rocks is well established. Correlation is slightly stronger in the heavy rare earth elements. An inverse relationship between V, Sc, Ti, Co, and Mn on the one hand and Si, U, Ta, Nb, and Zr on the other loads Factor 2, account for 18% of the variance. Factor 2 includes the high field strength elements (Ti, Zr, Nb, Sc, Ta), which are typically immobile during hydrothermal alteration. This variation is thus likely the result of fundamental differences in the relative proportions of these elements with increasing primary silica content of the suite of volcanic rocks sampled.

Factors 3-9 are related to elements, or element suites that behave in a similar fashion during hydrothermal alteration and mineralization. Extreme values of these factors stand out as anomalously high or low concentrations of the corresponding elements.

Strontium is the only component loading Factor 3, which accounts for 9% of the variance, and Ni, Mo, Cr, and Ba load Factor 4, accounting for 7% of the variance. Tl, Rb, and K load Factor 5, accounting for 5% of the variance. Sb and Pb load Factor 6, accounting for 4% of the variance. Zn, Cu, and W load Factors 7, 8, and 9, accounting for 8% of the variance between the three.

The most significant result of this exercise is that the samples collected in drill core and altered samples collected from glacial drift are statistically indistinguishable. Figure 16 is a plot of the factor scores for Factors 1 and 2 showing the complete overlap. In addition, the results of the students test indicates no difference in sample means at the 95% confidence level.

CONCLUSIONS

Results of this study indicate that distinctive rock types are readily identified in glacial sediments in the Vermilion District. The distribution of these distinctive clasts can be quantified and is directly related to bedrock source areas. The proportion of distinctive rock types drops off logarithmically with distance from the source. The changes in concentration in a particular size fraction are related to dilution as a result of addition of sediment by glacial erosion, and by comminution as clasts are broken down during transport. The results of this investigation are essentially the same as the results of similar studies in Canada and Scandinavia.

IMPLICATIONS FOR MINERAL EXPLORATION IN THE VERMILION DISTRICT

In contrast to much of Minnesota, the record of glacial erosion and deposition and its relation to bedrock is relatively simple in the Vermilion District. Consequently, glacial drift reflects local bedrock sources, whereas in thick-drift areas glacial sediments are ultimately derived from distant bedrock sources. Perhaps most significantly, the complicating factor of having multiple till sheets preserved in one area is eliminated. This means the last glacial event was in contact with the bedrock surface, and thus the composition of surface drift exposures is a direct reflection of the underlying bedrock. These factors combine to suggest glacial drift prospecting is a viable exploration tool in the Vermilion District on a number of scales.

In contrast to previous studies (see Introduction), results of the present study indicate that application of glacial drift prospecting techniques to the thin drift areas of northern and northeastern Minnesota promises to be enormously successful. Glacial dispersal trains from distinctive lithologies are present and identifiable. Even with the limited sample density of this investigation it is possible to calculate dilution and comminution rates. Therefore if host rock lithologic signals can be found in the drift there is a mechanism for determining potential distance from source.

The till unit examined in this study is the youngest stratigraphically, and therefore the uppermost, in northeastern Minnesota. Therefore, the potential exists for recognition of indicator dispersal trains, derived from bedrock in the Vermilion District, in this surface till in the down-ice direction beyond the point where it overlaps older drift units. Dilution and comminution clearly play a role in the evolution of indicator signals in the area where active quarrying and abrasion of bedrock and subsequent entrainment of debris are occurring. The factors and processes affecting the evolution of an indicator signal in a glacier overriding older drift deposits are as yet problematic.

This problematic relationship suggests that the fundamental problem in extrapolating glacial indicator exploration techniques from areas of thin drift (like the Vermilion District) to areas of thick drift (like the bulk of Minnesota) lays in deciphering how local, bedrock derived indicator signals evolve into regional signals. Parent et al. (1996) have demonstrated that distinctive dispersal trains in drift can be remobilized by subsequent glacial advances and remain distinctive signals of nearby mineralization. Bird and Coker (1987) showed how indicator-rich drift could be incorporated into tills deposited from subsequent, overriding glacial events. Even though the two aforementioned studies show that dispersal trains can persist through multiple glaciations and can be preserved in multiple stratigraphic units, we still have no fundamental understanding of how local bedrock indicators are transformed into a regional signature that can be mapped and traced to a source.

UTILITY OF LITHOLOGIC STUDY OF TILLS FOR MINERAL EXPLORATION

Results of this study indicate a strong correlation between drift lithology and local bedrock exists in the Vermilion District. Thus in addition to the conventional glacial indicator tracing techniques of heavy mineral and fine- or clay-fraction geochemistry, careful consideration of drift lithology may serve as a powerful exploration tool. In addition to conventional uses for till lithologic data (namely determining transport distances) it may be useful for:

Correlation of specific lithologies with coincident geochemical anomalies
This study has demonstrated that particular alteration styles associated with VMS and lode gold occurrences can have as distinctive a lithologic signature as one might expect of their trace-element geochemical signature. By examining the cobble and pebble fractions of tills, it is possible to distinguish any number of unique lithologies, and quantify their occurrence. Careful consideration of the presence of one or more unique lithologies coincident with a geochemical anomaly may serve to place an otherwise 'generic' anomaly into a lithologic framework.

In the same way that correlation can be established between geochemical variables in a till, it may be possible to establish correlation between unique lithological and geochemical variables. In addition to helping constrain the geological environment of the source of the geochemical anomaly, a lithologic dispersal train is much more readily identifiable in the field, and may assist in speeding up the process of tracing glacial dispersal trains to their sources.

Reconnaissance scale mapping, and lithologic/geochemical characterization in poorly exposed areas
Despite the Vermilion District standing out as an area of 'better' outcrop relative to the rest of Minnesota, it is in absolute terms still an area of poor exposure. Glacial drift, dense vegetation, swamps, or water cover a relatively large amount of this area.

It has been shown that the composition of coarser fractions of till in the Vermilion District is in large part controlled by local bedrock compositions. Thus, careful consideration of the relative amounts of till components and their dispersal patterns in combination with previous geologic mapping promises to provide a greater understanding of the bedrock composition of covered terrain.

DIRECTIONS FOR FUTURE STUDY

This investigation set out to investigate the fundamental relation between drift and associated bedrock. Therefore the lithologic components of the glacial sediments were chosen as the primary variables as they fundamentally reflect bedrock lithology. Geochemical and heavy mineral signatures were not considered by this study because they do not elucidate these relationships. Results of this study suggest three primary directions for further investigation into the fundamental nature of the relations between glacial drift composition and bedrock geology.

1. The readily identifiable lithologic dispersal trains associated with VMS and Lode Gold alteration must be associated with coincident geochemical and heavy mineral indicators. The exact relationship between these lithologic and geochemical and heavy mineral indicators has yet to be elucidated. Additional sampling and geochemical and heavy mineral analyses would provide the data necessary to quantify the relations between lithology and mineralization as recorded in drift, and in bedrock. For example, VMS-associated alteration haloes are typically much more extensive than the actual mineralization. Therefore, one would not expect a Cu-Zn till geochemical anomaly (indicative of mineralization) to have as large an aerial extent as the lithologic signature indicative of the alteration zone.

2. The Rainy lobe till sampled in this investigation extends farther to the south where it overlies older glacial sediment. The continuity of lithologic and geochemical anomalies over the transition from thin to thick drift has never been satisfactorily explored. Extension of the sampling and analyses from the present study area into the thick drift area to the south and west will provide information necessary to evaluate factors and processes controlling preservation of indicator trains in areas with multiple glacial stratigraphies. Knowledge of the variability of indicator trains in thick drift areas can be extended to the subsurface for optimizing exploration using buried stratigraphic units.

3. Geostatistical and multivariate techniques could be employed to evaluate the spatial relations among glacial stratigraphy, sedimentology, and sample geochemistry from previous overburden drilling programs (e.g. Martin et al., 1988, Martin et al., 1989, Martin et al., 1991). Such investigations would better define

stratigraphy and the factors that control variability in till units in this region. Geochemical anomalies and their spatial scales can be defined, related to parent glacial units, and mapped. A clear understanding of the spatial scales of variability of stratigraphic units and geochemical signatures would allow definition of appropriate exploration drill hole density. Results of spatial analyses of buried tills could be compared to the spatial scales of variability of surface tills that lie over bedrock or older glacial sediment. Such a comparison may enhance the use of buried drift geochemistry as an exploration tool.

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TABLES

Table 1 Sample Locations and Descriptions

Sample Number	UTMN Coordinates Easting	Northing	Drift Material
326-002	587326	5305729	Till/Unstratified
326-003	583457	5301936	Outwash/Stratified
326-005	576319	5300390	Till/Unstratified
326-006	561440	5296244	Till/Unstratified
326-007	561906	5296149	Outwash/Stratified
326-008	563143	5296259	Till/Unstratified
326-009	564302	5296363	Ice-Contact
326-010	562293	5294554	Lacustrine
326-011	562367	5294307	Till/Unstratified
326-012	562774	5294150	Till/Unstratified
326-013	563585	5294318	Till/Unstratified
326-014	563787	5295226	Till/Unstratified
326-015	564135	5295302	Outwash/Stratified
326-016	558531	5285384	Indeterminate
326-017	558476	5285609	Till/Unstratified
326-018	557289	5288791	Outwash/Stratified
326-019	558551	5289466	Ice-Contact
326-020	559011	5289808	Till/Unstratified
326-021	558942	5289891	Ice-Contact
326-022	559020	5290291	Till/Unstratified
326-023	558875	5289668	Till/Unstratified
326-024	557251	5287076	Ice-Contact
326-025	557565	5287161	Till/Unstratified
326-026	558201	5287161	Till/Unstratified
326-027	557811	5286131	Outwash/Stratified
326-028	558436	5287161	Till/Unstratified
326-029	559221	5287290	Till/Unstratified
326-031	559862	5287437	Till/Unstratified
326-032	560083	5287627	Till/Unstratified
326-033	560145	5287827	Ice-Contact
326-034	560446	5287818	Ice-Contact
326-035	560925	5287479	Till/Unstratified
326-036	561071	5287506	Till/Unstratified
326-037	561157	5287489	Till/Unstratified
326-038	561359	5287536	Till/Unstratified
326-039	553684	5287039	Till/Unstratified
326-040	552427	5286597	Till/Unstratified
326-041	549927	5286168	Till/Unstratified
326-042	547292	5286319	Outwash/Stratified
326-043	546812	5286341	Outwash/Stratified
326-044	561258	5297474	Outwash/Stratified
326-045	554129	5292863	Outwash/Stratified
326-046	564443	5292744	Outwash/Stratified
326-047	565298	5292100	Till/Unstratified
326-048	565624	5292008	Till/Unstratified
326-049	565865	5291998	Till/Unstratified
326-050	565704	5291281	Till/Unstratified
326-051	565326	5290802	Till/Unstratified
326-053	563046	5292493	Till/Unstratified
326-054	562676	5292691	Till/Unstratified
326-055	562191	5293577	Outwash/Stratified
326-057	561533	5297935	Till/Unstratified
326-058	561693	5298371	Ice-Contact
326-059	562185	5298910	Outwash/Stratified
326-060	563220	5298895	Indeterminate
326-061	554080	5289427	Outwash/Stratified
326-062	555059	5289388	Till/Unstratified
326-063	554137	5289238	Outwash/Stratified
326-064	553767	5289210	Outwash/Stratified
326-065	554272	5292330	Outwash/Stratified
326-066	554523	5292229	Outwash/Stratified
326-067	555166	5291445	Till/Unstratified
326-068	556012	5291160	Outwash/Stratified
326-069	556743	5290985	Till/Unstratified
326-070	557584	5291442	Till/Unstratified
326-072	557890	5291800	Till/Unstratified
326-072	558532	5291899	Till/Unstratified
326-073	559025	5292195	Till/Unstratified
326-074	558990	5292689	Till/Unstratified
326-075	558700	5293151	Till/Unstratified
326-076	558142	5293518	Till/Unstratified
326-077	558024	5295482	Outwash/Stratified
326-078	563135	5298333	Till/Unstratified
326-079	564425	5298530	Till/Unstratified
326-080	565545	5298646	Indeterminate
326-081	580881	5304751	Outwash/Stratified
326-082	579827	5305351	Till/Unstratified
326-083	579194	5305765	Till/Unstratified
326-084	578767	5306176	Till/Unstratified
326-085	578675	5306614	Outwash/Stratified
326-086	578946	5308093	Till/Unstratified
326-087	577551	5307232	Outwash/Stratified
326-088	577210	5307396	Outwash/Stratified
326-089	574246	5297409	Outwash/Stratified
326-090	573801	5297309	Outwash/Stratified
326-091	573241	5297047	Till/Unstratified
326-092	572648	5296778	Till/Unstratified
326-093	572036	5296826	Till/Unstratified
326-094	571455	5296854	Indeterminate
326-095	565882	5296374	Ice-Contact
326-096	566138	5296978	Till/Unstratified
Sample Number	**UTMN Coordinates**		**Drift Material**

	Easting	Northing	
326-097	566761	5296834	Till/Unstratified
326-098	566521	5297514	Ice-Contact
326-099	566648	5298802	Ice-Contact
326-100	566963	5299691	Outwash/Stratified
326-101	567826	5299155	Till/Unstratified
326-102	567731	5298165	Till/Unstratified
326-103	567789	5297503	Till/Unstratified
326-104	569601	5296969	Outwash/Stratified
326-105	567909	5294899	Outwash/Stratified
326-106	567515	5294699	Outwash/Stratified
326-107	566781	5294388	Outwash/Stratified
326-108	566271	5294493	Outwash/Stratified
326-109	566093	5294977	Ice-Contact
326-110	566884	5295629	Outwash/Stratified
326-111	566978	5296153	Ice-Contact
326-112	567494	5296713	Outwash/Stratified
326-113	568164	5297298	Till/Unstratified
326-114	576388	5300694	Till/Unstratified
326-115	576364	5301405	Till/Unstratified
326-116	569258	5290302	Outwash/Stratified
326-117	569293	5289601	Outwash/Stratified
326-118	568699	5288948	Outwash/Stratified
326-119	568569	5288254	Outwash/Stratified
326-120	567501	5287372	Ice-Contact
326-121	566433	5287677	Outwash/Stratified
326-122	565682	5288187	Outwash/Stratified
326-123	564848	5288141	Till/Unstratified

Table 2 Categories used to classify lithology of clasts in drift

1 Mafic Volcanic Rocks
- 1a Massive Mafic Volcanic
- 1b Porphyritic Mafic Volcanic
- 1c Mafic Breccia
- 1d Mafic Hyaloclastite
- 1e Mafic Volcaniclastic Sediments
- 1f Ultramafic/Komatiite

2 Felsic Volcanic Rocks
- 2a Massive Felsic Lava
- 2b Porphyritic Felsic Volcanic
- 2c Felsic Breccia
- 2d Felsic Volcaniclastic Sediments
- 2e Felsic Tuff/Pyroclastic

3 Clastic Sedimentary Rocks
- 3a Greywacke-Slate
- 3b Shale-Phyllite
- 3c Siltstone
- 3d Conglomerate
- 3e Graphitic Argillite

4 Chemical Sedimentary Rocks
- 4a Oxide Facies BIF
- 4b Sulfide Facies BIF
- 4c Carbonate Facies BIF
- 4d Silicate Facies BIF
- 4e Chert
- 4f Carbonate Rock

5 Sheared Rocks
- 5a Quartz-sericite Schist
- 5b Quartz-ankerite Schist
- 5c Quartz-sericite-ankerite Schist
- 5d Chlorite Schist/Phyllite
- 5e Carbonaceous Phyllite
- 5f Talc-Chlorite Schist
- 5g Carbonate-Fuchsite Schist
- 5h Qtz/ser/green mica Schist
- 5i Mylonitic Rock

6 Felsic Intrusive Rocks
- 6a Kspar/plag bearing Granitoid
- 6b Plagioclase bearing Granitoid
- 6c Granite
- 6d Granodiorite
- 6e Monzonite
- 6f Tonalite
- 6g Trondhjemite
- 6h Diorite
- 6i Syenite
- 6j Quartz Monzonite

7 Mafic Intrusive Rocks
- 7a Microgabbro
- 7b Gabbro
- 7c Peridotite
- 7d Lamprophyre

8 High-grade Metamorphic Rocks
- 8a Biotite Schist
- 8b Amphibolite
- 8c Gneiss
- 8d Migmatite

9 Other (including altered rocks and individual mineral grains)
- QV Quartz vein material

Table 3 Factor loadings for drift lithology data

Lithology	**Factor**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mafic Volcanic Rocks	VAR3	0.0831	-0.8396	0.1729	0.3095	-0.1520	0.0240	-0.0898
Felsic Volcanic Rocks	VAR4	-0.1933	0.1737	0.1152	-0.7315	0.1984	0.2126	-0.0650
Clastic Sedimentary Rocks	VAR5	0.2788	0.6587	0.2780	-0.1551	0.0298	-0.4511	0.0112
Chemical Sedimentary Rocks	VAR6	-0.8068	0.0167	0.0190	-0.3675	0.1505	0.1373	0.0347
Sheared Rocks	VAR7	-0.1565	0.0270	0.2860	-0.0680	0.7941	-0.0910	0.0294
Felsic Intrusive Rocks	VAR8	-0.0895	0.2527	-0.8477	0.0061	-0.1778	0.0029	0.0471
Mafic Intrusive Rocks	VAR9	0.4381	-0.2405	0.3194	0.0420	-0.2437	0.3181	-0.3020
High-grade Metamorphic Rocks	VAR10	0.2182	0.5307	0.0623	0.4834	-0.0689	0.2410	0.2183
Other (including mineral grains)	VAR11	-0.0302	0.0654	-0.0799	-0.1225	0.2911	-0.8319	0.0240
Quartz-Epidote Alteration	VAR12	0.4244	-0.3308	-0.1140	-0.4250	0.1588	0.0670	-0.3209
Quartz-Ankerite(-Sericite) Alteration	VAR13	0.1292	-0.0740	-0.1100	-0.0196	0.8799	-0.0305	-0.0595
Iron Formation	VAR14	-0.7915	-0.0873	0.0385	-0.2506	0.1076	0.0621	0.1355
Mafic Volcanic Rocks	VAR15	0.1413	-0.7153	0.3666	0.0266	0.0934	0.0923	0.0043
Felsic Volcanic Rocks	VAR16	-0.0422	0.0746	0.2861	-0.8514	-0.0145	0.0137	0.1513
Clastic Sedimentary Rocks	VAR17	-0.1232	-0.1026	0.1581	0.0064	0.0312	0.0521	-0.8980
Chemical Sedimentary Rocks	VAR18	-0.8350	0.0587	0.0028	-0.1464	-0.0788	0.0274	-0.1957
Sheared Rocks	VAR19	0.1168	0.0785	0.1603	0.1419	-0.1420	-0.8286	0.0388
Felsic Intrusive Rocks	VAR20	0.1998	0.1440	-0.8525	0.0528	0.0590	0.1483	0.1417
Mafic Intrusive Rocks	VAR21	0.1665	-0.2242	0.2763	0.5224	0.1843	0.1811	-0.0756
High-grade Metamorphic Rocks	VAR22	0.1670	0.2741	0.3102	0.5147	-0.0487	0.1403	0.1832
Other (including mineral grains)	VAR23	-0.2129	0.6674	-0.3801	0.1657	-0.1406	-0.0778	0.0852
Iron Formation	VAR24	-0.8315	0.0980	-0.0262	0.1701	-0.1378	-0.0370	-0.1619
	Expl.Var	3.44913	2.83862	2.37163	2.65285	1.82286	1.91773	1.24311
	Prp.Totl	0.15677	0.12902	0.10780	0.12058	0.08285	0.08717	0.05650

Table 4 Factor loadings for Project 318 data.

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Au	0.780	0.140	0.110	-0.050	-0.090
Ag	0.490	0.270	-0.450	0.000	-0.270
Cu	0.000	0.750	0.000	0.000	0.000
Pb	0.590	-0.170	0.140	-0.520	0.140
Zn	0.000	0.300	-0.080	-0.620	0.240
As	0.740	0.000	-0.120	0.110	-0.120
V	-0.450	0.450	-0.510	-0.310	-0.080
Cr	-0.060	0.370	0.740	-0.220	-0.110
Co	0.090	0.770	0.000	-0.280	0.140
Ni	0.000	0.310	0.090	-0.710	0.000
Ba	-0.580	0.000	-0.400	-0.360	-0.190
Cd	-0.100	0.150	-0.860	0.000	0.150
Variance (%)	20.78	17.06	13.12	9.12	7.62
Total Variance = 67.70%					

ILLUSTRATIONS

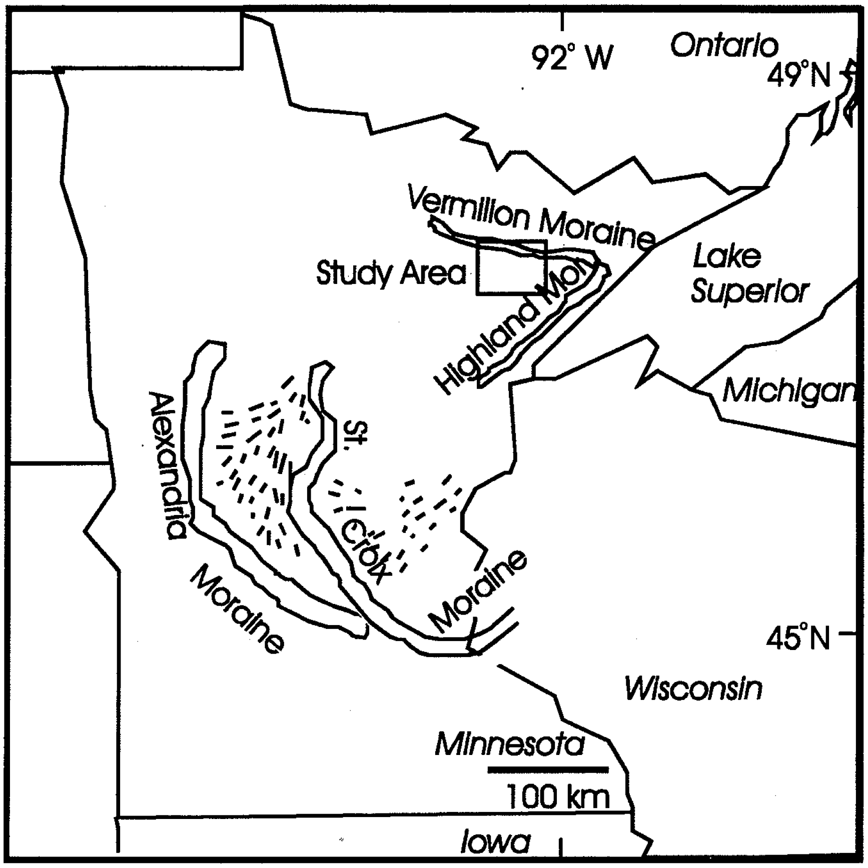

Figure 1. *General location of study area in relation to major Late Wisconsinan glacial landforms*

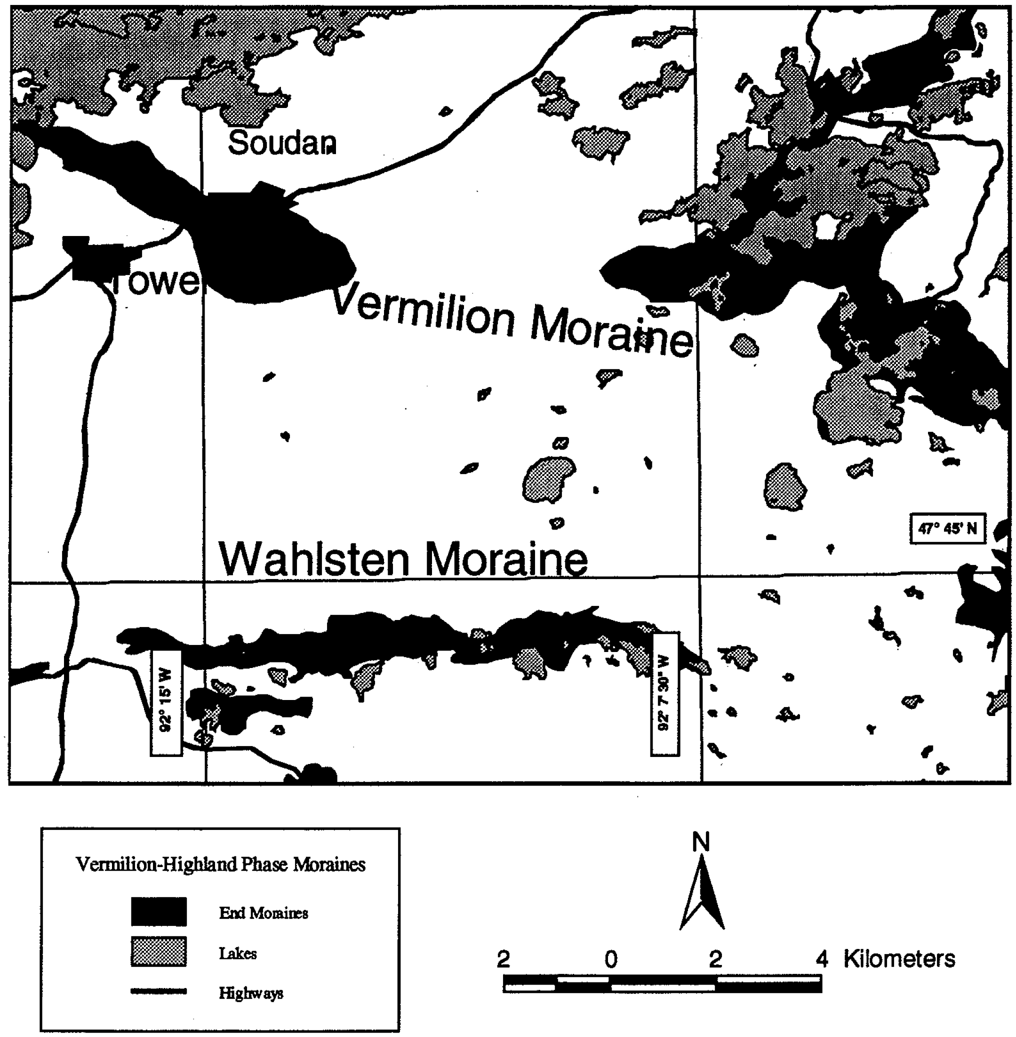

Figure 2. *Major Rainy lobe landforms in study area.*

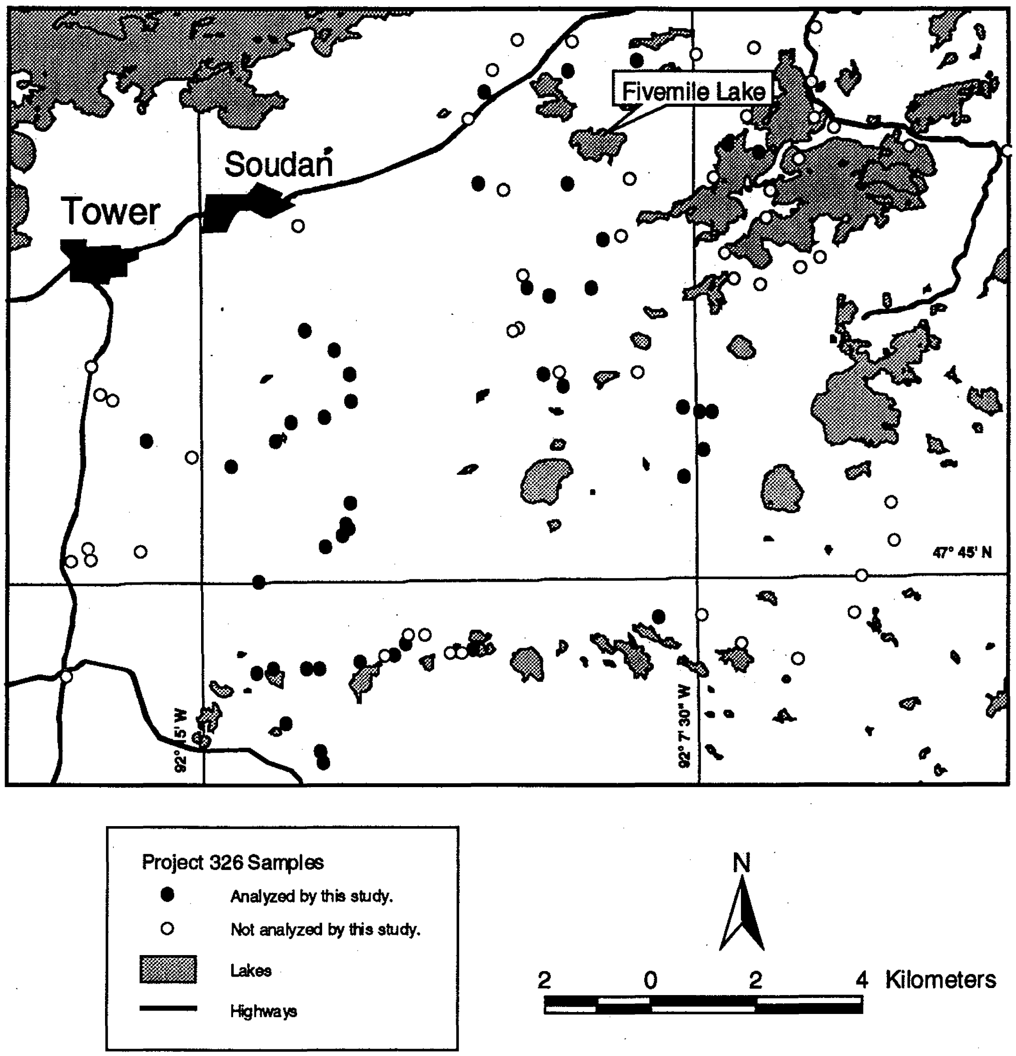

Figure 3. Location of study area, showing sample locations.

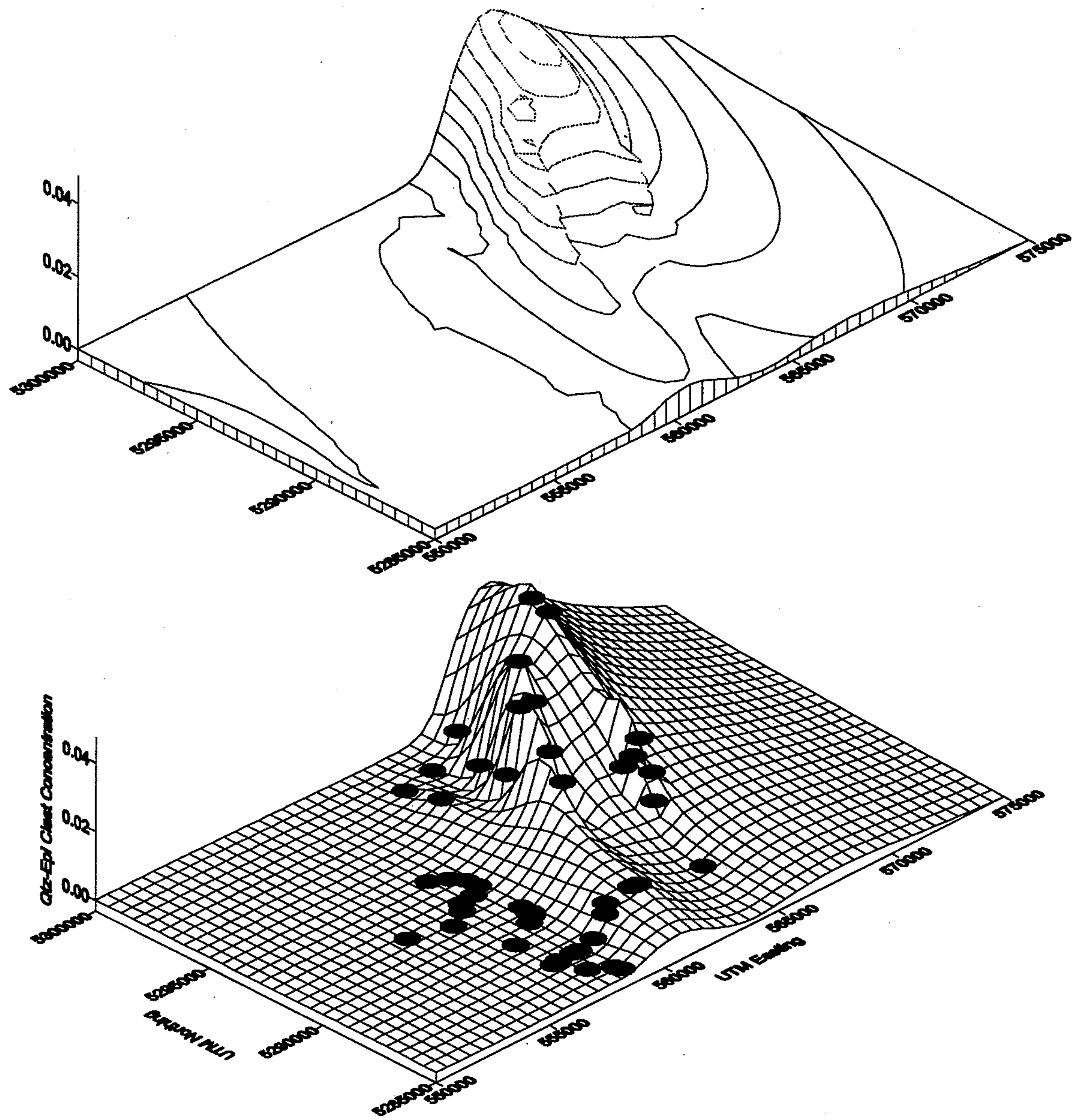

Figure 4. *Three-dimensional plot of quartz-epidote alteration dispersal train.*

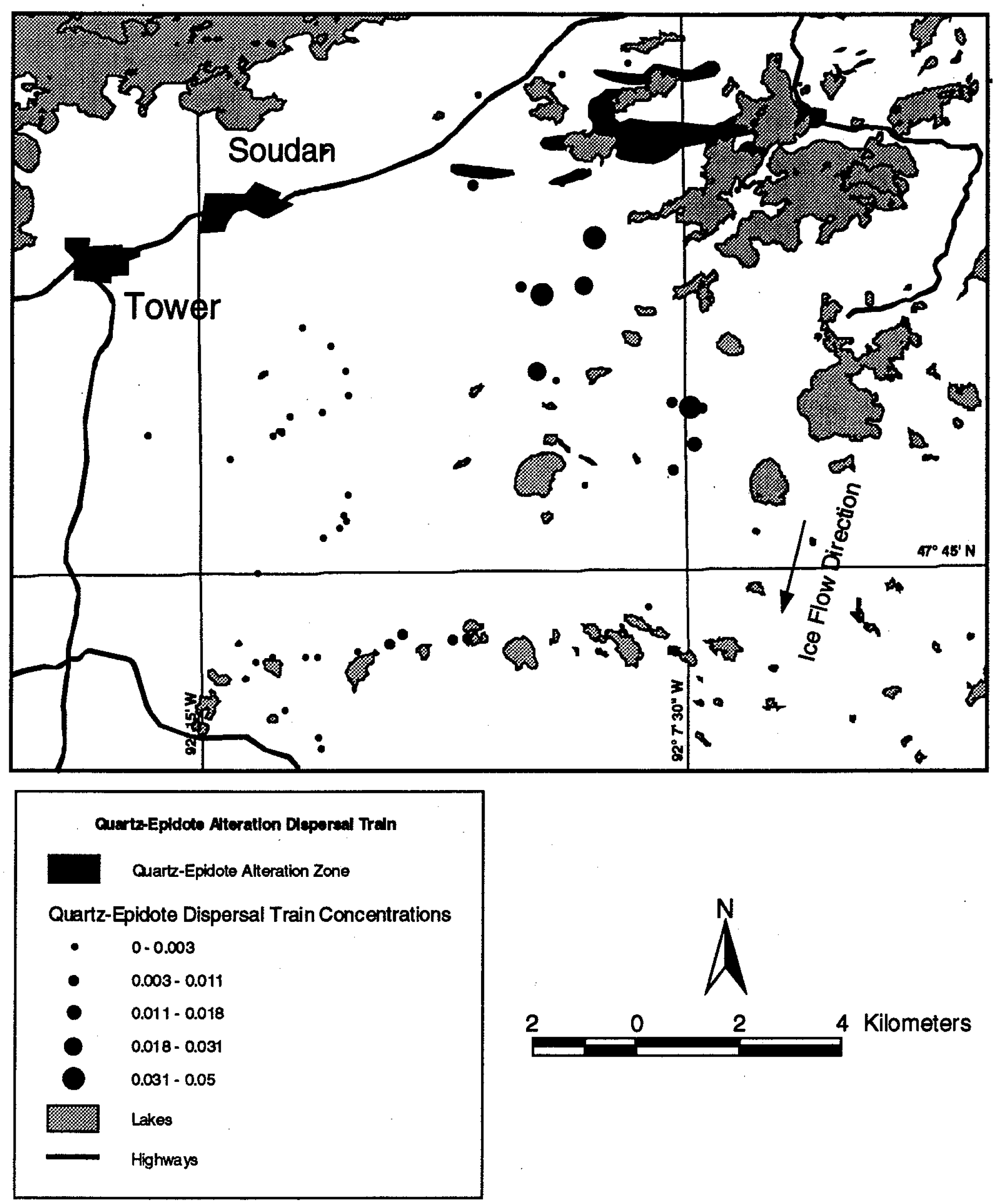

Figure 5. *Map of quartz-epidote alteration dispersal train*

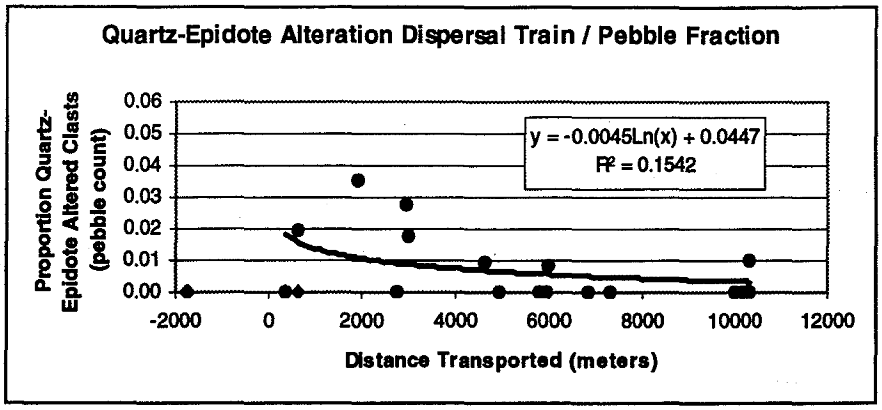

Figure 6. *Cross-sectional view of quartz-epidote alteration dispersal train, pebble fraction (stone count).* Circles are samples from dispersal train; diamonds are 'background' values up-ice from the head of the train. Note the low coefficient of multiple determination.

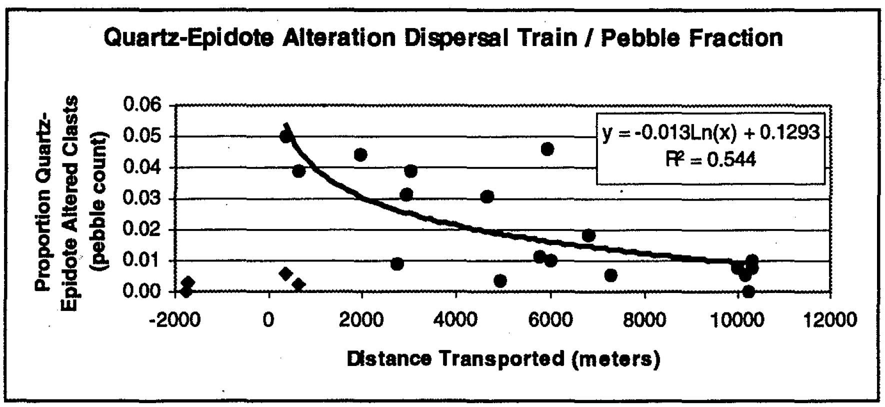

Figure 7. *Cross-sectional view of quartz-epidote alteration dispersal train, pebble fraction (weight pct.).* Circles are samples from dispersal train; diamonds are 'background' values up-ice from the head of the train. Note the high coefficient of multiple determination, relative to Figure 17.

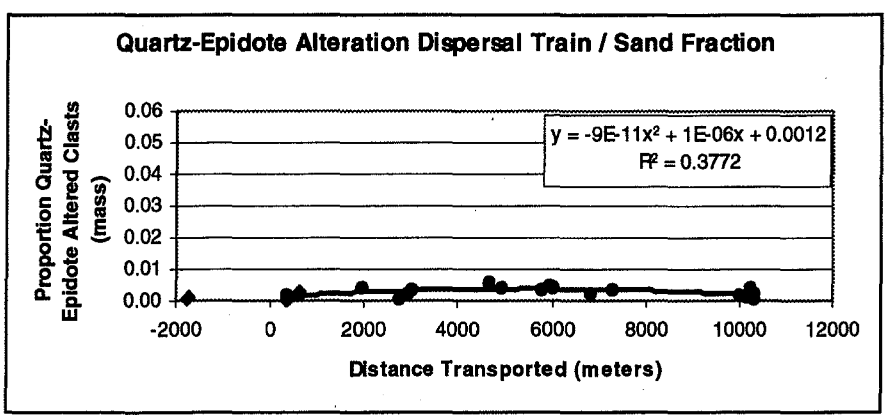

Figure 8. *Cross-sectional view of quartz-epidote alteration dispersal train, sand fraction.* Circles are samples from dispersal train; diamonds are 'background' values up-ice from the head of the train. Note the concave-downward shape of dispersal pattern.

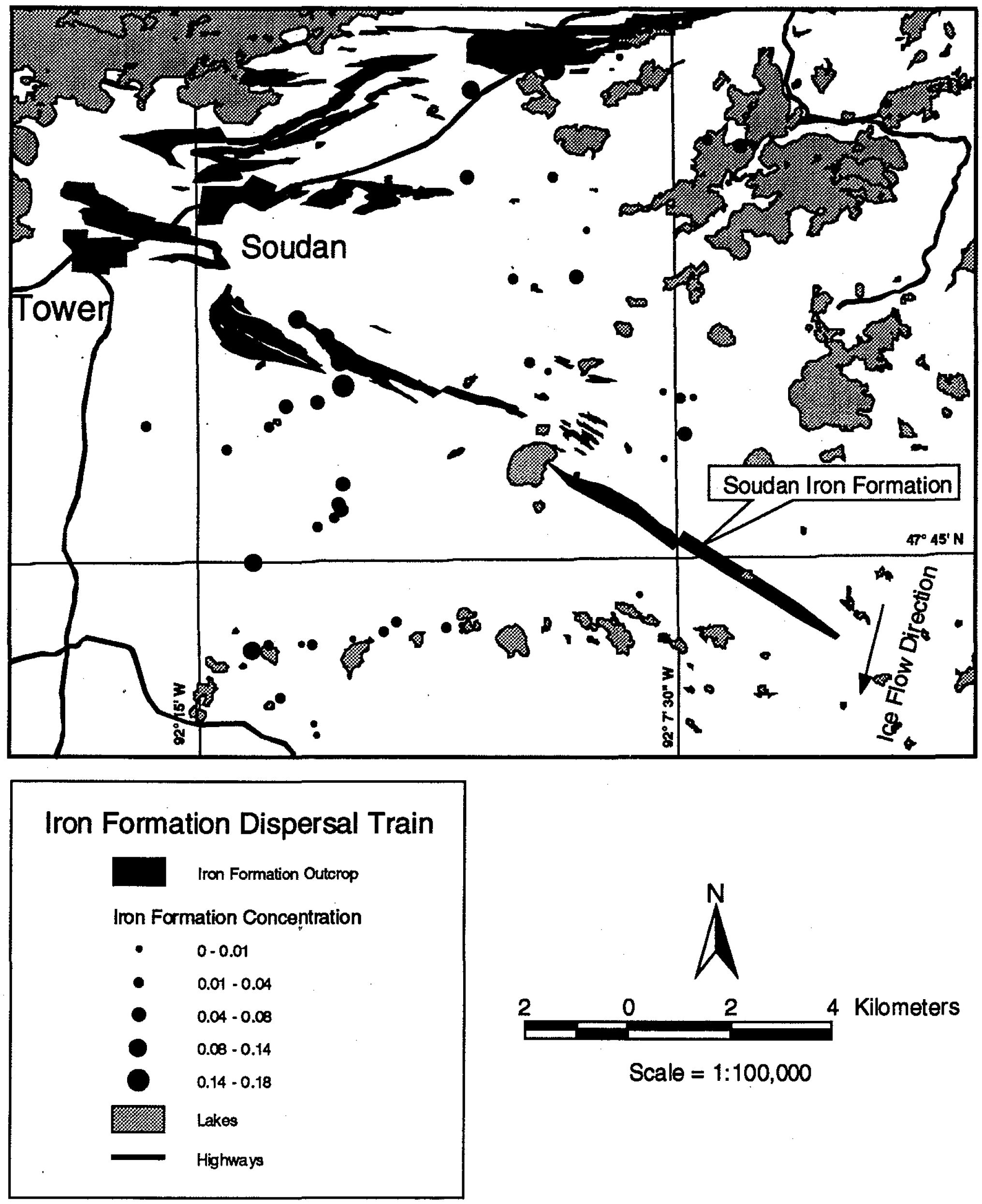

Figure 9. Map of iron formation dispersal train.

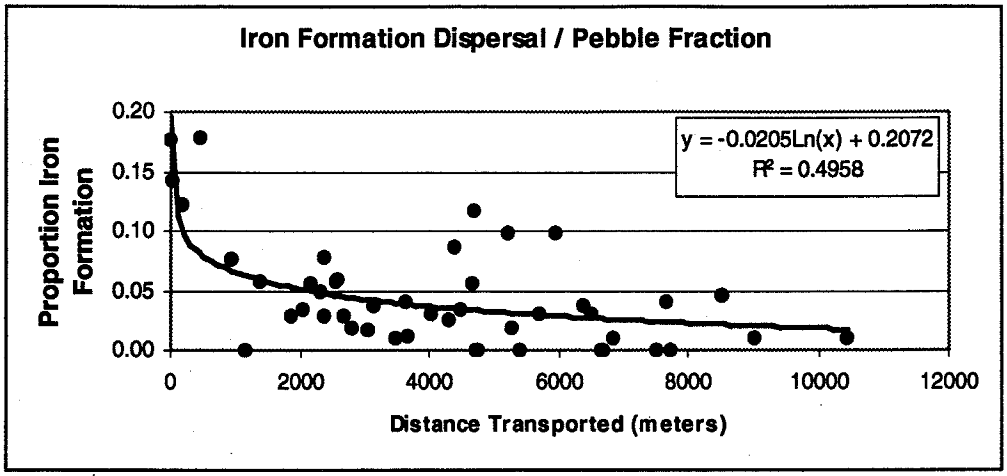

Figure 10. *Cross-sectional view of iron formation dispersal pattern, pebble fraction.* Note the logarithmic decay of dispersal pattern, similar to that in Figure 7.

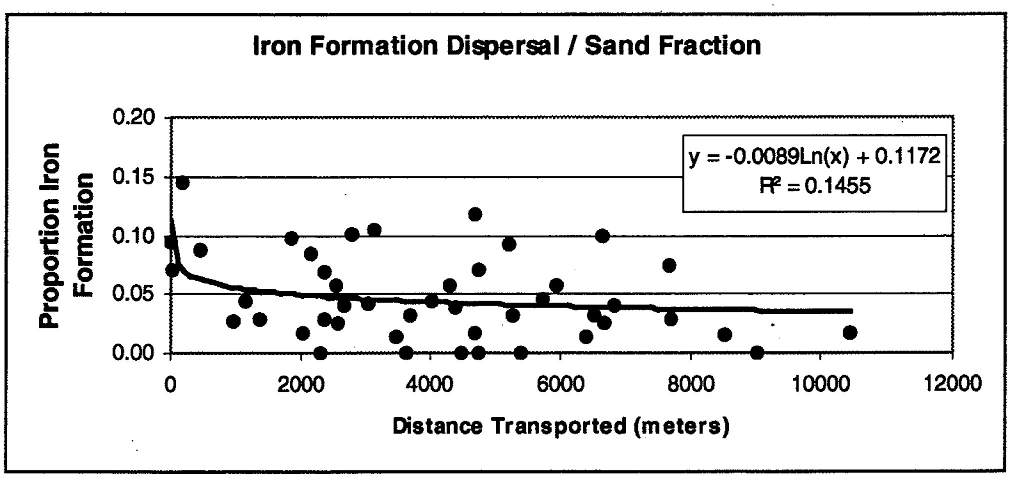

Figure 11. *Cross-sectional view of iron formation dispersal pattern, sand fraction.* Note the 'flattening' of curve between ~2000 and 6000 meters. The form is intermediate to the curves seen in Figures 7 and 8.

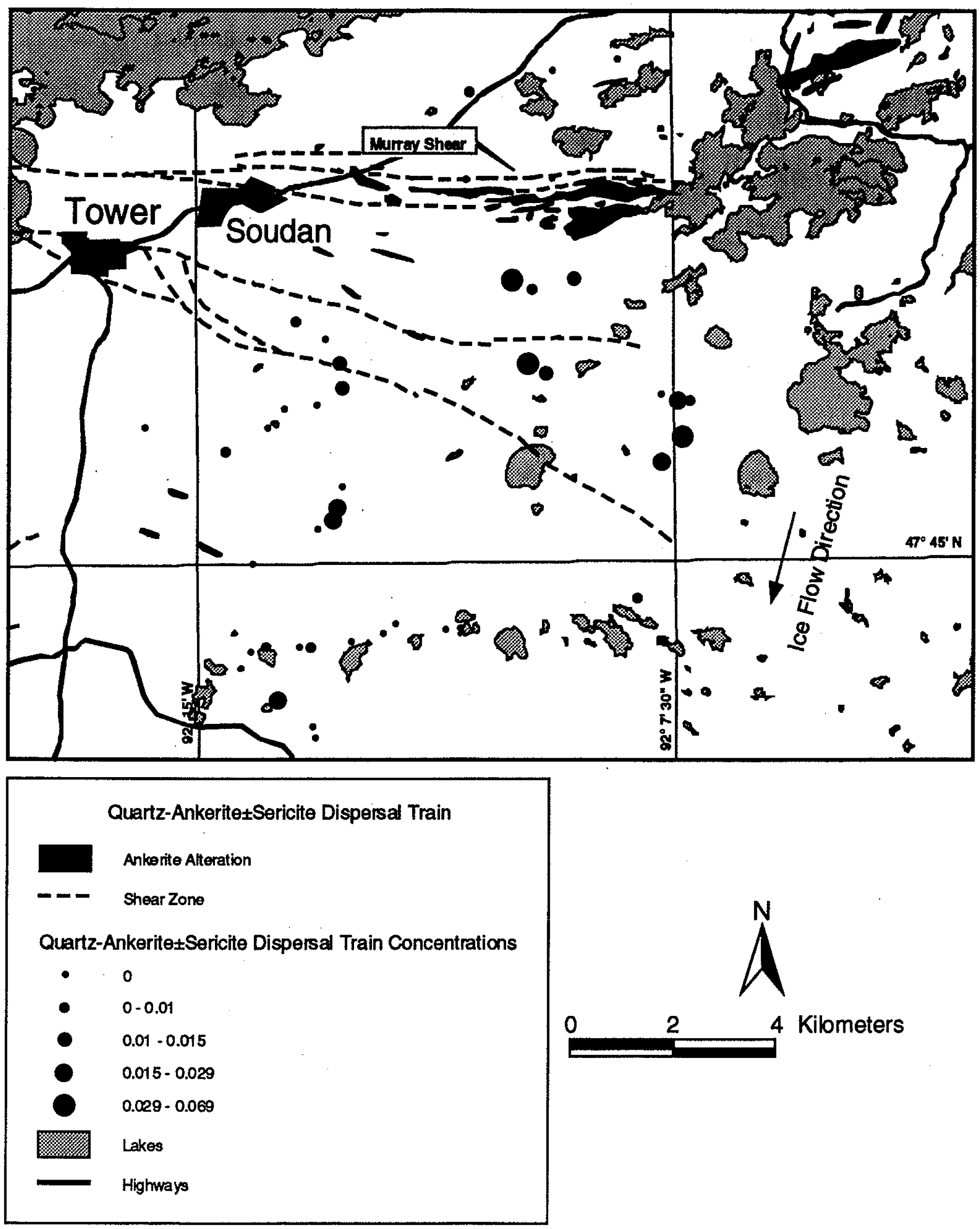

Figure 12. Map of quartz-ankerite±sericite alteration dispersal trains.

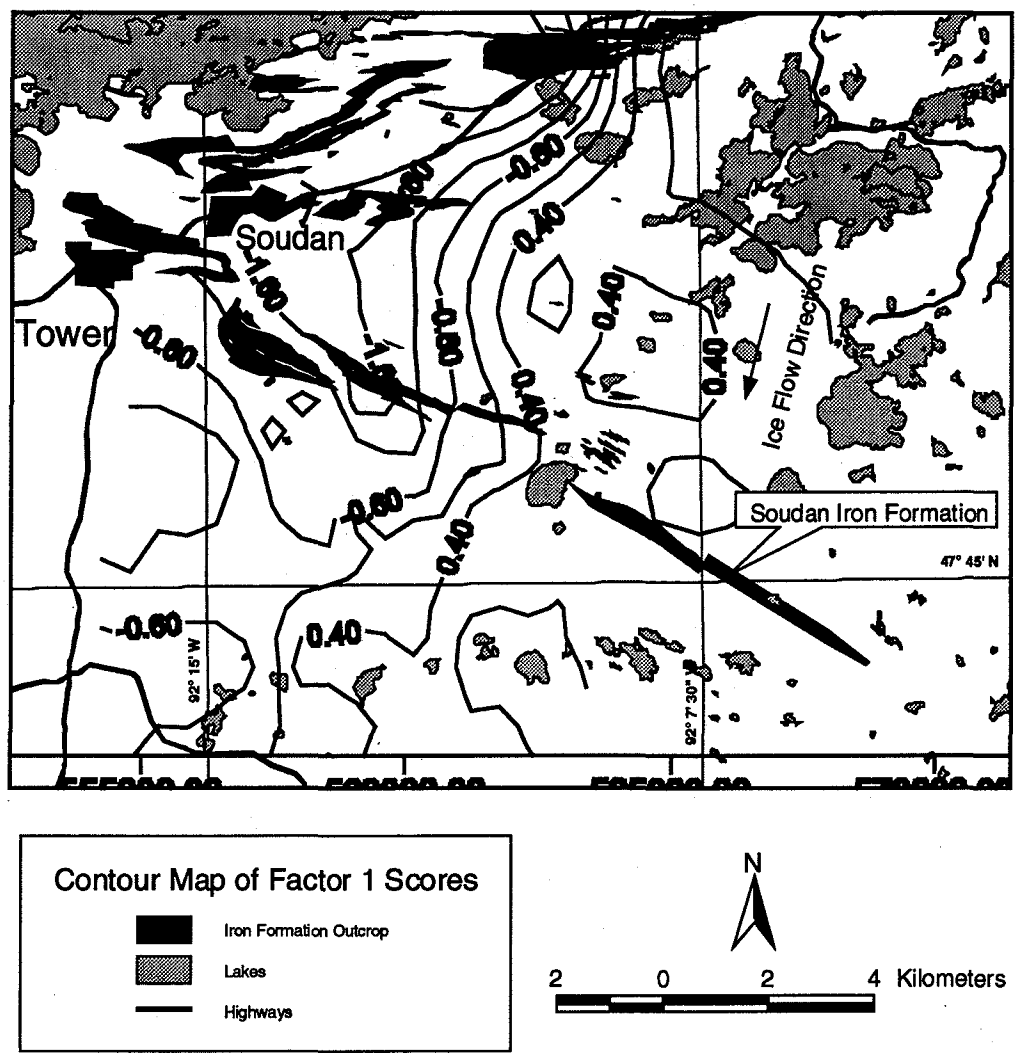

Figure 13. *Contour map of Factor 1 (Drift Lithology) scores in relation to iron formation outcrop.*

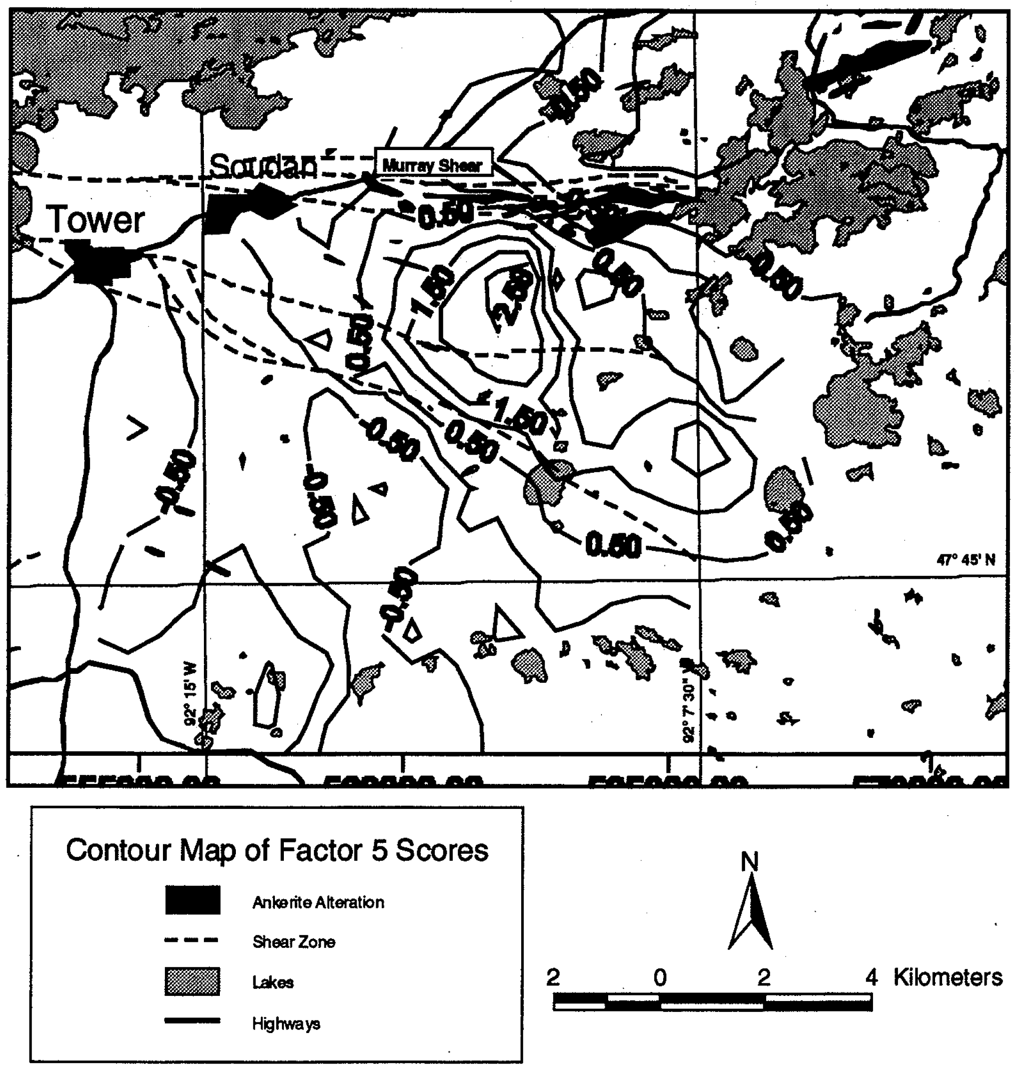

Figure 14. Contour map of Factor 5 (Drift Lithology) scores in relation to quartz-ankerite±sericite alteration

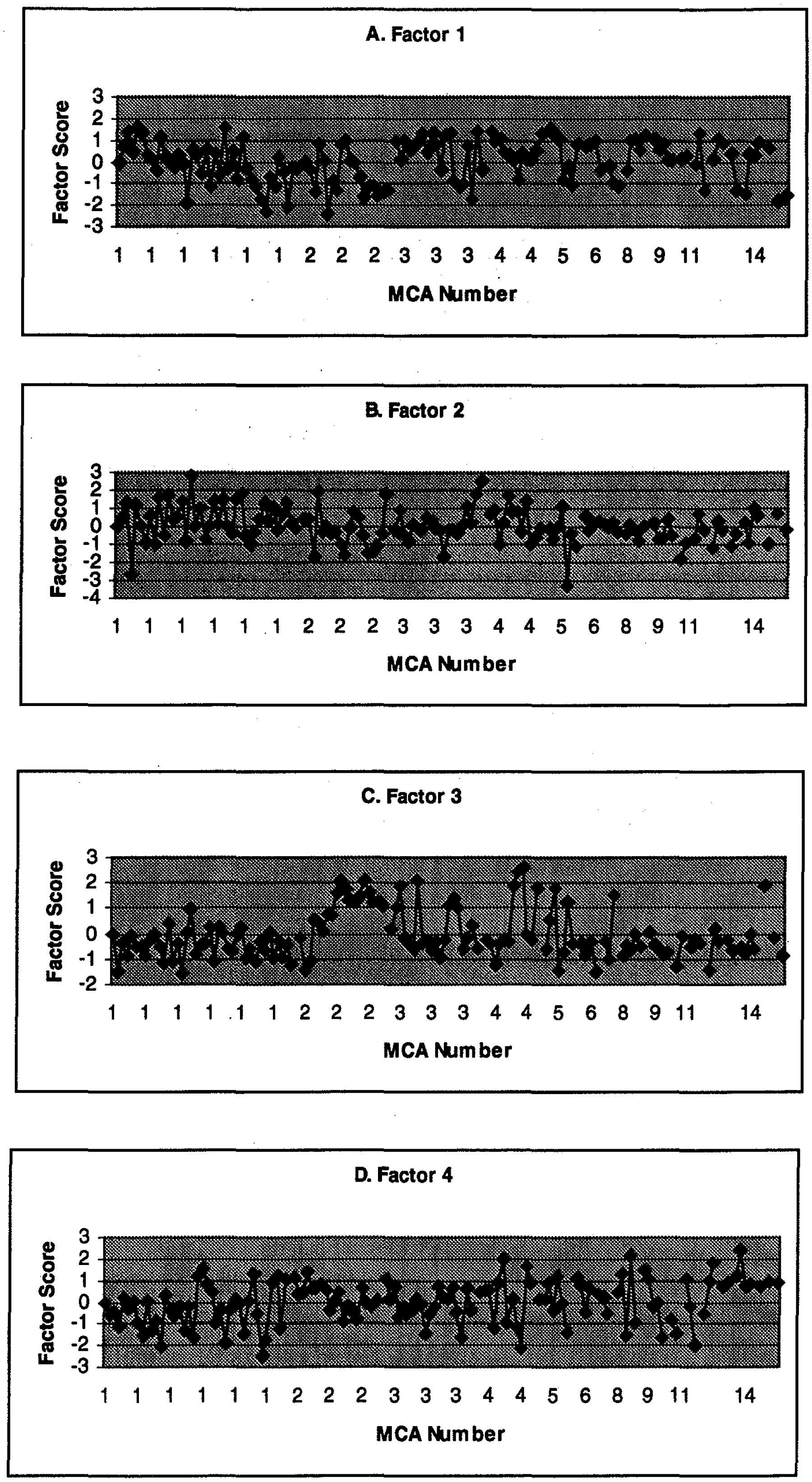

Figure 15. *Project 318 data factor scores.* Classified by Mineralized Clast Area.

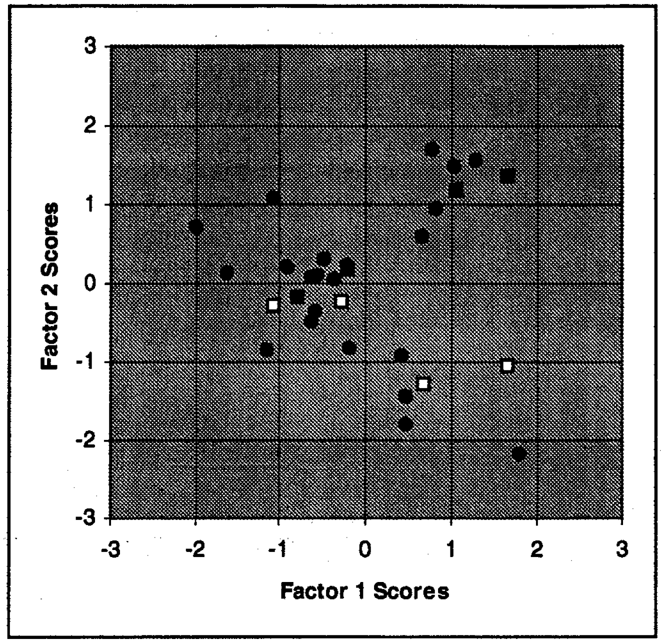

Figure 16. *Plot of Factor 1 vs. Factor 2 for Fivemile geochemical data.* Factor 1 is loaded by the rare earth elements; Factor 2 is loaded by high field strength elements. Circles are drill core collected at the Fivemile Lake Prospect, closed squares are altered basalt cobbles collected from drift 2 km down-ice of the prospect, and open squares are unaltered basalts collected from drift.

APPENDICES

APPENDIX A: GLACIAL PROCESSES

Processes of Glacial Erosion

Glacier Velocity

For a glacier that is in a state of dynamic balance between accumulation and ablation, the annual accumulation of ice a (ma-1) over some distance x (m) from the ice divide must pass through a vertical section of thickness h (m) with a velocity u (ma-1) such that:

$$ax = uh\,, \tag{1}$$

and the glacier's velocity is given by

$$u = \frac{ax}{h}\,. \tag{2}$$

The net accumulation generally increases from the ice divide to a position a short distance above the equilibrium line (EL), and from there decreases to zero at the EL. From the EL to the glacier margin the net accumulation is negative (ablation). The EL therefore separates the glacier into accumulation and ablation areas (Figure 17). The accumulation pattern therefore controls the glacier velocity. u increases from divide to EL and u decreases from EL to margin. This condition sets up the fundamental flow pattern of glaciers and ice sheets. Velocity increases in the downglacier direction within the accumulation area resulting in extending flow. Velocity decreases in the downglacier direction within the ablation area resulting in compressive flow. The maximum glacier velocity is therefore achieved at the EL.

The vertical distribution of velocity is a function of depth within the glacier. The principal driving force in glacier flow is the gravitationally induced stress that is related to the glaciers surface slope (α). This slope stress can be calculated as

$$\tau_h = \rho g h\, \alpha, \tag{3}$$

where τ_h is the shear stress at depth h, ρ is the density of ice (900 kg m^{-3}), and g is the gravitational constant (9.8 m s^{-2}). In differential form equation 3 becomes

$$\tau_h = \rho g h \frac{dh}{dx}\,. \tag{4}$$

The strain rate *e* in the direction of glacier flow is defined as

$$e_{xh} = 1/2 \left(\frac{du}{dh} + \frac{dv}{dx} \right), \tag{5}$$

where u is the horizontal velocity in the x direction and v is the vertical velocity in the h direction. With the exception of near the ice divide and near the glacier margin, dv/dx is small and the strain rate in the xy (or xh plane) is given by

$$e_{xh} = 1/2 \left(\frac{du}{dh} \right), \tag{6}$$

The rate of strain is a function of the viscosity of ice (B) and the applied shear stress as indicated in Glen's flow law of ice,

$$e_{xh} = \left(\frac{\tau}{B}\right)^n, \tag{7}$$

where n is approximately equal to 3, showing that the relation between applied stress and strain is non linear.
Therefore,

$$e_{xy} = {}^1/_2 \left(\frac{du}{dh}\right) = 1/B^n \, (\rho gh \sin \alpha)^n, \tag{8}$$

and integrating the velocity, u, over the total thickness of the glacier from the surface (s) to any depth (h) yields

$$\int_{u_h}^{u_s} du = \int_0^{\eta} 2B(\rho g \sin\alpha)^n h^n dh, \tag{9}$$

after simplification the velocity at any depth h is given by

$$u_h = u_s - 2\,B\,(\rho g \sin \alpha)^n \frac{h^{n+1}}{n+1}. \tag{10}$$

The reason for this analysis is to illustrate the mechanical reason for the velocity distribution in glaciers and ice sheets and to emphasize that the strain rate (i.e. ice velocity) is related to h^4 and α^3. Small increases in thickness and surface slope lead to large changes in velocity. Such small changes in thickness and slope can occur as ice flows over significant topographic elements.

Thus far the discussion of velocity distribution has focused only on internal deformation of the ice. Sliding also contributes significantly to glacier flow (Paterson, 1994; Hooke, 1998; Drewry, 1986). Sliding occurs by three main mechanisms: regelation, enhanced creep, and deformation of subglacial sediment. Since we are concerned primarily with a bedrock terrain, we will focus on the first two processes only.

Regelation
As ice flows around obstacles at the glacier bed, pressure is enhanced on the up glacier side. The melting point of ice is depressed because of the higher pressure and the ice melts. Pressure is lower on downglacier side of the obstacle so the melting point of ice is higher, setting up a thermal gradient through the obstacle. Water flows around the obstacle and refreezes. Heat released by refreezing (80 cal/gm) flows back through the obstacle to the upglacier side and is used to melt more ice. This mechanism is controlled by heat flow through the rock. Some heat is lost so the size of the bump is important, and regelation is only important on small bumps, say < 1 meter in dimension.

Enhanced Creep
Stress increases on upglacier side of obstacles as they form a resistance to the flow, and deformation increases according to equation 7. The larger the bump the greater the stress difference and therefore the greater the creep enhancement around the obstacle. Therefore small bumps are accommodated primarily by regelation while enhanced creep accommodates large bumps. Obstacles of about 1m is size provide the most resistance to sliding and control the sliding velocity.

In summary, the sliding velocity is controlled by bumps in roughly the 1 meter size range. Stresses are greatly enhanced around large obstacles (and also processes of quarrying and abrasion as we shall see), whereas small bumps are easily accommodated by regelation; the ice slides past quickly but stresses are not greatly enhanced.

Quarrying

Processes of quarrying and crushing are controlled by factors including pre-existing fractures, joints, faults, degree of weathering, mineral grain size of the rock, etc. The normal stress or weight of ice is usually less than that required to fracture rock, but it may, however, lead to fatigue or weakening. Fragments of rock in the basal ice may significantly increase the stress locally, and repeated cycles of stress increase and decrease causes elastic strain that is not completely recovered (Figure 18). Quarrying involves the loosening and removal of large clasts. Greatly facilitated by preexisting fractures and joints, several mechanisms of quarrying are identified. The heat pump mechanism of Robin (1976) involves melting in the high-pressure zone on the upglacier side of bed asperities and subsequent freezing of the water on the crests of obstacles as the pressure decreases (Figure 19). Loosened rock fragments are then removed and entrained, often some distance above the average bed elevation (Figure 19). Quarrying is enhanced by water pressure as increasing hydraulic head reduces the effective stress. The hydraulic jack effect involves sudden increases in water-pressure, which results in opening of cavities at the glacier bed and can result in rapid movement of the ice. The movement may only be a small amount, but the ice during such movement may break off edges of fractured steps that are frozen to the ice in the lee of obstacles.

Abrasion

Abrasion is small-scale rock failure that is typically associated movement of debris laden ice over bedrock. Abrasion rates are determined by several factors including:
1. hardness of the fragments and bedrock,
2. the velocity and amount of ice that passes over an area,
3. the sediment load in the basal ice,

Drewry (1986, p. 52) shows that the abrasion rate (Ab) can be quantified as:

$$Ab = f[\, dH, F, Up, Co, c', Sr] \qquad (11)$$

where

dH is the relative hardness of rock and clast,
F is the force pressing clast against the bed,
Up is the velocity of the particle,
Co is the concentration of particles,
c' is the ratio of abrading clasts to particles removed
and Sr is the area of bed in contact with clast (clast size to bed roughness).

Essentially abrasion requires particles in the ice to impinge on the bed, which requires downward motion as well as forward sliding. The downward motion comes from basal melting and the forward motion from sliding by regelation or enhanced creep (Figure 20). The nature of the downward normal force was first proposed by Boulton (1972). The buoyant weight of particle is given by:

$$(\rho_r - \rho_i)\, g\, 2\, r_c^3 , \qquad (12)$$

where ρ_i and ρ_r are the densities of ice and rock, respectively, and rc is the radius of a clast.

The effective normal stress (the weight of ice column - water pressure) is given by

$$(P_n - P_W)\, 2\, r_c^{\,2} \qquad (13)$$

where Pn and Pw are the total overburden pressure and the water pressure, respectively.

The net force on the particle is therefore:

$$F = (\rho_r - \rho_i)\, g\, 2\, r_c^3 + (P_n - P_W)\, 2\, r_c^2 . \qquad (14)$$

Hallet (1979), however, showed that the force on a particle striating the bed is proportional to the drag force of the ice flowing downward around the particle. The viscous drag can be calculated but is dependent on the basal melt rates and the viscosity of the ice (Hallet, 1979) (Figure 21).

An important factor in the processes of abrasion is the removal of abrasion products. If fines are not removed they fill spaces between bed asperities and reduce abrasion rates. Fines can be removed by the action of water flowing at the bed in small channels or the movement in a film of basal water. Removal by regelation, or refreezing of water produced by melting on upglacier side of bump will allow sediment to be entrained on the downglacier side of bumps. This material is available to impinge on other obstacles down glacier. This debris is usually in the lowest layers of the ice, but thickness of debris layer depends on topography, the more subglacial relief, the greater the thickness of ice over which sediment is incorporated.

Block Incorporation

Another important mechanism of incorporation of debris is by refreezing of meltwater to the bed. Goldthwait (1951) and Bishop (1957) described steeply dipping debris bands in active glaciers as shear planes, that presumably originated at the glacier bed (Figure 22). Numerous studies indicate that this process does not operate. There are sometimes faults in glacial ice, but the overall transport of debris along faults is relatively minor. Weertman (1961) was first to describe the formation of steeply dipping debris bands as a function of freezing-on or ice-debris accretion. Far from the ice margin, where ice is thick, the combination of geothermal heat (Qg) and frictional heat (Qf) is greater than can be conducted to the ice surface. The heat (Qtotal) that can be conducted upward is given by

$$Q_{total} = -K\, dT/dh, \qquad (15)$$

where K is the thermal conductivity of ice and dT/dh is the temperature gradient (Figure 23). Near the glacier margin where the ice is thin and the velocity lower, all of the geothermal and frictional heat may be conducted to the surface (Figure 23). Between these two areas is a zone where basal meltwater is accreted onto the glacier bed (Figure 23).

In this situation, debris can be accreted to the glacier bed as water is frozen on. Since this is near the margin in the zone of compression, the debris is moved upward into the ice. Block incorporation or thrusting of large blocks of the glacier be can occur in the frozen zone near the margin (Moran, 1971; Bluemle and Clayton, 1984; Mooers, 1990).

Processes Of Glacial Transport

Effects of Glacial Transport on Entrained Clasts

At the site of glacial erosion there will be an initial particle size distribution of an indicator lithology that will include abrasion and quarrying products. Two processes, dilution and comminution, alter the particle size distribution and the absolute concentration of the indicator lithology entrained in the glacier. Dilution by addition of the products of continued erosion tends to decrease the absolute concentration of the indicator lithology in the debris load. Comminution of coarser particles will tend to move indicator lithology mass from coarser to the finer size fractions.

Dilution results in a logarithmic decrease in the concentration of an indicator lithology. Each time the glacier doubles its debris load the concentration of the indicator is reduced by 50%. The effect is illustrated in Figure 24.

The effects of comminution, however, are more complicated and are grain size dependent. Comminution occurs dominantly by brittle fracture exploiting pre-existing fractures in the clast. For a given material, the stresses required to cause a fracture to propagate tend to increase as particle size decreases (Sharp and Gomez, 1986). Hence, as larger clasts are comminuted more effectively than smaller clasts, the rate of particle breakdown is higher for coarser fragments. The concentration of the large fragments produced by quarrying decreases logarithmically (Figure 25). For a smaller size fraction the same process takes place but at a lower rate due to the size dependence of comminution. Consequently, cobbles are broken down into pebbles faster than pebbles are comminuted into sand.

The minimum clast size produced by comminution, or terminal grade, will generally be in the fine sand/coarse silt range (Dreimanis and Vagners, 1971). However, the proportion of the smaller size fraction of the absolute mass of the indicator lithology can actually increase as larger clasts are broken down to the smaller clast size.

The concentration of the intermediate size clast increases with transport distance as large clasts are comminuted to intermediate size. Once the concentration of large particles is sufficiently reduced so that additions to the intermediate size diminish, the concentration of the intermediate clasts also diminishes. The proportion of particles at the terminal grade will increase over a longer transport distances, theoretically eventually reaching 100% (Figure 26).

The resulting concentration of a particular grain size of a particular indicator lithology will be a combination of the processes of dilution and comminution. The concentration of large clasts entrained in a glacier will decrease logarithmically as a consequence of both dilution and comminution (Figure 27). Concentration of intermediate and smaller clast sizes will decrease logarithmically as function of dilution, but may increase over certain intermediate length transport distances due to the comminution of larger clasts.

Effects of Grain Size on Geochemical Indicators

At the point of erosion clast size distribution is related to the ratio of quarrying to abrasion. If quarrying is dominant, clasts size distribution will be relatively coarse whereas in an abrasion-dominated system relative clasts size distribution will be finer. In either case, the minimum clast size will be in the fine sand/coarse silt range. Therefore the geochemical signature of a mineral deposit or its host rocks will initially reside in coarser fragments relative to the <0.06 or <0.002 mm fractions typically used for till geochemical studies.

With increasing transport distance comminution will increasingly move the geochemical signature into the finer fraction. After deposition grain size distribution will be a controlling factor in the rate of weathering and remobilization of geochemical signature residing in labile mineral phases, such as the components of primary VMS mineralization (Shilts and Kettles, 1990). Coarser grained labile mineral phases are typically more resistant to oxidation and weathering than their fine-grained equivalents. Consequently, the strength of a fine-fraction geochemical signature will be a function not only of the degree of oxidation of the till, but of the erosion and transport history of the primary mineral phase(s) as well.

Effects of Comminution and Dilution on Strength of Dispersal Trains

As the process of comminution progresses on a particular component, the size of individual particles will, on average, decrease until the terminal grade is achieved. The terminal grade, while dependent on the material properties (grain size, hardness, cleavage, etc.) of the particular component in question, is typically a fine fraction (<2 mm).

The fine fraction of a till thus tends to become an integrated record of the composition of all bedrock the glacier has passed over and eroded, while the progressively coarser fractions in the till tend to reflect bedrock compositions of progressively more local origin.

This phenomenon can be noted in the results of this study. The higher proportion of the sand size fraction lithologies assigned to the 'Other' category significantly reflects the greater percentage of monomineralic clasts whose provenance is indeterminable (see Appendix A).

Trace-metal geochemical signatures of mineralization (Cu, Zn, Pb, Au, As, etc.) in till are in general significantly amplified in the fine fraction. These elements tend to reside in labile phases such as sulfides, which tend to rapidly comminute, and are readily susceptible to chemical weathering and dissolution. Over longer transport distances, the economically significant minerals are comminuted to fine particles. Over shorter transport distances, the ubiquity of weathering and oxidation processes results in dissolution of metals and adsorption onto clay minerals.

In contrast, the lithologic signature of local bedrock in till can be expected to amplify in the coarser fractions. The tendency of far-traveled material to reside in the finer fractions tends mask a local signature.

Summary

In summary, processes acting at the ice/bed interface control the spatial and temporal distribution of quarrying and abrasion. Abrasion is enhanced where velocities are higher and where particles are impinging on the bed. Quarrying is greatest where rocks are fractured or jointed where stresses are high, and where clasts can effectively be entrained into the ice. Although abrasion and quarrying can occur on all surfaces in the subglacial environment, certain areas favor erosion. Sliding effectively accommodates large protuberances such as large bedrock hills. Rapid deformation by enhanced creep leads to locally high sliding velocities and enhanced erosion by both abrasion and quarrying. Relatively level beds are not subject to the stress enhancements of large bumps; abrasion and quarrying occur but at lower rates. The relative contribution of abrasion vs. quarrying depends on a number of factors including bedrock type.

Once debris has been incorporated into the basal debris layer of a glacier, dilution and comminution will alter the concentration and distribution of indicator lithologies. Comminution will decrease the average particle size, and dilution will decrease the concentration of indicator clasts. Decreasing particle size increases susceptibility of elements of economic interest to chemical weathering and remobilization. The finer fractions of till tend to reflect the farthest transported material. Conversely, coarser fractions of till tend to reflect the shortest transported, or locally derived material.

Illustrations for Appendix A

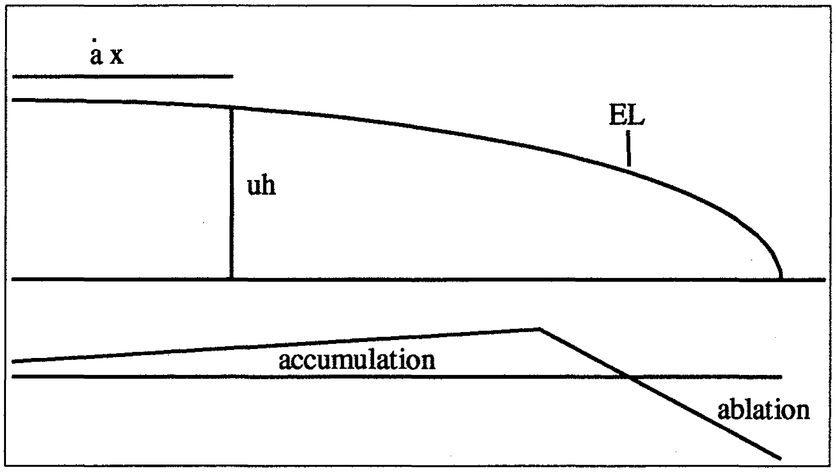

Figure 17. Profile of glacier showing locations of ELA, accumulation area, and ablation area.

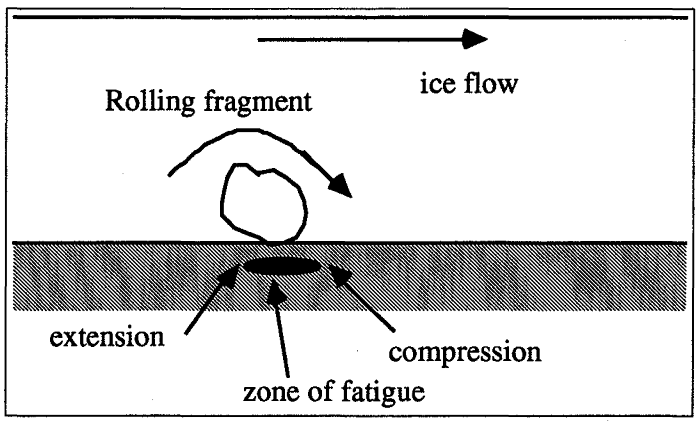

Figure 18. Entrained fragment impinging upon glacier bed

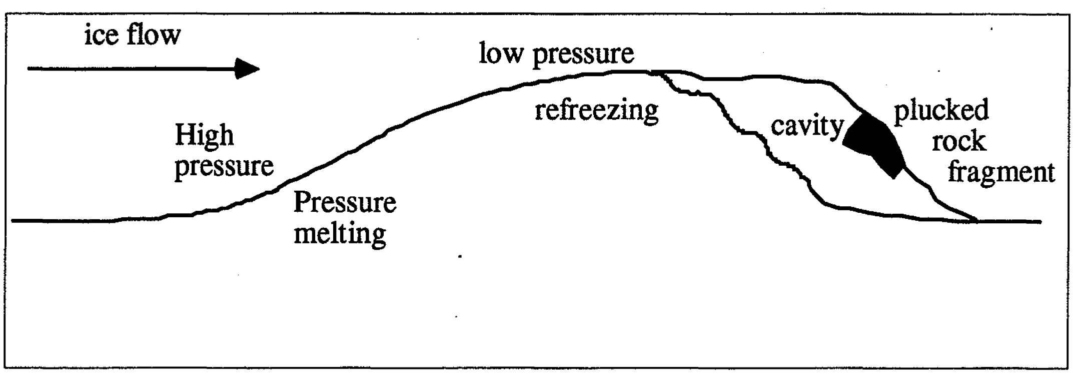

Figure 19. Pressure melting and regelation around bed asperity

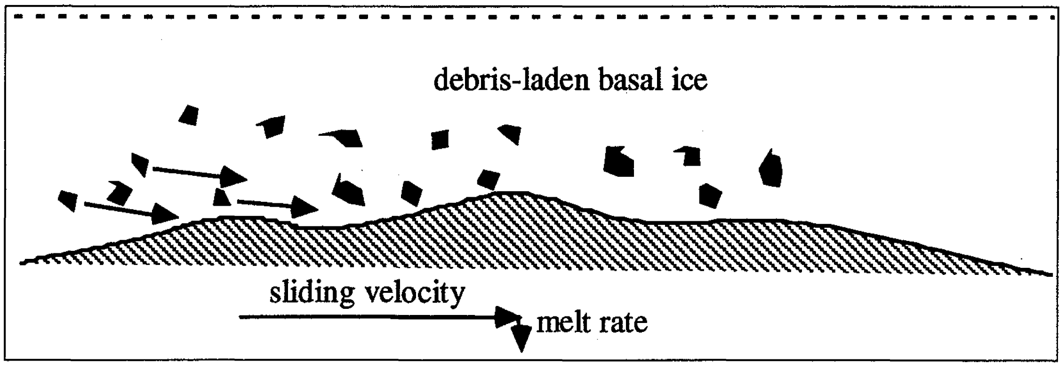

Figure 20. Causes of abrasion.

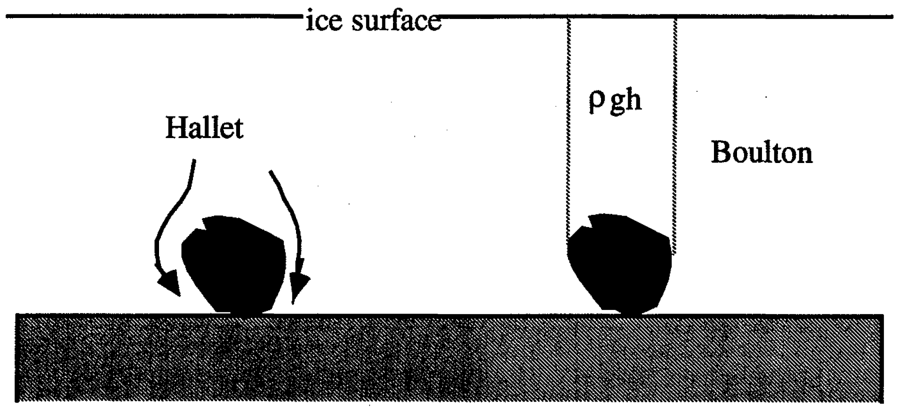

Figure 21. Hallett and Boulton models of forces acting on entrained particles.

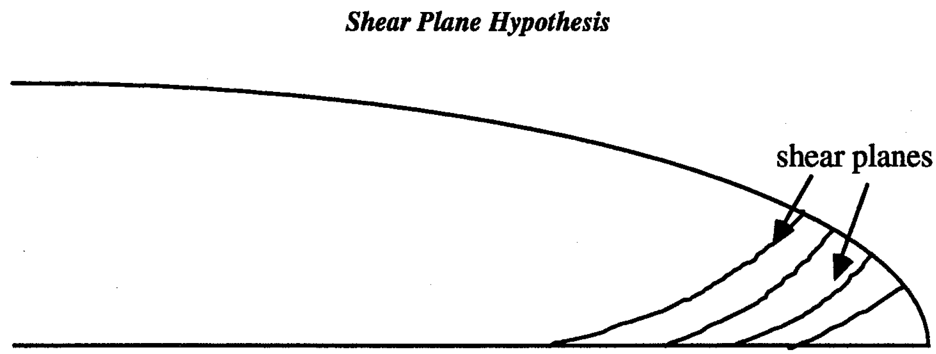

Figure 22. Illustration of shear plane hypothesis.

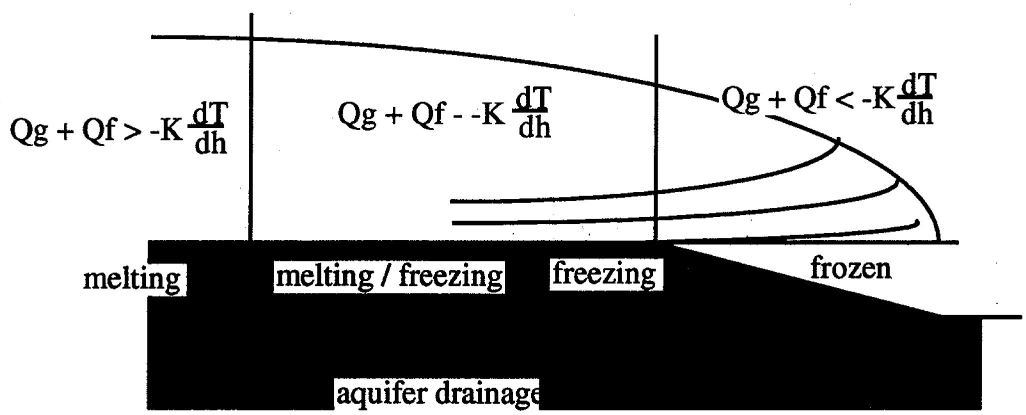

Figure 23. Wertmann model of glacial marginal thermal regime.

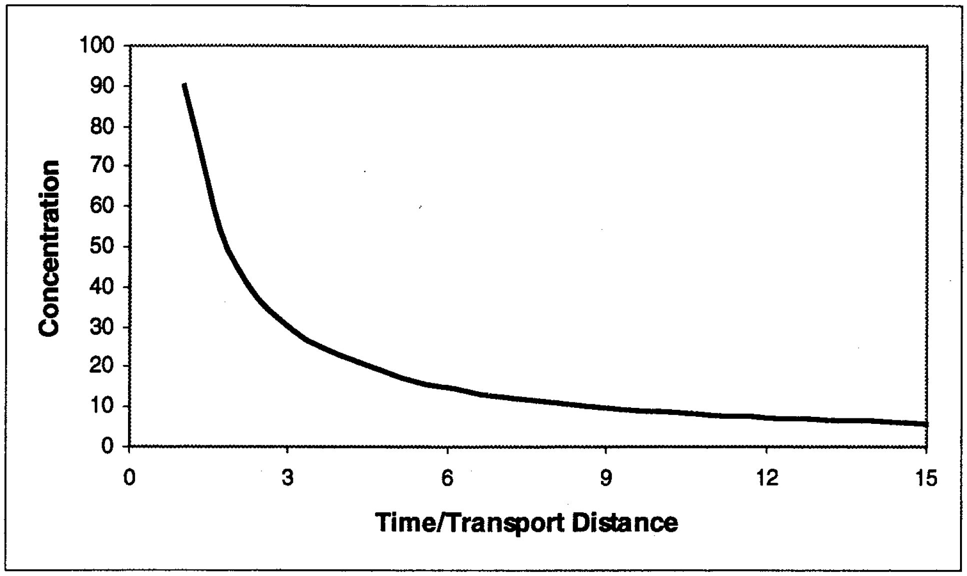

Figure 24. Effect of dilution on indicator concentration. As down-ice erosion doubles the debris load of the glacier, the concentration of the indicator decreases by half.

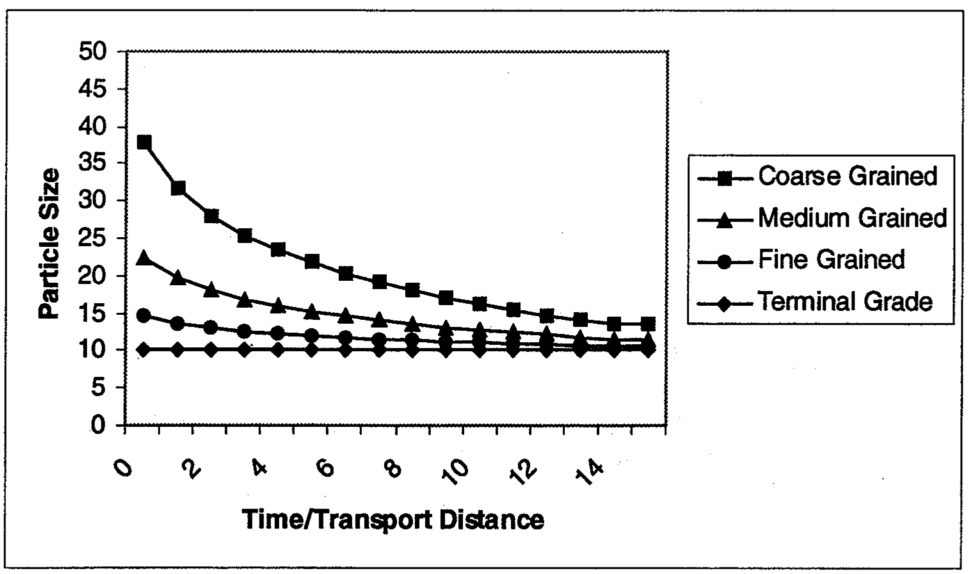

Figure 25. Effects of grain size on comminution rate. Coarser particles break down at a faster rate than fine particles.

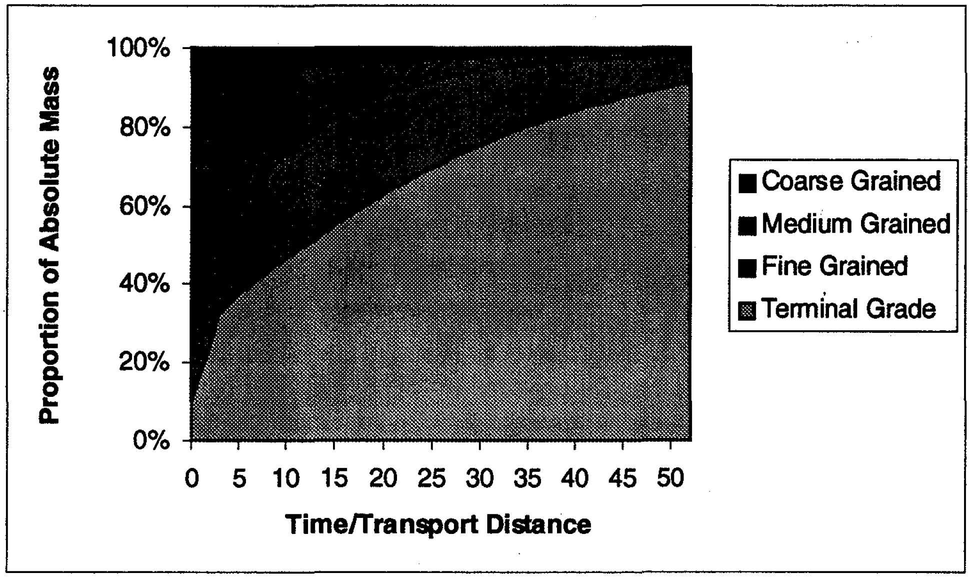

Figure 26. Effects of comminution on particle size distribution of indicator.

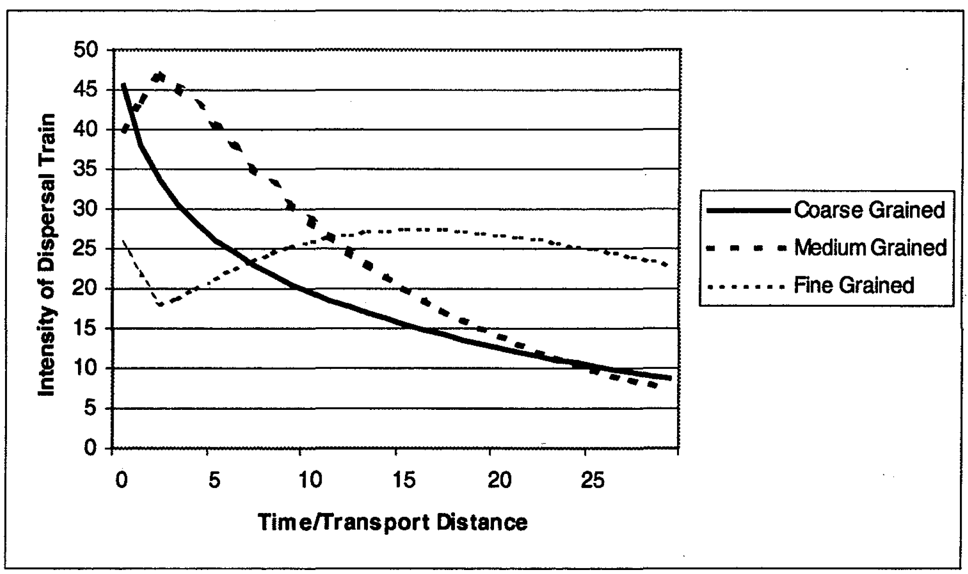

Figure 27. Cross-sectional dispersal patterns of different indicator size fractions. The concentration of fine grained particles may increase over intermediate transport distances due to breakdown of larger particles to fine particles.

APPENDIX B. SAND FRACTION LITHOLOGIES

Lithology			**Sample Number**								
			326-005	326-006	326-008	326-011	326-012	326-013	326-014	326-016	326-017
1	Mafic Volcanic Rocks		3	4	14	21	26	25	14	1	14
1a	Massive Mafic Volcanic										1
1b	Porphyritic Mafic Volcanic			8		1				1	
2	Felsic Volcanic Rocks		13	14	14	13	10	19	7	1	7
2a	Massive Felsic Lava										
2b	Porphyritic Felsic Volcanic		3	14	16	6	5	5	6		
2c	Felsic Breccia										
2d	Felsic Volcaniclastic Sediments										
2e	Felsic Tuff/Pyroclastic										
3	Clastic Sedimentary Rocks				1						
3a	Greywacke-Slate		1	1	2	1	1		1		
3b	Shale-Phyllite										
3c	Siltstone					1	2			1	
3e	Graphitic Argillite			1							
4	Chemical Sedimentary Rocks				1						
4a	Oxide Facies BIF		1	4	2			1	2	3	4
4b	Sulfide Facies BIF			1							1
4c	Carbonate Facies BIF		1								
4d	Silicate Facies BIF										
4e	Chert			2	4		1	3	1		2
5	Sheared Rocks					1					
5a	Quartz-sericite Schist		6				1		3		1
5b	Quartz-ankerite Schist		5								
5c	Quartz-sericite-ankerite Schist		7								
5d	Chlorite Schist/Phyllite		1	2							
5e	Carbonaceous Phyllite										
5h	Quartz/sericite/green mica Schist		1								
6	Felsic Intrusive Rocks			1	3	2	2	3	13		5
6a	Kspar-plagioclase bearing Granitoid		5	6	3	7	10	2	8	35	4
6b	Plagioclase bearing Granitoid			2		4				6	3
6c	Granite		1							6	
6d	Granodiorite										
7	Mafic Intrusive Rocks			1	1						2
7a	Microgabbro								2	1	1
7b	Gabbro			1							
7c	Peridotite		1								
7d	Lamprophyre										
8	High-grade Metamorphic Rocks										
8a	Biotite Schist			2							
8b	Amphibolite		1							1	
8c	Gneiss										
9	Other (including altered rocks)					1	1	1	1		
QV	Quartz vein material		3	1		3	1		1	1	1
KS	Kspar Grain		5	4	4		3		3	8	8
Qz	Quartz grain		1	1	4	5		2	1	7	3
Pl	Plagioclase grain					1				1	
Mag	Magnetite grain										2
Hem	Hematite grain										
Gt	Garnet grain										
Am	Amphibole grain										
QP	Quartz-pyrite grain										
HCl	Hematite cemented clast		3	2							11
	TOTAL CLASTS:										
1	Mafic Volcanic Rocks		3	12	14	22	26	25	14	2	15
2	Felsic Volcanic Rocks		16	28	30	19	15	24	13	1	7
3	Clastic Sedimentary Rocks		1	2	3	2	3	0	1	1	0
4	Chemical Sedimentary Rocks		2	7	7	0	1	4	3	3	7
5	Sheared Rocks		20	2	0	1	1	0	3	0	1
6	Felsic Intrusive Rocks		6	9	6	13	12	5	21	47	12
7	Mafic Intrusive Rocks		1	2	1	0	0	0	2	1	3
8	High-grade Metamorphic Rocks		1	2	0	0	0	0	0	1	0
9	Other (including altered rocks)		12	8	8	10	5	3	6	17	25
		Sum:	**62**	**72**	**69**	**67**	**63**	**61**	**63**	**73**	**70**
	PERCENT CLASTS:										
1	Mafic Volcanic Rocks		5%	17%	20%	33%	41%	41%	22%	3%	21%
2	Felsic Volcanic Rocks		26%	39%	43%	28%	24%	39%	21%	1%	10%
3	Clastic Sedimentary Rocks		2%	3%	4%	3%	5%	0%	2%	1%	0%
4	Chemical Sedimentary Rocks		3%	10%	10%	0%	2%	7%	5%	4%	10%
5	Sheared Rocks		32%	3%	0%	1%	2%	0%	5%	0%	1%
6	Felsic Intrusive Rocks		10%	13%	9%	19%	19%	8%	33%	64%	17%
7	Mafic Intrusive Rocks		2%	3%	1%	0%	0%	0%	3%	1%	4%
8	High-grade Metamorphic Rocks		2%	3%	0%	0%	0%	0%	0%	1%	0%
9	Other (including altered rocks)		19%	11%	12%	15%	8%	5%	10%	23%	36%

Lithology		Sample Number								
		326-018	326-019	326-020	326-021	326-022	326-023	326-024	326-025	326-026
1	Mafic Volcanic Rocks	12	14	11	17	12	31	9	13	9
1a	Massive Mafic Volcanic									1
1b	Porphyritic Mafic Volcanic	3	2		4	1	7	1		3
2	Felsic Volcanic Rocks	11	6	15	2	6	8	6	4	8
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic	8	4	9		4	1	1	4	12
2c	Felsic Breccia									
2d	Felsic Volcaniclastic Sediments					1				
2e	Felsic Tuff/Pyroclastic									
3	Clastic Sedimentary Rocks									
3a	Greywacke-Slate	1	1		5			1	2	4
3b	Shale-Phyllite	2						1		
3c	Siltstone	1				1		3	2	
3e	Graphitic Argillite									
4	Chemical Sedimentary Rocks									
4a	Oxide Facies BIF	1	3	2	3	4	6	3	2	
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4d	Silicate Facies BIF						2			
4e	Chert	1	3		1		1		4	1
5	Sheared Rocks					1		1	1	
5a	Quartz-sericite Schist	3	6	2			2	4		2
5b	Quartz-ankerite Schist	1				2				
5c	Quartz-sericite-ankerite Schist									
5d	Chlorite Schist/Phyllite		1	3	5		1			1
5e	Carbonaceous Phyllite				1					
5h	Quartz/sericite/green mica Schist									
6	Felsic Intrusive Rocks	2		2	1	4	2	3	5	1
6a	Kspar-plagioclase bearing Granitoid	2	2	17	4	5	3	4	5	1
6b	Plagioclase bearing Granitoid	3	2			2		1	4	
6c	Granite									
6d	Granodiorite									
7	Mafic Intrusive Rocks	5			3	1		2	6	
7a	Microgabbro	2	1		3		2	2		2
7b	Gabbro		4		1	1	2		1	1
7c	Peridotite				1					
7d	Lamprophyre									
8	High-grade Metamorphic Rocks									
8a	Biotite Schist	2	1		1	1		6	2	6
8b	Amphibolite	4	1	2	14		4	3	2	4
8c	Gneiss									
9	Other (including altered rocks)					2		1	1	1
QV	Quartz vein material	1	3	3	1			2	1	4
KS	Kspar Grain	4	3	6	1	4	3	6	4	5
Qz	Quartz grain	3	5	6	2	6	4	8	2	2
Pl	Plagioclase grain	2	1					1	1	1
Mag	Magnetite grain	1				1				
Hem	Hematite grain	1	4		1			1	1	
Gt	Garnet grain									
Am	Amphibole grain									
QP	Quartz-pyrite grain									
HCl	Hematite cemented clast	3				1				
	TOTAL CLASTS:									
1	Mafic Volcanic Rocks	15	16	11	21	13	38	10	13	13
2	Felsic Volcanic Rocks	19	10	24	2	11	9	7	8	20
3	Clastic Sedimentary Rocks	4	1	0	5	1	0	5	4	4
4	Chemical Sedimentary Rocks	2	6	2	4	4	9	3	6	1
5	Sheared Rocks	4	7	5	6	3	3	5	1	3
6	Felsic Intrusive Rocks	7	4	19	5	11	5	8	14	2
7	Mafic Intrusive Rocks	7	5	0	8	2	4	4	7	3
8	High-grade Metamorphic Rocks	6	2	2	15	1	4	9	4	10
9	Other (including altered rocks)	15	16	15	5	14	7	19	10	13
	Sum:	**79**	**67**	**78**	**71**	**60**	**79**	**70**	**67**	**69**
	PERCENT CLASTS:									
1	Mafic Volcanic Rocks	19%	24%	14%	30%	22%	48%	14%	19%	19%
2	Felsic Volcanic Rocks	24%	15%	31%	3%	18%	11%	10%	12%	29%
3	Clastic Sedimentary Rocks	5%	1%	0%	7%	2%	0%	7%	6%	6%
4	Chemical Sedimentary Rocks	3%	9%	3%	6%	7%	11%	4%	9%	1%
5	Sheared Rocks	5%	10%	6%	8%	5%	4%	7%	1%	4%
6	Felsic Intrusive Rocks	9%	6%	24%	7%	18%	6%	11%	21%	3%
7	Mafic Intrusive Rocks	9%	7%	0%	11%	3%	5%	6%	10%	4%
8	High-grade Metamorphic Rocks	8%	3%	3%	21%	2%	5%	13%	6%	14%
9	Other (including altered rocks)	19%	24%	19%	7%	23%	9%	27%	15%	19%

Lithology		Sample Number								
		326-027	326-028	326-029	326-031	326-032	326-036	326-038	326-041	326-048
1	Mafic Volcanic Rocks	8	3	13	13	21	15	13		8
1a	Massive Mafic Volcanic				7					
1b	Porphyritic Mafic Volcanic	2		3	2	1	2	1		9
2	Felsic Volcanic Rocks	5	5	6	3	11	12	9	13	5
2a	Massive Felsic Lava						1			
2b	Porphyritic Felsic Volcanic	3	3	6	4	4	1	4	7	8
2c	Felsic Breccia				1					
2d	Felsic Volcaniclastic Sediments									
2e	Felsic Tuff/Pyroclastic									
3	Clastic Sedimentary Rocks									
3a	Greywacke-Slate				4	1	1		2	5
3b	Shale-Phyllite									3
3c	Siltstone			1				1		3
3e	Graphitic Argillite	1								
4	Chemical Sedimentary Rocks									
4a	Oxide Facies BIF	2	2		3	2		1	1	6
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4d	Silicate Facies BIF									
4e	Chert	2	1	1		2			1	
5	Sheared Rocks									
5a	Quartz-sericite Schist	1	1	5	1	1	1		1	5
5b	Quartz-ankerite Schist	1								
5c	Quartz-sericite-ankerite Schist	1								
5d	Chlorite Schist/Phyllite	1		1	2					
5e	Carbonaceous Phyllite				1		1			
5h	Quartz/sericite/green mica Schist									
6	Felsic Intrusive Rocks	3		14	2	4	7	9	1	
6a	Kspar-plagioclase bearing Granitoid	15	8	1	7		3	7	8	5
6b	Plagioclase bearing Granitoid	2		3			1	4	1	6
6c	Granite		2						1	
6d	Granodiorite									
7	Mafic Intrusive Rocks			2		8	6	7		
7a	Microgabbro	1		1		2		3		3
7b	Gabbro	2			4		2	2		9
7c	Peridotite		4			1				
7d	Lamprophyre									
8	High-grade Metamorphic Rocks									
8a	Biotite Schist		6	2		1			3	
8b	Amphibolite	3	12	4	10	5	7	2		
8c	Gneiss	2								
9	Other (including altered rocks)								1	
QV	Quartz vein material		2		4		4	4	8	2
KS	Kspar Grain	5	12			3	3	4	12	1
Qz	Quartz grain	3		2	1			2		3
Pl	Plagioclase grain		2			1			1	
Mag	Magnetite grain					1				
Hem	Hematite grain			5	1					
Gt	Garnet grain									
Am	Amphibole grain									
QP	Quartz-pyrite grain									
HCl	Hematite cemented clast						2		1	
	TOTAL CLASTS:									
1	Mafic Volcanic Rocks	10	3	16	22	22	17	14	0	17
2	Felsic Volcanic Rocks	8	8	12	8	15	14	13	20	13
3	Clastic Sedimentary Rocks	1	0	1	4	1	1	1	2	11
4	Chemical Sedimentary Rocks	4	3	1	3	4	0	1	2	6
5	Sheared Rocks	4	1	6	4	1	2	0	1	5
6	Felsic Intrusive Rocks	20	10	18	9	4	11	20	11	11
7	Mafic Intrusive Rocks	3	4	3	4	11	8	12	0	12
8	High-grade Metamorphic Rocks	5	18	6	10	6	7	2	3	0
9	Other (including altered rocks)	8	16	7	6	5	9	10	23	6
	Sum:	**63**	**63**	**70**	**70**	**69**	**69**	**73**	**62**	**81**
	PERCENT CLASTS:									
1	Mafic Volcanic Rocks	16%	5%	23%	31%	32%	25%	19%	0%	21%
2	Felsic Volcanic Rocks	13%	13%	17%	11%	22%	20%	18%	32%	16%
3	Clastic Sedimentary Rocks	2%	0%	1%	6%	1%	1%	1%	3%	14%
4	Chemical Sedimentary Rocks	6%	5%	1%	4%	6%	0%	1%	3%	7%
5	Sheared Rocks	6%	2%	9%	6%	1%	3%	0%	2%	6%
6	Felsic Intrusive Rocks	32%	16%	26%	13%	6%	16%	27%	18%	14%
7	Mafic Intrusive Rocks	5%	6%	4%	6%	16%	12%	16%	0%	15%
8	High-grade Metamorphic Rocks	8%	29%	9%	14%	9%	10%	3%	5%	0%
9	Other (including altered rocks)	13%	25%	10%	9%	7%	13%	14%	37%	7%

Lithology		**Sample Number** 326-049	326-050	326-051	326-053	326-054	326-057	326-067	326-069	326-070
1	Mafic Volcanic Rocks	3	11	6	9	19	10	8	22	16
1a	Massive Mafic Volcanic									
1b	Porphyritic Mafic Volcanic	6	3	3	8	3				
2	Felsic Volcanic Rocks	3	7	8	12	8	8	3	9	6
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic	6	7	9	3	3	9	2	4	4
2c	Felsic Breccia									
2d	Felsic Volcaniclastic Sediments									1
2e	Felsic Tuff/Pyroclastic						1			
3	Clastic Sedimentary Rocks						1			
3a	Greywacke-Slate	8	2	2	2	3	1	1	6	4
3b	Shale-Phyllite									4
3c	Siltstone	5	2	2		2	4	2	2	4
3e	Graphitic Argillite						1			
4	Chemical Sedimentary Rocks									
4a	Oxide Facies BIF	2	1		2	1	8	1	2	6
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4d	Silicate Facies BIF									
4e	Chert		1		3	1	4	2	2	5
5	Sheared Rocks							1	1	
5a	Quartz-sericite Schist	2			3					
5b	Quartz-ankerite Schist				2					
5c	Quartz-sericite-ankerite Schist									
5d	Chlorite Schist/Phyllite	5			6				1	
5e	Carbonaceous Phyllite									
5h	Quartz/sericite/green mica Schist									
6	Felsic Intrusive Rocks	2	15	6	6	8	7	17	1	3
6a	Kspar-plagioclase bearing Granitoid	6	3	8	3	8	1	3		
6b	Plagioclase bearing Granitoid	2				2	1	1	1	
6c	Granite				2			3		
6d	Granodiorite				2					
7	Mafic Intrusive Rocks	3	3	3		3	1		8	
7a	Microgabbro		2	1	3	2		1		
7b	Gabbro		3		2			1		
7c	Peridotite	2								
7d	Lamprophyre									
8	High-grade Metamorphic Rocks									
8a	Biotite Schist	5		1						
8b	Amphibolite	3		1					1	
8c	Gneiss									
9	Other (including altered rocks)				2	1	1	1	2	
QV	Quartz vein material	3	1	5	1	3		4	1	
KS	Kspar Grain	2	4	1	2	3	1	9	3	5
Qz	Quartz grain		2	5	6	1	7	9	1	4
Pl	Plagioclase grain		1				1	1	5	
Mag	Magnetite grain						1			
Hem	Hematite grain						1	2	1	
Gt	Garnet grain								1	
Am	Amphibole grain									
QP	Quartz-pyrite grain									
HCl	Hematite cemented clast									
	TOTAL CLASTS:									
1	Mafic Volcanic Rocks	9	14	9	17	22	10	8	22	16
2	Felsic Volcanic Rocks	9	14	17	15	11	18	5	13	11
3	Clastic Sedimentary Rocks	13	4	4	2	5	7	3	8	12
4	Chemical Sedimentary Rocks	2	2	0	5	2	12	3	4	11
5	Sheared Rocks	7	0	0	11	0	0	1	2	0
6	Felsic Intrusive Rocks	10	18	14	13	18	9	24	2	3
7	Mafic Intrusive Rocks	5	8	4	5	5	1	2	8	0
8	High-grade Metamorphic Rocks	8	0	2	0	0	0	0	1	0
9	Other (including altered rocks)	5	8	11	11	8	12	26	14	9
	Sum:	**68**	**68**	**61**	**79**	**71**	**69**	**72**	**74**	**62**
	PERCENT CLASTS:									
1	Mafic Volcanic Rocks	13%	21%	15%	22%	31%	14%	11%	30%	26%
2	Felsic Volcanic Rocks	13%	21%	28%	19%	15%	26%	7%	18%	18%
3	Clastic Sedimentary Rocks	19%	6%	7%	3%	7%	10%	4%	11%	19%
4	Chemical Sedimentary Rocks	3%	3%	0%	6%	3%	17%	4%	5%	18%
5	Sheared Rocks	10%	0%	0%	14%	0%	0%	1%	3%	0%
6	Felsic Intrusive Rocks	15%	26%	23%	16%	25%	13%	33%	3%	5%
7	Mafic Intrusive Rocks	7%	12%	7%	6%	7%	1%	3%	11%	0%
8	High-grade Metamorphic Rocks	12%	0%	3%	0%	0%	0%	0%	1%	0%
9	Other (including altered rocks)	7%	12%	18%	14%	11%	17%	36%	19%	15%

Lithology		Sample Number								
		326-071	326-072	326-073	326-074	326-075	326-076	326-078	326-079	326-096
1	Mafic Volcanic Rocks	44	11	7	7	4	12	14	30	19
1a	Massive Mafic Volcanic									
1b	Porphyritic Mafic Volcanic	1	2				2	1	4	2
2	Felsic Volcanic Rocks	4	15	11	12	16	6	17	11	14
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic	2	2	5	7	4	3	8	2	3
2c	Felsic Breccia									
2d	Felsic Volcaniclastic Sediments		2	1						
2e	Felsic Tuff/Pyroclastic		3	1						
3	Clastic Sedimentary Rocks									
3a	Greywacke-Slate	1	3				3	2	4	2
3b	Shale-Phyllite									2
3c	Siltstone			1		1	3	2	3	2
3e	Graphitic Argillite				1		1	2		
4	Chemical Sedimentary Rocks									
4a	Oxide Facies BIF	2	2	4	1	6	6	4		1
4b	Sulfide Facies BIF				3					
4c	Carbonate Facies BIF									
4d	Silicate Facies BIF							1		
4e	Chert		3	7	2	5	2	2	1	3
5	Sheared Rocks									
5a	Quartz-sericite Schist		3	4		1				
5b	Quartz-ankerite Schist									
5c	Quartz-sericite-ankerite Schist									
5d	Chlorite Schist/Phyllite	4	3							
5e	Carbonaceous Phyllite									
5h	Quartz/sericite/green mica Schist									
6	Felsic Intrusive Rocks		5	8	9	10	8	1	2	6
6a	Kspar-plagioclase bearing Granitoid	1	3	5	4	3	1		1	
6b	Plagioclase bearing Granitoid		3	3	2	1	1			3
6c	Granite									
6d	Granodiorite									
7	Mafic Intrusive Rocks	5		1	4	1	1	1		
7a	Microgabbro	2						1	3	2
7b	Gabbro	1	2		2		1		2	
7c	Peridotite									
7d	Lamprophyre									
8	High-grade Metamorphic Rocks			1						
8a	Biotite Schist	1	2							
8b	Amphibolite									
8c	Gneiss									
9	Other (including altered rocks)								1	
QV	Quartz vein material			2	3	1	2	1		1
KS	Kspar Grain		2	4	5	7	6	2		
Qz	Quartz grain	1	5	1	4	4	6	3		1
Pl	Plagioclase grain		3	1	1	1		1		1
Mag	Magnetite grain			2			1	1		
Hem	Hematite grain				1		1			
Gt	Garnet grain									
Am	Amphibole grain				1					
QP	Quartz-pyrite grain				1					
HCl	Hematite cemented clast.						2			
	TOTAL CLASTS:									
1	Mafic Volcanic Rocks	45	13	7	7	4	14	15	34	21
2	Felsic Volcanic Rocks	6	22	18	19	20	9	25	13	17
3	Clastic Sedimentary Rocks	1	3	1	1	1	7	6	7	6
4	Chemical Sedimentary Rocks	2	5	11	6	11	8	7	1	4
5	Sheared Rocks	4	6	4	0	1	0	0	0	0
6	Felsic Intrusive Rocks	1	11	16	15	14	10	1	3	9
7	Mafic Intrusive Rocks	8	2	1	6	1	2	2	5	2
8	High-grade Metamorphic Rocks	1	2	1	0	0	0	0	0	0
9	Other (including altered rocks)	1	10	10	16	13	18	8	1	3
	Sum:	**69**	**74**	**69**	**70**	**65**	**68**	**64**	**64**	**62**
	PERCENT CLASTS:									
1	Mafic Volcanic Rocks	65%	18%	10%	10%	6%	21%	23%	53%	34%
2	Felsic Volcanic Rocks	9%	30%	26%	27%	31%	13%	39%	20%	27%
3	Clastic Sedimentary Rocks	1%	4%	1%	1%	2%	10%	9%	11%	10%
4	Chemical Sedimentary Rocks	3%	7%	16%	9%	17%	12%	11%	2%	6%
5	Sheared Rocks	6%	8%	6%	0%	2%	0%	0%	0%	0%
6	Felsic Intrusive Rocks	1%	15%	23%	21%	22%	15%	2%	5%	15%
7	Mafic Intrusive Rocks	12%	3%	1%	9%	2%	3%	3%	8%	3%
8	High-grade Metamorphic Rocks	1%	3%	1%	0%	0%	0%	0%	0%	0%
9	Other (including altered rocks)	1%	14%	14%	23%	20%	26%	13%	2%	5%

Lithology		Sample Number	
		326-097	326-123
1	Mafic Volcanic Rocks	16	11
1a	Massive Mafic Volcanic		
1b	Porphyritic Mafic Volcanic		1
2	Felsic Volcanic Rocks	19	8
2a	Massive Felsic Lava		
2b	Porphyritic Felsic Volcanic	7	2
2c	Felsic Breccia		
2d	Felsic Volcaniclastic Sediments		1
2e	Felsic Tuff/Pyroclastic		
3	Clastic Sedimentary Rocks		
3a	Greywacke-Slate	2	
3b	Shale-Phyllite		
3c	Siltstone	2	
3e	Graphitic Argillite		1
4	Chemical Sedimentary Rocks		
4a	Oxide Facies BIF		4
4b	Sulfide Facies BIF		
4c	Carbonate Facies BIF		
4d	Silicate Facies BIF		
4e	Chert	1	
5	Sheared Rocks		
5a	Quartz-sericite Schist	1	
5b	Quartz-ankerite Schist		
5c	Quartz-sericite-ankerite Schist		
5d	Chlorite Schist/Phyllite		3
5e	Carbonaceous Phyllite		
5h	Quartz/sericite/green mica Schist		
6	Felsic Intrusive Rocks	7	15
6a	Kspar-plagioclase bearing Granitoid	2	15
6b	Plagioclase bearing Granitoid	1	3
6c	Granite		
6d	Granodiorite		
7	Mafic Intrusive Rocks	3	2
7a	Microgabbro		
7b	Gabbro	1	
7c	Peridotite		
7d	Lamprophyre		
8	High-grade Metamorphic Rocks		1
8a	Biotite Schist		3
8b	Amphibolite		32
8c	Gneiss		
9	Other (including altered rocks)	1	
QV	Quartz vein material	4	3
KS	Kspar Grain	1	4
Qz	Quartz grain		4
Pl	Plagioclase grain		
Mag	Magnetite grain		
Hem	Hematite grain		1
Gt	Garnet grain	1	
Am	Amphibole grain		
QP	Quartz-pyrite grain		
HCl	Hematite cemented clast		1
	TOTAL CLASTS:		
1	Mafic Volcanic Rocks	16	12
2	Felsic Volcanic Rocks	26	11
3	Clastic Sedimentary Rocks	4	1
4	Chemical Sedimentary Rocks	1	4
5	Sheared Rocks	1	3
6	Felsic Intrusive Rocks	10	33
7	Mafic Intrusive Rocks	4	2
8	High-grade Metamorphic Rocks	0	36
9	Other (including altered rocks)	7	13
	Sum:	**69**	**115**
	PERCENT CLASTS:		
1	Mafic Volcanic Rocks	23%	10%
2	Felsic Volcanic Rocks	38%	10%
3	Clastic Sedimentary Rocks	6%	1%
4	Chemical Sedimentary Rocks	1%	3%
5	Sheared Rocks	1%	3%
6	Felsic Intrusive Rocks	14%	29%
7	Mafic Intrusive Rocks	6%	2%
8	High-grade Metamorphic Rocks	0%	31%
9	Other (including altered rocks)	10%	11%

APPENDIX C. LITHOLOGIC CLASSIFICATION OF PEBBLE FRACTION

Lithology		326-005	326-006	326-008	326-011	326-012	326-013	326-014	326-016	326-017
		Sample Number								
1	**Mafic Volcanic Rocks**	5	19	31	35	39	26	27	11	15
1b	Porphyritic Mafic Volcanic									
2	**Felsic Volcanic Rocks**	6	47	25	33	20	17	14	7	13
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic	2	7	5	4	8		2	4	5
2d	Felsic Volcaniclastic Sediments									
3	**Clastic Sedimentary Rocks**	5	1	3		3		2		
3a	Greywacke-Slate	14		5	1	11	3	4		4
3b	Shale-Phyllite	25		2	7					1
3c	Siltstone	8	3	6	4	8	1			9
4	**Chemical Sedimentary Rocks**									
4a	Oxide Facies BIF		8	3	4		4	1		
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF								1	
4e	Chert		6	5	3	3	3	3	3	2
4f	Carbonate Rock									
5	**Sheared Rocks**	2	1	2	5	1	3		1	
5a	Quartz-sericite Schist	4		1			6	1		
5b	Quartz-ankerite Schist									
5c	Quartz-sericite-ankerite Schist	1			8	1	1			
5d	Chlorite Schist/Phyllite		2		1					
5i	Mylonitic Rock									
6	**Felsic Intrusive Rocks**	4	3	11	5	7	2	18	33	17
6a	Kspar-plagioclase bearing Granitoid	3	2			2		6	13	2
6b	Plagioclase bearing Granitoid	6	1			1			18	
7	**Mafic Intrusive Rocks**	1		5	1	3		1	1	1
7a	Microgabbro		1			1				
8	**High-grade Metamorphic Rocks**								1	9
8a	Biotite Schist				2				1	17
8b	Amphibolite									10
8c	Gneiss							1	7	30
9	**Other (including altered rocks)**			1	1	1	2			1
QV	Quartz vein material	14	1		2	3	2	2		3
Qtz-Epi	Quartz-epidote Alteration					2	2	3		
Qz	Quartz grain									
	TOTAL CLASTS:									
1	**Mafic Volcanic Rocks**	5	19	31	35	39	26	27	11	15
2	**Felsic Volcanic Rocks**	8	54	30	37	28	17	16	11	18
3	**Clastic Sedimentary Rocks**	52	4	16	12	22	4	6	0	14
4	**Chemical Sedimentary Rocks**	0	14	8	7	3	7	4	4	2
5	**Sheared Rocks**	7	3	3	14	2	10	1	1	0
6	**Felsic Intrusive Rocks**	13	6	11	5	10	2	24	64	19
7	**Mafic Intrusive Rocks**	1	1	5	1	4	0	1	1	1
8	**High-grade Metamorphic Rocks**	0	0	0	2	0	0	1	9	66
9	**Other (including altered rocks)**	14	1	1	3	6	6	5	0	4
	Sum:	**100**	**102**	**105**	**116**	**114**	**72**	**85**	**101**	**139**
	PERCENT CLASTS:									
1	**Mafic Volcanic Rocks**	5%	19%	30%	30%	34%	36%	32%	11%	11%
2	**Felsic Volcanic Rocks**	8%	53%	29%	32%	25%	24%	19%	11%	13%
3	**Clastic Sedimentary Rocks**	52%	4%	15%	10%	19%	6%	7%	0%	10%
4	**Chemical Sedimentary Rocks**	0%	14%	8%	6%	3%	10%	5%	4%	1%
5	**Sheared Rocks**	7%	3%	3%	12%	2%	14%	1%	1%	0%
6	**Felsic Intrusive Rocks**	13%	6%	10%	4%	9%	3%	28%	63%	14%
7	**Mafic Intrusive Rocks**	1%	1%	5%	1%	4%	0%	1%	1%	1%
8	**High-grade Metamorphic Rocks**	0%	0%	0%	2%	0%	0%	1%	9%	47%
9	**Other (including altered rocks)**	14%	1%	1%	3%	5%	8%	6%	0%	3%
	Iron Formation	0%	8%	3%	3%	0%	6%	1%	1%	0%
	Qtz-Epi	0%	0%	0%	0%	2%	3%	4%	0%	0%
	Qtz-Ank	1%	0%	0%	7%	1%	1%	0%	0%	0%

Lithology		Sample Number								
		326-018	326-019	326-020	326-021	326-022	326-023	326-024	326-025	326-026
1	**Mafic Volcanic Rocks**	33	60	57	72	59	55	22	20	16
1b	Porphyritic Mafic Volcanic									
2	**Felsic Volcanic Rocks**	18	10	8	8	1	13	16	13	12
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic				2		2	1	3	
2d	Felsic Volcaniclastic Sediments									
3	**Clastic Sedimentary Rocks**	3	1				2	1		5
3a	Greywacke-Slate	5		3				4	5	3
3b	Shale-Phyllite	5	4	1			1	2	8	12
3c	Siltstone	7	1		1	3	3	6	6	6
4	**Chemical Sedimentary Rocks**									
4a	Oxide Facies BIF	9	4	6	6	6	2	9	3	
4b	Sulfide Facies BIF							1		
4c	Carbonate Facies BIF									
4e	Chert	4	1					1	4	3
4f	Carbonate Rock									
5	**Sheared Rocks**	4	1			1	4	3		4
5a	Quartz-sericite Schist	2	4	1	1			3	4	2
5b	Quartz-ankerite Schist				1					
5c	Quartz-sericite-ankerite Schist				1		2		1	
5d	Chlorite Schist/Phyllite					1				
5i	Mylonitic Rock									
6	**Felsic Intrusive Rocks**	2	1	7	4	10	8	11	5	2
6a	Kspar-plagioclase bearing Granitoid	3	4			13	3		3	9
6b	Plagioclase bearing Granitoid	1	2	12	1	3		2		5
7	**Mafic Intrusive Rocks**	2	1		1	1	4	1		4
7a	Microgabbro		4	1	2					
8	**High-grade Metamorphic Rocks**	1	3			2	2	3	10	8
8a	Biotite Schist					1	1	6	5	7
8b	Amphibolite	4	2	1				4		1
8c	Gneiss		3		1				7	13
9	**Other (including altered rocks)**	1		1		1		1		
QV	Quartz vein material	1	3	2	2	5	3	4	4	2
Qtz-Epi	Quartz-epidote Alteration									
Qz	Quartz grain									
	TOTAL CLASTS:									
1	**Mafic Volcanic Rocks**	33	60	57	72	59	55	22	20	16
2	**Felsic Volcanic Rocks**	18	10	8	10	1	15	17	16	12
3	**Clastic Sedimentary Rocks**	20	6	4	1	3	6	13	19	26
4	**Chemical Sedimentary Rocks**	13	5	6	6	6	2	11	7	3
5	**Sheared Rocks**	6	5	1	3	2	6	6	5	6
6	**Felsic Intrusive Rocks**	6	7	19	5	26	11	13	8	16
7	**Mafic Intrusive Rocks**	2	5	1	3	1	4	1	0	4
8	**High-grade Metamorphic Rocks**	5	8	1	1	3	3	13	22	29
9	**Other (including altered rocks)**	2	3	3	2	6	3	5	4	2
	Sum:	**105**	**109**	**100**	**103**	**107**	**105**	**101**	**101**	**114**
	PERCENT CLASTS:									
1	**Mafic Volcanic Rocks**	31%	55%	57%	70%	55%	52%	22%	20%	14%
2	**Felsic Volcanic Rocks**	17%	9%	8%	10%	1%	14%	17%	16%	11%
3	**Clastic Sedimentary Rocks**	19%	6%	4%	1%	3%	6%	13%	19%	23%
4	**Chemical Sedimentary Rocks**	12%	5%	6%	6%	6%	2%	11%	7%	3%
5	**Sheared Rocks**	6%	5%	1%	3%	2%	6%	6%	5%	5%
6	**Felsic Intrusive Rocks**	6%	6%	19%	5%	24%	10%	13%	8%	14%
7	**Mafic Intrusive Rocks**	2%	5%	1%	3%	1%	4%	1%	0%	4%
8	**High-grade Metamorphic Rocks**	5%	7%	1%	1%	3%	3%	13%	22%	25%
9	**Other (including altered rocks)**	2%	3%	3%	2%	6%	3%	5%	4%	2%
	Iron Formation	9%	4%	6%	6%	6%	2%	10%	3%	0%
	Qtz-Epi	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Qtz-Ank	0%	0%	0%	2%	0%	2%	0%	1%	0%

Lithology		Sample Number 326-027	326-028	326-029	326-031	326-032	326-036	326-038	326-041	326-047
1	**Mafic Volcanic Rocks**	28	15	20	51	58	39	40		26
1b	Porphyritic Mafic Volcanic		1			1				
2	**Felsic Volcanic Rocks**	10	10	6	11	6	4	7	19	31
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic		1	1	3	1	1	1	2	2
2d	Felsic Volcaniclastic Sediments								6	
3	**Clastic Sedimentary Rocks**		1					2	3	4
3a	Greywacke-Slate	2	9	3	2	3	6	4	25	2
3b	Shale-Phyllite	2	4	5		5		6	8	
3c	Siltstone	3	10		5	1	3	4	3	1
4	**Chemical Sedimentary Rocks**	1	1							
4a	Oxide Facies BIF	3	2		3	3	4	1	1	
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4e	Chert	5	1	1	1		1		1	
4f	Carbonate Rock									
5	**Sheared Rocks**	2	2			5		4	2	2
5a	Quartz-sericite Schist	1	2		9	2				1
5b	Quartz-ankerite Schist									
5c	Quartz-sericite-ankerite Schist	2	1							
5d	Chlorite Schist/Phyllite					1				
5i	Mylonitic Rock							1		
6	**Felsic Intrusive Rocks**	6	1	3	3	4	6	8	7	8
6a	Kspar-plagioclase bearing Granitoid	4	7		5	2	3	4	10	5
6b	Plagioclase bearing Granitoid	5	4		1		1		11	3
7	**Mafic Intrusive Rocks**	1			17	2	6	6		8
7a	Microgabbro									
8	**High-grade Metamorphic Rocks**	4	9			4	3	4	1	
8a	Biotite Schist	3	7				7	3		
8b	Amphibolite	9	4		2		11			3
8c	Gneiss	6	14	15	5	2	2	10	2	1
9	**Other (including altered rocks)**	1								
QV	Quartz vein material	3	4	2		1		2	2	4
Qtz-Epi	Quartz-epidote Alteration						1			
Qz	Quartz grain									
	TOTAL CLASTS:									
1	**Mafic Volcanic Rocks**	28	16	20	51	59	39	40	0	26
2	**Felsic Volcanic Rocks**	10	11	7	14	7	5	8	27	33
3	**Clastic Sedimentary Rocks**	7	24	8	7	9	9	16	39	7
4	**Chemical Sedimentary Rocks**	9	4	1	4	3	5	1	2	0
5	**Sheared Rocks**	5	5	0	9	8	0	5	2	3
6	**Felsic Intrusive Rocks**	15	12	3	9	6	10	12	28	16
7	**Mafic Intrusive Rocks**	1	0	0	17	2	6	6	0	8
8	**High-grade Metamorphic Rocks**	22	34	15	7	6	23	17	3	4
9	**Other (including altered rocks)**	4	4	2	0	1	1	2	2	4
	Sum:	**101**	**110**	**56**	**118**	**101**	**98**	**107**	**103**	**101**
	PERCENT CLASTS:									
1	**Mafic Volcanic Rocks**	28%	15%	36%	43%	58%	40%	37%	0%	26%
2	**Felsic Volcanic Rocks**	10%	10%	13%	12%	7%	5%	7%	26%	33%
3	**Clastic Sedimentary Rocks**	7%	22%	14%	6%	9%	9%	15%	38%	7%
4	**Chemical Sedimentary Rocks**	9%	4%	2%	3%	3%	5%	1%	2%	0%
5	**Sheared Rocks**	5%	5%	0%	8%	8%	0%	5%	2%	3%
6	**Felsic Intrusive Rocks**	15%	11%	5%	8%	6%	10%	11%	27%	16%
7	**Mafic Intrusive Rocks**	1%	0%	0%	14%	2%	6%	6%	0%	8%
8	**High-grade Metamorphic Rocks**	22%	31%	27%	6%	6%	23%	16%	3%	4%
9	**Other (including altered rocks)**	4%	4%	4%	0%	1%	1%	2%	2%	4%
	Iron Formation	3%	2%	0%	3%	3%	4%	1%	1%	0%
	Qtz-Epi	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Qtz-Ank	2%	1%	0%	0%	0%	0%	0%	0%	0%

Lithology		Sample Number								
		326-048	326-049	326-050	326-051	326-053	326-054	326-057	326-067	326-069
1	**Mafic Volcanic Rocks**	51	79	29	38	40	41	7	24	49
1b	Porphyritic Mafic Volcanic	1					3			
2	**Felsic Volcanic Rocks**	12	10	24	12	38	16	31		7
2a	Massive Felsic Lava		2							
2b	Porphyritic Felsic Volcanic					3	2	1		
2d	Felsic Volcaniclastic Sediments									
3	**Clastic Sedimentary Rocks**			2		2	1	3		4
3a	Greywacke-Slate	6	2	4	1	5	1	2	1	4
3b	Shale-Phyllite	2		2	4		3	2		4
3c	Siltstone	1	3	3	2	1	2	2		3
4	**Chemical Sedimentary Rocks**			1				5		
4a	Oxide Facies BIF	4		5	1		4	13	1	3
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4e	Chert	1	1	3	1	4	1	6		1
4f	Carbonate Rock									
5	**Sheared Rocks**	2		3	6	2	3	3		3
5a	Quartz-sericite Schist	2	2		1	1	1			2
5b	Quartz-ankerite Schist					2		1		
5c	Quartz-sericite-ankerite Schist	2	1	5	3		5			1
5d	Chlorite Schist/Phyllite					2				
5i	Mylonitic Rock					1				
6	**Felsic Intrusive Rocks**	5	1	11	6	5	8	8	12	2
6a	Kspar-plagioclase bearing Granitoid	1	3	4	1	8	5	1	7	1
6b	Plagioclase bearing Granitoid	3		3	1	9	1	17	10	8
7	**Mafic Intrusive Rocks**	2	5	4	6	1				6
7a	Microgabbro						1			
8	**High-grade Metamorphic Rocks**				3					2
8a	Biotite Schist	1	1	1	3				4	1
8b	Amphibolite	3	1		11	3				
8c	Gneiss		1							
9	**Other (including altered rocks)**	1	3		1		7			
QV	Quartz vein material		2	4	2	5	1	3	1	3
Qtz-Epi	Quartz-epidote Alteration		1			0	1			
Qz	Quartz grain							1		
	TOTAL CLASTS:									
1	**Mafic Volcanic Rocks**	52	79	29	38	40	44	7	24	49
2	**Felsic Volcanic Rocks**	12	12	24	12	41	18	32	0	7
3	**Clastic Sedimentary Rocks**	9	5	11	7	8	7	9	1	15
4	**Chemical Sedimentary Rocks**	5	1	9	2	4	5	24	1	4
5	**Sheared Rocks**	6	3	8	10	8	9	4	0	6
6	**Felsic Intrusive Rocks**	9	4	18	8	22	14	26	29	11
7	**Mafic Intrusive Rocks**	2	5	4	6	1	1	0	0	6
8	**High-grade Metamorphic Rocks**	4	3	1	17	3	0	0	4	3
9	**Other (including altered rocks)**	1	6	4	3	5	9	4	1	3
	Sum:	**100**	**118**	**108**	**103**	**132**	**107**	**106**	**60**	**104**
	PERCENT CLASTS:									
1	**Mafic Volcanic Rocks**	52%	67%	27%	37%	30%	41%	7%	40%	47%
2	**Felsic Volcanic Rocks**	12%	10%	22%	12%	31%	17%	30%	0%	7%
3	**Clastic Sedimentary Rocks**	9%	4%	10%	7%	6%	7%	8%	2%	14%
4	**Chemical Sedimentary Rocks**	5%	1%	8%	2%	3%	5%	23%	2%	4%
5	**Sheared Rocks**	6%	3%	7%	10%	6%	8%	4%	0%	6%
6	**Felsic Intrusive Rocks**	9%	3%	17%	8%	17%	13%	25%	48%	11%
7	**Mafic Intrusive Rocks**	2%	4%	4%	6%	1%	1%	0%	0%	6%
8	**High-grade Metamorphic Rocks**	4%	3%	1%	17%	2%	0%	0%	7%	3%
9	**Other (including altered rocks)**	1%	5%	4%	3%	4%	8%	4%	2%	3%
	Iron Formation	4%	0%	5%	1%	0%	4%	12%	2%	3%
	Qtz-Epi	0%	1%	0%	0%	0%	1%	0%	0%	0%
	Qtz-Ank	2%	1%	5%	3%	2%	5%	1%	0%	1%

Lithology		Sample Number								
		326-070	326-071	326-072	326-073	326-074	326-075	326-076	326-078	326-079
1	**Mafic Volcanic Rocks**	52	83	44	28	21	29	44	13	88
1b	Porphyritic Mafic Volcanic									
2	**Felsic Volcanic Rocks**	15	4	9	13	8	30	12	24	10
2a	Massive Felsic Lava									
2b	Porphyritic Felsic Volcanic	8	1		3			2	4	
2d	Felsic Volcaniclastic Sediments									
3	**Clastic Sedimentary Rocks**						1	2		
3a	Greywacke-Slate					2			3	
3b	Shale-Phyllite	1		2	1	1	4	2		
3c	Siltstone				1				18	
4	**Chemical Sedimentary Rocks**									
4a	Oxide Facies BIF	3	6	6	14	10	10	12	20	
4b	Sulfide Facies BIF									
4c	Carbonate Facies BIF									
4e	Chert	9			1	3	3	1	3	1
.4f	Carbonate Rock			1						
5	**Sheared Rocks**	6	1				7	1	1	
5a	Quartz-sericite Schist	1	4		2	4	1	2	8	
5b	Quartz-ankerite Schist									
5c	Quartz-sericite-ankerite Schist				1	1		1		
5d	Chlorite Schist/Phyllite							1		1
5i	Mylonitic Rock									
6	**Felsic Intrusive Rocks**		1	12	10	7	8	5	17	
6a	Kspar-plagioclase bearing Granitoid	5		1		8	6	6	1	
6b	Plagioclase bearing Granitoid					1		6		
7	**Mafic Intrusive Rocks**	1	1		1					3
7a	Microgabbro						1	1		5
8	**High-grade Metamorphic Rocks**									
8a	Biotite Schist									
8b	Amphibolite									
8c	Gneiss					1				
9	**Other (including altered rocks)**					3		2	2	
QV	Quartz vein material	4	2	4	4		2	3		
Qtz-Epi	Quartz-epidote Alteration									
Qz	Quartz grain									
	TOTAL CLASTS:									
1	**Mafic Volcanic Rocks**	52	83	44	28	21	29	44	13	88
2	**Felsic Volcanic Rocks**	23	5	9	16	8	30	14	28	10
3	**Clastic Sedimentary Rocks**	1	0	2	2	3	5	4	21	0
4	**Chemical Sedimentary Rocks**	12	6	7	15	13	13	13	23	1
5	**Sheared Rocks**	7	5	0	3	5	8	5	9	1
6	**Felsic Intrusive Rocks**	5	1	13	10	16	14	17	18	0
7	**Mafic Intrusive Rocks**	1	1	0	1	0	1	1	0	8
8	**High-grade Metamorphic Rocks**	0	0	0	0	1	0	0	0	0
9	**Other (including altered rocks)**	4	2	4	4	3	2	5	2	0
	Sum:	**105**	**103**	**79**	**79**	**70**	**102**	**103**	**114**	**108**
	PERCENT CLASTS:									
1	**Mafic Volcanic Rocks**	50%	81%	56%	35%	30%	28%	43%	11%	81%
2	**Felsic Volcanic Rocks**	22%	5%	11%	20%	11%	29%	14%	25%	9%
3	**Clastic Sedimentary Rocks**	1%	0%	3%	3%	4%	5%	4%	18%	0%
4	**Chemical Sedimentary Rocks**	11%	6%	9%	19%	19%	13%	13%	20%	1%
5	**Sheared Rocks**	7%	5%	0%	4%	7%	8%	5%	8%	1%
6	**Felsic Intrusive Rocks**	5%	1%	16%	13%	23%	14%	17%	16%	0%
7	**Mafic Intrusive Rocks**	1%	1%	0%	1%	0%	1%	1%	0%	7%
8	**High-grade Metamorphic Rocks**	0%	0%	0%	0%	1%	0%	0%	0%	0%
9	**Other (including altered rocks)**	4%	2%	5%	5%	4%	2%	5%	2%	0%
	Iron Formation	3%	6%	8%	18%	14%	10%	12%	18%	0%
	Qtz-Epi	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Qtz-Ank	0%	0%	0%	1%	1%	0%	1%	0%	0%

Lithology		Sample Number		
		326-096	326-097	326-123
1	**Mafic Volcanic Rocks**	42	56	69
1b	Porphyritic Mafic Volcanic			
2	**Felsic Volcanic Rocks**	19	12	21
2a	Massive Felsic Lava			
2b	Porphyritic Felsic Volcanic		10	
2d	Felsic Volcaniclastic Sediments			
3	**Clastic Sedimentary Rocks**	1		
3a	Greywacke-Slate		2	4
3b	Shale-Phyllite			
3c	Siltstone	3	2	3
4	**Chemical Sedimentary Rocks**			
4a	Oxide Facies BIF	3	5	
4b	Sulfide Facies BIF			
4c	Carbonate Facies BIF			
4e	Chert	2	1	2
4f	Carbonate Rock			
5	**Sheared Rocks**			
5a	Quartz-sericite Schist			3
5b	Quartz-ankerite Schist			
5c	Quartz-sericite-ankerite Schist			1
5d	Chlorite Schist/Phyllite			
5i	Mylonitic Rock			1
6	**Felsic Intrusive Rocks**	6	3	7
6a	Kspar-plagioclase bearing Granitoid	2	2	3
6b	Plagioclase bearing Granitoid			
7	**Mafic Intrusive Rocks**	10	6	4
7a	Microgabbro			
8	**High-grade Metamorphic Rocks**			4
8a	Biotite Schist			2
8b	Amphibolite			4
8c	Gneiss			1
9	**Other (including altered rocks)**		1	
QV	Quartz vein material			2
Qtz-Epi	Quartz-epidote Alteration		2	
Qz	Quartz grain			
	TOTAL CLASTS:			
1	**Mafic Volcanic Rocks**	42	56	69
2	**Felsic Volcanic Rocks**	19	22	21
3	**Clastic Sedimentary Rocks**	4	4	7
4	**Chemical Sedimentary Rocks**	5	6	2
5	**Sheared Rocks**	0	0	5
6	**Felsic Intrusive Rocks**	8	5	10
7	**Mafic Intrusive Rocks**	10	6	4
8	**High-grade Metamorphic Rocks**	0	0	11
9	**Other (including altered rocks)**	0	3	2
	Sum:	**88**	**102**	**131**
	PERCENT CLASTS:			
1	**Mafic Volcanic Rocks**	48%	55%	53%
2	**Felsic Volcanic Rocks**	22%	22%	16%
3	**Clastic Sedimentary Rocks**	5%	4%	5%
4	**Chemical Sedimentary Rocks**	6%	6%	2%
5	**Sheared Rocks**	0%	0%	4%
6	**Felsic Intrusive Rocks**	9%	5%	8%
7	**Mafic Intrusive Rocks**	11%	6%	3%
8	**High-grade Metamorphic Rocks**	0%	0%	8%
9	**Other (including altered rocks)**	0%	3%	2%
	Iron Formation	3%	5%	0%
	Qtz-Epi	0%	2%	0%
	Qtz-Ank	0%	0%	1%

APPENDIX D. FACTOR SCORES - DRIFT LITHOLOGY

Sample Number	UTME	UTMN	Factor 1	2	3	4	5	6	7
326-005	576319	5300390	1.000	1.583	0.705	-0.437	-0.088	-5.396	-0.097
326-006	561440	5296244	-0.815	0.442	0.762	-2.143	-0.494	1.094	0.631
326-008	563143	5296259	0.158	0.394	0.833	-1.854	-1.040	0.733	0.098
326-011	562367	5294307	0.817	-0.007	-0.106	-0.989	3.340	0.477	0.675
326-012	562774	5294150	1.596	-0.545	-0.219	-1.618	-0.217	-0.393	-0.368
326-013	563585	5294318	0.073	-1.055	0.599	-1.776	1.720	-0.626	1.394
326-014	563787	5295226	0.922	-0.728	-1.752	-1.091	-0.480	-0.625	-0.060
326-016	558531	5285384	0.416	0.531	-4.126	0.545	-0.599	1.020	0.162
326-017	558476	5285609	-0.235	1.774	-0.274	1.213	-0.828	0.636	0.332
326-018	557289	5288791	-0.309	0.557	1.050	-0.042	-0.008	0.136	0.449
326-019	558551	5289466	-0.726	-0.347	0.578	1.004	-0.829	-0.673	0.127
326-020	559011	5289808	0.107	-0.724	-0.827	-0.497	-1.215	-0.540	1.520
326-021	558942	5289891	-0.418	-1.066	0.769	1.877	0.236	-0.092	-0.126
326-022	559020	5290291	-0.691	-0.803	-1.016	0.624	-0.932	-1.054	0.630
326-023	558875	5289668	-0.549	-1.103	0.478	0.802	0.192	-0.206	0.468
326-024	557251	5287076	-0.740	1.058	0.370	0.787	0.201	-0.394	-0.132
326-025	557565	5287161	-0.119	1.024	0.290	0.838	0.715	0.263	-0.240
326-026	558201	5287161	1.098	1.737	1.332	0.113	-0.400	0.426	0.222
326-027	557811	5286131	0.064	0.332	-0.625	0.796	0.755	0.021	0.817
326-028	558436	5287161	0.432	2.233	0.734	1.443	0.418	0.572	1.062
326-029	559221	5287290	0.706	0.381	0.284	0.635	-0.984	-0.217	0.706
326-031	559862	5287437	0.586	-0.176	1.180	0.747	-0.532	0.981	-0.767
326-032	560083	5287627	0.077	-0.795	1.146	0.928	0.278	0.487	0.856
326-036	561071	5287506	1.013	0.038	0.580	0.652	-0.816	0.991	0.964
326-038	561359	5287536	1.188	0.160	0.051	0.729	0.082	0.853	0.354
326-041	549927	5286168	0.892	2.609	-0.309	-1.329	-0.880	-0.078	-0.072
326-048	565624	5292008	0.146	-0.563	-0.029	0.486	0.889	0.108	-2.439
326-049	565865	5291998	0.660	-0.405	0.275	0.964	-0.309	-0.940	-2.586
326-050	565704	5291281	0.624	-0.065	-0.694	-0.230	2.312	0.618	-0.557
326-051	565326	5290802	1.166	0.508	0.052	0.171	1.467	0.814	-0.179
326-053	563046	5292493	0.351	-0.071	-0.207	-0.326	0.385	-0.874	0.215
326-054	562676	5292691	0.695	-0.851	-1.111	-0.087	2.624	-0.608	-0.663
326-057	561533	5297935	-2.582	0.798	-0.308	-0.863	0.034	0.326	-1.183
326-067	555166	5291445	0.092	0.123	-2.792	0.975	-1.086	-0.009	-0.158
326-069	556743	5290985	0.131	-0.052	0.736	0.734	0.050	-0.109	-1.321
326-070	557584	5291442	-1.636	-0.091	0.402	0.028	-0.172	-0.082	-2.754
326-071	557890	5291800	-0.253	-2.740	0.964	1.080	-0.169	-0.410	1.572
326-072	558532	5291899	-0.428	-0.914	-0.365	-0.455	-1.135	-0.990	0.839
326-073	559025	5292195	-2.163	-0.436	-0.414	-0.635	0.028	-0.346	0.913
326-074	558990	5292689	-1.619	-0.082	-0.705	-0.065	0.882	0.208	1.030
326-075	558700	5293151	-1.660	0.423	-0.151	-0.949	-0.070	0.511	0.463
326-076	558142	5293518	-1.893	-0.126	-0.612	0.495	0.135	-0.266	-1.101
326-078	563135	5298333	-1.996	0.639	1.093	-1.376	0.151	0.470	-0.077
326-079	564425	5298530	0.936	-1.996	0.959	0.208	-1.155	0.696	-0.565
326-096	566138	5296978	1.207	-0.946	0.146	-1.586	-1.301	1.268	-1.780
326-097	566761	5296834	1.126	-0.961	0.138	-1.655	-0.994	0.462	-0.218
326-123	564848	5288141	0.552	0.305	0.138	1.129	-0.162	0.756	0.945

APPENDIX E. FACTOR SCORES - PROJECT 318

SAMPLE	SITE#	UTME	UTMN	Factor 1	Factor 2	Factor 3	Factor 4
3180100001	7	498010	5291505	-0.810	0.830	1.900	-1.010
3180100002	8	495295	5302040	0.420	-0.260	2.470	0.160
3180100003	8	495300	5302045	0.100	1.360	2.590	-1.240
3180100004	10	487860	5297085	0.520	-1.410	1.950	0.700
3180100005	14	517195	5291105	1.170	-1.290	2.290	-0.720
3180100006	22	533360	5297515	-0.880	-0.190	1.080	0.230
3180100007	23	542970	5291805	0.590	-1.200	1.940	-0.280
3180100008	25	543890	5281060	-1.570	-1.070	1.230	-0.070
3180100009	26	548100	5294860	-1.100	-0.250	1.550	-0.560
3180100010	27	555890	5294645	-1.100	-1.520	2.050	-0.810
3180100011	28	553460	5292130	-1.160	-1.370	1.570	0.620
3180100012	28	553455	5292125	-1.670	-0.450	1.400	-0.430
3180100013	29	551795	5285350	-1.360	-0.440	1.240	-0.200
3180100015	31	552730	5293670	1.240	-1.160	2.180	-0.550
3180100016	32	558080	5295410	-0.920	-0.370	0.780	0.820
3180100017	35	519980	5288675	-1.290	-0.330	0.730	0.590
3180100018	37	472410	5295575	0.620	-1.010	1.900	0.690
3180100019	43	505100	5313590	-1.080	-0.390	1.270	-0.050
3180100020	45	514565	5306420	-1.480	-0.580	1.410	0.030
3180100020	45	514570	5306425	-1.620	-0.110	1.540	0.550
3180100021	49	525995	5292785	-1.960	0.100	1.450	0.080
3180100022	53	519030	5301480	-1.160	-0.350	1.410	0.110
3180100023	56	528505	5291420	-1.090	0.000	1.040	0.650
3180100024	57	522805	5293285	-1.700	1.820	0.870	0.150
3180100025	58	547385	5286405	1.310	-0.150	2.050	-0.360
3180100026	59	554920	5291920	0.970	-1.620	2.080	0.030
3180100027	60	554345	5293640	-0.750	0.540	1.250	-0.230
3180100028	61	554205	5293005	-1.310	1.800	1.110	0.060
3180100029	62	548485	5288635	0.800	-1.010	1.580	-0.400
3180100030	63	546780	5288390	0.030	-0.280	0.420	0.650
3180100031	65	561210	5297460	0.010	-0.140	1.760	0.470
3180100033	28	553450	5292120	-0.520	0.480	1.050	0.480
3180100034	8	495290	5302035	-0.080	0.850	1.320	-0.860
3180100035	37	472415	5295580	-2.450	0.020	0.120	0.640
3180100036	49	525990	5292780	1.320	-0.110	1.790	0.910
3180100037	57	522810	5293290	1.070	0.030	1.810	0.850
3180100038	57	522800	5293280	0.950	-0.460	1.880	0.710
3180100039	61	554200	5293000	0.120	0.860	1.000	0.100
3180100040	62	548480	5288630	0.950	-0.170	0.170	1.080
3180100043	65	561205	5297455	-0.070	0.360	-0.200	1.170
3180100044	66	552531	5269344	-1.650	0.460	-0.920	-0.180
3180100045	66	552536	5269349	0.030	-0.250	-0.900	1.220
3180100046	50	486095	5290200	-0.400	0.410	-1.410	0.370
3180100047	32	558085	5295415	-1.430	-1.720	-1.060	0.430
3180100048	66	552526	5269339	0.940	0.070	-0.450	1.320
3180100049	66	552521	5269334	-0.340	-0.410	-0.890	0.450
3180100050	67	557125	5276102	0.140	-0.970	-0.060	-2.140

SAMPLE	SITE#	UTME	UTMN	Factor 1	Factor 2	Factor 3	Factor 4
3180100051	68	583331	5301871	0.810	1.880	0.510	1.360
3180100052	68	583336	5301876	0.550	-0.800	-0.050	2.160
3180100053	68	583326	5301866	1.200	0.040	-0.500	-0.960
3180100054	70	588827	5309357	1.080	-0.150	-0.580	-1.530
3180100055	70	588822	5309352	0.120	0.640	-0.840	-0.980
3180100056	72	588327	5305578	-0.390	-0.960	-0.260	-1.580
3180100057	72	588332	5305583	1.170	1.590	-0.020	0.020
3180100058	72	588322	5305573	0.230	-0.540	-0.550	-1.350
3180100059	72	588317	5305568	-0.020	1.710	-1.150	-0.850
3180100060	73	582728	5311088	-0.270	0.450	0.420	-2.030
3180100061	73	582723	5311083	0.490	-0.420	-0.560	-0.340
3180100062	74	580882	5304755	-0.820	1.550	-0.690	-1.920
3180100063	74	580877	5304750	1.130	1.790	-0.030	-0.350
3180100064	75	592848	5306081	-0.300	0.160	-0.460	-1.250
3180100065	75	592843	5306076	-0.300	-0.050	-1.210	1.030
3180100066	77	527620	5294516	-1.130	1.000	0.050	-2.490
3180100067	77	527615	5294511	0.240	-0.220	-0.960	-1.730
3180100068	78	530172	5295282	-0.500	0.750	-0.330	0.850
3180100069	78	530177	5295287	-1.970	0.820	-0.900	1.310
3180100070	78	530167	5295277	-0.330	0.000	0.070	-1.000
3180100071	79	526272	5289786	1.430	1.770	0.330	0.600
3180100072	79	526267	5289781	0.680	1.080	-0.560	-0.480
3180100073	82	524326	5301703	-1.770	0.220	-0.190	-1.610
3180100074	83	513017	5296007	-0.410	2.530	-0.610	-0.380
3180100075	83	513012	5296002	-1.350	-0.230	-0.360	-1.960
3180100076	84	519723	5296060	1.270	0.720	-0.240	-0.170
3180100077	85	529210	5294640	0.210	1.930	0.380	-2.600
3180100078	86	519502	5298961	1.330	0.330	-0.220	-0.090
3180100079	86	519497	5298956	0.830	-0.060	-0.630	-1.520
3180100080	87	530158	5304199	-0.340	-0.190	-0.300	-0.590
3180100081	88	534781	5304072	0.620	0.150	-0.360	-0.240
3180100082	88	534776	5304067	0.970	-0.100	-0.580	-0.510
3180100083	90	510789	5299610	0.540	-0.780	-0.200	-0.700
3180100084	92	524918	5309873	0.130	-1.190	-1.440	-0.550
3180100085	92	524913	5309868	1.050	0.330	0.150	0.990
3180100086	93	507172	5300774	0.900	-0.150	-0.290	1.820
3180100087	93	507167	5300769	0.450	0.520	-0.370	0.120
3180100088	94	538710	5301202	0.360	-1.060	-0.240	0.700
3180100089	96	528431	5287912	-1.280	-0.430	-0.660	0.910
3180100090	98	449166	5283507	1.220	-1.680	-0.910	-0.240
3180100091	98	449171	5283512	0.630	-0.180	-0.280	0.720
3180100092	99	469096	5294546	1.330	-0.190	-0.210	0.680
3180100093	99	469101	5294551	-0.110	-0.740	-0.510	1.030
3180100094	99	469091	5294541	1.090	0.170	0.020	1.520
3180100095	98	449161	5283502	0.580	-0.680	-0.470	1.040
3180100096	100	505565	5317660	1.570	-0.140	-0.580	0.110
3180100097	100	505560	5317655	1.330	-0.650	0.560	0.160
3180100098	101	498199	5324086	-0.800	1.120	-1.440	-0.390

SAMPLE	SITE#	UTME	UTMN	Factor 1	Factor 2	Factor 3	Factor 4
3180100099	102	489118	5323017	0.810	-0.700	-0.590	-0.210
3180100100	102	489113	5323012	0.060	-2.220	-1.150	0.320
3180100101	103	571695	5301077	1.210	1.350	-0.210	-0.380
3180100102	103	571700	5301082	0.730	0.570	-0.410	1.160
3180100103	103	571690	5301072	0.780	-0.230	-0.810	0.800
3180100104	104	570320	5304452	0.970	0.160	-0.290	-0.470
3180100105	105	581358	5308713	0.680	0.490	-1.480	-0.540
3180100106	105	581353	5308708	1.340	0.040	-0.510	-0.290
3180100107	106	584510	5305498	0.330	-0.900	-0.530	0.070
3180100108	107	587304	5305922	1.550	1.210	-0.120	0.230
3180100109	107	587309	5305927	1.430	1.270	-0.360	-0.430
3180100110	107	587299	5305917	0.440	-2.680	-0.890	-1.130
3180100111	107	587294	5305912	-0.110	1.360	-0.360	-0.400
3180100112	108	588268	5298325	-1.880	-0.760	-1.560	-0.650
3180100113	109	584940	5290077	0.590	2.760	0.050	-0.230
3180100114	110	577311	5307360	0.280	0.490	-1.110	0.280
3180100115	110	577316	5307365	-0.650	0.100	-1.110	0.800
3180100116	110	577306	5307355	1.530	1.510	0.270	0.460
3180100117	110	577301	5307350	-0.320	-0.530	0.220	0.100
3180100118	111	574194	5303333	-1.160	-0.280	-0.590	-1.520
3180100119	111	574199	5303338	-1.760	0.390	-1.080	0.050
3180100120	111	574189	5303328	-2.330	1.350	-0.330	1.330
3180100121	111	574184	5303323	-0.720	0.340	-0.640	-0.510
3180100122	112	579242	5291400	-2.080	1.290	-0.940	1.200
3180100123	113	586751	5294610	-0.830	-0.950	-0.950	-0.070
3180100124	114	587567	5296678	0.530	-0.680	-0.480	-1.610
3180100125	114	587562	5296673	-1.110	0.000	-0.380	1.240
3180100126	115	574799	5288329	1.260	0.100	-0.030	1.000
3180100127	115	574794	5288324	0.340	1.430	0.270	1.590
3180100128	119	539353	5313524	0.330	-0.010	0.930	-1.280
3180100129	120	447624	5277327	-0.580	0.960	-0.820	-0.250
3180100130	120	447619	5277322	0.600	0.180	-0.360	-0.520
3180100131	123	470241	5281757	-1.530	-0.170	-0.870	0.850
3180100132	123	470236	5281752	1.130	-1.050	-0.780	-1.260
3180100133	38	468010	5302940	0.100	0.370	-0.780	-0.010
3180100134	127	470042	5310502	0.070	-0.460	-0.760	-1.620
3180100135	128	448482	5284844	0.310	-0.880	-0.090	-1.480
3180100136	132	482521	5294437	0.110	-1.820	-1.300	-0.790
3180100137	133	473434	5331773	0.800	-1.110	-0.390	-1.400
3180100138	134	514485	5319284	-0.200	-3.250	-0.750	1.200
3180100139	136	492175	5300642	-0.100	-1.960	-1.420	1.710
3180100140	138	492137	5293255	0.320	-1.950	-0.860	-0.370
3180100141	139	488812	5295064	-1.780	0.690	-0.180	0.990
3180100142	140	492808	5302238	-0.360	0.330	-1.500	0.670
3180100143	141	493567	5300971	1.010	0.870	-0.370	0.510
3180100144	48	512710	5308030	1.390	0.700	-0.220	0.470
3180100145	48	512715	5308035	0.450	0.250	-0.350	-1.230
3180100146	48	512705	5308025	1.090	-1.030	-1.240	0.570

SAMPLE	SITE#	UTME	UTMN	Factor 1	Factor 2	Factor 3	Factor 4
3180100147	48	512700	5308020	0.530	-0.560	-0.230	1.670
3180100148	141	493562	5300966	0.320	0.980	0.000	0.710
3180100149	142	488495	5304590	0.350	-0.940	-0.800	2.380
3180100150	144	546166	5298731	-1.480	0.220	-0.550	1.220
3180100151	142	488500	5304595	0.880	0.600	-0.590	0.810
3180100152	67	557120	5276097	0.260	1.710	-0.230	0.910
3180100160	37	472420	5295585	0.110	0.810	-0.300	1.970
3180100161	37	472405	5295570	-0.220	-0.090	-0.290	0.360
3180100162	37	472395	5295560	-0.970	0.230	-1.010	0.180
3180100163	37	472400	5295565	-0.670	-0.550	-0.860	-2.070

APPENDIX F. FACTOR SCORES - FIVEMILE LAKE DRILL CORE AND CLAST GEOCHEMISTRY

Sample Number	Factors VF1	VF2	VF3	VF4	VF5	VF6	VF7	VF8	VF9
Drill Core Sample									
3260000093	-0.56	0.09	0.34	0.39	0.8		-1.03	0.06	-1.18
3260000094	-1.99	0.71	-1.99	0.15	0.41	0.26	-0.59	2.03	0.45
3260000096	-0.91	0.2	0.23	0.27	0.52	0.27	-1.07	-1.01	-0.38
3260000097	-1.13	-0.84	-0.73	-0.58	-0.65	0.2	3.91	0.64	-0.05
3260000099	0.47	-1.43	-0.43	-0.18	-1.24	-0.53	0.12	0.34	-0.44
3260000102	1.8	-2.18	-0.26	-0.13	-1.04	-0.97	-0.23	-1.62	0.2
3260000105	-1.63	0.14	-1.6	0.38	1.27	0.16	0.92	-3.69	-0.26
3260000115	-0.37	0.04	1.19	0.39	-0.76	0.53	-0.01	-0.16	-0.27
3260000121	1.29	1.57	-0.7	0.78	-0.52	-0.13	0.15	-0.2	-0.02
3260000122	0.77	1.69	-1.1	0.7	-0.76	-0.29	0.59	-0.4	1.26
3260000124	1.02	1.5	-0.46	0.64	-0.22	-0.12	-0.21	-0.22	-0.64
3260000127	-0.62	0.07	-0.57	0.36	-0.72	-0.19	-1.37	0.04	0.29
3260000131	-0.59	-0.35	0.25	0.02	-2.28	0.23	-0.78	-0.15	-0.69
3260000132	-1.06	1.08	1.17	-0.56	0.68	-3.88	1.03	0.47	-1.26
3260000106	0.66	0.58	-0.38	0.55	-0.52	0.36	1.03	0.3	-0.68
3260000109	-0.22	0.24	1.17	0.31	-1.52	-0.4	0.18	0.02	1.25
3260000111	-0.5	0.31	1.09	0.15	0	0.43	-0.47	-0.45	-0.74
3260000133	0.81	0.94	-0.68	-4.87	-0.17	0.45	-0.61	-0.22	0.2
3260000135	-0.63	-0.48	-1.14	0.41	-0.42	0.38	-0.89	1.3	1.53
3260000146	-0.18	-0.82	-1.1	-0.03	1.06	1.07	0.02	-0.53	-0.69
3260000152	0.41	-0.93	-0.87	0.36	0.88	-2.32	-1.61	-0.03	0.99
3260000155	0.47	-1.8	-0.2	0.08	-0.53	-0.36	0.07	0.92	0.29
Glacially-transported clasts									
326-C-1	0.67	-1.28	0.38	0.07	1.49	0.38	0.45	1.33	-0.03
326-C-2	-1.06	-0.29	1.72	-0.63	-0.67	1.16	-0.27	0.04	-0.35
326-C-3	1.64	1.35	0.65	0.75	-0.19	0.3	0.27	-0.34	-0.74
326-C-4	-0.79	-0.19	0.72	-0.02	1.34	-0.4	-0.74	0.67	-0.69
326-C-5	-0.2	0.19	2.31	-0.06	1.08	0.17	0.46	-0.78	3.55
326-C-6	1.66	-1.04	0.09	0.16	1.81	0.72	0.56	0.5	-0.75
326-C-7	1.05	1.17	0.14	0.01	1.19	0.81	0.56	1.24	0.47
326-C-8	-0.28	-0.23	0.76	0.16	-0.33	0.88	-0.44	-0.1	-0.62

APPENDIX G. QUARTZ-EPIDOTE ALTERED CLAST MASS PROPORTIONS

Sample Number	Pebble Fraction			Sand Fraction		
	Total Wt (g)	Qtz-Epi Clast Wt (g)	Prop QE	Total Wt (g)	Qtz-Epi Clast Wt (g)	Prop QE
326-096	209.30	10.4601	0.04998	43.0225	0.0762	0.0018
326-097	294.66	11.4450	0.03884	36.9449	0.0583	0.0016
326-014	251.90	11.1585	0.04430	60.5763	0.2430	0.0040
326-011	228.42	2.0804	0.00911	55.9203	0.0475	0.0008
326-013	140.97	4.4016	0.03122	49.7836	0.1288	0.0026
326-012	540.38	21.0889	0.03903	40.3685	0.1333	0.0033
326-054	675.98	20.5660	0.03042	44.3076	0.2592	0.0059
326-053	135.74	0.4677	0.00345	45.2288	0.1854	0.0041
326-047	239.45	2.6860	0.01122			
326-048	450.11	20.5595	0.04568	60.5084	0.2747	0.0045
326-049	346.60	3.3934	0.00979	54.7458	0.2181	0.0040
326-050	584.55	10.7942	0.01847	61.1013	0.1373	0.0022
326-051	219.77	1.1491	0.00523	57.4456	0.2085	0.0036
326-032	660.21	5.1347	0.00778	70.4909	0.1067	0.0015
326-031	407.88	2.1414	0.00525	66.2286	0.0591	0.0009
326-029	78.86	0.0000	0.00000	17.5417	0.0717	0.0041
326-036	303.81	2.2555	0.00742	111.2585	0.0912	0.0008
326-038	297.95	3.0083	0.01010	45.9855	0.1088	0.0024
326-006	228.10	1.3074	0.00573	46.5679	0.0125	0.0003
326-008	586.48	1.5061	0.00257	13.6176	0.0392	0.0029
326-078	452.67	0.0000	0.00000	54.4124	0.0328	0.0006
326-079	614.56	1.6542	0.00269	47.7023	0.0459	0.0010