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PROPERTIES AND AGGREGATE POTENTIAL OF COARSE TACONITE TAILINGS FROM FIVE MINNESOTA TACONITE OPERATIONS

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The goal of this study is to evaluate the technical and economic viability of using coarse taconite tailings for aggregate purposes in road construction. Making use of this mining byproduct makes environmental sense because it maximizes the use of a resource that has already been mined and crushed. The report presents well-documented, technical data from five sites relating geological, mineralogical, and chemical properties to performance when used in road construction. A series of aggregate tests demonstrated the suitability and durability of coarse tailings as a component of bituminous asphalt. In addition, state-of-the-art testing methods showed that none of the samples contained asbestos. In terms of the marketing potential, low-cost rail transportation and a workable distribution plan would be key for expanding the use of coarse taconite tailings as aggregate in markets beyond Northeastern Minnesota.

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Properties and Aggregate Potential of Coarse Taconite Tailings from Five Minnesota Taconite Operations

Final Report

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Lastly, the authors give special recognition to the late Gerry Rohrbach, who passed away last winter. Gerry was Director of Mn/DOT's Office of Materials and Road Research and an enthusiastic and dedicated transportation professional. He was an early project supporter who recognized taconite's aggregate potential. He was also a genuinely nice guy.

FINAL NOTES

- Changes of ownership have recently occurred at two of the project's taconite operations. First, National Steel was purchased by U.S. Steel, and National Steel Pellet Company (NSPC) has been re-named; it is now called Keewatin Taconite. Second, EVTAC Mining Co. was purchased by Cleveland-Cliffs, Inc. and China's Laiwu Steel Group, and EVTAC will be called United Taconite. However, all references to NSPC and EVTAC will remain as NSPC and EVTAC in this report, unless otherwise noted.

- This report will also be made available by the Natural Resources Research Institute, as Technical Report NRRI/TR-2003/44

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EXECUTIVE SUMMARY

Eighteen coarse taconite tailings samples were collected from five Minnesota Mesabi Range taconite operations, i.e., EVTAC, Hibbing Taconite (Hibtac), USX Minntac, Ispat Inland (Minorca), and National Steel Pellet Company (NSPC), in 2000-2001 to test their physical, geological, mineralogical, and chemical properties. By undertaking and completing such a testing program, the technical and economic viability of using a crushed taconite mining byproduct like coarse tailings for construction aggregate purposes could be better evaluated.

The end result is a report that stands as a major technical reference for coarse taconite tailings. It provides well-documented baseline data that can be used by the taconite companies, transportation officials, highway engineers, contractors, aggregate producers, and the public for making rational decisions about the use of taconite mining byproducts like coarse tailings to supplement current and future aggregate requirements, not only on the Iron Range, but in other areas of the state, and beyond. Furthermore, making greater use of materials that have long been considered "waste" byproducts makes environmental sense because it maximizes the use of a resource that has already been mined and crushed, and could reduce the pressure to expand existing (or develop new) "natural" aggregate sources.

The technical information within the report can also be used to better-define, optimize, or modify current and/or future aggregate specification standards for these coarse tailings materials, especially with regard to bituminous applications. Prior to this project, the technical data needed for making such determinations, i.e., relating geological, mineralogical, and chemical properties to performance, was neither well documented nor well developed. This lack of good information may have also contributed to perceptions about taconite mining byproducts like coarse tailings that needlessly limited their aggregate usage potential.

Due to the vast quantities of coarse tailings and other byproducts that are generated by taconite mining activity, a large (and separate) sampling statistical analysis for the engineering, chemical, regulatory, and health finding characteristics was not possible as a part of this study. Future use of such materials should provide for ongoing sampling and testing. Still, it is believed that the project's sampling strategy not only provided materials that reflected the typical range of taconite ore blends processed by each company during a production year, it also provided materials that would actually be used by potential aggregate consumers in real applications.

Major project findings include the following:

- A significant source of fine aggregate (coarse taconite tailings) is available at each of the taconite operations assessed in this study. Nearly one ton of coarse tailings are generated for every ton of finished taconite pellets produced on the Iron Range. The mines use a large fraction of their coarse tailings on-site, but considerable excess is available.

- Operations that make an in-plant separation of coarse and fine tailings, e.g., Ispat Inland, EVTAC, and Minntac, produce a more consistent size gradation and a minimal (less than 2.5%) amount of fines (-200 mesh material), compared to the two operations that do not segregate fine and coarse tailings, Hibtac and NSPC. Even so, suitably sized material can be obtained relatively easily at Hibtac and NSPC.

- The series of aggregate tests performed on all samples clearly demonstrates the suitability of coarse tailings for use in road construction applications, e.g., as a superior draining, granular-fill material when confined, and as a durable, Superpave bituminous surface component. For example, coarse tailings have been successfully used in bituminous surfaces for several highway projects on the Iron Range, such as comprising 100% of the wear surface on Highway 53 south of Virginia.

- Mineralogical and chemical analyses are available for all five taconite operations. Quartz is, by far, the dominant mineral in all samples (typically 55% to 60%), followed by hematite (8% to 12%), and iron-bearing carbonates like siderite and ankerite, silicates like stilpnomelane, minnesotaite, and talc, and minor magnetite (much less than 10% each). Trace element concentrations of heavy metals are typical for these materials, and are comparable to other forms of aggregate.

- Specialized mineralogical analyses, using state-of-the-art testing and analytical methods like scanning and transmission electron microscopy (SEM and TEM), show that neither amphibole minerals nor asbestos minerals are present in any of the tailings samples.

- Coarse tailings and other taconite mining byproducts should be treated with the same common sense safety and industrial hygiene approach practiced for all mineral-based materials that have the potential to generate respirable dust.

- Low-cost transportation and workable distribution logistics will be key for expanded use of taconite mining byproducts like coarse tailings in markets beyond northeastern Minnesota. The extensive rail network that services the Iron Range is well positioned to do just that. Other transportation options like trucking, barge, and Great Lakes shipping are also available. A back-haul component of any transportation option would help keep costs down.

Recommendations

Based on the project's findings, the following recommendations are made for future lines of research:

- Evaluate the market potential (and market acceptance) of taconite aggregates beyond northern Minnesota; investigate the economics and logistics of rail transport; and develop a plan (preferably with the private sector) for making it a cost-effective option for moving large volumes of taconite aggregate to new markets, both inside and outside Minnesota.

- Conduct a field evaluation of, and collect historical technical information for construction projects (past and present) in which taconite aggregates have been used. The goal would be to assess and document quality and performance over time.

- Perform a full-cost accounting comparison between aggregates that are byproducts of taconite mining and "conventionally produced" aggregates, with an emphasis on the energy differential.

- Develop modified or new aggregate specifications and/or bituminous formulations that encourage the use of coarse tailings. The highest value for coarse taconite tailings reuse is in bituminous mixtures since they add durability and skid resistance. Then, evaluate the modifications with laboratory testing and by conducting field trials, e.g., at the MnRoad test facility.

- Compile and generate baseline technical information on coarser (>3/8 in.) taconite aggregate. For example, the inclusion of coarser materials, such as 3/4 in. rejects, in mix designs would add to the marketability of the <3/8 in. coarse tailings. Furthermore, coarser aggregates typically have a higher unit value than finer aggregates.

- Conduct additional shear tests on coarse tailings to determine their stability in saturated and unsaturated conditions. Because stability is largely dependent on gradation, and the gradation can vary in some tailing products (especially products obtained from tailings basins where a well controlled coarse/fine segregation has not been made), if it can be more precisely defined under what conditions certain materials fail, some coarse tailings products may be used as backslope fill or in other unconfined situations.

CHAPTER 1: INTRODUCTION

Over 50 million short tons of aggregate are used annually in Minnesota, with 75% coming from sand and gravel sources, and the remaining 25% from crushed stone sources. Recent studies by Southwick et al., and the Aggregate Resources Task Force, have addressed the growing pressure on aggregate resources in the state of Minnesota, particularly in the seven-county Twin Cities (Minneapolis and Saint Paul) Metro Area [1]; [2]; [3]. There, aggregate shortages have been predicted within the next 10 to 15 years, as currently permitted reserves near exhaustion, and as residential and commercial developments expand and encroach on remaining aggregate resources. Other areas of the state, like the Highway 61 corridor along the north shore of Lake Superior, have also had difficulty supplying new sources of high quality crushed aggregate for local construction jobs. Southeastern Minnesota carbonate (limestone and dolomite) quarries have experienced similar pressures for providing quality construction aggregates that meet Superpave (**SU**perior **PER**forming asphalt **PAVE**ment) specifications. Compounding these resource pressures, the permitting of pit and quarry expansions and new aggregate mines has become more complex and difficult, environmentally and socially, given the growing "not in my back yard" (NIMBY) reaction to such projects.

While the predicted shortages and ongoing permitting difficulties present challenges to "traditional" aggregate resource development in many parts of the state, millions of tons of crushed taconite mining byproducts are being generated by Minnesota's taconite mining operations every year. Because these materials represent a potentially huge alternative or supplement to conventional crushed stone aggregates, it was felt that a project should be conducted that evaluated, in greater detail, one of the most volumetrically significant byproducts of taconite mining and processing: coarse taconite tailings.

Despite being used extensively for road and other construction applications at the mines, coarse tailings usage beyond the confines of the mining properties has, for many years, generally been limited to local construction projects. This is unfortunate, because coarse tailings are a byproduct of tremendous expenditures of energy and capital used in mining and processing taconite. However, if one or more taconite mining byproducts like coarse tailings are found suitable for uses in large-scale road and construction aggregate applications, and are demonstrably superior to other types of aggregate, then the economic and environmental benefit to the taconite companies and the state of Minnesota could be significant, given their potential to offset some of the impending aggregate shortages just discussed.

The project's main goal, therefore, was to generate and document, following a one-year sampling program, the technical data needed for making such determinations, i.e., relating geological, mineralogical, and chemical properties to potential aggregate performance, and to address some of the important economic issues like transportation. It was also believed that the lack of well-documented technical information on several fronts may have been contributing to perceptions about taconite mining byproducts like coarse tailings that were needlessly limiting their use potential.

BACKGROUND

Mine Locations

Figure 1.1 shows the relative location of each taconite operation on the Iron Range. Coarse tailings generated at the five westernmost operations, i.e., Ispat Inland (Minorca), EVTAC, Minntac, Hibbing Taconite (Hibtac), and National Steel Pellet Company (NSPC), were the focus of this study. The two easternmost taconite facilities, i.e., Northshore Mining Company in Babbitt and Silver Bay, and the now closed LTV Steel operation in Hoyt Lakes, were not part of the study.

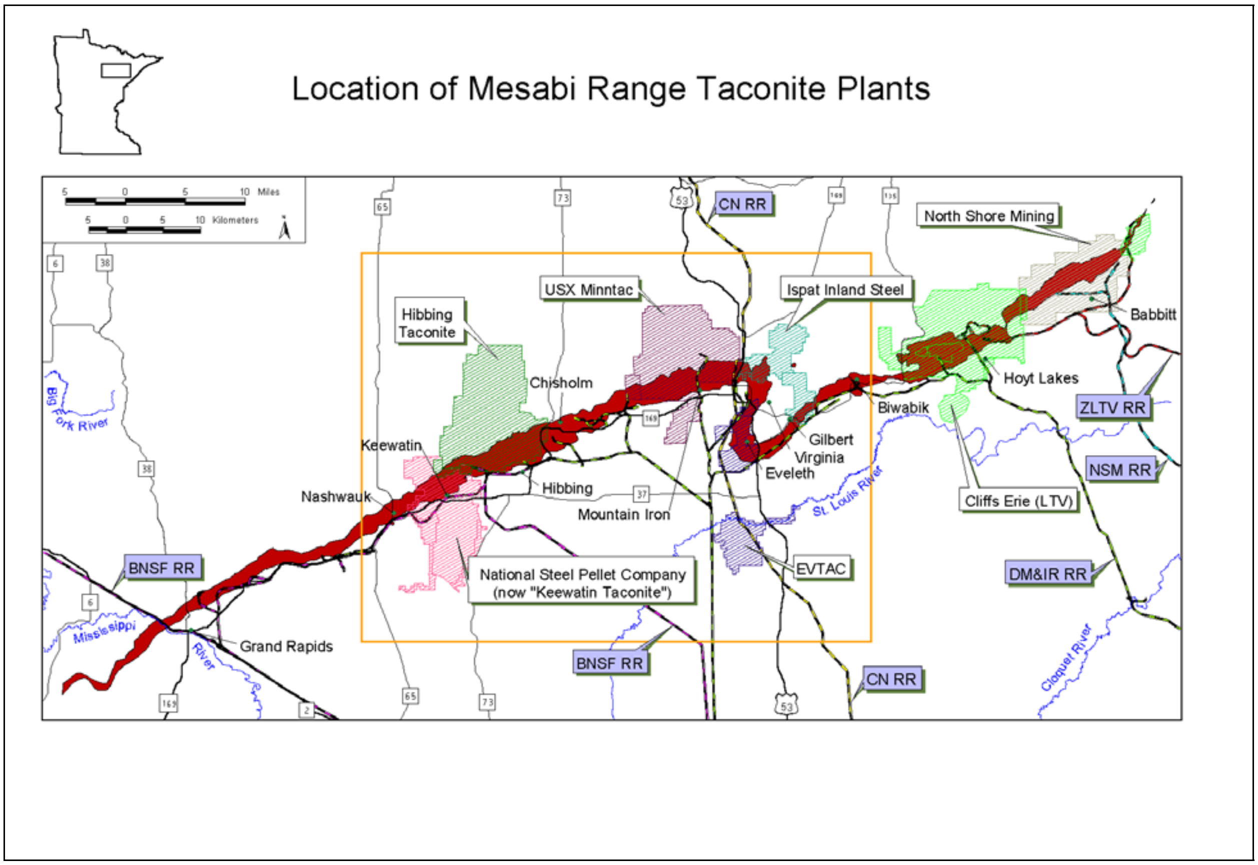

Figure 1.1 Taconite mine location map.

Geology

The following geological description of the Biwabik Iron Formation (BIF) was prepared by NRRI geologist Mark Severson, and is taken from the project, *Oxidized Taconite Geological Resources for a Portion of the Western Mesabi Range(West Half of the Arcturus Mine to the East Half of the Canisteo Mine), Itasca County, Minnesota -A GIS-based Resource Analysis for Land-Use Planning* [4]. It is presented as a quick primer on how each mine's primary taconite ore horizons relate to the stratigraphy of the Biwabik Iron Formation across Minnesota's Iron Range.

Biwabik Iron Formation

The Biwabik Iron Formation (BIF) has typically been subdivided into four members that include (from bottom to top): Lower Cherty (LC), Lower Slaty (LS), Upper Cherty (UC), and Upper Slaty (US). The cherty iron-formation members are generally thick-bedded and contain round-shaped grains (0.5-2.0 mm) of chert that are referred to as granules. These "cherty" members typically contain higher percentages of iron oxides (magnetite, hematite and/or goethite). In contrast, the "slaty" members are thin-bedded (0.5-3.0 mm thick beds) and very fine-grained. They are composed mostly of iron silicates and iron carbonates (Fe-silicates and Fe-carbonates, respectively). Both cherty and slaty iron-formation types are interlayered at all scales. However, one rock type often predominates in each of the four lithostratigraphic members, and are so-named due to this dominance, i.e., thick-bedded cherty iron-formation is dominant in the Lower Cherty member, whereas thin-bedded iron-formation is dominant in the Lower Slaty member. The "cherty" and "slaty" members are envisioned to have been deposited on a continental shelf in "shallower" and "deeper" water, respectively [5]. Overall, the change from cherty to slaty members is indicative of two cycles of progressive deposition in shallow water to deeper water that form an earlier cycle of Lower Cherty (shallower) to Lower Slaty (deeper) followed by a later cycle of Upper Cherty (shallower) to Upper Slaty (deeper).

The four-fold stratigraphy within the BIF has long been recognized, and is still used, at each of currently operating (and inactive) taconite mines/mining areas along the length of the Mesabi Range (nine properties total, from the former Butler operation at the west, to the former LTV Dunka Pit property at the east). However, each of the mining companies further subdivide the BIF into several submembers on the basis of sedimentological textures (Fig. 1.2) and mineralogical changes (some of which are probably related to diagenetic changes).

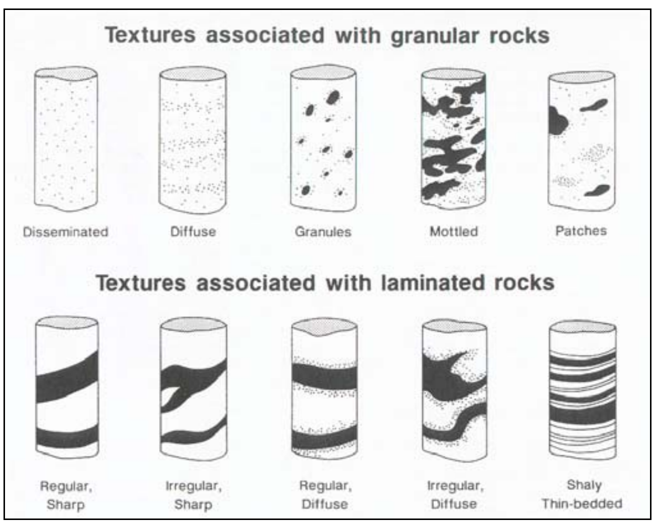

Figure 1.2 Textural characteristics of the Biwabik Iron Formation (modified from a classification by the Hanna Mining Co.) [6]

Figure 1.3 attempts to correlate each of the submembers of the BIF, as used at each of the individual mine sites along the entire Mesabi Range. Most of the correlations in Figure 1.3 are based on sedimentological textures that are described for the various "cherty" and "slaty" iron-formation types. The Coleraine Area, on the left side of Figure 1.3, illustrates the submember terminology used by U.S. Steel relative to the submember terminology used elsewhere along the Mesabi Range. The ***major*** taconite ore horizons, i.e., the source for most of this project's tailings samples, are indicated by the narrow cross-hatched bars adjacent to each property's stratigraphic column. Some taconite operations nonetheless take material from other horizons when appropriate. Note that the westernmost mines in this study, NSPC (now called Keewatin Taconite) and Hibtac, produce ore from the Lower Cherty exclusively, whereas ore from Minntac, EVTAC, and Ispat Inland's Laurentian mine come from both the Lower and Upper Cherty. Additional geological detail about the samples collected during this project is provided in the Chapter 3 (Sample Acquisition) discussion.

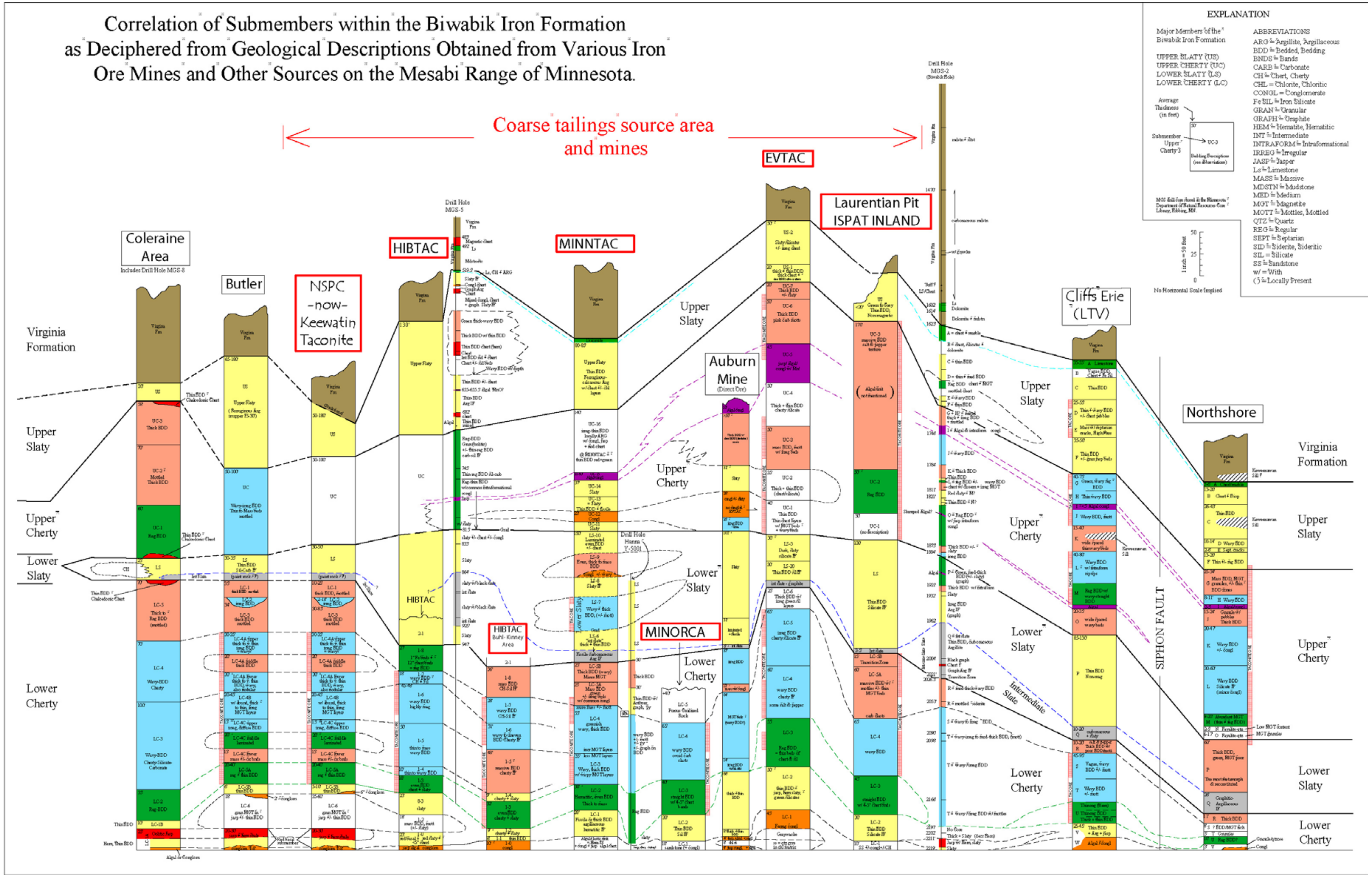

Figure 1.3 Stratigraphic relationships in the Biwabic Iron Formation from west to east, as summarized by geologist M.J. Severson, NRRI [4].

Tailings

NOTE: *In ensuing discussions, tonnages mean "long tons" (2,240 lbs.), because a long ton is the standard unit of weighing for iron ore and taconite in the United States.*

Mine tailings are non- to weakly-mineralized particles of rock that remain after the separation and extraction of an economically valuable mineral from its host ore. In this study, coarse tailings from taconite mining operations are the focus.

Taconite tailings, ranging in size from clay (<2 microns) to coarse sand (3/8 in.), are produced during various stages of crude taconite ore beneficiation. They are highly siliceous and have a low magnetic iron (Mag Fe) content relative to the crude ore, i.e., 3-5 percent versus 18 to 24 percent Mag Fe. Following crushing and grinding of the taconite ore, various combinations of magnetic, gravity, and flotation separation techniques are used to upgrade the pulverized crude taconite ore from a material that typically contains 18 to 24 percent magnetic iron, i.e., magnetite (Fe_3O_4), and more than 50 percent quartz, to a powdered, magnetite-rich concentrate that typically contains less than 4 percent SiO_2. The concentrate is mixed with a small amount of clay or organic binder, and is agglomerated to form marble-size pellets. These "green" pellets are fired in kilns/furnaces, and the hardened pellets, which contain about 65 percent iron, are sold and shipped, mostly to steel-makers on the lower Great Lakes.

The study's five companies mined and processed ***122 million tons*** of crude taconite ore in the year 2000 to produce 33.5 million tons of finished taconite pellets. The 2000 totals are similar to the tonnage totals of the preceding four years from 1996-1999 (Table 1.1), as illustrated in Figure 1.4; the 2001 totals were down about 13% from 2000 [7].

Table 1.1 Crude ore and pellet production, in tons, by company: 1996-2001 [7]

CRUDE ORE	1996	1997	1998	1999	2000	2001
EVTAC	16,517,165	16,249,707	15,291,580	14,005,931	12,692,100	13,449,311
Hibtac	29,408,702	28,467,532	29,579,704	26,557,214	30,533,879	22,458,384
Ispat/Minorca	7,832,557	7,748,820	8,233,999	8,081,731	8,630,112	8,211,395
NSPC	16,933,415	19,141,563	19,803,145	20,329,303	19,759,549	16,836,232
USX Minntac	49,773,665	53,819,074	48,980,515	44,651,316	50,291,700	45,303,626
TOTAL	120,465,504	125,426,696	121,888,943	113,625,495	121,907,340	106,258,948
PELLETS	1996	1997	1998	1999	2000	2001
EVTAC	4,842,571	4,964,481	4,773,026	4,342,770	3,850,443	4,180,091
Hibtac	7,910,004	7,479,612	7,608,548	6,623,571	8,008,869	5,898,926
Ispat/Minorca	2,530,053	2,388,631	2,550,795	2,658,663	2,660,988	2,770,396
NSPC	4,775,999	5,108,503	5,260,207	5,225,632	5,459,565	4,396,955
USX Minntac	12,560,634	13,646,373	13,291,377	12,169,971	13,561,035	12,323,418
TOTAL	32,619,261	33,587,600	33,483,953	31,020,607	33,540,900	29,569,786

During the 6-year period (1996-2001), the companies mined and processed an average of about 3.7 tons of crude ore for each ton of pellets produced (refer to the relative scale of the bars plotted on the crude ore and pellet chart in Figure 1.4 to better visualize the 3.7 to 1 ratio). The remaining 2.7 tons that did not go into the finished pellets are mostly tailings, and stay at the mines as a mining byproduct. Approximately 2/3 of these tailings are classified as "fine", and 1/3 are classified as "coarse". Therefore, the total amount of coarse tailings generated annually on Minnesota's Mesabi Range nearly equals the total tonnage of finished taconite pellets. For the study's five companies, this translates to roughly 30 *million* tons per year.

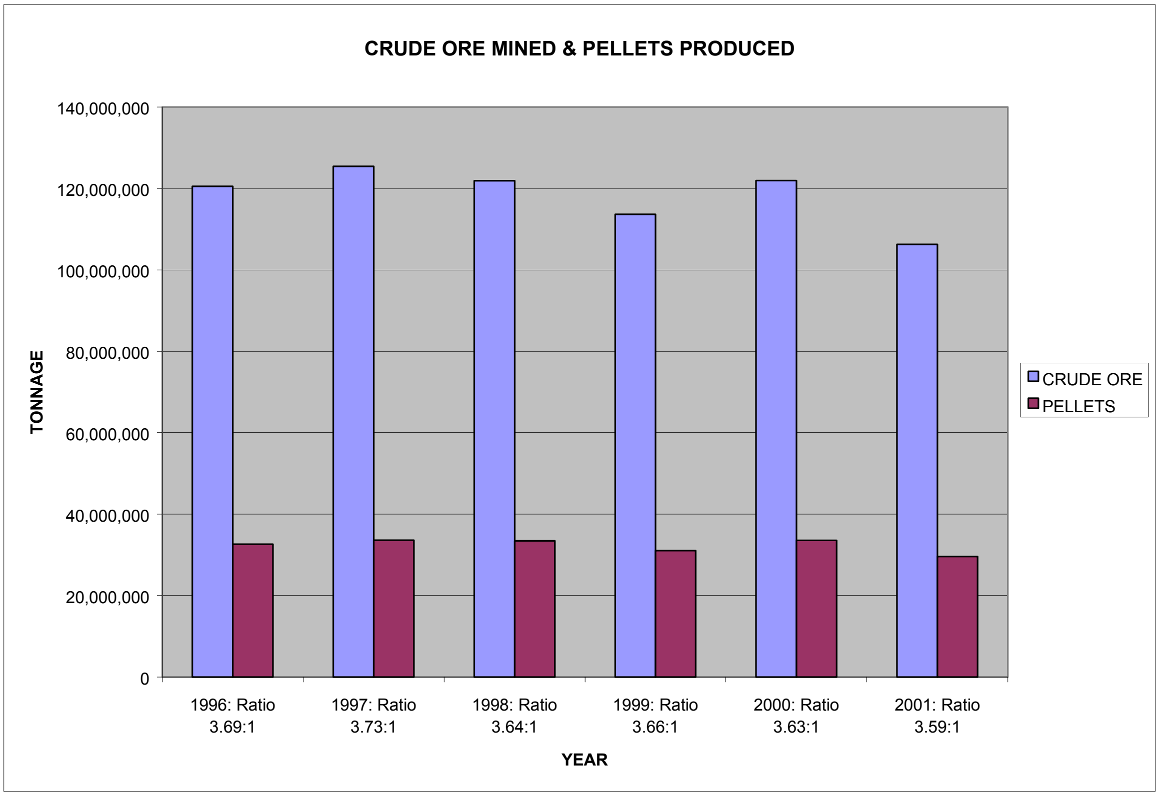

Figure 1.4 Crude ore and pellet production (1996-2001), with crude to pellet ratio.

Mine tailings are typically described as being fine and/or coarse, based on their particle size characteristics and distribution (see Chapter 4: Sample Preparation and Size Analyses). **Fine tailings** are composed of extremely fine rock particles, more than 90% of which are smaller than 0.003 in. (0.075 mm, or -200 mesh); they have little practical use at the mines, and end up in tailings basins. **Coarse tailings** are typically 100% finer than 3/8 in., but 90% coarser than 0.003 in. (0.075 mm, or -200 mesh), and are used for mine-site projects like tailings basin containment cells, dikes, dams, as construction fill material, and for building and maintaining haul roads. Coarse tailings generally meet the definition of *fine aggregate*, i.e., aggregate particles are less than 3/8 in., and, being a byproduct of crushing and grinding, are very angular and comparable to manufactured fine aggregates used widely in construction (N. Whiting, pers. comm., 2002). Consequently, the physical properties that make them suitable for heavy-duty applications at the mines suggest that their expanded use in highway construction projects is worth examining.

Despite the prodigious amounts generated, on-site usage of coarse tailings is extensive, but large amounts still go unused, and the amount of excess varies from mine to mine   For example, Ispat Inland and Minntac use almost all of their coarse tailings for on-site purposes, but EVTAC, Hibtac, and NSPC generate considerably more than they consume. For example, EVTAC has an estimated 37-year supply (tens of millions of tons) of coarse tailings in stockpiles, and Hibtac generates over 2 million excess tons annually.

Why Coarse Tailings?

The project has focused on coarse tailings for reasons that include, but are not limited to, the following:

- the sheer amounts generated by the mines annually;
- the relative ease by which these materials can be obtained;
- the minimal amount of additional processing and/or screening required to produce a suitable product, especially at facilities where a separate and clean coarse tailings product is generated;
- the relatively consistent size distribution/gradation that is a result of a tightly controlled industrial process;
- the high strength and hardness of taconite;
- the inherent particle angularity of coarse tailings as a crushed product, i.e., 100 percent fractured faces; and
- the long-term potential of coarse tailings and other taconite mining byproducts as a significant alternative or supplemental source of aggregate, particularly for meeting Superpave specifications.

PROJECT TASKS

The project involved completing nine specific tasks. Task results (deliverables) are presented as individual chapters in the remainder of this report. Because some technical information naturally applies to more than one task, some overlap of task discussion is inevitable. Documents or images that are task-specific are presented at the end of each task chapter, rather than being presented in a general appendix. The only exception to this is Chapter 8: Specialized Microscopy. Because of their format and size, documents and images related to that chapter are presented in Appendix A.   Project tasks and chapters are listed below:

- Chapter 2:   Data Compilation
- Chapter 3:   Sample Acquisition and Geology
- Chapter 4:   Sample Preparation and Size Analyses
- Chapter 5:   Aggregate Testing
- Chapter 6:   Chemical Analyses
- Chapter 7:   Quantitative Mineralogy
- Chapter 8:   Specialized Microscopy
- Chapter 9:   Markets and Economics
- Chapter 10: Interpretation and Reporting

CHAPTER 2: DATA COMPLILATION

Data compilation took place throughout the project, and spanned all tasks. For example, the project work plan described Data Compilation this way:

Locate and compile existing technical data related to crushed taconite byproducts, e.g., location, volume (tonnage, cubic yards, etc.), size characteristics, color, geology, chemistry, mineralogy, etc., that each company has assembled. All other potential technical data sources will be investigated.

Therefore, rather than present Data Compilation in a stand-alone chapter or section, it was more appropriate to incorporate the compiled data into the other task chapters, and note their source(s). Remaining tasks (Chapters 3-10), however, are presented individually.

Data were compiled from many sources. The participating taconite mines, the Minnesota Department of Transportation (Mn/DOT), the Minnesota Department of Natural Resources (MDNR), the Minnesota Geological Survey (MGS), the Minnesota Department of Health (MDH), the Internet, contractors, and various trade and technical publications all contributed important information, whether background or specific.

A previously funded LRRB study, titled, *Scoping Study for Taconite Tailings Use in Road Construction*, touched on several of the issues examined in the current study [8]. However, its focus was on environmental and health issues related to the use of tailings as aggregate for road construction from Northshore Mining Company, located on the eastern end of the Mesabi Iron Range.

A much earlier study, titled, *Evaluation of Solid Waste Materials for Highway Uses: Investigation No. 638*, highlighted the use of taconite tailings in road construction applications, and summarized many of its positive characteristics [9]. In fact, some of the technical issues addressed in that 1975 study are revisited and expanded upon in the current study.

CHAPTER 3: SAMPLE ACQUISITION AND GEOLOGY

Coarse tailing samples from the five westernmost taconite operations were acquired on a quarterly basis over a one-year period, as illustrated in Figure 3.1, beginning in the Fall of 2000. Following their acquisition, samples were prepared by the University of Minnesota's Coleraine Minerals Research Laboratory (CMRL) of NRRI for all subsequent project testing.

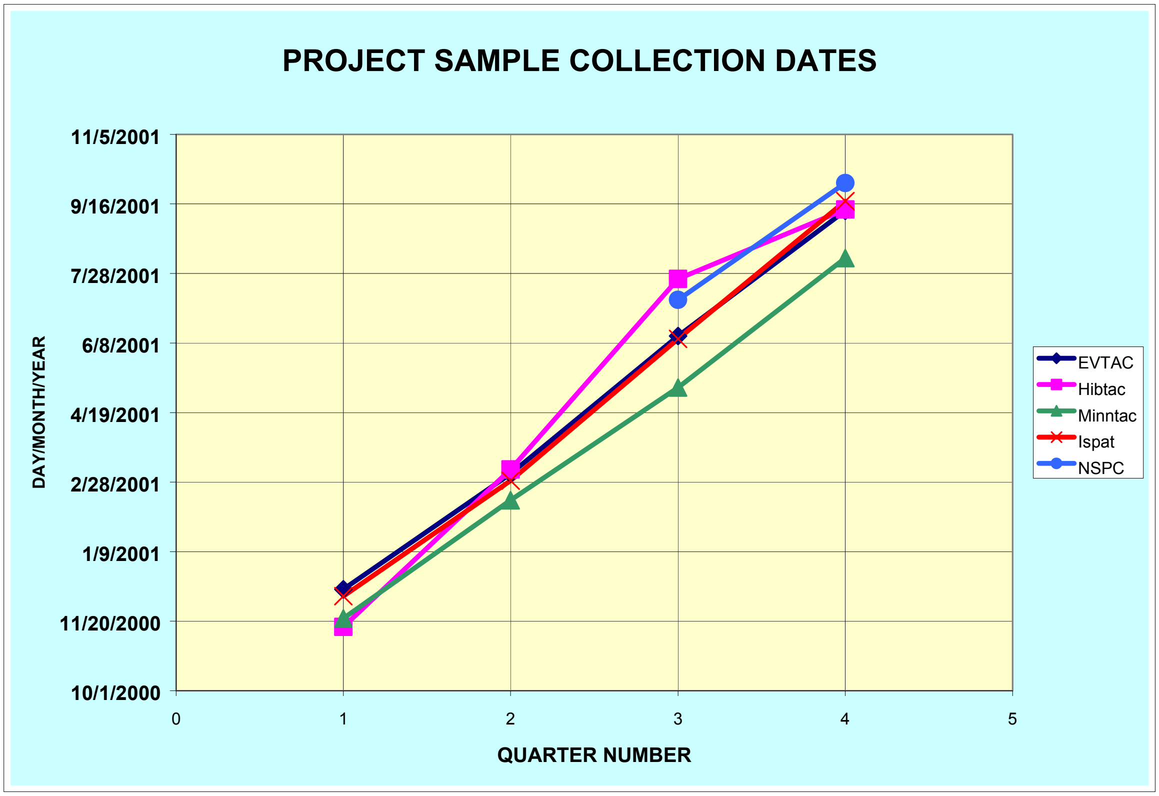

Figure 3.1 Plot of project sample collection dates during 2000 and 2001.

Tailings from EVTAC, Ispat Inland, and Hibtac were sampled by CMRL research technicians; at Minntac and NSPC, the samples were collected by plant personnel. Sufficient sample was collected at each operation to fill one plastic-lined 55-gallon drum. Each drum contained about 450 lbs. (200 kg) of sample.

Samples were typically collected during an 8-hour shift; at Minntac, samples were collected over several days and shifts. By collecting samples in this manner, it was felt that the coarse tailings would be more representative of the portions of the iron-formation from which the ore originated, i.e., multiple shovel positions located throughout each mine. Table 3.1 shows the sample collection dates, and the corresponding sample numbers used throughout the project.

Table 3.1 Sampling dates and sample numbers.

	EVTAC		Hibtac		Minntac		Minorca		NSPC	
Event	Date	Sample #	Date	Sample #	Date	Sample #	Date	Sample #	Date	Sample #
Sampling 1	12/13/2000	NRRI-40-00	11/16/2000	NRRI-36-00	11/22/2000	NRRI-37-00	12/8/2000	NRRI-39-00		
Sampling 2	3/6/2001	NRRI-10-01	3/9/2001	NRRI-11-01	2/15/2001	NRRI-08-01	3/1/2001	NRRI-09-01		
Sampling 3	6/13/2001	NRRI-31-01	7/24/2001	NRRI-42-01	5/7/2001	NRRI-17-01	6/11/2001	NRRI-30-01	7/9/2001	NRRI-37-01
Sampling 4	9/11/2001	NRRI-49-01	9/12/2001	NRRI-50-01	8/8/2001	NRRI-46-01	9/18/2001	NRRI-52-01	10/1/2001	NRRI-62-01

SAMPLING STRATEGY

Some concern was expressed that the study did not conduct an appropriate pre-field sampling statistical analysis to determine the number and type of samples necessary to achieve the project's stated goals. Admittedly, characterizing coarse tailings from all five taconite operations was a compromise in sampling practicality, given that about 30 *million* long tons of coarse tailings would be generated during the sample collection year, which translates into over 80,000 long tons *per day*. Due to the vast quantities of coarse tailings and other byproducts that are generated by taconite mining activity, a large (and separate) sampling statistical analysis that addressed engineering, chemical, regulatory, and health finding characteristics was simply not practical, given the project's limited resources and intended outcome, i.e., to give potential users a more complete understanding of the general characteristics (geological, physical, engineering, chemical, and mineralogical) of coarse tailings. Future use of taconite aggregate materials should provide for ongoing sampling and testing opportunities.

Still, it is believed that the project's sampling strategy not only provided materials that reflected the typical range of taconite ore blends processed by each company during a production year, it provided materials that would actually be used by potential aggregate consumers. To put this discussion into a more practical, i.e., mining scale, perspective, taconite operations have historically decided where to mine based on drill holes spaced anywhere from 200 to 400 feet apart. For example, drilling on 200 foot centers means that each one-foot interval of one-inch diameter drill core (0.005454 cubic feet) characterizes 40,000 cubic feet (200 feet x 200 feet x 1 foot) of in-place ore, which is a ratio of 1 part core to ***7,333,860 parts*** ore. Acceptance of this sampling ratio reflects each company's understanding that the iron-formation has sufficient lateral consistency at that drilling density for making multi-million dollar mine planning and production decisions, particularly within individual stratigraphic horizons. Therefore, the 400 to 450 lbs. of coarse tailings samples that were collected from each mine during each sample event were large enough to be reasonably representative of the ore from which they were derived.

As pointed out by Mn/DOT geologist Nancy Whiting (N. Whiting, pers. comm., 2003), "…sampling frequency varies widely depending on intended aggregate use. For established sources when aggregate is being produced for a specific project, the sampling rates are higher than what was done for the taconite tailings. However, when investigating potential new sources, the sampling rate will depend on the use, the source uniformity, anticipated quantity, site accessibility, time, and resource availability for investigation, among other considerations. As little as one sample may be obtained, while a grid with 300 ft. spacing may be established, or anything in between. This is considered background information, and once the source is used for a project the sampling interval increases to match the specifications listed on Mn/DOT's website."

http://www.mrr.dot.state.mn.us/materials/2003MCS4.pdf

TAILINGS SOURCE DETAIL BY COMPANY, AND CURRENT USES

EVTAC, Ispat Inland, and Minntac have separate coarse and fine tailings circuits in their plants, whereas no separation of coarse and fine tailings occurs at the Hibtac and NSPC plants.

Tailings at EVTAC, Ispat Inland, and Hibtac were sampled by CMRL research technicians; at Minntac and NSPC, the samples were collected by plant personnel.

At EVTAC, Ispat Inland, and Minntac, coarse tailings are produced from cobber tailings (non-magnetics) and are separated from the fine fraction with spiral classifiers. EVTAC samples were taken at the conveyor discharge above the truck pocket. Ispat Inland samples were taken at a conveyor discharge point inside the concentrator building. At Minntac, samples were collected directly from spiral classifier discharge points.

Coarse tailings are *not* separated from fine tailings in the Hibtac and NSPC concentrators. Combined tailings flow as a slurry to the tailings basin in two flumes at Hibtac, and through a pipe at NSPC. However, some size separation is achieved as the larger particles settle out of the slurries near the points of entry to the basins. Over time, the tailings build up, much like sediments in a river delta, and periodically this buildup of coarser tailings is excavated and placed in piles. At Hibtac, a dragline removes these coarse tailings when they tend to dam the entry to the basin. NRRI personnel sampled the dragline spoils at areas that had recently been deposited. At NSPC, the coarser tails are pushed by bulldozer out of the channel that leads into the basin. The dozer spoils piles were sampled by NSPC personnel to provide the two coarse tailing samples. NSPC had been shut down when the first two rounds of samples were taken at the other four operations, so only two samples were collected during the project. The spoils areas at Hibtac and NSPC would be the most likely sources of coarse tailings for aggregate usage, given their relative accessibility; therefore, no dredging would be required.

Supplemental detail on tailings generation has been provided by each company, and is summarized below. Again, a-rule-of-thumb method for estimating coarse tailings production at the taconite mines is to multiply the annual pellet production by a factor of about 0.9. This number can vary depending on the liberation characteristics of the ore, and on the process flow sheet of each mine. Refer again to Table 1.1 for annual pellet production figures at each company.

EVTAC

The coarse tailings stockpile is located at the Fairlane Plant in Forbes, south of the mine. The stockpile is enormous, and is estimated to contain 37 years worth of tails. In a typical production year, over 10,000 tons of coarse tailings are produced daily.

Coarse and fine tailings are separated at EVTAC. At the time of collection, coarse tails were being trucked to construct the outside perimeter of the new tailings basin. Fine tails are pumped out to the basin, via a pipeline that is moved every so often to a new position.

> **NOTE:** The physical properties of the coarse tailings, e.g., their angularity, make them well suited for constructing basin dams, dikes, and cells at EVTAC (and at the other mines). Because coarse tailings are highly drainable, their primary function in tailings basin dam, dike, and cell construction is to provide a stable retaining perimeter to the much more voluminous and "fluid" fine tailings particles, not to retain water like a conventional dam. The outer perimeter of tailings basins is usually constructed of less permeable earthen (glacial) material and/or incorporates the natural topography to hold back the process water contained in the tailings slurry. This water is typically collected and pumped back to the taconite plants for re-use, or is discharged following treatment.

Hibtac

About 20,000 long tons of coarse tailings per day are generated at Hibtac in a normal production year. Generally, about 3 million cubic yards (4.17 million long tons) of coarse tailing borrow material is available (dry above water). Much more is made available when de-watering measures are put into place, and the "water table" in this area is lowered.

A dragline, operating about 3,000 hours per year, excavates from the present tailing flow channel and stockpiles the coarse tailings. In a typical year, the dragline will move about 2.4 million cubic yards of coarse tailings into stockpile and into the road that is needed to move the machine itself. About one-half of these coarse tailings are used by Hibtac in its mining operations as follows:

- as cover over blasted rock areas to create a smooth driving surface
- on all haulage equipment roads as an aggregate top dressing
- as base fill under concrete slabs
- mixed with salt for de-icing access roads in the winter
- as granular fill material in both interior dam and exterior dam construction in the tailings basin area (this constitutes the greatest use).

Recent project use:

- tailings were used as granular base material and granular backfill material in the installation of a precast concrete arch tunnel (also known as a BEBO Arch™ System*) at a railroad and roadway intersection (Fig. 3.2).

- *The authors and the Minnesota Department of Transportation and/or Center for Transportation Studies do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.*

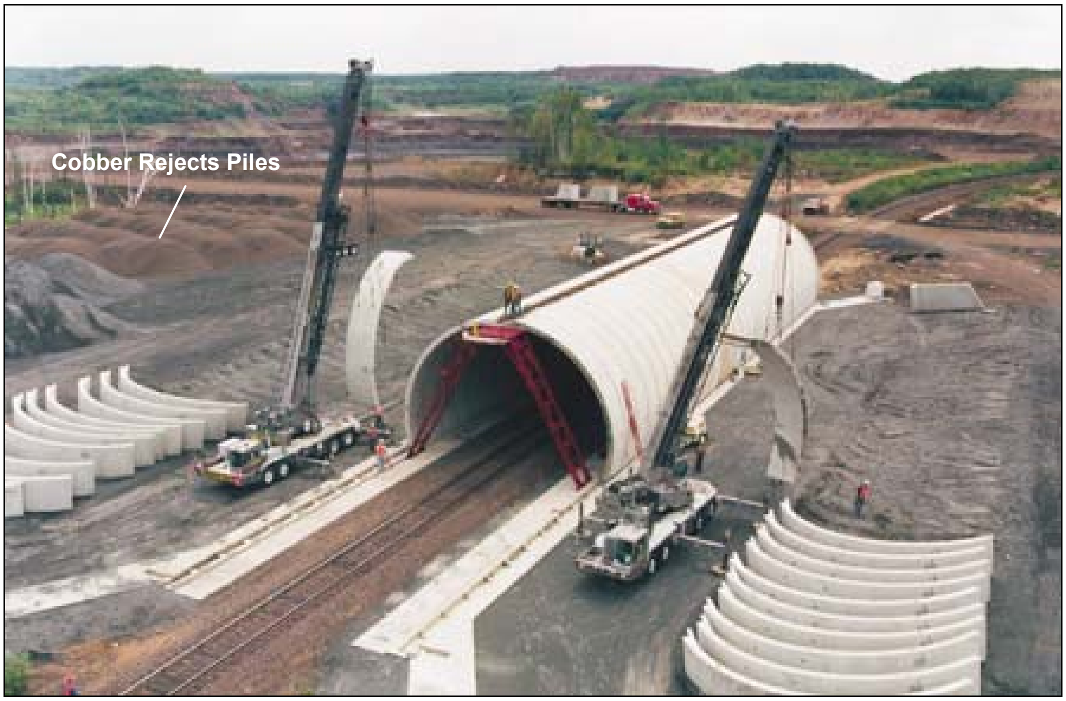

Figure 3.2 Hibtac railroad arch tunnel - tailings used as base and fill material (photo used with permission, courtesy of Lakehead Constructors).

The arch tunnel footings were 5 feet deep, and underlain and surrounded by coarse tailings for drainage. The entire arch tunnel was backfilled about 1/3 of the way up with tailings, and the remainder was covered with cobber rejects (another mining byproduct; see reddish brown piles in the photograph) which are similar in size to gravel (J. Heller, pers. comm., 2003). Their larger size and larger void spaces provided a lower bulk density material for final tunnel backfill and coverage. When the tunnel was completely covered, a mining haul road was built over it, fixing what was once a problematic rail and road intersection situation.

Krech Ojard & Associates of Duluth did the engineering work on this project, and found the coarse tailings to be a superior quality fill material in terms of drainage and compaction. Each precast tunnel section weighs about 50 tons (1 million lbs.), yet the photograph shows how well the tailings resisted compaction (note the minimal indentation), even with the sections laying on-edge (J. Heller, pers. comm., 2003)

Minntac

Minntac is the largest capacity taconite operation on the Mesabi Range, and generates about 30,000 long tons per day of coarse tailings during a normal production year. Coarse and fine tails are separated at Minntac. After the ore has gone through the rod mills, the coarse tails are separated from the rest of the ore by "cobber" magnetic separators. The remaining material is further ground in ball mills and separated from the remaining concentrate by "rougher" magnetic separators, then "finisher" magnetic separators. Coarse tails are conveyed north, out of the concentrator, into one of two pockets (temporary storage bins), and then trucked away.

The bulk of the coarse tails (~ 75%) are used for tailings basin cell construction. Approximately 25% are used in the pit as follows: for road material; for filling (stemming) blast holes; for preparing level and stable loading areas for both shovels and trucks; and other applications.

Ispat Inland (Minorca)

About 6,500 long tons per day of coarse tailings are generated at Ispat Inland's Minorca operation during normal production. Coarse and fine tailings have historically been separated. Unlike EVTAC, there are no substantial stockpiles of coarse tailings at Ispat Inland. Stockpiled tailings are sold to a local contractor as they accumulate or are used in pit roads and at shovel locations. Greater quantities of coarse tailings may be sold in the next few years due to some significant highway work in the area, e.g., Highway 53.

The majority of coarse tailings are used in the construction of tailings dams and cells, and this will continue for the foreseeable future. Early project discussions suggested that coarse tailings might be pumped into the old Minorca mine pit, and co-mingled with fine tailings. However, more recent discussions (J. Holmes, pers. comm., 2003) suggest that this may not be the case should the demand for coarse tailings increase.

NSPC

NSPC generates about 12,000 long tons of coarse tailings per day. At NSPC, coarse and fine tailings go out together like they do at Hibtac, except via a pipeline rather than a flume. Coarse tailings are spigotted out of multiple openings in the bottom of the pipe for dike building. The coarsest tailings settle out quickly in the vicinity of the pipe. The pipe is periodically moved as the tailings build up around it.

Coarse tailings are used for base (subgrade), granular fill for roads and sewer and water lines, and for surfacing gravel driveways.

GEOLOGY OF COARSE TAILINGS SAMPLES

The tailings studied in this project were derived from taconite ore mined primarily from the Upper Cherty (UC) and Lower Cherty (LC) members of the Biwabik Iron Formation (BIF). The major exception was at Minntac, where moderate amounts of taconite were also mined from the BIF's Lower Slaty (LS) member. The sources for each company's samples are summarized below. This information was provided by each company's geology and/or engineering staff, and varied in its level of detail. Each mine uses its own stratigraphic nomenclature, so please refer to Figure 1.3 for reference.

Terminology

Before continuing, some taconite- and geology-related terms that are used in the upcoming geology discussion are presented and defined for clarity.

Gangue: The valueless rock or mineral aggregates in ore that cannot be avoided in mining, but are separated from the ore minerals during concentration [10].

Concentrate: The valuable fraction of an ore that is left after worthless material (gangue) is removed in processing [10].

Induration: The hardening of a taconite pellet by heating in a kiln.

Davis Tube: A laboratory device developed by E.W. Davis at the University of Minnesota School of Mines for measuring the percentage of silica and magnetic iron contained in taconite processing products and byproducts such as concentrate and tailings. Values are typically reported as *Davis Tube silica* (DT Si) or *Davis Tube magnetic iron* (DT Mag Fe).

Liberat(e)(ion)(ing): Terms that are related to the size to which an ore must be crushed or ground to produce separate particles of valuable mineral (or gangue) that can be removed from the ore as concentrate (or tailings) with an acceptable efficiency by a commercial unit process. Liberation size does not imply pure mineral species, but rather an economic trade-off of grade and recovery [11]. For example, taconite ore that is said to have a liberation grind at 78% -325 mesh requires less grinding than an ore that achieves a liberation grind at 90% -325 mesh, in terms of achieving the desired magnetic iron recovery for producing pellet-grade taconite concentrate. Consequently, the liberation properties of an ore will influence the size distribution of the tailings that are generated, especially in the finer fraction. Coarse-grained taconite generally liberates easier than fine-grained taconite.

EVTAC Sample Geology

The lower portion of the Upper Cherty (UC) member was EVTAC's primary mining horizon during the project; it is referred to as the Lower Upper Cherty (LUC). Lesser amounts of the Lower Cherty (LC) member were also part of the ore blend, and included the top and lower portions of the Lower Cherty, or TLC and LLC, respectively. Table 3.2 and Figure 3.3 depict the relative contribution of each member to the project samples. "Minor" in parentheses, i.e., (Minor), means that the interval contributed the least to the overall ore blend. Refer again to Figure 1.3 to view the stratigraphic position of each EVTAC ore member relative to the other mines in the study.

Table 3.2 EVTAC sample geology.

EVTAC Member/Submember	Sampling 1 12/13/2000 NRRI-40-00	Sampling 2 3/6/2001 NRRI-10-01	Sampling 3 6/13/2001 NRRI-31-01	Sampling 4 9/11/2001 NRRI-49-01
Top Upper Cherty (TUC)				
Lower Upper Cherty (LUC)	Major	Major	Major	Major
Top Lower Cherty (TLC)	Minor	Minor	Minor	(Minor)
Lower Lower Cherty (LLC)			(Minor)	Minor

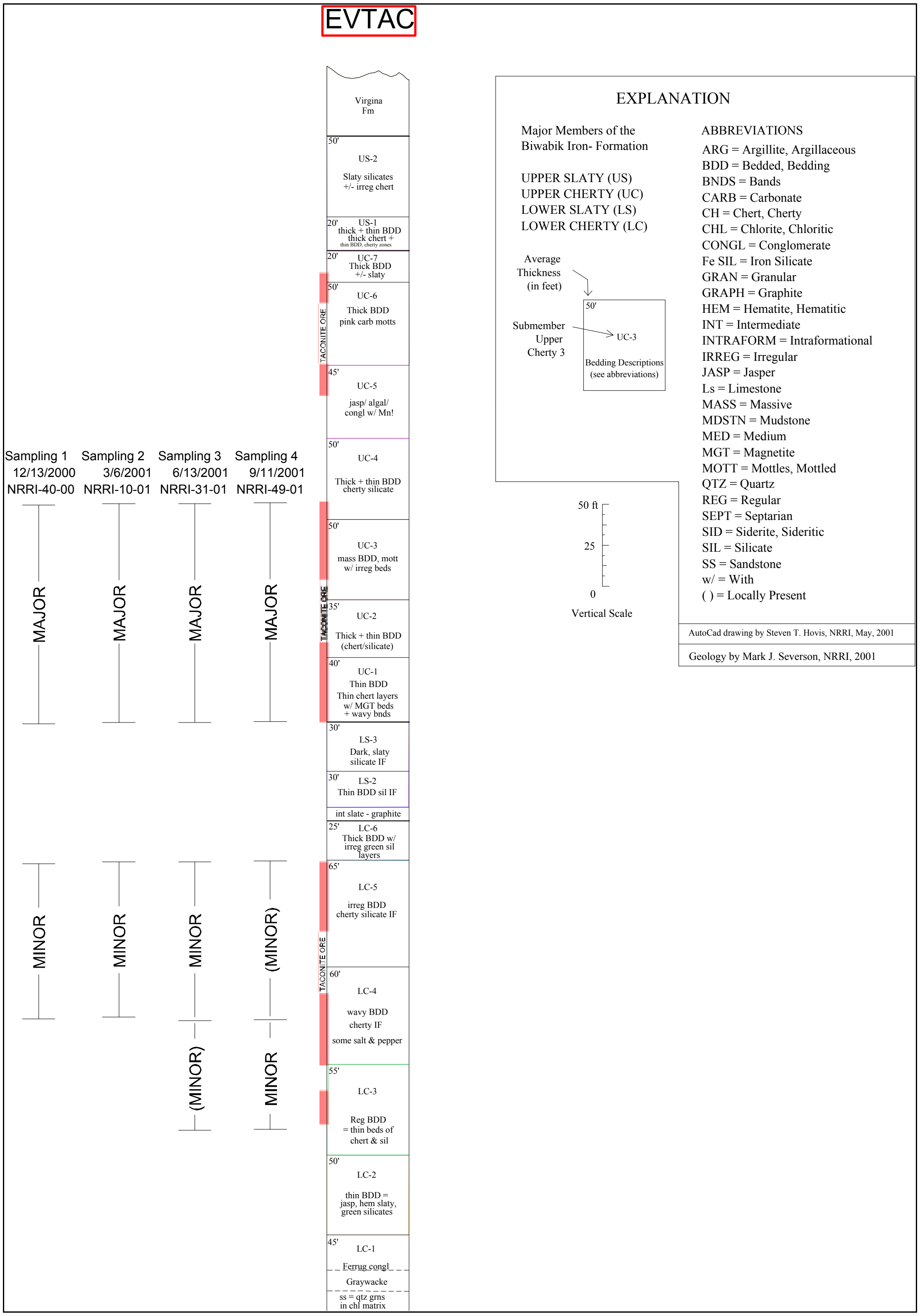

Figure 3.3 EVTAC samples relative to geology.

The following discussion highlights mineralogical details about EVTAC's coarse tailings in relation to the ore horizons from which they are derived.

Lower Upper Cherty (LUC)

The coarse tailings from this horizon reflect how there are very few iron carbonates in the gangue, i.e., matrix, or non-ore, minerals. However, gangue from this horizon also contains the highest potential amount of iron silicates, such as minnesotaite, stilpnomelane*, and also chert, which is ubiquitous.

> *Stilpnomelane is the only possible contributor of K (potassium), and it is found only in the slaty units (both upper and lower); therefore by EVTAC's classification, any stilpnomelane had to come from slaty intervals found within the lower portions of the Upper Cherty. EVTAC mines near the bottom of the Upper Cherty member, which might be correlative to Minntac's Lower Slaty; EVTAC simply uses a different naming convention.

Mn (manganese) is usually found in the Top of the Upper Cherty (TUC) at EVTAC, particularly in the stromatolite (fossilized algal structure) horizon. Since none of the samples comes from the TUC, any Mn in the gangue must come from the Top of the Lower Cherty (TLC), in the form of higher than normal Mn-bearing siderite ($FeCO_3$).

Top Lower Cherty (TLC) submembers:

LC-5A
LC-5B
LC-4; top and middle

These Lower Cherty submembers contain a mishmash combination of iron silicates, iron carbonates, and chert in the gangue, but especially iron carbonates like ankerite and siderite. Therefore, coarse tailings will reflect this mineralogy.

> NOTES: LC-5 is the single contributor of ankerite, which is the only source of Ca (calcium) in the gangue. Sampling 4 from September 11, 2001, contains the largest amount of TLC. Siderite comes mainly from the TLC.

The split between Top and Bottom Lower Cherty occurs at the point where the Davis Tube silica drops below 2.5%.

Lower Lower Cherty (LLC) submembers:

The lower Lower Cherty (LLC) submembers include:

LC-4; bottom
LC-3
LC-2
LC-1

The LLC submembers contain very few iron silicates and carbonates in gangue; they concentrate and liberate well.

Hibtac Sample Geology

All Hibbing Taconite ores come from the Lower Cherty (LC) member. The dip (tilt) of the iron-formation is 8-9E to the south and east. The Hibtac stratigraphic column, in terms of taconite production, is summarized in Table 3.3.

Table 3.3 Hibtac ore summary.

Member	Thickness	Unit	Grade	Description
LS	-	2-1	Waste, if present	Lower Slaty
LC	27'	1-8	Low Grade Tac. or Waste	Slightly to Non-Magnetic, granular and massive bedded, Cherty-Silicate Taconite.
LC		1-7	Low Grade Tac. or Waste	Slightly to Moderately Magnetic, wavy bedded, Cherty-Silicate Taconite.
LC	45'	1-6	High Grade Tac.	Highly Magnetic, wavy to uneven bedded, Cherty Taconite.
LC	48'	1-5	High Grade Tac.	Highly Magnetic, massive bedded, granular Cherty Taconite.
LC		1-4	Low Grade Tac.	Highly to Moderately Magnetic, Cherty to Slaty bedded Taconite.
LC		1-3	Low Grade Tac.	Moderately Magnetic, even bedded, Cherty and Slaty Taconite.
LC	23'	8-3	Basal Unit	Slightly Magnetic, thin even bedded, Slaty to Fissile Taconite.
LC		1-2	Basal Unit	Moderately to Slightly Magnetic Cherty and Slaty Taconite.
LC	23'	1-0	Basal Unit	Non-Magnetic, Basal Conglomerate.
PQ		0-0	Basal Unit	Pokegama Quartzite.

- Units 1-6 and 1-5 are the high grade ores; they account for approximately 70 % of the total ore blend.
- Units 1-7 and 1-4/3 are the lower grade ores; they account for approximately 30 % of the total ore blend.

Only Sampling 1, conducted on November 16, 2000 (NRRI-36-00) differed from the three remaining samples in terms of the ore blend. Tailings were placed into the pile by the dragline on 10/13/00. Assuming approx. 2-3 days for the ore to proceed through the crusher surge pile and concentrator, the tailing samples most likely originated from ore mined on 10/10/00 or 10/11/00. The ore blends for those two days are described as follows:

Date	Unit 1-5/1-6	Unit 1-4/1-3
10/10/00	84%	16%
10/11/00	77%	23%
Average	80.5%	19.5%

All four Hibtac sampling events are summarized in Table 3.4, and illustrated in Figure 3.4.

Table 3.4 Hibtac sample ore types.

Hibtac		Sampling 1 11/16/2000	Sampling 2 3/9/2001	Sampling 3 7/24/2001	Sampling 4 9/12/2001
Member	Unit	NRRI-36-00	NRRI-11-01	NRRI-42-01	NRRI-50-01
LC	1-6/1-5	80.5	70	70	70
LC	1-4/1-3	19.5			
LC	1-7 & 1-4/1-3		30	30	30

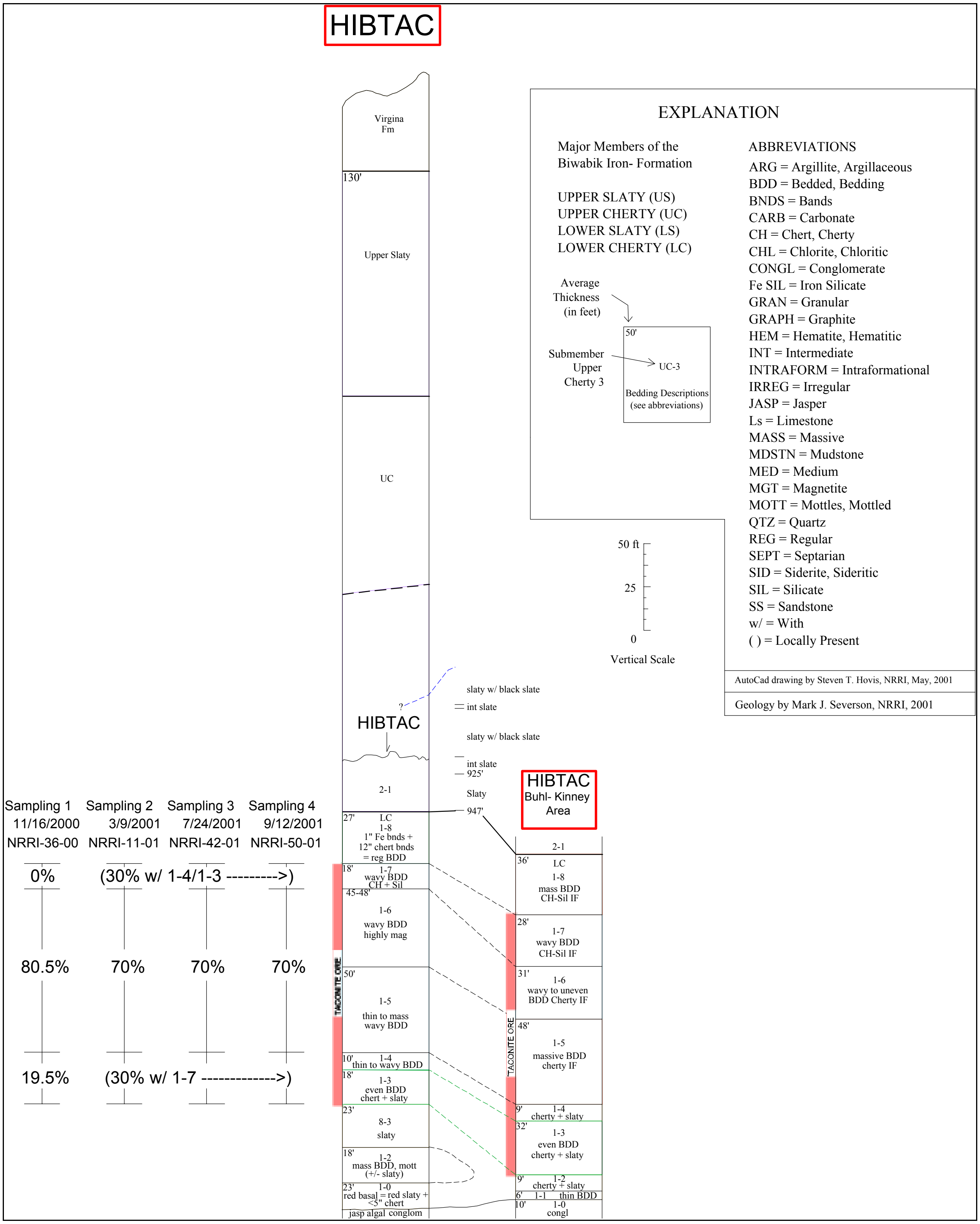

Figure 3.4 Hibtac samples relative to geology.

Minntac Sample Geology

Minntac was the only company to have mined appreciable amounts of slaty taconite (Lower Slaty, or LS) during the project. All other taconite mined at Minntac came from Lower Cherty (LC) submembers. The percent contribution of each submember to the Minntac project samples is presented in Table 3.5, and illustrated in Figure 3.5. Also note that significant amounts of ore were mined from horizons not typically associated with Minntac's major ore-producing submembers. For example, 31% and 20%, respectively, of the ore associated with Sampling 3 and 4 originated in the LC-2 submember.

Table 3.5 Minntac ore blend composition during project sampling as a percentage of BIF member/submember.

Member/Submember	Sampling 1 11/22/2000 NRRI-37-00	Sampling 2 2/15/2001 NRRI-08-01	Sampling 3 5/7/2001 NRRI-17-01	Sampling 4 8/8/2001 NRRI-46-01
Upper Cherty (UC)	0	0	0	0
High Silica (Lower Slaty)	20	36	15	10
Inter-bedded Chert (Lower Slaty)	13	12	6	3
LC-5B	1	7	0	3
LC-5A	2	4	0	0
LC-4	16	32	7	45
LC-3	46	9	37	18
LC-2	2	0	31	20
LC-1	0	0	4	1
Total	100	100	100	100

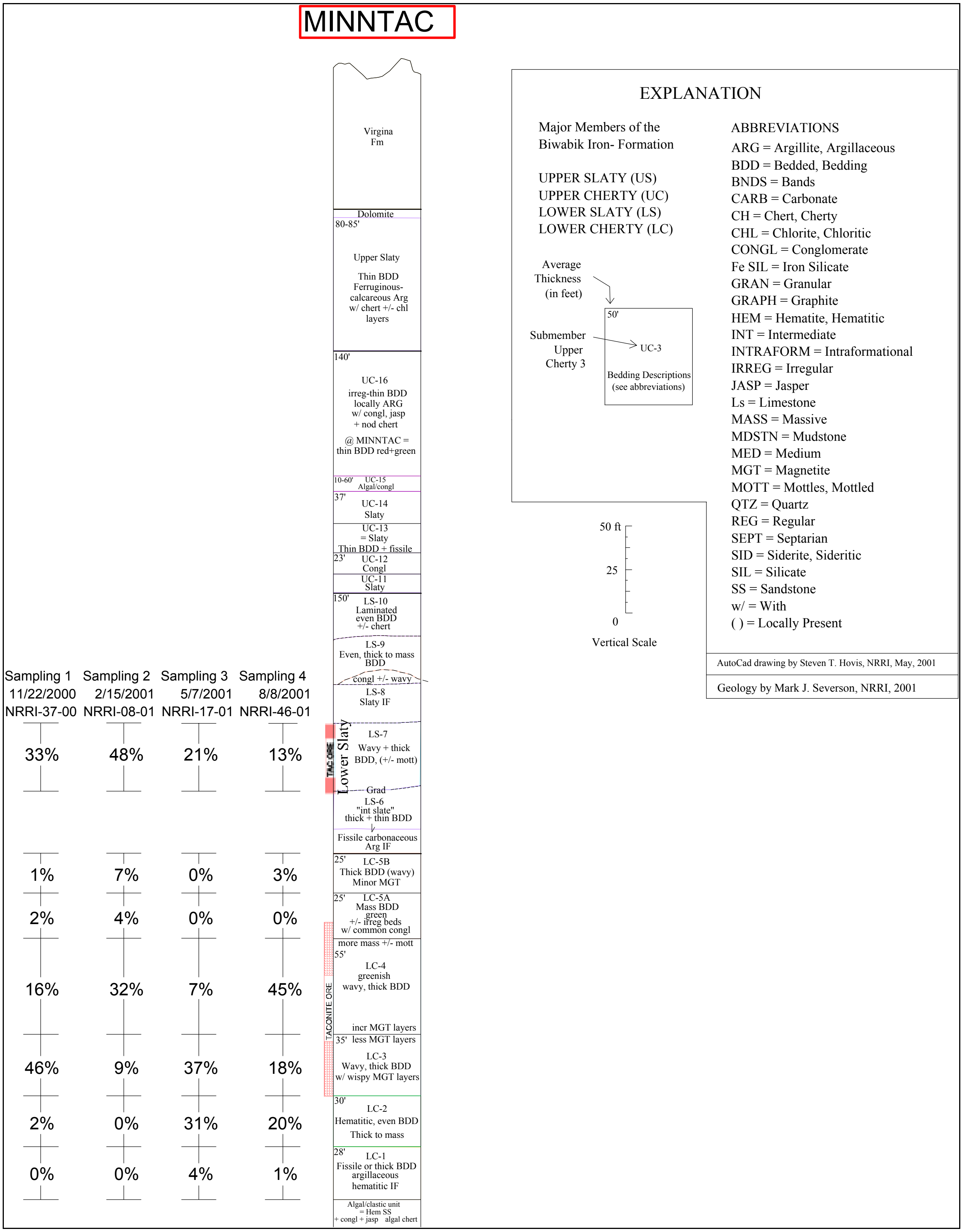

Figure 3.5 Minntac samples relative to geology.

Ispat Inland (Minorca) Sample Geology

Two ore blends are produced from the Laurentian pit, and are typically alternated every other month:

1) 70% LC-4; 30% UC-3
2) 70% LC-5a,b; 30 % UC-1

UC-2 is intermittently used and blended with UC-3 and UC-1; its percent contribution to the ore blends during this project is uncertain.

Two working faces are mined at any given time as the Laurentian Pit is progressively mined. There is little variance in processing with the two blends although there are some indurating (pellet hardening) differences. Ferrous Fe is a little lower in the LC-4/UC-3 blend. Overall, the aim is to produce a consistent float feed silica. Table 3.6 and Figure 3.6 show the ore blends for each project sampling.

Table 3.6 Laurentian pit ore blend composition during sampling as a percentage of BIF member/submember at Ispat Inland's Minorca operation.

Member/Submember	Sampling 1 12/8/2000 NRRI-39-00	Sampling 2 3/1/2001 NRRI-09-01	Sampling 3 6/11/2001 NRRI-30-01	Sampling 4 9/18/2001 NRRI-52-01
UC-3	0	30	0	0
UC-1	0	0	20	30
LC-5	100	0	80	70
LC-4	0	70	0	0
Total	100	100	100	100

Laurentian Mine and Minorca Mine

The Laurentian Mine was opened in the mid 1990s to replace the depleted Minorca pit, and is now the active source of taconite ore for Ispat Inland's Minorca operation. In contrast to the Minorca pit, the Laurentian pit contains unoxidized, highly magnetic (24% average magnetic iron) taconite. This extremely fine-grained hard rock liberates at 90% -325 mesh. Conversely, the taconite in the Minorca pit is broken and fractured, due to its location at the north tip of the Virginia Horn, i.e., the s-shaped "kink" in the Biwabik Iron Formation (see Fig. 1.1). This fracturing led to slight to moderate oxidation of the rock. The taconite was weakly to moderately magnetic (21% average magnetic iron), but coarse liberating at a 78% -325 mesh grind (J. Arola, pers. comm., 2001). In other words, the Minorca taconite required less fine grinding to achieve the desired iron recovery in comparison to the much finer-grained Laurentian pit ore.

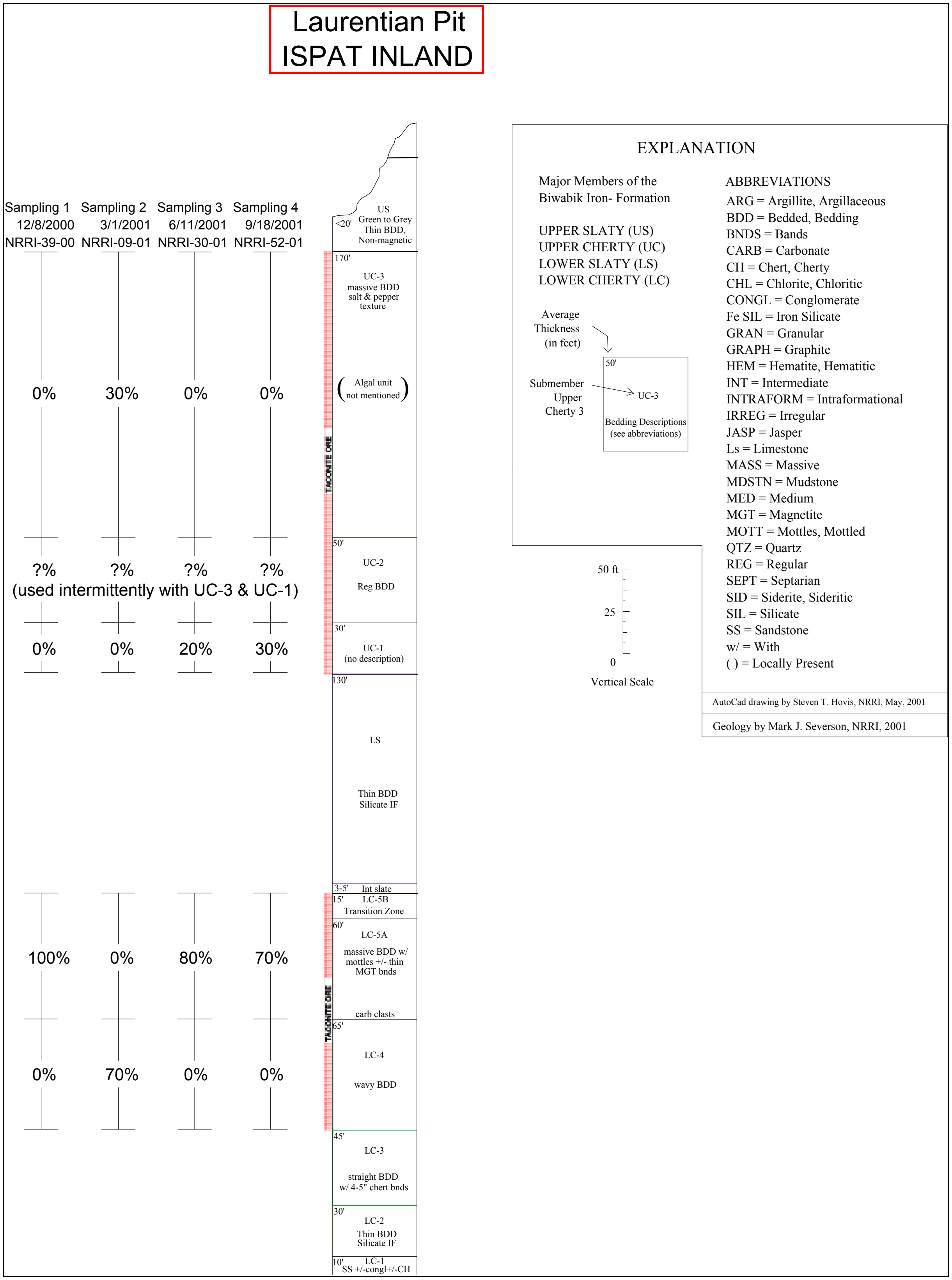

Figure 3.6 Ispat Inland samples relative to geology.

NSPC Sample Geology

Only two samples were obtained from NSPC because the mine had been shut down when the first two rounds of samples were taken at the other four operations. Both tailings samples are from ore mined from the Lower Cherty (LC) member of the BIF (Fig. 3.7).

Sampling 3: July 9, 2001 (NRRI-37-01)
Lower Cherty
Sampling 4: October 1, 2001 (NRRI-62-01)
Lower Cherty

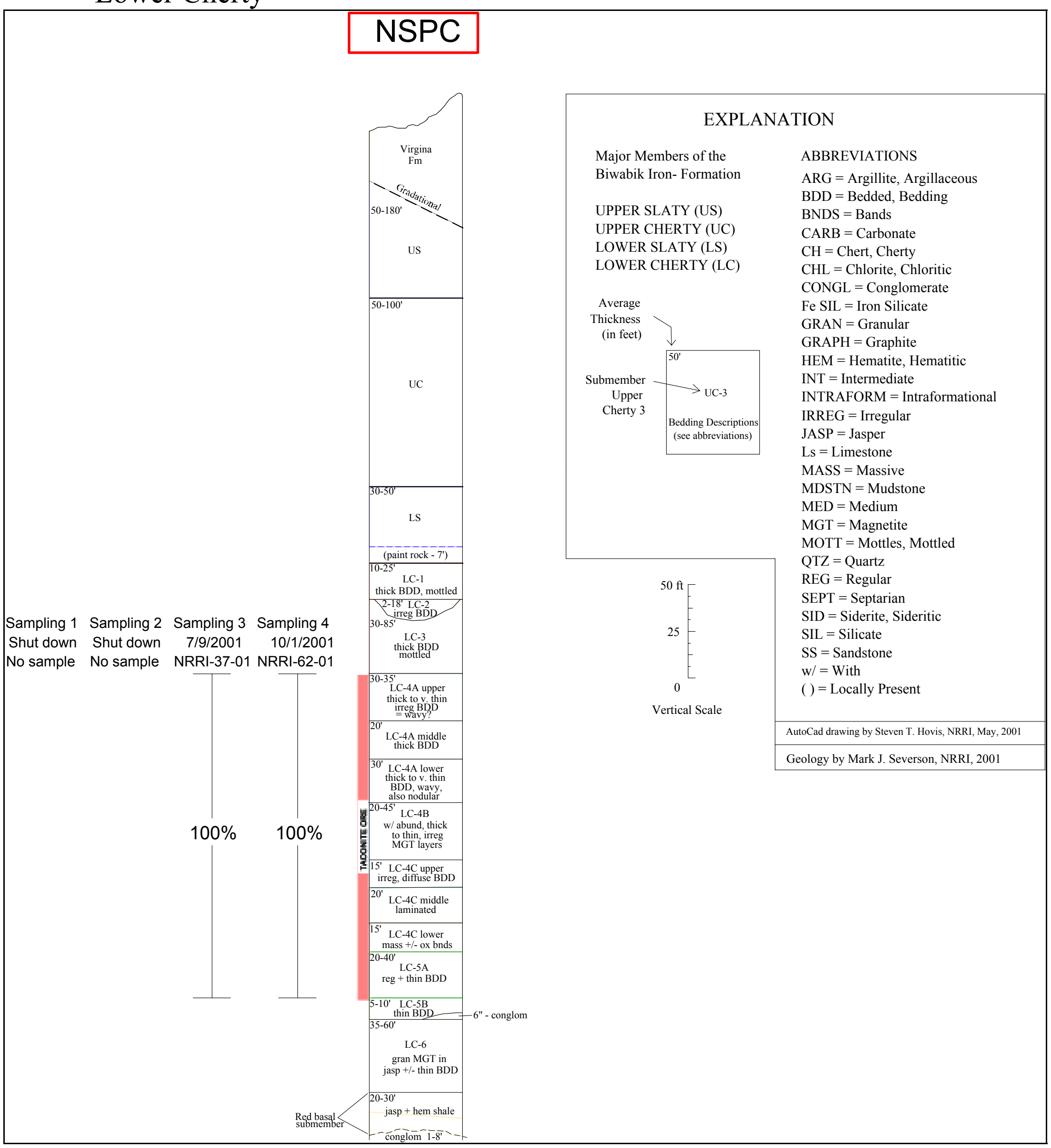

Figure 3.7 NSPC samples relative to geology.

CHAPTER 4: SAMPLE PREPARATION AND SIZE ANALYSES

SAMPLE PREPARATION

Each coarse tailing sample was placed in a plastic-lined 55-gallon drum, and typically weighed 400 to 450 pounds. At CMRL, each sample was dumped into a rotating hopper that fed an eight-way rotary splitter. The eight splits were dumped back into the drum twice to blend each sample before representative portions were removed for testing and analyses.

After another pass through the rotary splitter, the one-eighth portions were adjusted using a Jones riffle to provide two 50-pound samples for testing by Mn/DOT, one 50-pound and six 25-pound samples for tests by Braun Intertec Engineering, Inc., and a 25-pound head sample for processing at CMRL. All sample pails were tagged with sample identification and all drums and pails were tightly closed with lids to retain the moisture that was present when sampled at each taconite facility. Mn/DOT samples were delivered to the District 1 Duluth facility on Mesaba Avenue. Braun Intertec, having a facility relatively nearby in Hibbing, picked up their samples at CMRL.

CMRL head samples were weighed, dried at 110°C and weighed to determine moisture percentages. After the dried samples were mixed, approximately 1,000 grams were split out (riffled) for size analyses, and approximately 2,000 grams were split out for chemical analyses and x-ray diffraction (XRD). The latter were further prepared by standard CMRL procedures. They were stage crushed in a roll crusher to pass 20 mesh; 150- to 200-gram portions were split out and stage pulverized in a Braun pulverizer to pass 200 mesh. About 20 grams were split and bagged for XRD, and the balance of pulverized samples were submitted for chemical analyses. Samples were similarly prepared for specialized microscopy (Chapter 8).

SIZE ANALYSES

CMRL, Mn/DOT, and Braun-Intertec conducted size analyses on each coarse tails sample. CMRL also performed moisture analyses. Some of the participating mines also provided their own size distribution data from previous and/or ongoing analyses. The CMRL results are summarized in tabular form on the following pages (Tables 4.1 to 4.5) for each mine.

The analyses show that a minimal amount of fines (-200 mesh material) is present in most of the coarse tailings samples. This is especially true for EVTAC, Minntac, and Ispat Inland, where coarse and fine tailings are separated. In fact, their size distribution plots are very similar. Overall, samples from Hibtac and NSPC contain a larger percentage of particles finer than 0.5 mm, while EVTAC and Minntac samples contain a smaller percentage.

Table 4.1 EVTAC: Coarse tailings gradations by CMRL

Sample:		NRRI-40-00		NRRI-10-01		NRRI-31-01		NRRI-49-01	
Date Collected:		12/13/00		03/06/01		06/13/01		09/11/01	
% Moisture:		5.6		7.3		9.6		7.8	
Mesh Size	Sieve Opening (mm)	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing
4	4.699	8.3	91.7	1.9	98.1	5.4	94.6	4.7	95.3
6	3.327	9.7	82.0	3.8	94.3	8.5	86.1	8.3	87.0
8	2.362	10.9	71.1	9.0	85.4	11.9	74.2	11.7	75.3
10	1.651	7.9	63.2	6.5	78.9	7.2	67.0	15.3	60.0
14	1.168	16.7	46.5	16.9	62.0	15.1	51.9	10.3	49.7
20	0.833	16.1	30.4	19.0	43.0	15.6	36.3	11.5	38.2
28	0.589	8	22.4	10.5	32.5	8.4	27.9	9.4	28.8
35	0.417	6.5	15.9	9.4	23.1	7.3	20.6	7.7	21.1
48	0.295	5.7	10.2	8.3	14.8	6.5	14.1	7.0	14.2
65	0.208	3.7	6.5	5.7	9.2	4.6	9.5	5.5	8.6
100	0.147	3.1	3.4	4.6	4.6	4.3	5.2	2.3	6.4
150	0.104	1.7	1.7	2.3	2.4	2.7	2.5	3.8	2.5
200	0.074	0.6	1.1	0.7	1.6	1.0	1.5	1.2	1.3
270	0.053	0.3	0.8	0.3	1.3	0.5	1.0	0.5	0.9
-270		0.8		1.3		1.0		0.9	

Table 4.2 Hibbing Taconite (Hibtac): Coarse tailings gradations by CMRL.

Sample:		NRRI-36-00		NRRI-11-01		NRRI-42-01		NRRI-50-01	
Date Collected:		11/16/00		03/09/01		07/24/01		09/12/01	
% Moisture:		7.9		2.6		1		N.A.	
Mesh Size	Sieve Opening (mm)	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing
4	4.699	11.7	88.3	5.3	94.7	6.8	93.2	6.8	93.2
6	3.327	5.9	82.4	4.4	90.4	5.3	87.9	5.8	87.4
8	2.362	4.4	78.0	4.2	86.2	3.2	84.7	5.1	82.3
10	1.651	1.8	76.2	2.1	84.1	2.1	82.5	5.8	76.5
14	1.168	4.9	71.3	4.9	79.2	5.5	77.0	4.9	71.6
20	0.833	3.6	67.7	7.0	72.2	9.3	67.8	7.2	64.5
28	0.589	4.0	63.7	6.4	65.8	9.4	58.4	8.6	55.9
35	0.417	5.1	58.6	9.4	56.4	13.8	44.6	10.4	45.5
48	0.295	7.1	51.5	13.7	42.7	19.1	25.4	12.6	32.9
65	0.208	9.2	42.3	12.8	29.8	14.4	11.0	11.8	21.1
100	0.147	9.0	33.3	13.3	16.5	8.6	2.4	6.3	14.7
150	0.104	11.5	21.8	8.8	7.7	1.7	0.7	7.4	7.3
200	0.074	9.3	12.5	3.6	4.1	0.3	0.4	3.5	3.9
270	0.053	4.8	7.7	1.5	2.5	0.1	0.3	1.4	2.4
-270		7.7		2.5		0.3		2.4	

Table 4.3 Minntac: Coarse tailings gradation by CMRL.

	Sample:	NRRI-37-00		NRRI-08-01		NRRI-17-01		NRRI-46-01	
	Date Collected:	11/22/00		02/15/01		05/07/01		08/08/01	
	% Moisture:	7.6		7.9		8.9		7.43	
Mesh Size	Sieve Opening (mm)	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing
4	4.699	1.5	98.5	1.5	98.5	1.2	98.8	3.0	97.0
6	3.327	4.3	94.2	3.4	95.1	3.9	94.9	5.8	91.2
8	2.362	8.1	86.1	8.2	87.0	7.2	87.7	10.6	80.6
10	1.651	5.0	81.1	6.2	80.8	14.1	73.6	7.1	73.4
14	1.168	20.8	60.3	18.0	62.8	14.3	59.3	17.1	56.4
20	0.833	14.9	45.4	22.6	40.2	14.9	44.4	19.3	37.1
28	0.589	13.6	31.8	13.4	26.8	13.7	30.7	10.8	26.3
35	0.417	11.6	20.2	11.2	15.6	11.5	19.2	9.1	17.1
48	0.295	9.3	10.9	8.0	7.6	8.1	11.1	7.4	9.7
65	0.208	5.4	5.5	3.7	4.0	5.1	6.0	4.2	5.5
100	0.147	1.5	4.0	1.9	2.0	2.6	3.4	2.8	2.8
150	0.104	2.1	1.9	0.9	1.2	1.5	1.9	1.3	1.5
200	0.074	0.6	1.3	0.3	0.8	0.5	1.4	0.4	1.0
270	0.053	0.3	1.0	0.1	0.7	0.4	1.0	0.3	0.7
-270		1.0		0.7		1.0		0.7	

Table 4.4 Ispat Inland (Minorca): Coarse tailings gradations by CMRL

Sample:		NRRI-39-00		NRRI-09-01		NRRI-30-01		NRRI-52-01	
Date Collected:		12/08/00		03/01/01		06/11/01		09/18/01	
% Moisture:		N.A.		9.1		8.0		6.7	
Mesh Size	Sieve Opening (mm)	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing
4	4.699	0.7	99.3	0.4	99.6	0.9	99.1	1.5	98.5
6	3.327	2.3	97.0	0.9	98.7	1.9	97.2	3.5	95.0
8	2.362	3.2	93.8	3.2	95.5	3.8	93.4	6.7	88.4
10	1.651	4.0	89.8	3.4	92.1	3.7	89.7	11.9	76.5
14	1.168	19.9	69.9	12.1	79.9	12.5	77.2	10.0	66.5
20	0.833	15.7	54.2	20.0	59.9	19.6	57.5	13.4	53.1
28	0.589	15.2	39.0	13.7	46.2	12.8	44.7	12.5	40.5
35	0.417	13.3	25.7	13.1	33.1	12.1	32.7	10.8	29.7
48	0.295	9.9	15.8	12.5	20.7	11.1	21.6	9.9	19.8
65	0.208	7.4	8.4	8.5	12.2	7.6	14.0	7.8	12.0
100	0.147	3.9	4.5	6.5	5.6	6.9	7.1	3.3	8.7
150	0.104	2.0	2.5	2.9	2.7	3.6	3.5	5.2	3.5
200	0.074	0.6	1.9	0.9	1.9	1.2	2.3	1.5	2.1
270	0.053	0.5	1.4	0.3	1.5	0.6	1.7	0.6	1.5
-270		1.4		1.5		1.7		1.5	

Table 4.5 NSPC: Coarse tailings gradations by CMRL.

	Sample:	NRRI-37-01		NRRI-62-01	
	Date Collected:	07/0901		10/01/01	
	% Moisture:	1.2		3.2	
Mesh Size	Sieve Opening (mm)	Wt.% on	Wt.% Passing	Wt.% on	Wt.% Passing
4	4.699	1.5	98.5	1.4	98.6
6	3.327	8.0	90.5	4.5	94.1
8	2.362	10.4	80.1	5.6	88.5
10	1.651	14.7	65.4	3.9	84.6
14	1.168	10.6	54.8	9.7	74.9
20	0.833	9.6	45.1	12.9	62.0
28	0.589	8.5	36.6	8.6	53.4
35	0.417	7.6	29.0	8.4	45.0
48	0.295	5.9	23.1	8.2	36.8
65	0.208	5.1	18.0	6.1	30.8
100	0.147	3.9	14.2	6.2	24.6
150	0.104	3.6	10.6	5.5	19.1
200	0.074	2.0	8.6	3.8	15.2
270	0.053	2.2	6.5	3.2	12.1
-270		6.5		12.1	

The CMRL size data has been composited for each mine, and is presented in Figure 4.1. Note how similarly the CMRL gradations plot for EVTAC, Minntac, and Ispat Inland, and the minimal amount of -200 mesh material that is present in their samples. The Hibtac and NSPC plots reflect the more variable composition of their coarse tails, and the higher percentage of -200 mesh material. The difference between the size distribution of samples collected at Hibtac and NSPC and those collected from the other three operations (at which coarse and fine tailings are separated) simply reflects the basic differences in each company's process flowsheet. The plots also show that EVTAC and Minntac tailings contain a smaller percentage of <1 mm particles than do tailings from the other companies.

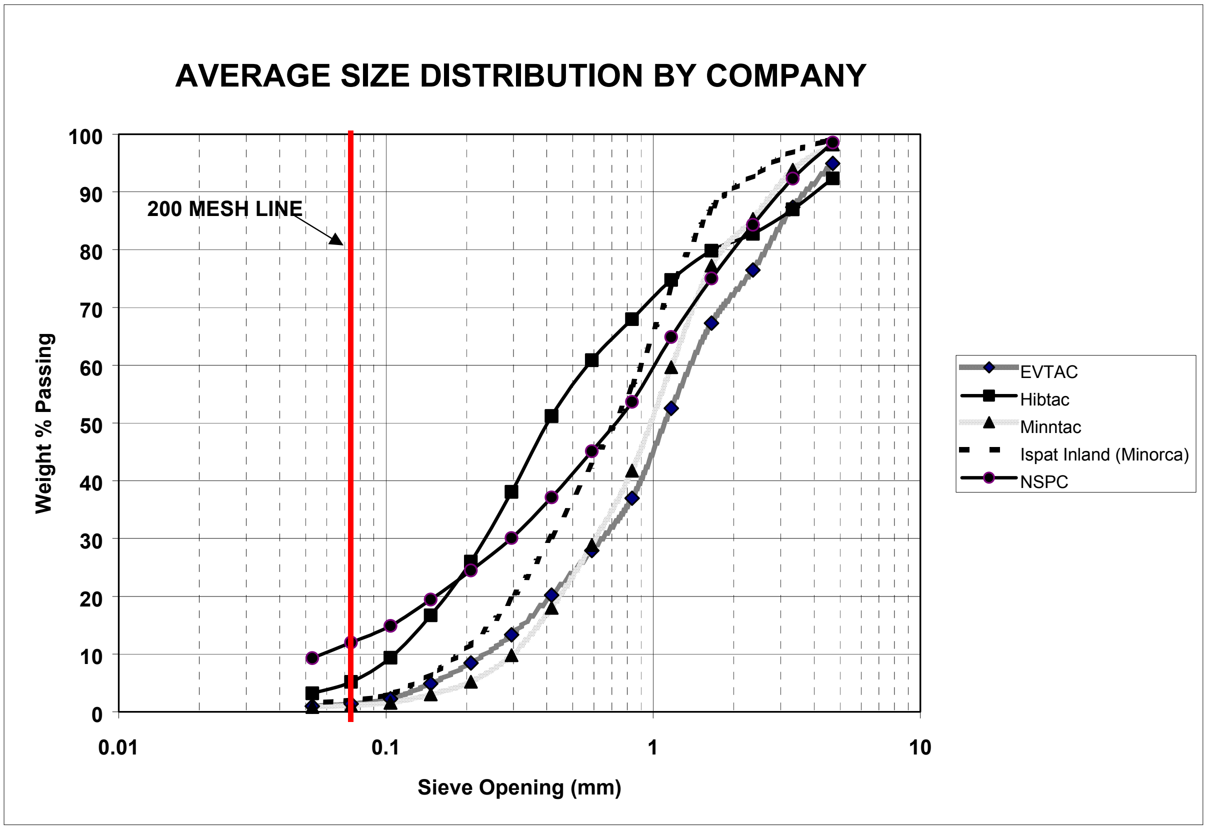

Figure 4.1 Coarse tailings size distribution, composited for each mine by CMRL.

Screen analyses were also conducted by Braun-Intertec and Mn/DOT. Figures 4.2 to 4.6 illustrate the average size distribution for each mine's coarse tailings (by lab), and the 200 mesh line is included for reference. Note the consistency between the three sets of analyses from the three laboratories. Figure 4.7 displays the composited coarse tailings size distributions for all five mines and all three labs. The Hibtac and NSPC plots are dashed in Figure 4.7. Note also the similarity in the shape of the EVTAC and Minntac plots. The complete set of analyses for all three labs is summarized in Table 4.6

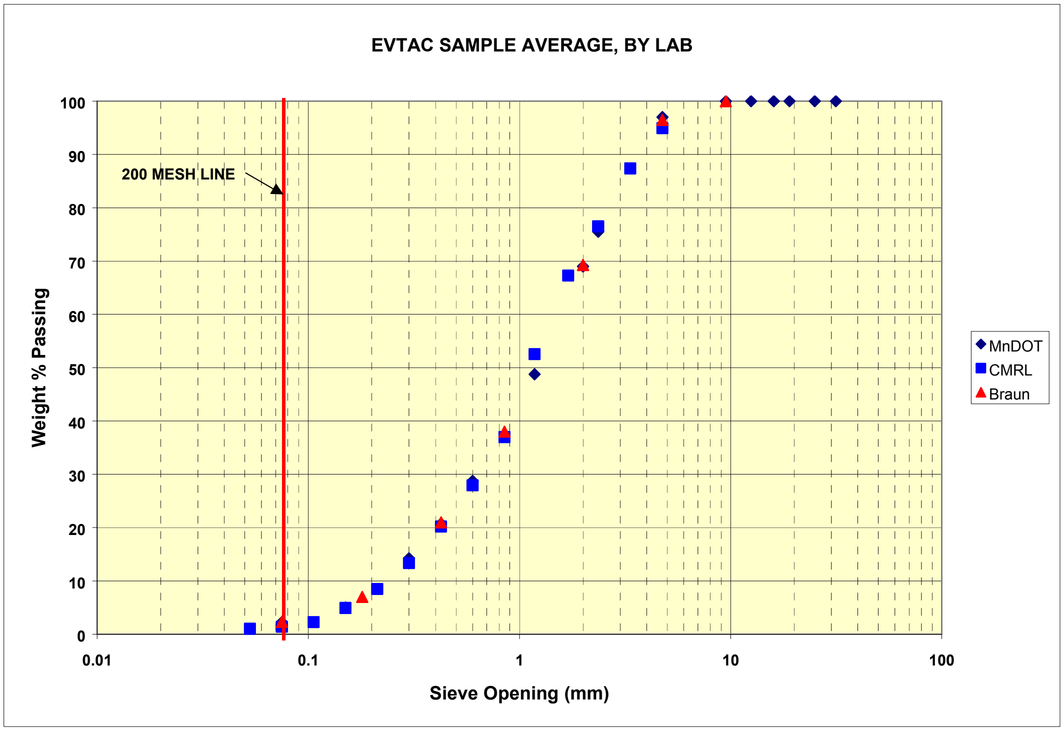

Figure 4.2 EVTAC coarse tailings average screen analysis, by laboratory.

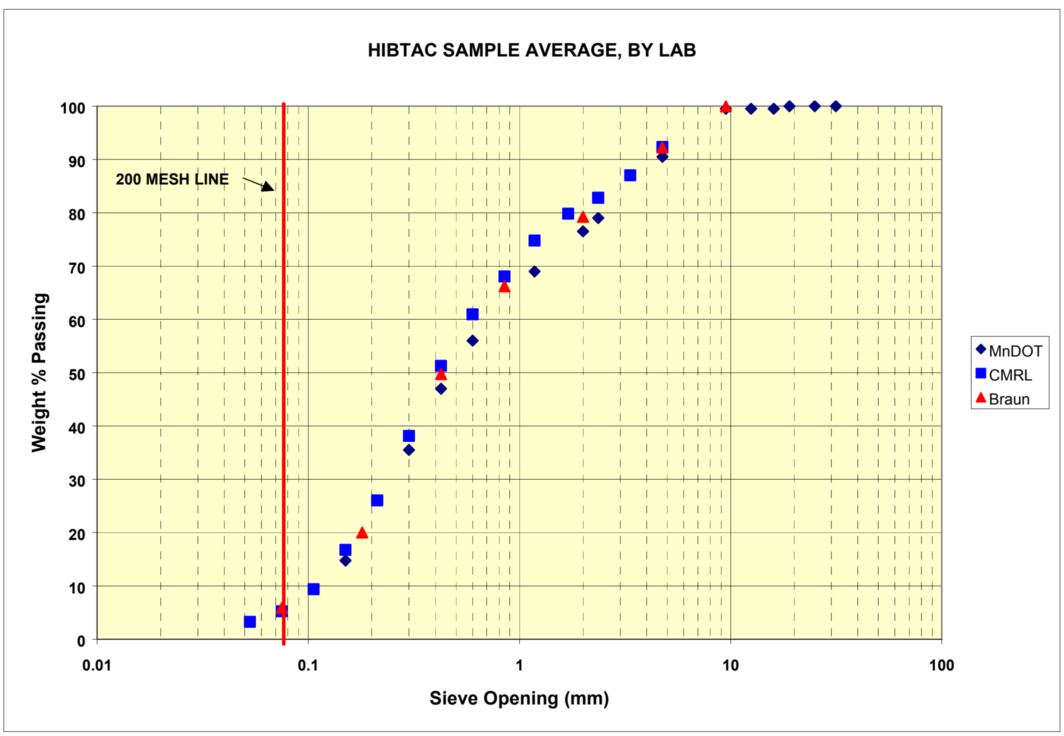

Figure 4.3 Hibtac coarse tailings average screen analysis, by laboratory.

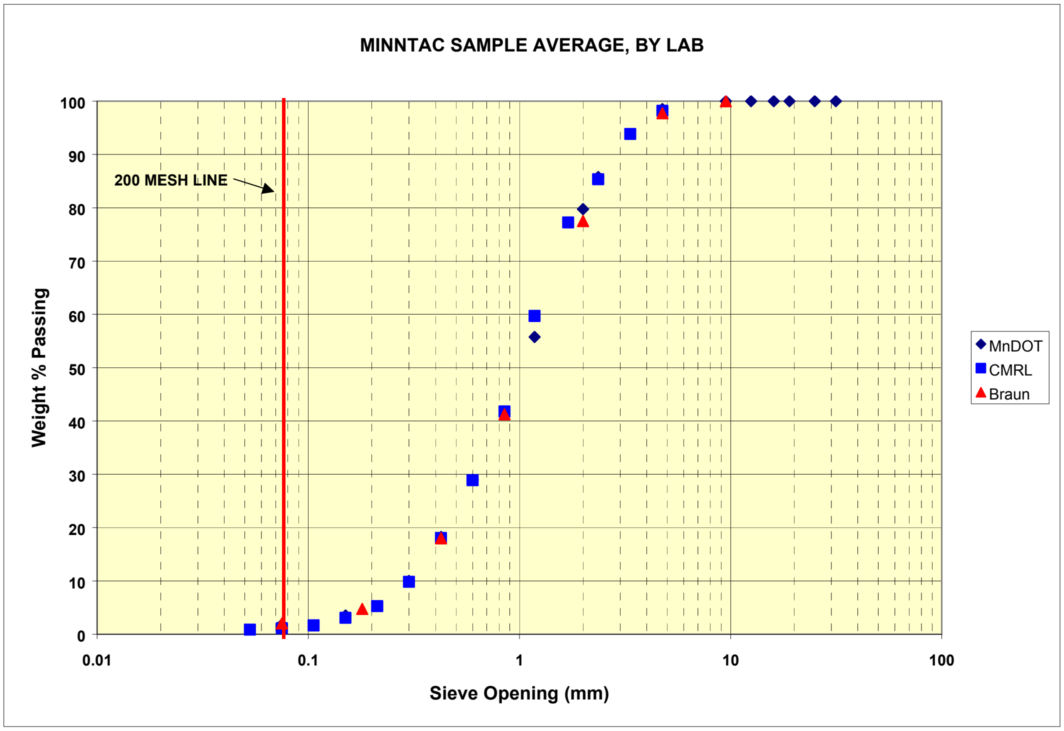

Figure 4.4 Minntac coarse tailings average screen analysis, by laboratory.

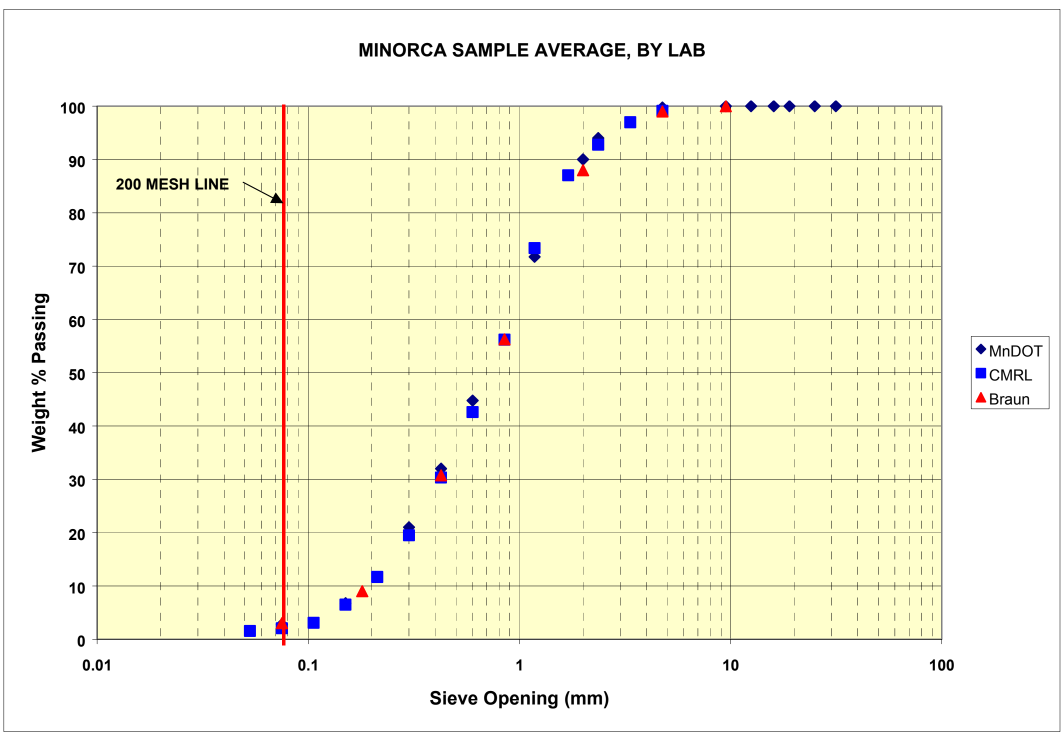

Figure 4.5 Minorca coarse tailings average screen analysis, by laboratory.

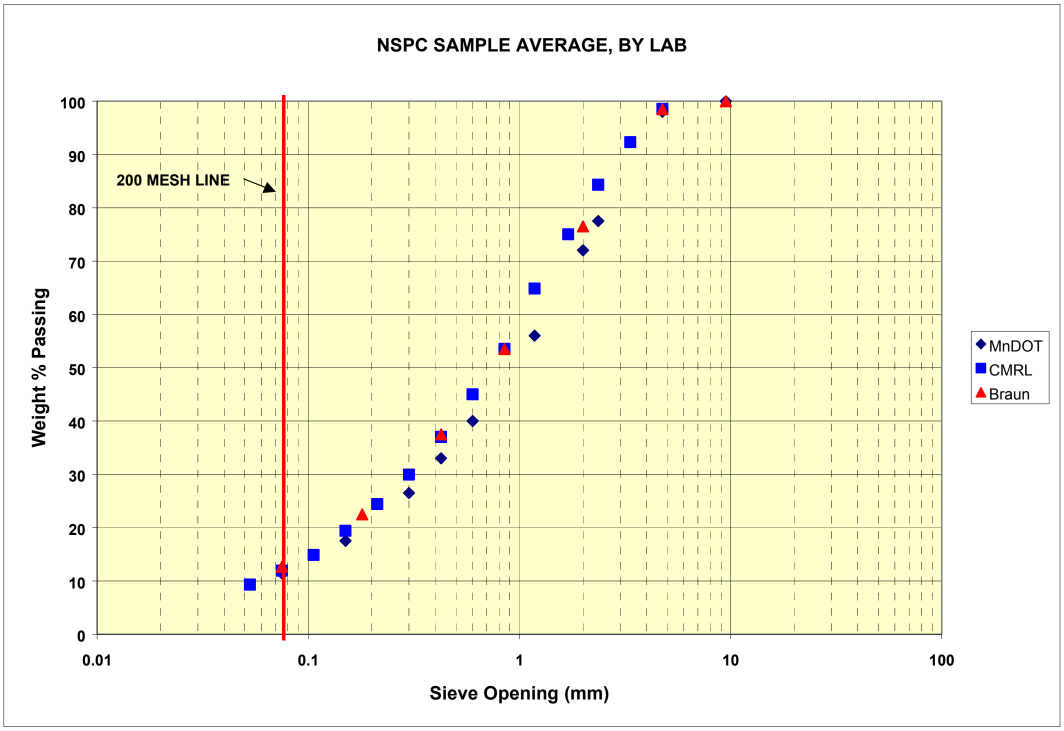

Figure 4.6 NSPC coarse tailings average screen analysis, by laboratory.

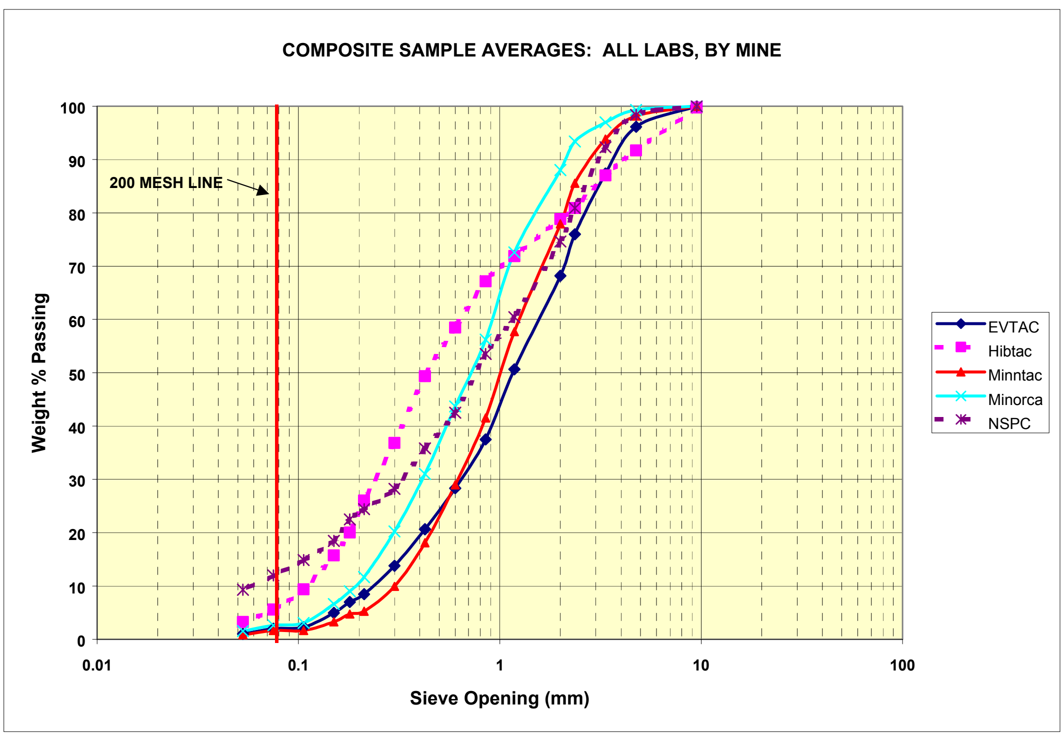

Figure 4.7 Composited coarse tailings screen analyses: all mines and all labs.

Table 4.6 Complete screen analysis results for all labs.

					EVTAC				Hibtac				Minntac				Minorca/Ispat				NSPC			AVERAGES			
				LAB	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN	BRAUN
				COMPANY	EVTAC	EVTAC	EVTAC	EVTAC	Hibtac	Hibtac	Hibtac	Hibtac	Minntac	Minntac	Minntac	Minntac	Minorca	Minorca	Minorca	Minorca	NSPC	NSPC	EVTAC	Hibtac	Minntac	Minorca	NSPC
US STANDARD	TYLER	OPENING	OPENING	SAMPLE	NRRI 40-00	NRRI 10-01	NRRI 31-01	NRRI 49-01	NRRI 36-00	NRRI 11-01	NRRI 42-01	NRRI 50-01	NRRI 37-00	NRRI 8-01	NRRI 17-01	NRRI 46-01	NRRI 39-00	NRRI 9-01	NRRI 30-01	NRRI 52-01	NRRI 37-01	NRRI-62-01	All Samples	All Samples	All Samples	All Samples	All Samples
NUMBER	MESH	mm	inch	DATE	12/13/00	03/06/01	06/13/01	09/11/01	11/16/00	03/09/01	07/24/01	09/12/01	11/22/00	02/15/01	05/07/01	08/08/01	12/08/00	03/01/01	06/11/01	09/18/01	07/09/01	10/01/01	Average	Average	Average	Average	Average
3/8"	.371"	9.5	0.375	% passing	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100.0	100.0	100.0	100.0	100.0
NO. 4	4	4.75	0.187	% passing	96	99	96	95	90	94	94	91	99	97	99	96	99	99	99	99	98	99	96.5	92.3	97.8	99.0	98.5
NO. 10	9	2	0.0787	% passing	66	74	69	68	77	82	82	76	81	78	81	70	89	89	89	85	74	79	69.3	79.3	77.5	88.0	76.5
NO. 20	20	0.85	0.0331	% passing	34	41	39	38	68	70	66	61	44	40	44	37	55	57	59	54	49	58	38.0	66.3	41.3	56.3	53.5
NO. 40	35	0.425	0.0165	% passing	18	22	22	22	59	55	42	43	19	16	20	17	27	31	34	31	33	42	21.0	49.8	18.0	30.8	37.5
NO. 80	80	0.18	0.007	% passing	6	7	8	7	37	21	5	17	5	4	5	5	7	8	11	10	19	26	7.0	20.0	4.8	9.0	22.5
NO. 200	200	0.075	0.0029	% passing	2.09	2.53	2.72	2.00	13.50	4.55	0.53	5.00	2.20	1.68	2.26	1.91	3.00	2.52	3.51	3.00	10.33	15.00	2.3	5.9	2.0	3.0	12.7

				LAB	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL	CMRL
				COMPANY	EVTAC	EVTAC	EVTAC	EVTAC	Hibtac	Hibtac	Hibtac	Hibtac	Minntac	Minntac	Minntac	Minntac	Minorca	Minorca	Minorca	Minorca	NSPC	NSPC	EVTAC	Hibtac	Minntac	Minorca	NSPC
US STANDARD	TYLER	OPENING	OPENING	SAMPLE	NRRI-40-00	NRRI-10-01	NRRI-31-01	NRRI-49-01	NRRI-36-00	NRRI-11-01	NRRI-42-01	NRRI-50-01	NRRI-37-00	NRRI-08-01	NRRI-17-01	NRRI-46-01	NRRI-39-00	NRRI-09-01	NRRI-30-01	NRRI-52-01	NRRI-37-01	NRRI-62-01	All Samples	All Samples	All Samples	All Samples	All Samples
NUMBER	MESH	mm	inch	DATE	12/13/2000	3/6/2001	6/13/2001	9/11/2001	11/16/2000	3/9/2001	7/24/2001	9/12/2001	11/22/2000	2/15/2001	5/7/2001	8/8/2001	12/8/2000	3/1/2001	6/11/2001	9/18/2001	07/0901	10/1/2001	Average	Average	Average	Average	Average
NO. 4	4	4.75	0.187	% passing	91.7	98.1	94.6	95.3	88.3	94.7	93.2	93.2	98.5	98.5	98.8	97.0	99.3	99.6	99.1	98.5	98.5	98.6	94.9	92.4	98.2	99.1	98.6
NO. 6	6	3.35	0.132	% passing	82.0	94.3	86.1	87.0	82.4	90.4	87.9	87.4	94.2	95.1	94.9	91.2	97.0	98.7	97.2	95.0	90.5	94.1	87.4	87.0	93.9	97.0	92.3
NO. 8	8	2.36	0.0937	% passing	71.1	85.4	74.2	75.3	78.0	86.2	84.7	82.3	86.1	87.0	87.7	80.6	93.8	95.5	93.4	88.4	80.1	88.5	76.5	82.8	85.4	92.8	84.3
NO. 12	10	1.7	0.0661	% passing	63.2	78.9	67.0	60.0	76.2	84.1	82.5	76.5	81.1	80.8	73.6	73.4	89.8	92.1	89.7	76.5	65.4	84.6	67.3	79.8	77.2	87.0	75.0
NO. 16	14	1.18	0.0469	% passing	46.5	62.0	51.9	49.7	71.3	79.2	77.0	71.6	60.3	62.8	59.3	56.4	69.9	79.9	77.2	66.5	54.8	74.9	52.5	74.8	59.7	73.4	64.9
NO. 20	20	0.85	0.0331	% passing	30.4	43.0	36.3	38.2	67.7	72.2	67.8	64.5	45.4	40.2	44.4	37.1	54.2	59.9	57.5	53.1	45.1	62.0	37.0	68.1	41.8	56.2	53.6
NO. 30	28	0.6	0.0234	% passing	22.4	32.5	27.9	28.8	63.7	65.8	58.4	55.9	31.8	26.8	30.7	26.3	39.0	46.2	44.7	40.5	36.6	53.4	27.9	61.0	28.9	42.6	45.0
NO. 40	35	0.425	0.0165	% passing	15.9	23.1	20.6	21.1	58.6	56.4	44.6	45.5	20.2	15.6	19.2	17.1	25.7	33.1	32.7	29.7	29.0	45.0	20.2	51.3	18.0	30.3	37.0
NO. 50	48	0.3	0.0117	% passing	10.2	14.8	14.1	14.2	51.5	42.7	25.4	32.9	10.9	7.6	11.1	9.7	15.8	20.7	21.6	19.8	23.1	36.8	13.3	38.1	9.8	19.5	30.0
NO. 70	65	0.212	0.0083	% passing	6.5	9.2	9.5	8.6	42.3	29.8	11.0	21.1	5.5	4.0	6.0	5.5	8.4	12.2	14.0	12.0	18.0	30.8	8.5	26.1	5.3	11.7	24.4
NO. 100	100	0.15	0.0059	% passing	3.4	4.6	5.2	6.4	33.3	16.5	2.4	14.7	4.0	2.0	3.4	2.8	4.5	5.6	7.1	8.7	14.2	24.6	4.9	16.7	3.1	6.5	19.4
NO. 140	150	0.106	0.0041	% passing	1.7	2.4	2.5	2.5	21.8	7.7	0.7	7.3	1.9	1.2	1.9	1.5	2.5	2.7	3.5	3.5	10.6	19.1	2.3	9.4	1.6	3.1	14.9
NO. 200	200	0.075	0.0029	% passing	1.1	1.6	1.5	1.3	12.5	4.1	0.4	3.9	1.3	0.8	1.4	1.0	1.9	1.9	2.3	2.1	8.6	15.2	1.4	5.2	1.1	2.1	11.9
NO. 270	270	0.053	0.0021	% passing	0.8	1.3	1.0	0.9	7.7	2.5	0.3	2.4	1.0	0.7	1.0	0.7	1.4	1.5	1.7	1.5	6.5	12.1	1.0	3.2	0.9	1.5	9.3

				LAB	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT	MnDOT
				COMPANY	EVTAC	EVTAC	EVTAC	EVTAC	Hibtac	Hibtac	Hibtac	Hibtac	Minntac	Minntac	Minntac	Minntac	Minorca	Minorca	Minorca	Minorca	NSPC	NSPC	EVTAC	Hibtac	Minntac	Minorca	NSPC
US STANDARD	TYLER	OPENING	OPENING	SAMPLE	NRRI-40-00	NRRI-10-01	NRRI-30-01	NRRI-49-01	NRRI-36-00	NRRI-11-01	NRRI-42-01	NRRI-50-01	NRRI-37-00	NRRI-08-01	NRRI-17-01	NRRI-46-01	NRRI-39-00	NRRI-09-01	NRRI-30-01	NRRI-52-01	NRRI-37-01	NRRI-62-01	All Samples	All Samples	All Samples	All Samples	All Samples
NUMBER	MESH	mm	inch	DATE	12/13/2000	3/6/2001	6/13/2001	9/11/2001	11/16/2000	3/9/2001	7/24/2001	9/12/2001	11/22/2000	2/15/2001	5/7/2001	8/8/2001	12/8/2000	3/1/2001	6/11/2001	9/18/2001	07/0901	10/1/2001	Average	Average	Average	Average	Average
1 1/4"		31.5	1.25	% passing	100.0	100.0			100.0	100.0			100.0				100.0	100.0					100.0	100.0	100.0	100.0	
1.00"		25	1	% passing	100.0	100.0			100.0	100.0			100.0				100.0	100.0					100.0	100.0	100.0	100.0	
3/4"	.742"	19	0.75	% passing	100.0	100.0			100.0	100.0			100.0				100.0	100.0					100.0	100.0	100.0	100.0	
5/8"	.624"	16	0.625	% passing	100.0	100.0			99.0	100.0			100.0				100.0	100.0					100.0	99.5	100.0	100.0	
1/2"		12.5	0.5	% passing	100.0	100.0			99.0	100.0			100.0				100.0	100.0					100.0	99.5	100.0	100.0	
3/8"	.371"	9.5	0.375	% passing	100.0	100.0	100.0	100.0	98.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0
NO. 4	4	4.75	0.187	% passing	96.0	97.0	100.0	95.0	86.0	94.0	93.0	89.0	99.0	98.0	100.0	97.0	100.0	100.0	100.0	99.0	98.0	98.0	97.0	90.5	98.5	99.8	98.0
NO. 8	8	2.36	0.0937	% passing	76.0	83.0	69.0	74.0	75.0	84.0	81.0	76.0	90.0	85.0	89.0	79.0	95.0	95.0	97.0	89.0	76.0	79.0	75.5	79.0	85.8	94.0	77.5
NO. 10	9	2	0.0787	% passing	69.0	77.0	62.0	68.0	73.0	82.0	78.0	73.0	85.0	79.0	82.0	73.0	91.0	91.0	94.0	84.0	69.0	75.0	69.0	76.5	79.8	90.0	72.0
NO. 16	14	1.18	0.0469	% passing	47.0	57.0	42.0	49.0	67.0	75.0	69.0	65.0	62.0	55.0	56.0	50.0	72.0	73.0	77.0	65.0	52.0	60.0	48.8	69.0	55.8	71.8	56.0
NO. 30	28	0.6	0.0234	% passing	26.0	36.0	24.0	29.0	59.0	64.0	50.0	51.0	35.0	27.0	28.0	26.0	43.0	47.0	49.0	40.0	35.0	45.0	28.8	56.0	29.0	44.8	40.0
NO. 40	35	0.425	0.0165	% passing	18.0	26.0	17.0	22.0	54.0	55.0	36.0	43.0	22.0	16.0	17.0	18.0	29.0	34.0	35.0	30.0	28.0	38.0	20.8	47.0	18.3	32.0	33.0
NO. 50	48	0.3	0.0117	% passing	12.0	18.0	12.0	15.0	47.0	43.0	20.0	32.0	12.0	8.0	9.0	11.0	18.0	22.0	24.0	20.0	22.0	31.0	14.3	35.5	10.0	21.0	26.5
NO. 100	100	0.15	0.0059	% passing	4.0	6.0	5.0	5.0	29.0	16.0	1.0	13.0	4.0	3.0	3.0	4.0	6.0	6.0	8.0	7.0	14.0	21.0	5.0	14.8	3.5	6.8	17.5
NO. 200	200	0.075	0.0029	% passing	1.8	3.0	2.2	2.1	12.6	4.7	0.3	4.8	2.0	1.5	1.9	1.8	2.8	2.6	3.4	2.3	8.9	13.9	2.3	5.6	1.8	2.8	11.4
				MnDOT #	CO-GS01-0020	CO-GS01-0015	CO-GS01-0089	CO-GS01-0234	CO-GS01-0018	CO-GS01-0022	CO-GS01-0235	CO-GS01-0240	CO-GS01-0021	CO-GS01-0016	CO-GS01-0091	CO-GS01-0236	CO-GS01-0019	CO-GS01-0017	CO-GS01-0090	CO-GS01-0239	CO-GS01-0237	CO-GS01-0238					

CHAPTER 5: AGGREGATE TESTING

The following aggregate tests were performed on the samples by Braun-Intertec Corporation:

- Gradation (see Chapter 4 discussion)
- Specific Gravity and Absorption
- Micro-Deval Abrasion Test
- Sand Equivalency
- Fine Aggregate Angularity, Method A
- Magnesium Sulfate Soundness
- Lightweight Pieces in Aggregates
- Moisture-Density
- Hydraulic Conductivity (permeability) (ASTM D5084 Method C)

In addition to gradation, Mn/DOT performed the following supplemental tests at its Office of Materials and Road Research in Maplewood, MN:

- Optimum Moisture
- Maximum Density
- R-Value

Los Angeles Rattler (LAR) on +4 material had originally been considered, but virtually all of the coarse tailings samples passed a No. 4 sieve (refer to Chapter 4). Additional gradation tests were done by Mn/DOT and CMRL, and have been summarized in Chapter 4.

BRAUN-INTERTEC TESTING RESULTS

Braun-Intertec Corporation was provided with 200 pounds of sample from each mine for conducting tests at their Hibbing and Eden Prairie, MN, facilities. Testing results were reported in both hard-copy and spreadsheet form. All Braun-Intertec aggregate testing data sheets are included at the end of this section, with two pages per mine, per sample. The first page presents results for most of the aggregate testing; the second page presents the results for the Hydraulic Conductivity tests (ASTM D 5084, Method C). The spreadsheet-reported testing results are summarized in tabular form on the following pages. Tables 5.1 to 5.5 summarize these data.

Gradation

Braun's gradation test results are presented in Table 5.1. Averages for each mine have been added to the Braun data.

Table 5.1 Braun-Intertec gradation results.

Lab ID	Sample	Collected	Sampled	Location	Description	Pass 3/8	Pass #4	Pass #10	Pass #20	Pass #40	Pass #80	Pass #200
5419	NRRI 40-00	12/13/00	8/30/2001	Evtac	Coarse Taconite Tailings	100	96	66	34	18	6	2.09
5417	NRRI 10-01	03/06/01	8/30/2001	Evtac	Coarse Taconite Tailings	100	99	74	41	22	7	2.53
5428	NRRI 31-01	06/13/01	8/30/2001	Evtac	Coarse Taconite Tailings	100	96	69	39	22	8	2.72
5676	NRRI 49-01	09/11/01	10/8/2001	Evtac	Coarse Taconite Tailings	100	95	68	38	22	7	2.00
					Evtac Average	**100.0**	**96.5**	**69.3**	**38.0**	**21.0**	**7.0**	**2.3**
5421	NRRI 36-00	11/16/00	8/30/2001	Hibtac	Coarse Taconite Tailings	100	90	77	68	59	37	13.50
5425	NRRI 11-01	03/09/01	8/30/2001	Hibtac	Coarse Taconite Tailings	100	94	82	70	55	21	4.55
5418	NRRI 42-01	07/24/01	8/30/2001	Hibtac	Coarse Taconite Tailings	100	94	82	66	42	5	0.53
5677	NRRI 50-01	09/12/01	10/8/2001	Hibtac	Coarse Taconite Tailings	100	91	76	61	43	17	5.00
					Hibtac Average	**100.0**	**92.3**	**79.3**	**66.3**	**49.8**	**20.0**	**5.9**
5416	NRRI 37-00	11/22/00	8/30/2001	Minntac	Coarse Taconite Tailings	100	99	81	44	19	5	2.20
5423	NRRI 8-01	02/15/01	8/30/2001	Minntac	Coarse Taconite Tailings	100	97	78	40	16	4	1.68
5424	NRRI 17-01	05/07/01	8/30/2001	Minntac	Coarse Taconite Tailings	100	99	81	44	20	5	2.26
5420	NRRI 46-01	08/08/01	8/30/2001	Minntac	Coarse Taconite Tailings	100	96	70	37	17	5	1.91
					Minntac Average	**100.0**	**97.8**	**77.5**	**41.3**	**18.0**	**4.8**	**2.0**
5422	NRRI 39-00	12/08/00	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	100	99	89	55	27	7	3.00
5415	NRRI 9-01	03/01/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	100	99	89	57	31	8	2.52
5426	NRRI 30-01	06/11/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	100	99	89	59	34	11	3.51
5678	NRRI 52-01	09/18/01	10/8/2001	Ispat/Minorca	Coarse Taconite Tailings	100	99	85	54	31	10	3.00
					Ispat/Minorca Average	**100.0**	**99.0**	**88.0**	**56.3**	**30.8**	**9.0**	**3.0**
5427	NRRI 37-01	07/09/01	8/30/2001	NSPC	Coarse Taconite Tailings	100	98	74	49	33	19	10.33
5874	NRRI-62-01	10/01/01	11/12/2001	NSPC	Coarse Taconite Tailings	100	99	79	58	42	26	15.00
					NSPC Average	**100.0**	**98.5**	**76.5**	**53.5**	**37.5**	**22.5**	**12.7**

Specific Gravity and Absorption

Results for specific gravity (s.g.) and absorption are presented in Table 5.2.

Table 5.2 Braun-Intertec specific gravity and absorption results.

Lab ID	Sample	Collected	Sampled	Location	Description	SG BOD	SG BSSD	SG AOD	% ABS
5419	NRRI 40-00	12/13/00	8/30/2001	Evtac	Coarse Taconite Tailings	2.882	2.917	2.988	1.24
5417	NRRI 10-01	03/06/01	8/30/2001	Evtac	Coarse Taconite Tailings	2.958	2.990	3.057	1.09
5428	NRRI 31-01	06/13/01	8/30/2001	Evtac	Coarse Taconite Tailings	2.941	2.973	3.038	1.09
5676	NRRI 49-01	09/11/01	10/8/2001	Evtac	Coarse Taconite Tailings	2.907	2.927	2.968	0.70
					Evtac Average	**2.922**	**2.952**	**3.013**	**1.03**
5421	NRRI 36-00	11/16/00	8/30/2001	Hibtac	Coarse Taconite Tailings	2.869	2.902	2.968	1.15
5425	NRRI 11-01	03/09/01	8/30/2001	Hibtac	Coarse Taconite Tailings	2.919	2.945	2.995	0.87
5418	NRRI 42-01	07/24/01	8/30/2001	Hibtac	Coarse Taconite Tailings	2.834	2.865	2.926	1.11
5677	NRRI 50-01	09/12/01	10/8/2001	Hibtac	Coarse Taconite Tailings	2.848	2.877	2.932	1.01
					Hibtac Average	**2.868**	**2.897**	**2.955**	**1.04**
5416	NRRI 37-00	11/22/00	8/30/2001	Minntac	Coarse Taconite Tailings	2.837	2.880	2.965	1.52
5423	NRRI 8-01	02/15/01	8/30/2001	Minntac	Coarse Taconite Tailings	2.797	2.841	2.925	1.56
5424	NRRI 17-01	05/07/01	8/30/2001	Minntac	Coarse Taconite Tailings	2.913	2.952	3.029	1.32
5420	NRRI 46-01	08/08/01	8/30/2001	Minntac	Coarse Taconite Tailings	2.939	2.982	3.070	1.46
					Minntac Average	**2.872**	**2.914**	**2.997**	**1.47**
5422	NRRI 39-00	12/08/00	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	2.920	2.948	3.005	0.97
5415	NRRI 9-01	03/01/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	2.842	2.867	2.915	0.89
5426	NRRI 30-01	06/11/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	2.816	2.845	2.899	1.01
5678	NRRI 52-01	09/18/01	10/8/2001	Ispat/Minorca	Coarse Taconite Tailings	2.911	2.933	2.974	0.73
					Ispat/Minorca Average	**2.872**	**2.898**	**2.948**	**0.90**
5427	NRRI 37-01	07/09/01	8/30/2001	NSPC	Coarse Taconite Tailings	2.945	2.973	3.028	0.93
5874	NRRI-62-01	10/01/01	11/12/2001	NSPC	Coarse Taconite Tailings	2.991	3.014	3.061	0.77
					NSPC Average	**2.968**	**2.994**	**3.045**	**0.85**

TESTING KEY	
SG BOD	Specific Gravity: Bulk Oven Dry
SG BSSD	Specific Gravity: Bulk Saturated Surface Dry
SG AOD	Specific Gravity: Apparent Oven Dry
% ABS	% Absorption

Specific gravity has a fairly narrow range, averaging about 2.9 to 3.0 overall, depending on the method. Pure quartz has a specific gravity of 2.65, so the higher s.g. of coarse taconite tailings is due largely to the presence of the small amounts of iron oxides, silicates, and carbonates, and other trace minerals. Therefore, coarse tailings have a specific gravity that can be up to 10% higher than more "typical" aggregates. This means that if one considers only specific gravity, coarse tailings might be at a disadvantage to "less dense" aggregates, in terms of shipping weight per unit volume. For example, a truck would reach its rated weight capacity with a load that is 10% smaller, by volume, than if it were hauling a less dense aggregate. However, other properties of coarse tailings (like particle angularity) may partially offset this difference.

Moisture absorption is generally low, with values averaging around 1% or less at four of the five operations. Minntac's coarse tailings have an average moisture absorption value of about 1.5%, which might be a reflection of the higher percentage of slaty taconite that Minntac mines. High absorption values can be an indication of unsound aggregate. Strong aggregate will usually have absorption values below 1%. Low absorption values are more critical to aggregate used in cement-based concrete than aggregate used in bituminous mixes. However, high absorption values can lead to greater oil consumption in the latter.

Lightweight Pieces in Aggregates, Sand Equivalency, Fine Aggregate Angularity, Magnesium Sulfate Soundness, and Micro-Deval Abrasion Tests

The test results summarized in Table 5.3 are important in considering an aggregate's potential asphalt pavement performance, especially for Superpave mixture design.

Table 5.3 Braun-Intertec aggregate testing result for: Lightweight Pieces in Aggregates; Sand Equivalency; Fine Aggregate Angularity; Magnesium Sulfate Soundness; and Micro-Deval Abrasion.

Lab ID	Sample	Collected	Sampled	Location	Description	% LTWT	Sand EQ	FAA	MAG SOUND	MIC-DEV
5419	NRRI 40-00	12/13/00	8/30/2001	Evtac	Coarse Taconite Tailings	0	98	45.71	7.20	9.7
5417	NRRI 10-01	03/06/01	8/30/2001	Evtac	Coarse Taconite Tailings	0	95	45.73	9.04	10.7
5428	NRRI 31-01	06/13/01	8/30/2001	Evtac	Coarse Taconite Tailings	0	93	46.08	5.48	10.6
5676	NRRI 49-01	09/11/01	10/8/2001	Evtac	Coarse Taconite Tailings	0	92	47.12	3.52	10.0
					Evtac Average	**0**	**94.5**	**46.16**	**6.31**	**10.3**
5421	NRRI 36-00	11/16/00	8/30/2001	Hibtac	Coarse Taconite Tailings	0	80	45.18	6.17	15.8
5425	NRRI 11-01	03/09/01	8/30/2001	Hibtac	Coarse Taconite Tailings	0	90	47.33	7.59	13.2
5418	NRRI 42-01	07/24/01	8/30/2001	Hibtac	Coarse Taconite Tailings	0	90	45.42	6.03	9.9
5677	NRRI 50-01	09/12/01	10/8/2001	Hibtac	Coarse Taconite Tailings	0	80	45.77	4.60	12.2
					Hibtac Average	**0**	**85.0**	**45.93**	**6.10**	**12.8**
5416	NRRI 37-00	11/22/00	8/30/2001	Minntac	Coarse Taconite Tailings	0	93	46.81	12.12	9.4
5423	NRRI 8-01	02/15/01	8/30/2001	Minntac	Coarse Taconite Tailings	0	98	46.59	10.43	8.4
5424	NRRI 17-01	05/07/01	8/30/2001	Minntac	Coarse Taconite Tailings	0	92	47.87	7.28	10.2
5420	NRRI 46-01	08/08/01	8/30/2001	Minntac	Coarse Taconite Tailings	0	97	45.33	8.98	8.7
					Minntac Average	**0**	**95.0**	**46.65**	**9.70**	**9.2**
5422	NRRI 39-00	12/08/00	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	0	93	47.47	5.22	9.3
5415	NRRI 9-01	03/01/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	0	90	46.81	5.73	10.6
5426	NRRI 30-01	06/11/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	0	91	47.32	5.23	9.7
5678	NRRI 52-01	09/18/01	10/8/2001	Ispat/Minorca	Coarse Taconite Tailings	0	90	47.32	2.85	9.6
					Ispat/Minorca Average	**0**	**91.0**	**47.23**	**4.76**	**9.8**
5427	NRRI 37-01	07/09/01	8/30/2001	NSPC	Coarse Taconite Tailings	0	81	44.55	5.99	12.5
5874	NRRI-62-01	10/01/01	11/12/2001	NSPC	Coarse Taconite Tailings	0	66	46.40	11.46	12.6
					NSPC Average	**0**	**73.5**	**45.48**	**8.73**	**12.6**

TESTING KEY	
% LTWT	% Lightweight Particles
Sand EQ	Sand Equivalent
FAA	Fine Aggregate Angularity
MAG SOUND	Magnesium Sulfate Soundness
MIC-DEV	Micro-Deval Abbrasion Loss

Moisture-Density, and Hydraulic Conductivity (permeability) ASTM D5084 Method C

Testing results are summarized in Table 5.4. The tests indicate that the tailings are essentially free-draining.

Table 5.4 Braun-Intertec moisture density and hydraulic conductivity results.

Lab ID	Sample	Collected	Sampled	Location	Description	Sample Type	Initial Dry Unit Weight, pcf	Final Dry Unit Weight, pcf	Initial Maximum Density, pcf	Initial Optimum Moisture, %	Initial Saturation, %	Final Saturation, %	Final Relative Compaction, %	Final Specific Gravity	Average Hydraulic Conductivity; cm/sec
5419	NRRI 40-00	12/13/00	8/30/2001	Evtac	Coarse Taconite Tailings	Remold	112.2	113.3	116.5	9.0	43.4	97.9	97.3	2.92	9.00E-04
5417	NRRI 10-01	03/06/01	8/30/2001	Evtac	Coarse Taconite Tailings	Remold	113.2	114.6	117.5	4.0	20.4	97.0	97.5	2.88	4.20E-03
5428	NRRI 31-01	06/13/01	8/30/2001	Evtac	Coarse Taconite Tailings	Remold	105.5	106.4	109.5	5.0	21.9	97.7	97.2	2.84	2.00E-03
5676	NRRI 49-01	09/11/01	10/8/2001	Evtac	Coarse Taconite Tailings	Remold	115.7	117.4	121.0	4.0	20.9	98.7	97.1	2.94	2.50E-03
5421	NRRI 36-00	11/16/00	8/30/2001	Hibtac	Coarse Taconite Tailings	Remold	106.4	108.0	111.5	5.0	22.4	95.8	96.9	2.83	2.10E-03
5425	NRRI 11-01	03/09/01	8/30/2001	Hibtac	Coarse Taconite Tailings	Remold	111.3	111.0	115.0	12.0	55.0	97.3	96.5	2.91	2.00E-03
5418	NRRI 42-01	07/24/01	8/30/2001	Hibtac	Coarse Taconite Tailings	Remold	112.6	114.1	117.5	11.0	54.1	95.8	97.1	2.91	1.60E-03
5677	NRRI 50-01	09/12/01	10/8/2001	Hibtac	Coarse Taconite Tailings	Remold	104.9	105.5	108.5	11.5	49.7	98.8	97.3	2.80	1.40E-03
5416	NRRI 37-00	11/22/00	8/30/2001	Minntac	Coarse Taconite Tailings	Remold	117.5	119.1	124.5	10.0	53.6	96.5	95.6	2.94	2.20E-03
5423	NRRI 8-01	02/15/01	8/30/2001	Minntac	Coarse Taconite Tailings	Remold	112.6	114.5	118.0	11.5	59.5	101.6	97.0	2.82	1.70E-03
5424	NRRI 17-01	05/07/01	8/30/2001	Minntac	Coarse Taconite Tailings	Remold	108.6	110.0	114.0	9.5	42.1	97.3	96.5	2.92	8.90E-04
5420	NRRI 46-01	08/08/01	8/30/2001	Minntac	Coarse Taconite Tailings	Remold	118.2	120.0	123.5	8.5	48.8	102.9	97.1	2.87	7.10E-04
5422	NRRI 39-00	12/08/00	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	Remold	116.8	117.9	122.0	6.0	33.7	100.7	96.7	2.85	1.80E-03
5415	NRRI 9-01	03/01/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	Remold	113.9	115.7	119.0	6.0	29.7	96.7	97.2	2.96	6.50E-04
5426	NRRI 30-01	06/11/01	8/30/2001	Ispat/Minorca	Coarse Taconite Tailings	Remold	107.8	108.5	112.0	12.0	55.6	95.3	96.8	2.80	2.40E-03
5678	NRRI 52-01	09/18/01	10/8/2001	Ispat/Minorca	Coarse Taconite Tailings	Remold	134.7	135.8	141.5	8.5	71.0	102.8	96.0	2.94	3.60E-04
5427	NRRI 37-01	07/09/01	8/30/2001	NSPC	Coarse Taconite Tailings	Remold	106.9	107.4	110.5	11.0	47.4	99.2	97.2	2.91	1.60E-03
5874	NRRI-62-01	10/01/01	11/12/2001	NSPC	Coarse Taconite Tailings	Remold	131.7	133.2	138.5	9.0	85.6	100.2	96.2	2.90	5.50E-04

Braun-Intertec Aggregate Testing Data Sheets

The preceding summary tables (Tables 5.1 to 5.4) were based on the results presented on individual testing data sheets. These sheets are presented individually on the following pages for each mine as follows:

EVTAC

Sample number NRRI 40-00	Figure 5.1 and Figure 5.2
Sample number NRRI 10-01	Figure 5.3 and Figure 5.4
Sample number NRRI 31-01	Figure 5.5 and Figure 5.6
Sample number NRRI 49-01	Figure 5.7 and Figure 5.8

Hibtac

Sample number NRRI 36-00	Figure 5.9 and Figure 5.10
Sample number NRRI 11-01	Figure 5.11 and Figure 5.12
Sample number NRRI 42-01	Figure 5.13 and Figure 5.14
Sample number NRRI 50-01	Figure 5.15 and Figure 5.16

Minntac

Sample number NRRI 37-00	Figure 5.17 and Figure 5.18
Sample number NRRI 8-01	Figure 5.19 and Figure 5.20
Sample number NRRI 17-01	Figure 5.21 and Figure 5.22
Sample number NRRI 46-01	Figure 5.22 and Figure 5.24

Ispat Inland (Minorca)

Sample number NRRI 39-00	Figure 5.25 and Figure 5.26
Sample number NRRI 9-01	Figure 5.27 and Figure 5.28
Sample number NRRI 30-01	Figure 5.29 and Figure 5.30
Sample number NRRI 52-01	Figure 5.31 and Figure 5.32

NSPC

Sample number NRRI 37-01	Figure 5.33 and Figure 5.34
Sample number NRRI 62-01	Figure 5.35 and Figure 5.36

Braun-Intertec Testing Results – EVTAC Samples

BRAUN INTERTEC

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5419

Background Information

Sample Number :	NRRI 40-00	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Evtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.882	
Bulk Saturated Surface Dry	2.917	
% Absorption	1.24	
Soundness Loss MnDOT 1219	7.2	
Fine Angularity MnDOT ASTM C1252A	45.7	
Sand Equivalent MnDOT AASHTO T176	98.0	
Micro-Deval Abrasion Loss MnDOT 1217	9.7	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	96	
#10 (2.0mm)	66	
#20 (.85mm)	34	
#40 (.425mm)	18	
#80 (.18mm)	6	
#200(.075mm)	2.1	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

Figure 5.1 Braun-Intertec aggregate test sheet: EVTAC sample NRRI 40-00.

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Braun Intertec Corporation
3105 East Beltline Highway, Suite 6
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218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	40-00	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Evtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/26/01		

Laboratory Results

	Initial		Final
Moisture Content, %	4.2	Moisture Content, %	19.2
Diameter, in	2.81	Diameter, in	2.80
Initial Height, in	3.37	Height, in	3.36
Dry Unit Weight, pcf	113.2	Dry Unit Weight, pcf	114.6
Maximum Density, pcf	117.5	Relative Compaction, %	97.5
Optimum Moisture, %	4.0	*Final Saturation, %*	97.0
Initial Saturation, %	20.4	Specific Gravity	2.88

Type of Permeant Liquid:	Deaired Water			Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	7.9			Differential pressure, psi	0.7
Operating Pressures, psi	Cell: 83.4	Head:	76.3	Tail:	75.6

Average Hydraulic Conductivity: 4.2E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.2 Braun-Intertec hydraulic conductivity test sheet: EVTAC sample NRRI 40-00.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5417

Background Information

Sample Number :	NRRI 10-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Evtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.958	
Bulk Saturated Surface Dry	2.990	
% Absorption	1.09	
Soundness Loss MnDOT 1219	9.0	
Fine Angularity MnDOT ASTM C1252A	45.7	
Sand Equivalent MnDOT AASHTO T176	95.0	
Micro-Deval Abrasion Loss MnDOT 1217	10.7	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	74	
#20 (.85mm)	41	
#40 (.425mm)	22	
#80 (.18mm)	7	
#200(.075mm)	2.5	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

Figure 5.3 Braun-Intertec aggregate test sheet: EVTAC sample NRRI 10-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	10-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Evtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/25/01		

Laboratory Results

	Initial		Final
Moisture Content, %	6.2	Moisture Content, %	19.4
Diameter, in	2.82	Diameter, in	2.80
Initial Height, in	3.37	Height, in	3.36
Dry Unit Weight, pcf	113.9	Dry Unit Weight, pcf	115.7
Maximum Density, pcf	119.0	Relative Compaction, %	97.2
Optimum Moisture, %	6.0	Final Saturation, %	96.7
Initial Saturation, %	29.7	Specific Gravity	2.96

Type of Permeant Liquid: Deaired Water — Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 5.3 — Differential pressure, psi 1.2
Operating Pressures, psi Cell: 83.1 Head: 79.0 Tail: 77.9

Average Hydraulic Conductivity: 6.5E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.4 Braun-Intertec hydraulic conductivity test sheet: EVTAC sample NRRI 10-01.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5428

Background Information

Sample Number :	NRRI 31-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Evtac

Properties		Test Results	Spec's
Lightweight Particles	MnDOT 1207	0.0	
Specific Gravity	MnDOT 1204/1205		
Bulk Oven Dry		2.941	
Bulk Saturated Surface Dry		2.973	
% Absorption		1.09	
Soundness Loss	MnDOT 1219	5.5	
Fine Angularity	MnDOT ASTM C1252A	46.1	
Sand Equivalent	MnDOT AASHTO T176	93.0	
Micro-Deval Abrasion Loss	MnDOT 1217	10.6	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	96	
#10 (2.0mm)	69	
#20 (.85mm)	39	
#40 (.425mm)	22	
#80 (.18mm)	8	
#200(.075mm)	2.7	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.5 Braun-Intertec aggregate test sheet: EVTAC sample NRRI 31-01.

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Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	31-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Evtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/19/01		

Laboratory Results

	Initial		Final
Moisture Content, %	10.3	Moisture Content, %	17.8
Diameter, in	2.82	Diameter, in	2.81
Initial Height, in	3.40	Height, in	3.38
Dry Unit Weight, pcf	117.5	Dry Unit Weight, pcf	119.1
Maximum Density, pcf	124.5	Relative Compaction, %	95.6
Optimum Moisture, %	10.0	Final Saturation, %	96.5
Initial Saturation, %	53.6	Specific Gravity	2.94

Type of Permeant Liquid: Deaired Water   Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 2.4   Differential pressure, psi 1.1
Operating Pressures, psi   Cell: 80.0   Head: 78.7   Tail: 77.6

Average Hydraulic Conductivity: 2.2E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.6 Braun-Intertec hydraulic conductivity test sheet: EVTAC sample NRRI 31-01.

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Engineers and Scientists Serving the Built and Natural Environments™

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5676

Background Information

Sample Number :	NRRI 49-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	10/8/01	Test Method :	MnDOT
Date Tested :	10/18/01	Sampled by :	
Sample Location :		Source :	Evtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.907	
Bulk Saturated Surface Dry	2.927	
% Absorption	0.70	
Soundness Loss MnDOT 1219	3.5	
Fine Angularity MnDOT ASTM C1252A	47.1	
Sand Equivalent MnDOT AASHTO T176	92.0	
Micro-Deval Abrasion Loss MnDOT 1217	10.0	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	95	
#10 (2.0mm)	68	
#20 (.85mm)	38	
#40 (.425mm)	22	
#80 (.18mm)	7	
#200(.075mm)	2.0	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.7 Braun-Intertec aggregate test sheet: EVTAC sample NRRI 49-01.

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Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	49-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Evtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/24/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.4	Moisture Content, %	19.4
Diameter, in	2.82	Diameter, in	2.80
Initial Height, in	3.36	Height, in	3.35
Dry Unit Weight, pcf	112.6	Dry Unit Weight, pcf	114.1
Maximum Density, pcf	117.5	Relative Compaction, %	97.1
Optimum Moisture, %	11.0	Final Saturation, %	95.8
Initial Saturation, %	54.1	Specific Gravity	2.91

Type of Permeant Liquid: Deaired Water — Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 5.8 — Differential pressure, psi 0.8
Operating Pressures, psi Cell: 83.7 Head: 78.8 Tail: 78.0

***Average Hydraulic Conductivity:* 1.6E-03 cm/sec**

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.8 Braun-Intertec hydraulic conductivity test sheet: EVTAC sample NRRI 49-01.

Braun Intertec Testing Results – Hibtac Samples

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218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01 **Project Number :** BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5421

Background Information

Sample Number :	NRRI 36-00	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Hibtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.869	
Bulk Saturated Surface Dry	2.902	
% Absorption	1.15	
Soundness Loss MnDOT 1219	6.2	
Fine Angularity MnDOT ASTM C1252A	45.2	
Sand Equivalent MnDOT AASHTO T176	80.0	
Micro-Deval Abrasion Loss MnDOT 1217	15.8	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)	100	
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	90	
#10 (2.0mm)	77	
#20 (.85mm)	68	
#40 (.425mm)	59	
#80 (.18mm)	37	
#200(.075mm)	13.5	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.9 Braun-Intertec aggregate test sheet: Hibtac sample NRRI 36-00.

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Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	36-00	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Hibtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/26/01		

Laboratory Results

	Initial		Final
Moisture Content, %	8.8	Moisture Content, %	17.7
Diameter, in	2.81	Diameter, in	2.80
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	118.2	Dry Unit Weight, pcf	120.0
Maximum Density, pcf	123.5	Relative Compaction, %	97.1
Optimum Moisture, %	8.5	Final Saturation, %	102.9
Initial Saturation, %	48.8	Specific Gravity	2.87

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	6.5	Differential pressure, psi	1.0

Operating Pressures, psi Cell: 83.0 Head: 77.6 Tail: 76.6

Average Hydraulic Conductivity: 7.1E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.10 Braun-Intertec hydraulic conductivity test sheet: Hibtac sample NRRI 36-00.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01 **Project Number :** BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5425 **Background Information**

Sample Number :	NRRI 11-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Hibtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.919	
Bulk Saturated Surface Dry	2.945	
% Absorption	0.87	
Soundness Loss MnDOT 1219	7.6	
Fine Angularity MnDOT ASTM C1252A	47.3	
Sand Equivalent MnDOT AASHTO T176	90.0	
Micro-Deval Abrasion Loss MnDOT 1217	13.2	

Sieve Analysis
MnDOT 1202-1203

Sieve	**% Passing**	**Spec's**
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	94	
#10 (2.0mm)	82	
#20 (.85mm)	70	
#40 (.425mm)	55	
#80 (.18mm)	21	
#200(.075mm)	4.6	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.11 Braun-Intertec aggregate test sheet: Hibtac sample NRRI 11-01.

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Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	11-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	XXXXXXX Hibtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/17/01		

Laboratory Results

	Initial		Final
Moisture Content, %	9.3	Moisture Content, %	20.4
Diameter, in	2.80	Diameter, in	2.79
Initial Height, in	3.39	Height, in	3.38
Dry Unit Weight, pcf	112.2	Dry Unit Weight, pcf	113.3
Maximum Density, pcf	116.5	Relative Compaction, %	97.3
Optimum Moisture, %	9.0	Final Saturation, %	97.9
Initial Saturation, %	43.4	Specific Gravity	2.92

Type of Permeant Liquid: Deaired Water — Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 4.1 — Differential pressure, psi 0.5
Operating Pressures, psi — Cell: 82.8 Head: 79.2 Tail: 78.7

Average Hydraulic Conductivity: 9.0E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.12 Braun-Intertec hydraulic conductivity test sheet: Hibtac sample NRRI 11-01.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5418

Background Information

Sample Number :	NRRI 42-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Hibtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.834	
Bulk Saturated Surface Dry	2.865	
% Absorption	1.11	
Soundness Loss MnDOT 1219	6.0	
Fine Angularity MnDOT ASTM C1252A	45.4	
Sand Equivalent MnDOT AASHTO T176	90.0	
Micro-Deval Abrasion Loss MnDOT 1217	9.9	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	94	
#10 (2.0mm)	82	
#20 (.85mm)	66	
#40 (.425mm)	42	
#80 (.18mm)	5	
#200(.075mm)	0.5	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

Figure 5.13 Braun-Intertec aggregate test sheet: Hibtac sample NRRI 42-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	42-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Hibtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/16/01		

Laboratory Results

	Initial		Final
Moisture Content, %	5.2	Moisture Content, %	21.5
Diameter, in	2.82	Diameter, in	2.80
Initial Height, in	3.39	Height, in	3.38
Dry Unit Weight, pcf	106.4	Dry Unit Weight, pcf	108.0
Maximum Density, pcf	111.5	Relative Compaction, %	96.9
Optimum Moisture, %	5.0	Final Saturation, %	95.8
Initial Saturation, %	22.4	Specific Gravity	2.83

Type of Permeant Liquid:	Deaired Water			Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	3.7			Differential pressure, psi	0.8
Operating Pressures, psi	Cell: 79.7	Head:	76.9	Tail:	76.0

Average Hydraulic Conductivity: 2.1E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.14 Braun-Intertec hydraulic conductivity test sheet: Hibtac sample NRRI 42-01.

BRAUN INTERTEC

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3105 East Beltline Highway, Suite 6
P.O. Box 762
Hibbing, MN 55746-0762
218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5677

Background Information

Sample Number :	NRRI 50-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	10/8/01	Test Method :	MnDOT
Date Tested :	10/18/01	Sampled by :	
Sample Location :		Source :	Hibtac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.848	
Bulk Saturated Surface Dry	2.877	
% Absorption	1.01	
Soundness Loss MnDOT 1219	4.6	
Fine Angularity MnDOT ASTM C1252A	45.8	
Sand Equivalent MnDOT AASHTO T176	80.0	
Micro-Deval Abrasion Loss MnDOT 1217	12.2	

Sieve Analysis

MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	91	
#10 (2.0mm)	76	
#20 (.85mm)	61	
#40 (.425mm)	43	
#80 (.18mm)	17	
#200(.075mm)	5.0	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

Figure 5.15 Braun-Intertec aggregate test sheet: Hibtac sample NRRI 50-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	50-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Hibtac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/26/01		

Laboratory Results

	Initial		Final
Moisture Content, %	6.2	Moisture Content, %	17.9
Diameter, in	2.82	Diameter, in	2.81
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	116.8	Dry Unit Weight, pcf	117.9
Maximum Density, pcf	122.0	Relative Compaction, %	96.7
Optimum Moisture, %	6.0	Final Saturation, %	100.7
Initial Saturation, %	33.7	Specific Gravity	2.85

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	3.6	Differential pressure, psi	0.9
Operating Pressures, psi	Cell: 79.2	Head: 76.6	Tail: 75.7

Average Hydraulic Conductivity: 1.8E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.16 Braun-Intertec hydraulic conductivity test sheet: Hibtac sample NRRI 50-01.

Braun Intertec Testing Results – Minntac Samples

BRAUN INTERTEC

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5416

Background Information

Sample Number :	NRRI 37-00	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Minntac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.837	
Bulk Saturated Surface Dry	2.880	
% Absorption	1.52	
Soundness Loss MnDOT 1219	12.1	
Fine Angularity MnDOT ASTM C1252A	46.8	
Sand Equivalent MnDOT AASHTO T176	93.0	
Micro-Deval Abrasion Loss MnDOT 1217	9.4	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	81	
#20 (.85mm)	44	
#40 (.425mm)	19	
#80 (.18mm)	5	
#200(.075mm)	2.2	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

Figure 5.17 Braun-Intertec aggregate test sheet: Minntac sample NRRI 37-00.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01

Project: BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	37-00	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Minntac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/16/01		

Laboratory Results

	Initial		Final
Moisture Content, %	5.2	Moisture Content, %	22.9
Diameter, in	2.80	Diameter, in	2.79
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	105.5	Dry Unit Weight, pcf	106.4
Maximum Density, pcf	109.5	Relative Compaction, %	97.2
Optimum Moisture, %	5.0	Final Saturation, %	97.7
Initial Saturation, %	21.9	Specific Gravity	2.84

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	6.0	Differential pressure, psi	0.8
Operating Pressures, psi	Cell: 82.3	Head: 77.1	Tail: 76.3

Average Hydraulic Conductivity: 2.0E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.18 Braun-Intertec hydraulic conductivity test sheet: Minntac sample NRRI 37-00.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Background Information

Lab ID : 5423

Sample Number :	NRRI 8-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Minntac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.797	
Bulk Saturated Surface Dry	2.841	
% Absorption	1.56	
Soundness Loss MnDOT 1219	10.4	
Fine Angularity MnDOT ASTM C1252A	46.6	
Sand Equivalent MnDOT AASHTO T176	98.0	
Micro-Deval Abrasion Loss MnDOT 1217	8.4	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	97	
#10 (2.0mm)	78	
#20 (.85mm)	40	
#40 (.425mm)	16	
#80 (.18mm)	4	
#200(.075mm)	1.7	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.19 Braun-Intertec aggregate test sheet: Minntac sample NRRI 8-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	8-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Minntac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/17/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.8	Moisture Content, %	23.1
Diameter, in	2.80	Diameter, in	2.80
Initial Height, in	3.37	Height, in	3.36
Dry Unit Weight, pcf	104.9	Dry Unit Weight, pcf	105.5
Maximum Density, pcf	108.5	Relative Compaction, %	97.3
Optimum Moisture, %	11.5	Final Saturation, %	98.8
Initial Saturation, %	49.7	Specific Gravity	2.80

Type of Permeant Liquid: Deaired Water — Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 6.0 — Differential pressure, psi 1.3
Operating Pressures, psi Cell: 83.4 Head: 78.8 Tail: 77.5

Average Hydraulic Conductivity: 1.4E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.20 Braun-Intertec hydraulic conductivity test sheet: Minntac sample NRRI 8-01.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5424

Background Information

Sample Number :	NRRI 17-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Minntac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.913	
Bulk Saturated Surface Dry	2.952	
% Absorption	1.32	
Soundness Loss MnDOT 1219	7.3	
Fine Angularity MnDOT ASTM C1252A	47.9	
Sand Equivalent MnDOT AASHTO T176	92.0	
Micro-Deval Abrasion Loss MnDOT 1217	10.2	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	81	
#20 (.85mm)	44	
#40 (.425mm)	20	
#80 (.18mm)	5	
#200(.075mm)	2.3	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.21 Braun-Intertec aggregate test sheet: Minntac sample NRRI 17-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	17-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Minntac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/17/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.4	Moisture Content, %	23.6
Diameter, in	2.80	Diameter, in	2.80
Initial Height, in	3.37	Height, in	3.36
Dry Unit Weight, pcf	106.9	Dry Unit Weight, pcf	107.4
Maximum Density, pcf	110.5	Relative Compaction, %	97.2
Optimum Moisture, %	11.0	Final Saturation, %	99.2
Initial Saturation, %	47.4	Specific Gravity	2.91

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	3.8	Differential pressure, psi	1.1
Operating Pressures, psi	Cell: 81.5	Head: 78.8	Tail: 77.7

Average Hydraulic Conductivity: 1.6E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.22 Braun-Intertec hydraulic conductivity test sheet: Minntac sample NRRI 17-01.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5420

Background Information

Sample Number :	NRRI 46-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Minntac

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.939	
Bulk Saturated Surface Dry	2.982	
% Absorption	1.46	
Soundness Loss MnDOT 1219	9.0	
Fine Angularity MnDOT ASTM C1252A	45.3	
Sand Equivalent MnDOT AASHTO T176	97.0	
Micro-Deval Abrasion Loss MnDOT 1217	8.7	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	96	
#10 (2.0mm)	70	
#20 (.85mm)	37	
#40 (.425mm)	17	
#80 (.18mm)	5	
#200(.075mm)	1.9	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.23 Braun-Intertec aggregate test sheet: Minntac sample NRRI 46-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	46-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Minntac
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/24/01		

Laboratory Results

	Initial		Final
Moisture Content, %	4.2	Moisture Content, %	18.9
Diameter, in	2.82	Diameter, in	2.80
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	115.7	Dry Unit Weight, pcf	117.4
Maximum Density, pcf	121.0	Relative Compaction, %	97.1
Optimum Moisture, %	4.0	Final Saturation, %	98.7
Initial Saturation, %	20.9	Specific Gravity	2.94

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	4.5	Differential pressure, psi	0.7
Operating Pressures, psi	Cell: 81.8	Head: 78.0	Tail: 77.3

Average Hydraulic Conductivity: 2.5E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.24 Braun-Intertec hydraulic conductivity test sheet: Minntac sample NRRI 46-01.

Braun Intertec Testing Results – Ispat Inland (Minorca) Samples

BRAUN
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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5422

Background Information

Sample Number :	NRRI 39-00	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	9/21/01	Sampled by :	
Sample Location :		Source :	Ispat / Minorca

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.920	
Bulk Saturated Surface Dry	2.948	
% Absorption	0.97	
Soundness Loss MnDOT 1219	5.2	
Fine Angularity MnDOT ASTM C1252A	47.5	
Sand Equivalent MnDOT AASHTO T176	93.0	
Micro-Deval Abrasion Loss MnDOT 1217	9.3	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	89	
#20 (.85mm)	55	
#40 (.425mm)	27	
#80 (.18mm)	7	
#200(.075mm)	3.0	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.25 Braun-Intertec aggregate test sheet: Ispat Inland (Minorca) sample NRRI 39-00.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01

Project: BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	39-00	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Ispat / Minorca
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/16/01		

Laboratory Results

	Initial		Final
Moisture Content, %	9.8	Moisture Content, %	21.9
Diameter, in	2.82	Diameter, in	2.81
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	108.6	Dry Unit Weight, pcf	110.0
Maximum Density, pcf	114.0	Relative Compaction, %	96.5
Optimum Moisture, %	9.5	Final Saturation, %	97.3
Initial Saturation, %	42.1	Specific Gravity	2.92

Type of Permeant Liquid:	Deaired Water		Hydraulic Gradient Range		15.8-14.9
Consolidation Pressure, psi	7.3		Differential pressure, psi		0.7
Operating Pressures, psi	Cell: 83.1	Head:	76.5	Tail:	75.8

Average Hydraulic Conductivity: 8.9E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.26 Braun-Intertec hydraulic conductivity test sheet: Ispat Inland (Minorca) sample NRRI 39-00.

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Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5415

Background Information

Sample Number :	NRRI 9-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Ispat / Minorca

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.842	
Bulk Saturated Surface Dry	2.867	
% Absorption	0.89	
Soundness Loss MnDOT 1219	5.7	
Fine Angularity MnDOT ASTM C1252A	46.8	
Sand Equivalent MnDOT AASHTO T176	90.0	
Micro-Deval Abrasion Loss MnDOT 1217	10.6	

Sieve Analysis

MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	89	
#20 (.85mm)	57	
#40 (.425mm)	31	
#80 (.18mm)	8	
#200(.075mm)	2.5	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.27 Braun-Intertec aggregate test sheet: Ispat Inland (Minorca) sample NRRI 9-01.

BRAUN
INTERTEC

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Hibbing, MN 55746-0762
218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	9-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Ispat / Minorca
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/16/01		

Laboratory Results

	Initial		Final
Moisture Content, %	12.3	Moisture Content, %	20.7
Diameter, in	2.80	Diameter, in	2.80
Initial Height, in	3.39	Height, in	3.38
Dry Unit Weight, pcf	107.8	Dry Unit Weight, pcf	108.5
Maximum Density, pcf	112.0	Relative Compaction, %	96.8
Optimum Moisture, %	12.0	Final Saturation, %	95.3
Initial Saturation, %	55.6	Specific Gravity	2.80

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	6.1	Differential pressure, psi	1.0

Operating Pressures, psi Cell: 83.1 Head: 78.0 Tail: 77.0

Average Hydraulic Conductivity: 2.4E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.28 Braun-Intertec hydraulic conductivity test sheet: Ispat Inland (Minorca) sample NRRI 9-01.

BRAUN
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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5426

Background Information

Sample Number :	NRRI 30-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	Ispat/ Minorca

Properties		Test Results	Spec's
Lightweight Particles	MnDOT 1207	0.0	
Specific Gravity	MnDOT 1204/1205		
Bulk Oven Dry		2.816	
Bulk Saturated Surface Dry		2.845	
% Absorption		1.01	
Soundness Loss	MnDOT 1219	5.2	
Fine Angularity	MnDOT ASTM C1252A	47.3	
Sand Equivalent	MnDOT AASHTO T176	91.0	
Micro-Deval Abrasion Loss	MnDOT 1217	9.7	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	89	
#20 (.85mm)	59	
#40 (.425mm)	34	
#80 (.18mm)	11	
#200(.075mm)	3.5	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.29 Braun-Intertec aggregate test sheet: Ispat Inland (Minorca) sample NRRI 30-01.

BRAUN
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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	30-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Ispat /Minorca
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/19/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.9	Moisture Content, %	19.3
Diameter, in	2.82	Diameter, in	2.80
Initial Height, in	3.38	Height, in	3.37
Dry Unit Weight, pcf	112.6	Dry Unit Weight, pcf	114.5
Maximum Density, pcf	118.0	Relative Compaction, %	97.0
Optimum Moisture, %	11.5	Final Saturation, %	101.6
Initial Saturation, %	59.5	Specific Gravity	2.82

Type of Permeant Liquid: Deaired Water   Hydraulic Gradient Range 15.8-14.9
Consolidation Pressure, psi 5.2   Differential pressure, psi 0.8
Operating Pressures, psi   Cell: 82.8   Head: 78.4   Tail: 77.6

Average Hydraulic Conductivity: 1.7E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.30 Braun-Intertec hydraulic conductivity test sheet: Ispat Inland (Minorca) sample NRRI 30-01.

BRAUN
INTERTEC

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218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5678

Background Information

Sample Number : NRRI 52-01
Date Sampled :
Date Submitted : 10/8/01
Date Tested : 10/18/01
Sample Location :

Specification : Project
Classification : Coarse Taconite Tailings
Test Method : MnDOT
Sampled by :
Source : Ispat / Minorca

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.911	
Bulk Saturated Surface Dry	2.933	
% Absorption	0.73	
Soundness Loss MnDOT 1219	2.9	
Fine Angularity MnDOT ASTM C1252A	47.3	
Sand Equivalent MnDOT AASHTO T176	90.0	
Micro-Deval Abrasion Loss MnDOT 1217	9.6	

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	85	
#20 (.85mm)	54	
#40 (.425mm)	31	
#80 (.18mm)	10	
#200(.075mm)	3.0	

CC:

Sincerely,
Braun Intertec Corporation
Mark W. Gothard
Mark Gothard
Project Manager

Figure 5.31 Braun-Intertec aggregate test sheet: Ispat Inland (Minorca) sample NRRI 52-01.

Hydraulic Conductivity ASTM D 5084 Method C

Date: 04/01/02

Project: BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	NRRI-52-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	Ispat
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	11/12/01	Depth:	na
Date Tested:	11/19/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.9	Moisture Content, %	21.3
Diameter, in	2.81	Diameter, in	2.81
Initial Height, in	3.38	Height, in	3.39
Dry Unit Weight, pcf	111.3	Dry Unit Weight, pcf	111.0
Maximum Density, pcf	115.0	Relative Compaction, %	96.5
Optimum Moisture, %	12.0	Final Saturation, %	97.3
Initial Saturation, %	55.0	Specific Gravity	2.91

Type of Permeant Liquid:	Deaired Water			Hydraulic Gradient Range			15.8-14.9
Consolidation Pressure, psi	5.7			Differential pressure, psi			0.7
Operating Pressures, psi	Cell:	83.6	Head:	78.6		Tail:	77.9

Average Hydraulic Conductivity: 2.0E-03 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.32 Braun-Intertec hydraulic conductivity test sheet: Ispat Inland (Minorca) sample NRRI 52-01.

Braun Intertec Testing Results – NSPC Samples

BRAUN
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218-263-8869 Fax: 263-6700

Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5427

Background Information

Sample Number :	NRRI 37-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	8/30/01	Test Method :	MnDOT
Date Tested :	10/1/01	Sampled by :	
Sample Location :		Source :	NSPC

Properties	**Test Results**	**Spec's**
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.945	
Bulk Saturated Surface Dry	2.973	
% Absorption	0.93	
Soundness Loss MnDOT 1219	6.0	
Fine Angularity MnDOT ASTM C1252A	44.6	
Sand Equivalent MnDOT AASHTO T176	81.0	
Micro-Deval Abrasion Loss MnDOT 1217	12.5	

Sieve Analysis
MnDOT 1202-1203

Sieve	**% Passing**	**Spec's**
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	98	
#10 (2.0mm)	74	
#20 (.85mm)	49	
#40 (.425mm)	33	
#80 (.18mm)	19	
#200(.075mm)	10.3	

CC:

Sincerely,
Braun Intertec Corporation

Mark Gothard
Project Manager

Figure 5.33 Braun-Intertec aggregate test sheet: NSPC sample NRRI 37-01.

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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	37-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	XXXXX NSPC
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	08/30/01	Depth:	na
Date Tested:	10/16/01		

Laboratory Results

	Initial		Final
Moisture Content, %	8.8	Moisture Content, %	12.3
Diameter, in	2.81	Diameter, in	2.81
Initial Height, in	3.40	Height, in	3.39
Dry Unit Weight, pcf	134.7	Dry Unit Weight, pcf	135.8
Maximum Density, pcf	141.5	Relative Compaction, %	96.0
Optimum Moisture, %	8.5	Final Saturation, %	102.8
Initial Saturation, %	71.0	Specific Gravity	2.94

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	4.4	Differential pressure, psi	0.9
Operating Pressures, psi	Cell: 82.7	Head: 79.2	Tail: 78.3

Average Hydraulic Conductivity: 3.6E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.34 Braun-Intertec hydraulic conductivity test sheet: NSPC sample NRRI 37-01.

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Engineers and Scientists Serving the Built and Natural Environments

Coarse Taconite Tailings

Date : 12/18/01

Project Number : BEDX-01-0161D

Client : Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis MN 55454-1082

Project : Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie MN

Lab ID : 5874

Background Information

Sample Number :	NRRI-62-01	Specification :	Project
Date Sampled :		Classification :	Coarse Taconite Tailings
Date Submitted :	11/12/01	Test Method :	MnDOT
Date Tested :	11/30/01	Sampled by :	
Sample Location :		Source :	NSPC

Properties	Test Results	Spec's
Lightweight Particles MnDOT 1207	0.0	
Specific Gravity MnDOT 1204/1205		
Bulk Oven Dry	2.991	
Bulk Saturated Surface Dry	3.014	
% Absorption	0.77	
Soundness Loss MnDOT 1219	11.5	
Fine Angularity MnDOT ASTM C1252A	46.4	
Sand Equivalent MnDOT AASHTO T176	66.0	
Micro-Deval Abrasion Loss MnDOT 1217		

Sieve Analysis
MnDOT 1202-1203

Sieve	% Passing	Spec's
1.5" (37.5mm)		
1" (25mm)		
3/4" (19mm)		
1/2" (12.5mm)		
3/8" (9.5mm)	100	
#4 (4.75mm)	99	
#10 (2.0mm)	79	
#20 (.85mm)	58	
#40 (.425mm)	42	
#80 (.18mm)	26	
#200(.075mm)	15.0	

CC:

Sincerely,
Braun Intertec Corporation
Mark Gothard
Project Manager

PRELIMINARY

Figure 5.35 Braun-Intertec aggregate test sheet: NSPC sample NRRI 62-01.

BRAUN INTERTEC

Braun Intertec Corporation
3105 East Beltline Highway, Suite 6
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Hibbing, MN 55746-0762
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Engineers and Scientists Serving the Built and Natural Environments

Hydraulic Conductivity ASTM D 5084 Method C

Date: 12/21/01 **Project:** BEDX-01-0161D

Client: Joseph Hatfield
University of Minnesota
Purchasing Services
Suite 560, 1300 South 2nd
Minneapolis, MN 55454-1082

Project Description: Aggregate Research Project
Braun Intertec Laboratory
Eden Prairie, MN

Field Data

Sample Number:	NRRI-62-01	Classification:	Coarse Taconite Tailings
Sampled By:	na	Sample Location:	NSPC
Data Sampled:	na	Sample Type:	Remold
Date Recieved:	11/12/01	Depth:	na
Date Tested:	11/19/01		

Laboratory Results

	Initial		Final
Moisture Content, %	11.0	Moisture Content, %	12.4
Diameter, in	2.81	Diameter, in	2.80
Initial Height, in	3.39	Height, in	3.38
Dry Unit Weight, pcf	131.7	Dry Unit Weight, pcf	133.2
Maximum Density, pcf	138.5	Relative Compaction, %	96.2
Optimum Moisture, %	9.0	Final Saturation, %	100.2
Initial Saturation, %	85.6	Specific Gravity	2.9

Type of Permeant Liquid:	Deaired Water	Hydraulic Gradient Range	15.8-14.9
Consolidation Pressure, psi	4.6	Differential pressure, psi	1.1

Operating Pressures, psi Cell: 80.2 Head: 76.8 Tail: 75.7

Average Hydraulic Conductivity: 5.5E-04 cm/sec

Remarks: The hydraulic conductivity of a soil can vary significantly depending on its density, its structure and degree of saturation, the remolding moisture content and method, and the permeant, temperature, weathering and other factors.

Mark Gothard
Project Manager

Figure 5.36 Braun-Intertec hydraulic conductivity test sheet: NSPC sample NRRI 62-01.

Mn/DOT TESTING RESULTS

The additional aggregate tests conducted by Mn/DOT at its Maplewood facility are summarized and presented in Table 5.5, following adjustments for a couple of sample number mix-ups. The Mn/DOT testing was performed to assess the suitability of coarse tailings as a base material in road construction applications, and the R-value test is a specific test for making that assessment. It is used to measure the supporting capability (stability) of a soil or aggregate, as established by American Association of State Highway and Transportation Officials (AASHTO) designation T-190 and T-99, and American Society for Testing and Materials (ASTM) designation D 2844. R-values can vary from 0 to 100. An R-value of zero represents a liquid, and an R-value of 100 represents a material that transmits no horizontal pressure from an applied load. Therefore, the higher the R-value, the higher the load-carrying capacity. The tailings samples show that their R-values compare well with those for Mn/DOT's standard textural classification for sand [12].

Table 5.5 Mn/DOT tests: gradation, optimal moisture, maximum density, and R-value*.

MnDOT Lab test #	Field ID	Location	Date Completed	% Passing #4	Opt Moisture	Max Density	R-Value
SS01042	NRRI-10-01	Evtac	5/17/2001	99.2	11.5	124.2	53.1
SS01139	NRRI-31-01	Evtac	8/14/2001	100.0	9.5	124.8	63.8
SS01047	NRRI-40-00	Evtac	5/18/2001	95.7	12.0	119.8	62.7
SS01267	NRRI-49-01	Evtac	1/3/2002	95.0	10.1	124.1	52.6
SS01049	NRRI-11-01	Hibtac	5/18/2001	94.1	12.2	118.4	59.7
SS01045	NRRI-36-00	Hibtac	5/18/2001	86.2	10.3	124.8	81.9
SS01268	NRRI-42-01	Hibtac	1/3/2002	93.0	13.0	114.4	56.1
SS01273	NRRI-50-01	Hibtac	1/8/2002	89.0	10.6	123.0	63.0
SS01140	NRRI-30-01	Ispat	8/14/2001	100.0	11.7	113.7	63.3
SS01046	NRRI-39-00	Ispat	5/18/2001	99.6	11.1	113.9	52.8
SS01272	NRRI-52-01	Ispat	1/8/2002	99.0	13.7	117.3	65.9
SS01044	NRRI-09-01	Ispat	5/18/2001	99.7	12.8	116.0	56.5
SS01141	NRRI-17-01	Minntac	8/14/2001	100.0	11.3	114.5	60.0
SS01048	NRRI-37-00	Minntac	5/18/2001	97.2	11.8	109.1	53.7
SS01269	NRRI-46-01	Minntac	1/3/2002	97.0	8.1	126.1	54.7
SS01043	NRRI-08-01	Minntac	5/18/2001	98.4	13.8	111.2	60.3
SS01270	NRRI-37-01	NSPC	1/3/2002	98.0	10.8	128.3	55.8
SS01271	NRRI-62-01	NSPC	1/8/2002	98.0	8.1	141.4	72.7

*** Could not run tests precisely as required by AASHTO Procedures.**
Samples often did not hold onto optimum moisture and lost some water during testing.

Field ID and Mine name corrected. Used mine names listed in Braun's reports.
Field ID duplication corrected based on gradations.

The R-Value and Maximum Density results are summarized in Figure 5.37. As the Mn/DOT testing comments suggested, the samples drained so quickly that they did not retain optimum moisture. Therefore, the coarse tailings may require some level of confinement for road base or fill applications.

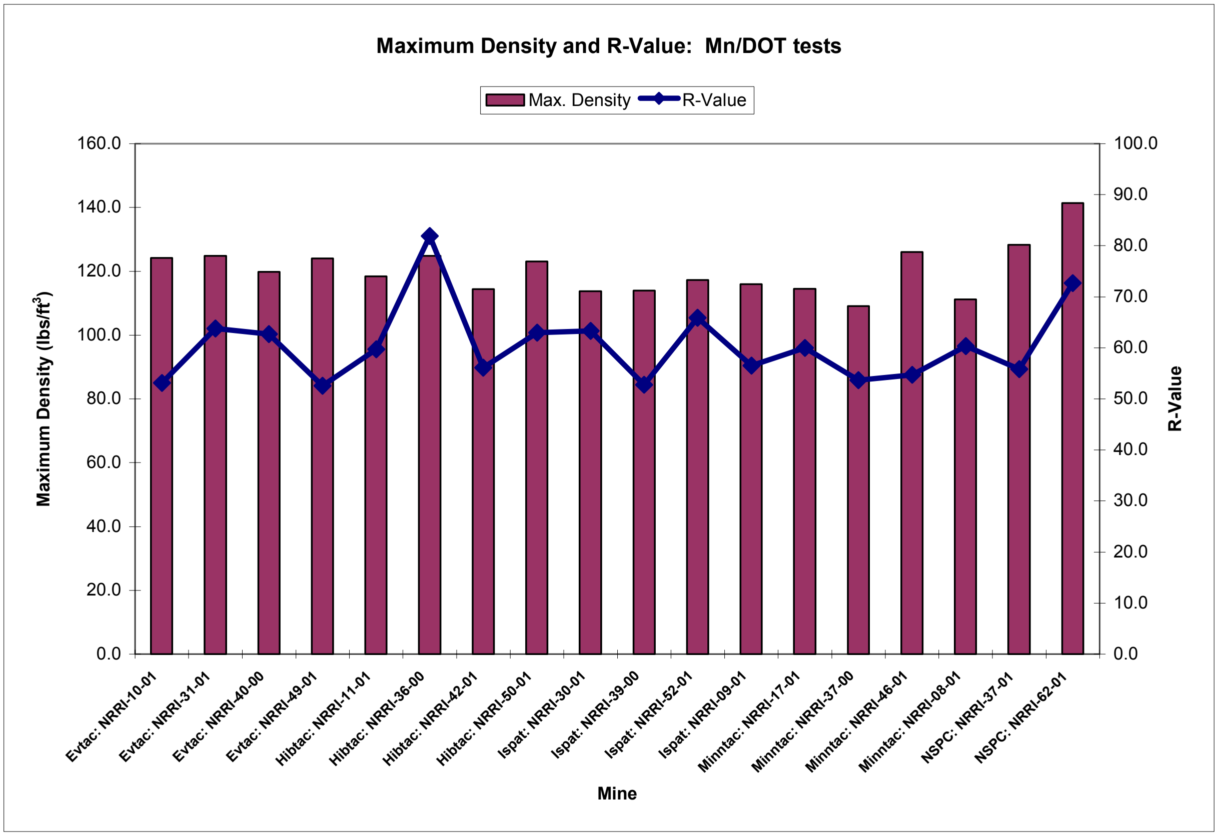


Figure 5.37 Maximum Density and R-Value Comparison: Mn/DOT test results.

Mn/DOT Aggregate Testing Data Sheets

Mn/DOT's aggregate testing results have been summarized completely in Table 5.5 and Figure 5.10. Available aggregate testing data sheets are reproduced on the following pages for selected samples, and are presented for each mine as follows:

EVTAC

Sample number NRRI 40-00*	Figure 5.38 and Figure 5.39*
Sample number NRRI 10-01	Figure 5.40 to Figure 5.49
Sample number NRRI 31-01	Figure 5.50

* Mislabeled as Minorca on Figure 5.39 data sheet.

Hibtac

Sample number NRRI 36-00	Figure 5.51 to Figure 5.59
Sample number NRRI 11-01	Figure 5.60 to Figure 5.68+

+ Mislabeled as Minntac on Figure 5.61 data sheet.

Minntac

Sample number NRRI 37-00	Figure 5.69 and Figure 5.70
Sample number NRRI 8-01	Figure 5.71 and Figure 5.72
Sample number NRRI 17-01	Figure 5.73

Ispat Inland (Minorca)

Sample number NRRI 39-00	Figure 5.74 and Figure 5.75
Sample number NRRI 9-01	Figure 5.76 and Figure 5.77
Sample number NRRI 30-01	Figure 5.78

NSPC

na

Mn/DOT Testing Results – EVTAC Samples

State of Minnesota Department of Transportation
Aggregates Test Report

MAY 01 2001

Sample ID CO-GS01-0020	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-40-00	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	96							
2.36mm (#8)	76							
2.00mm (#10)	69							
1.18mm (#16)	47							
600um (#30)	26							
425um (#40)	18							
300um (#50)	12							
150um (#100)	4							
75um (#200)	1.8							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value and Resilient Modulus results will come on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

Page 1 of 1 5/1/01 12:40:33 PM

Figure 5.38 Mn/DOT gradation test sheet: EVTAC sample NRRI 40-00.

MAY 18 2001

LAB NO SS01047

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH
TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINORCA	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-40-00
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	99.7	% SILT	
% PASSING #4	95.7	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	12
		MAX# DENSITY	119.8
		R-VALUE (240 psi)	62.7
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

REVIEWED BY

CHARGE OUT: [illegible] 1042 1056

Figure 5.39 Mn/DOT opt. moisture, max. density, R-value test sheet: EVTAC sample NRRI 40-00.

State of Minnesota Department of Transportation
Aggregates Test Report

MAY 01 2001

Sample ID CO-GS01-0015	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-10-01	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	97							
2.36mm (#8)	83							
2.00mm (#10)	77							
1.18mm (#16)	57							
600um (#30)	36							
425um (#40)	26							
300um (#50)	18							
150um (#100)	6							
75um (#200)	3.0							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value and Resilient Modulus results will come on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

Page 1 of 1 5/1/01 12:35:52 PM

Figure 5.40 Mn/DOT gradation test sheet: EVTAC sample NRRI 10-01.

MAY 17 2001

LAB NO SS01042

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH
TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	EVTAC	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-10-01
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	100.0	% SILT	
% PASSING #4	97.2	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	11.5
		MAX# DENSITY	124.2
		R-VALUE (240 psi)	53.1
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Paten
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.41 Mn/DOT optimum moisture, maximum density, R-value test sheet: EVTAC sample NRRI 10-01.

Soil and Granular Material Compaction Data sheet

Sample No: (SS01042) - (1001RM1A)	Taconite	Date:	5/31/01

Desired MC (%):	11.5	**Desired dry density (lbs/ft^3):**	124.2		
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735		
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829	**or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282	**or**	0.196344
No. of lifts:	6				

Hygroscopic MC

HMC wet wt of initial soil:	357.4
HMC dry wt of initial soil:	356.5
HMC tare wt:	183
Hygroscopic MC:	0.5

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs):	28.45021		
2) Wt of water needed based on Mold Vol [Ww] (lbs):	3.271774		
3) Total wt of oven dried soil needed [Ws+Was] (lbs)	29.55021	[add Was=1.1 lbs (500g) for MC determination]	
4) Wt of hygroscopic water in sample (lbs):	0.153286	8) Calc. Wet density (lbs/ft^3)	138.483
5) Total wt of existing soil needed [Wad] (lbs)		9) Desired compacted soil wt (lbs):	27.19027
	29.7035	Lbs	
	13473.2	g	
6) Wt of water needed to add in the existing soil [Waw] (lbs):	**3.244988**	Lbs.	
	1471.894	g	
7) Wt of soil on each lift (lbs):	**4.531712**	Lbs	
	2055.539	g	

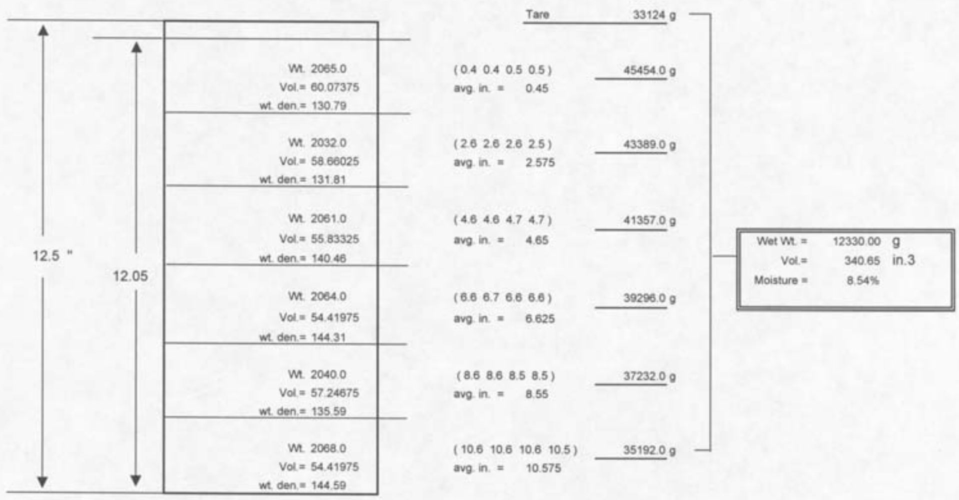
Figure 5.42 Mn/DOT compaction data test sheet 1: EVTAC sample NRRI 10-01 (1001RM1A).

Taconite Tailings

Date 5/31/01

File Name 1001RM1A
Field I.D. NRRI-10-01
Lab I.D. SS01042

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	189.9	526.0	523.9	2.1	0.6%
Moisture + 24 hrs.				0	#DIV/0!
Moisture from lifts	183.5	413.2	391.1	22.1	10.6%
Moisture from leftovers	336.2	2382.3	2160.7	221.6	12.1%
Moisture from top 1/2	2690.7	9133.6	8727.3	406.3	6.7%
Moisture from bottom 1/2	2649.4	8053.5	7546.9	506.6	10.3%



Notes

Wet Density = 137.72
Dry Density = 126.89
Void Ratio = 0.3278
Degree of Saturation = 70.33%

Passing 3/4" =	100.0%
Passing 3/8" =	100.0%
Passing #4 =	97.0%
Passing # 10 =	77.0%
Passing # 30 =	36.0%
Passing # 40 =	26.0%
Passing # 50 =	18.0%
Passing # 100 =	6.0%
Passing # 200 =	3.0%

Percometer	Hard	Soft
Dielectric	14.3	11.4
Conductivity	-334.0	20.0

Shear Test
Rate = 0.03 in/sec
Time = 12 sec

347.5 g of water lost during MR testing
most during 1000 conditioning cycles

Figure 5.43 Mn/DOT compaction data test sheet 2: EVTAC sample NRRI 10-01 (1001RM1A).

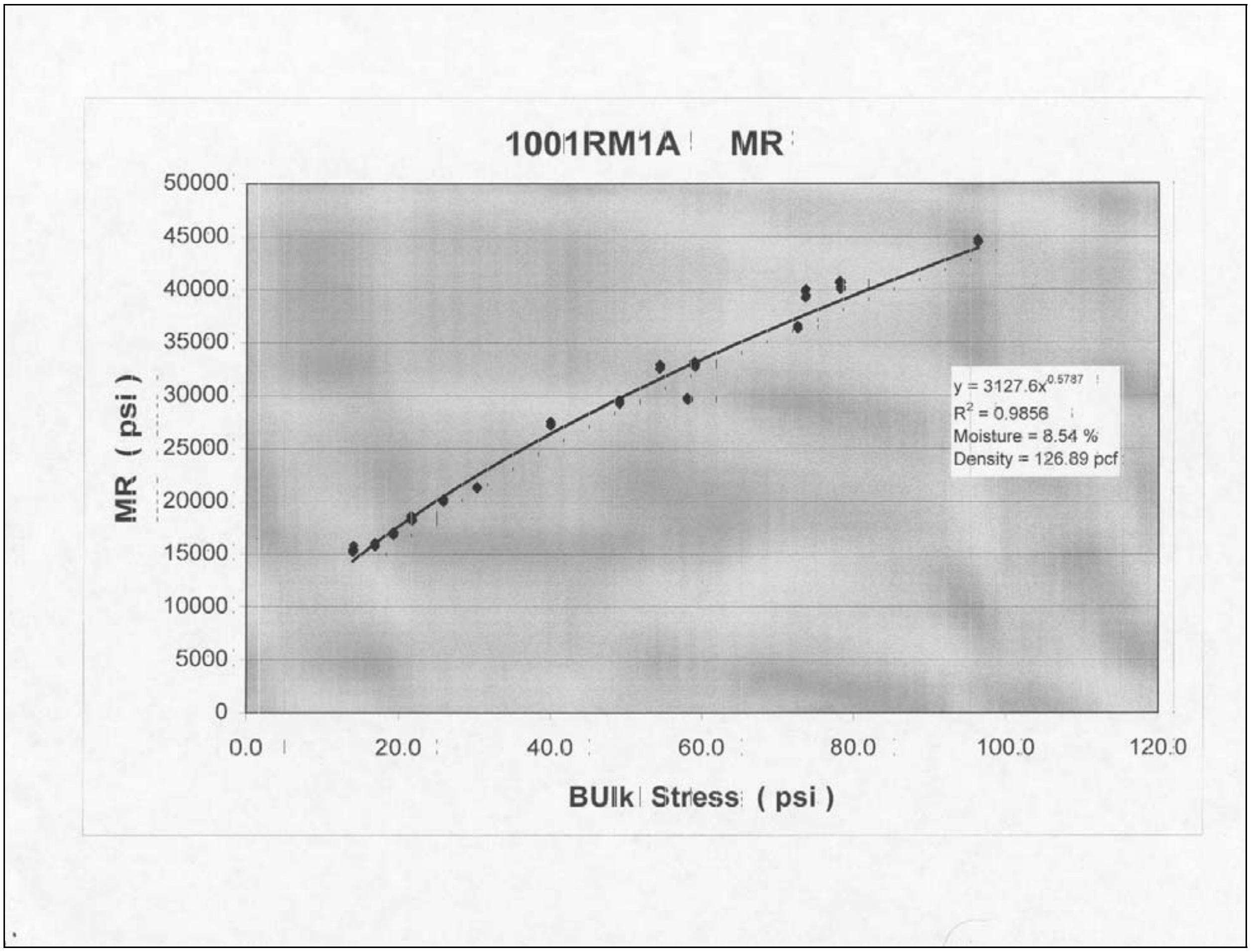


Figure 5.44 Mn/DOT MR graph: EVTAC sample NRRI 10-01 (1001RM1A).

Soil and Granular Material Compaction Data sheet

Sample No: (SS01042) - (1001RM2A)	Tcconite	Date:	6/4/01

Desired MC (%):	11.5	**Desired dry density (lbs/ft^3):**	124.2	
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735	
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829 **or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282 **or**	0.196344
No. of lifts:	6			

Hygroscopic MC

HMC wet wt of initial soil:	357.4
HMC dry wt of initial soil:	356.5
HMC tare wt:	183
Hygroscopic MC:	0.5

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs): 28.45021

2) Wt of water needed based on Mold Vol [Ww] (lbs): 3.271774

3) Total wt of oven dried soil needed [Ws+Was] (lbs): 29.55021 [add Was=1.1 lbs (500g) for MC determination]

4) Wt of hygroscopic water in sample (lbs): 0.153286

8) Calc. Wet density (lbs/ft^3): 138.483

5) Total wt of existing soil needed [Wad] (lbs) **29.7035** Lbs, **13473.2** g

9) Desired compacted soil wt (lbs): 27.19027

6) Wt of water needed to add in the existing soil [Waw] (lbs): **3.244988** Lbs., **1471.894** g

7) Wt of soil on each lift (lbs): **4.531712** Lbs, 2055.539 g

Figure 5.45 Mn/DOT compaction data test sheet 1: EVTAC sample NRRI 10-01 (1001RM2A).

Taconite Tailings

Date 6/4/01

File Name 1001RM2A
Field I.D. NRRI-10-01
Lab I.D. SS01042

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	189.9	526.0	523.9	2.1	0.6%
Moisture + 24 hrs.	178.2	401.7	383.8	17.9	8.7%
Moisture from lifts	178.3	520.0	486.6	33.4	10.8%
Moisture from leftovers	337.9	1742.0	1596.9	145.1	11.5%
Moisture from top 1/2	2691.1	8374.6	7883.1	491.5	9.5%
Moisture from bottom 1/2	2650.3	9137.3	8437.4	699.9	12.1%

12.5 "

12.00

Tare 33002 g

Wt. 2062.0 Vol.= 62.90075 wt. den.= 124.73	(0.5 0.5 0.5 0.5) avg. in. = 0.5		45331.0 g
Wt. 2052.0 Vol.= 56.54 wt. den.= 138.09	(2.8 2.7 2.7 2.7) avg. in. = 2.725		43269.0 g
Wt. 2050.0 Vol.= 53.713 wt. den.= 145.22	(4.8 4.7 4.7 4.7) avg. in. = 4.725		41217.0 g
Wt. 35457.0 Vol.= 57.24675 wt. den.= 2356.71	(6.7 6.5 6.6 6.7) avg. in. = 6.625		39167.0 g
Wt. -31334.0 Vol.= 55.83325 wt. den.= -2135.39	(8.8 8.6 8.6 8.6) avg. in. = 8.65		3710.0 g
Wt. 2042.0 Vol.= 53.00625 wt. den.= 146.58	(10.7 10.7 10.5 10.6) avg. in. = 10.625		35044.0 g

Wet Wt. = 12329.00 g
Vol.= 339.24 in.3
Moisture = 10.78%

Notes

Wet Density = 138.29
Dry Density = 124.83
Void Ratio = 0.3497
Degree of Saturation = 83.24%

Passing 3/4" = 100.0%
Passing 3/8" = 100.0%
Passing #4 = 97.0%
Passing # 10 = 77.0%
Passing # 30 = 36.0%
Passing # 40 = 26.0%
Passing # 50 = 18.0%
Passing # 100 = 6.0%
Passing # 200 = 3.0%

Percometer Hard Soft
Dielectric

Shear Test
Rate = 0.03 in/sec
Time = 12 sec
Start @ = -0.31495
End @ = 0.04505

Figure 5.46 Mn/DOT compaction data test sheet 2: EVTAC sample NRRI 10-01 (1001RM2A).

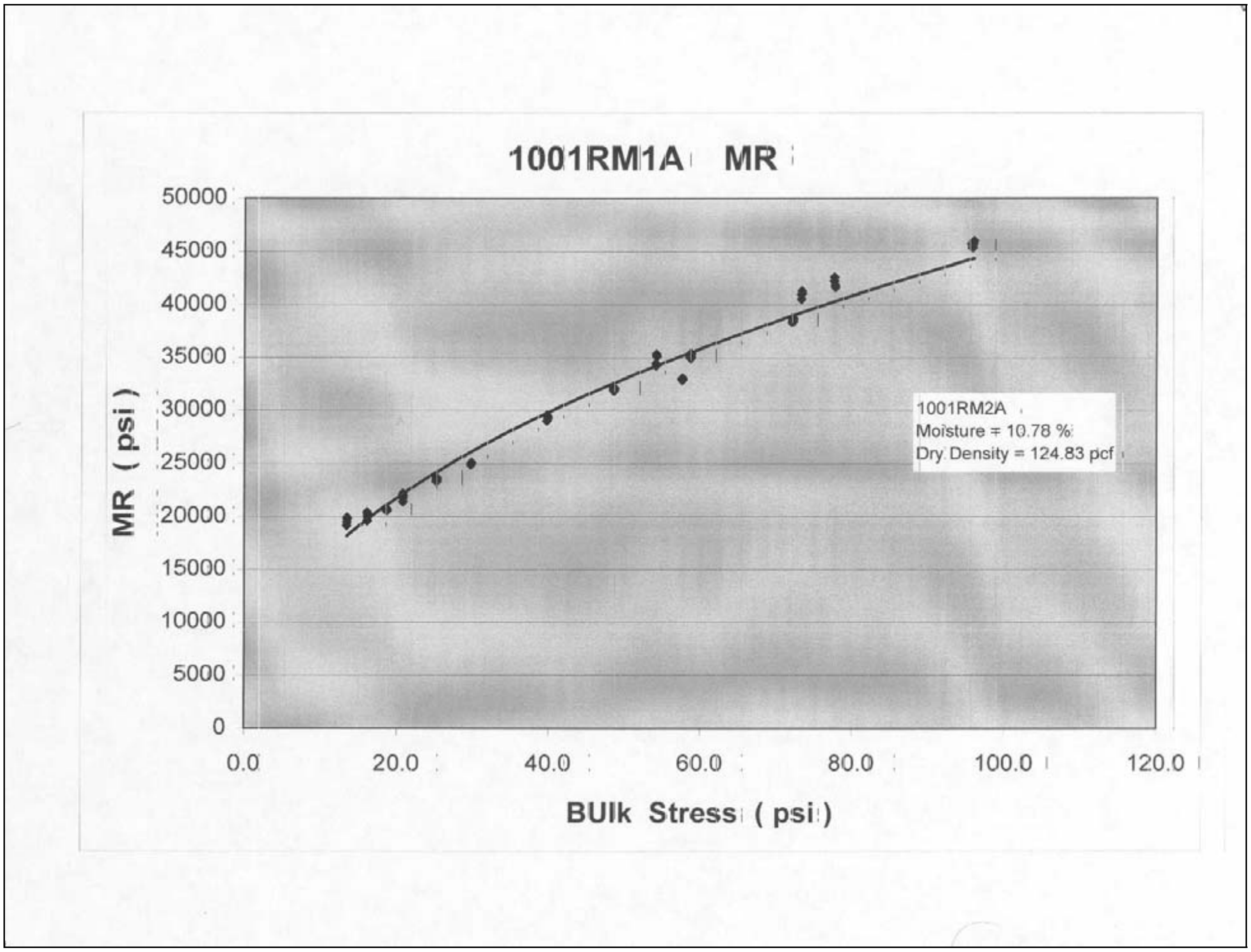


Figure 5.47 Mn/DOT MR graph: EVTAC sample NRRI 10-01 (1001RM2A).

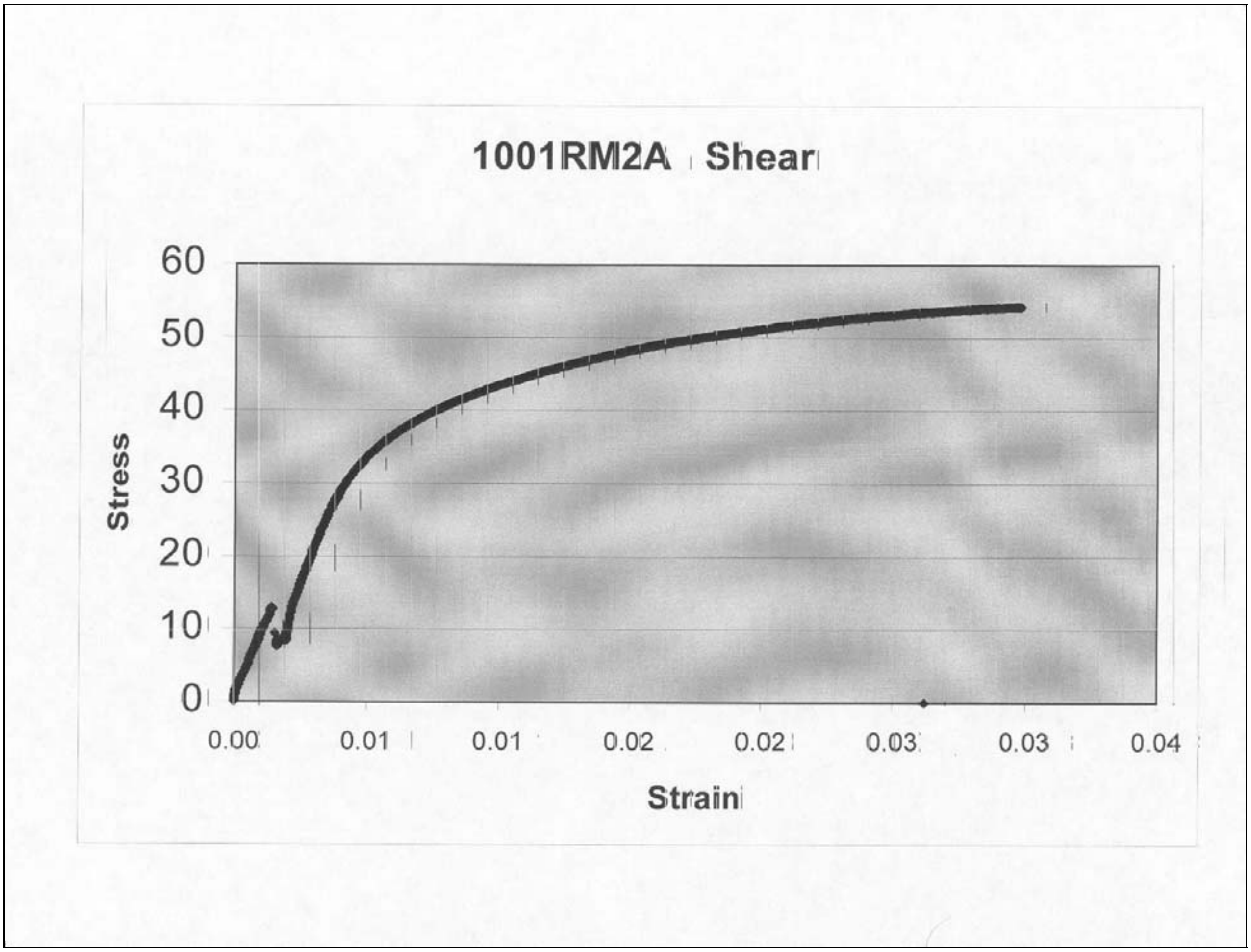


Figure 5.48 Mn/DOT stress/strain (shear) graph 1: EVTAC sample NRRI 10-01 (1001RM2A).

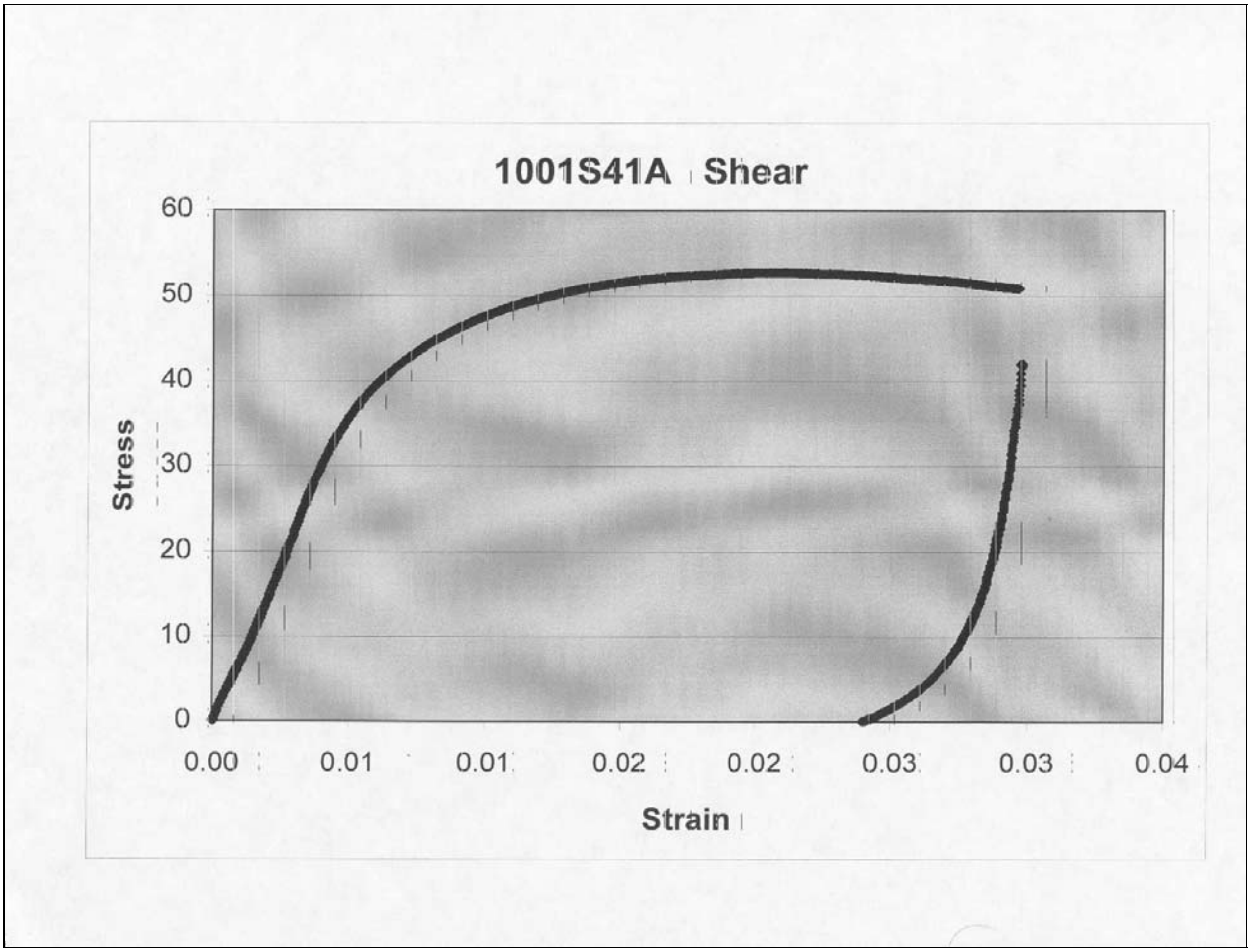


Figure 5.49 Mn/DOT stress/strain (shear) graph 2: EVTAC sample NRRI 10-01 (1001S41A).

AUG 14 2001

LAB NO SS01139

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	SP NRRI STUDY	DATE COMPLETED	8/14/2001
SOURCE	EVTAC	DATE RECEIVED	7/13/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED		FIELD ID	NRRI-31-01
SAMPLE TAKEN FROM:			

% PASSING 2"		LIQUID LIMIT	
% PASSING 1"		PLASTIC LIMIT	
% PASSING 3/4"		PLASTICITY INDEX	
% PASSING 3/8"		% SILT	
% PASSING #4		% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	9.5
		MAX# DENSITY	124.8
		R-VALUE (240 psi)	63.8
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Paterson
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.50 Mn/DOT optimum moisture, maximum density, R-value test sheet: EVTAC sample NRRI 31-01.

Mn/DOT Testing Results – Hibtac Sample

MAY 01 2001

State of Minnesota Department of Transportation
Aggregates Test Report

Sample ID CO-GS01-0018	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-36-00	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	99							
12.5mm (1/2")	99							
9.5mm (3/8")	98							
4.75mm (#4)	86							
2.36mm (#8)	75							
2.00mm (#10)	73							
1.18mm (#16)	67							
600um (#30)	59							
425um (#40)	54							
300um (#50)	47							
150um (#100)	29							
75um (#200)	12.6							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value and Resilient Modulus results will come on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

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Figure 5.51 Mn/DOT gradation test sheet: Hibtac sample NRRI 36-00.

MAY 18 2[illegible]

LAB NO SS01045

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	HIB. 1	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-36-00
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	98.1	% SILT	
% PASSING #4	86.2	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	10.3
		MAX# DENSITY	124.8
		R-VALUE (240 psi)	81.9
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Patrin
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.52 Mn/DOT optimum moisture, maximum density, R-value test sheet: Hibtac sample NRRI 36-00.

Soil and Granular Material Compaction Data sheet

Sample No: SS01 - 3600RM1A	Sample Type:	Date:	5/22/01

Desired MC (%):	10.3	**Desired dry density (lbs/ft^3):**	124.8		
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735		
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829	**or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282	**or**	0.196344
No. of lifts:	6				

Hygroscopic MC

HMC wet wt of initial soil:	358.1
HMC dry wt of initial soil:	357.2
HMC tare wt:	210.6
Hygroscopic MC:	0.6

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs): 28.58765

2) Wt of water needed based on Mold Vol [Ww] (lbs): 2.944528

3) Total wt of oven dried soil needed [Ws+Was] (lbs) 29.68765 [add Was=1.1 lbs (500g) for MC determination]

4) Wt of hygroscopic water in sample (lbs): 0.182257

8) Calc. Wet density (lbs/ft^3) 137.6544

5) Total wt of existing soil needed [Wad] (lbs) **29.86991** Lbs, **13548.7** g

9) Desired compacted soil wt (lbs): 27.02758

6) Wt of water needed to add in the existing soil [Waw] (lbs): **2.875571** Lbs., **1304.33** g

7) Wt of soil on each lift (lbs): **4.504597** Lbs, 2043.24 g

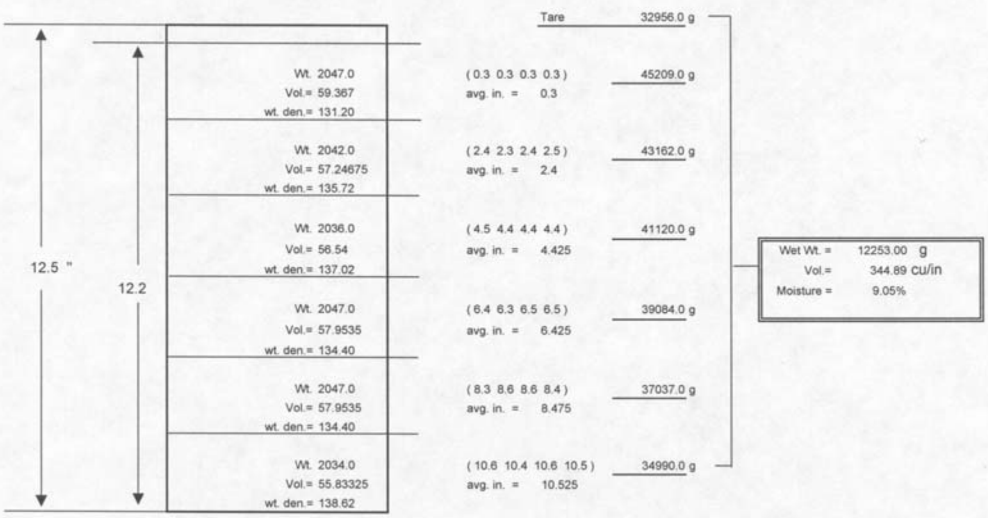
Figure 5.53 Mn/DOT compaction data test sheet 1: Hibtac sample NRRI 36-00 (3600RM1A).

Taconite Tailings

Date 5/23/01

File Name 3600RM1A
Field I.D. NRRI-36-00
Lab I.D. SS01045

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	210.6	358.1	357.2	0.9	0.6%
Moisture + 24 hrs.	210.0	417.4	398.6	18.8	10.0%
Moisture from lifts	183.4	773.0	719.5	53.5	10.0%
Moisture from leftovers	445.3	2171.5	2015.7	155.8	9.9%
Moisture from top 1/2	2691.9	8814.5	8314.5	500.0	8.9%
Moisture from bottom 1/2	2650.1	8677.7	8169.5	508.2	9.2%



Notes

Wet Density = 135.18
Dry Density = 123.96
Void Ratio = 0.3591
Degree of Saturation = 68.04%

Passing 3/4" = 100.0%
Passing 3/8" = 98.0%
Passing #4 = 86.0%
Passing # 10 = 73.0%
Passing # 30 = 59.0%
Passing # 40 = 54.0%
Passing # 50 = 47.0%
Passing # 100 = 29.0%
Passing # 200 = 12.6%

Figure 5.54 Mn/DOT compaction data test sheet 2: Hibtac sample NRRI 36-00 (3600RM1A).

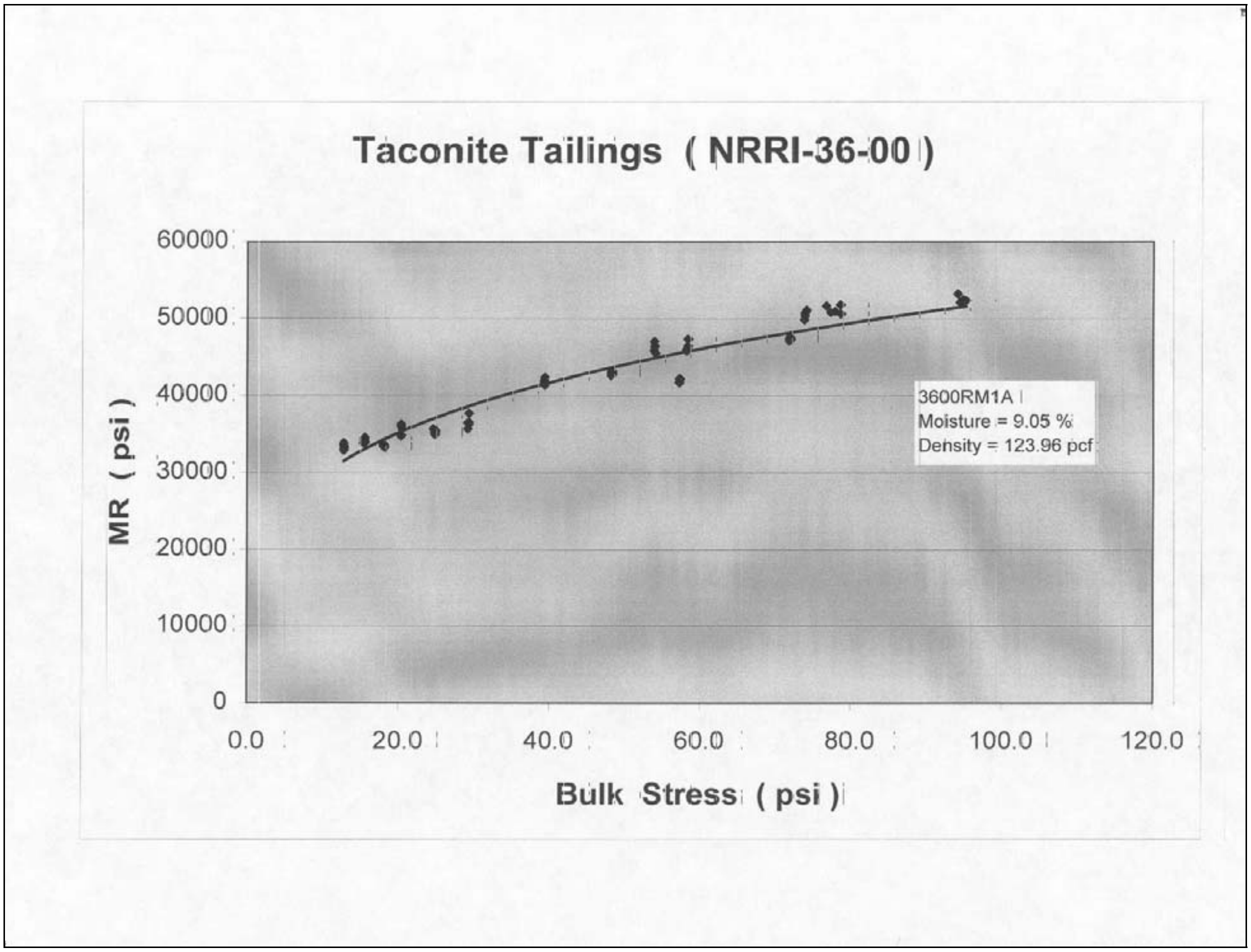


Figure 5.55 Mn/DOT MR graph: Hibtac sample NRRI 36-00 (3600RM1A).

Soil and Granular Material Compaction Data sheet

Sample No: SS01 - 3600RM2A	Sample Type:	Date:	5/30/01

Desired MC (%):	10.3	**Desired dry density (lbs/ft^3):**	124.8		
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735		
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829	**or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282	**or**	0.196344
No. of lifts:	6				

Hygroscopic MC

HMC wet wt of initial soil:	358.1
HMC dry wt of initial soil:	357.2
HMC tare wt:	210.6
Hygroscopic MC:	0.6

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs): 28.58765

2) Wt of water needed based on Mold Vol [Ww] (lbs): 2.944528

3) Total wt of oven dried soil needed [Ws+Was] (lbs) 29.68765 [add Was=1.1 lbs (500g) for MC determination]

4) Wt of hygroscopic water in sample (lbs): 0.182257 8) Calc. Wet density (lbs/ft^3) 137.6544

5) Total wt of existing soil needed [Wad] (lbs) 9) Desired compacted soil wt (lbs): 27.02758

29.86991 Lbs
13548.7 g

6) Wt of water needed to add in the existing soil [Waw] (lbs): **2.875571** Lbs.
1304.33 g

7) Wt of soil on each lift (lbs): **4.504597** Lbs
2043.24 g

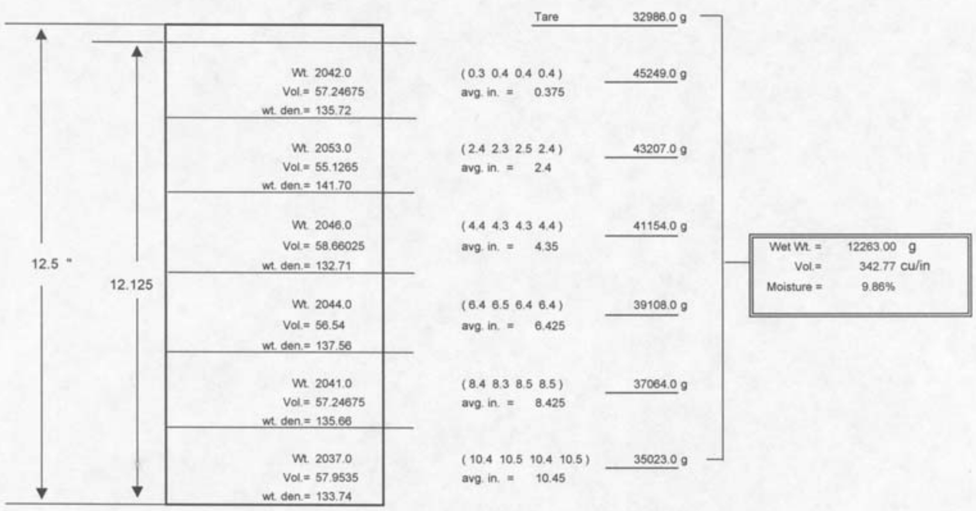
Figure 5.56 Mn/DOT compaction data test sheet 1: Hibtac sample NRRI 36-00 (3600RM2A).

Taconite Tailings

Date 5/30/01

File Name 3600RM2A
Field I.D. NRRI-36-00
Lab I.D. SS01045

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	210.6	358.1	357.2	0.9	0.6%
Moisture + 24 hrs.	187.3	423.1	405.1	18.0	8.3%
Moisture from lifts	809.4	1598.3	1526.7	71.6	10.0%
Moisture from leftovers	443.9	1970.7	1817.7	153.0	11.1%
Moisture from top 1/2	2691.3	9276.0	8712.6	563.4	9.4%
Moisture from bottom 1/2	2650.2	8277.9	7749.3	528.6	10.4%



Notes

Wet Density = 136.13
Dry Density = 123.91
Void Ratio = 0.3597
Degree of Saturation = 74.02%

Passing 3/4" =	100.0%
Passing 3/8" =	98.0%
Passing #4 =	86.0%
Passing # 10 =	73.0%
Passing # 30 =	59.0%
Passing # 40 =	54.0%
Passing # 50 =	47.0%
Passing # 100 =	29.0%
Passing # 200 =	12.6%

Percometer	Hard	Soft
Dielectric	15.2	12.5

Shear Test
Rate = 0.03 in/sec
Time = 15 sec
Start @ = -1.13602
End @ = -0.68602

Figure 5.57 Mn/DOT compaction data test sheet 2: Hibtac sample NRRI 36-00 (3600RM2A).

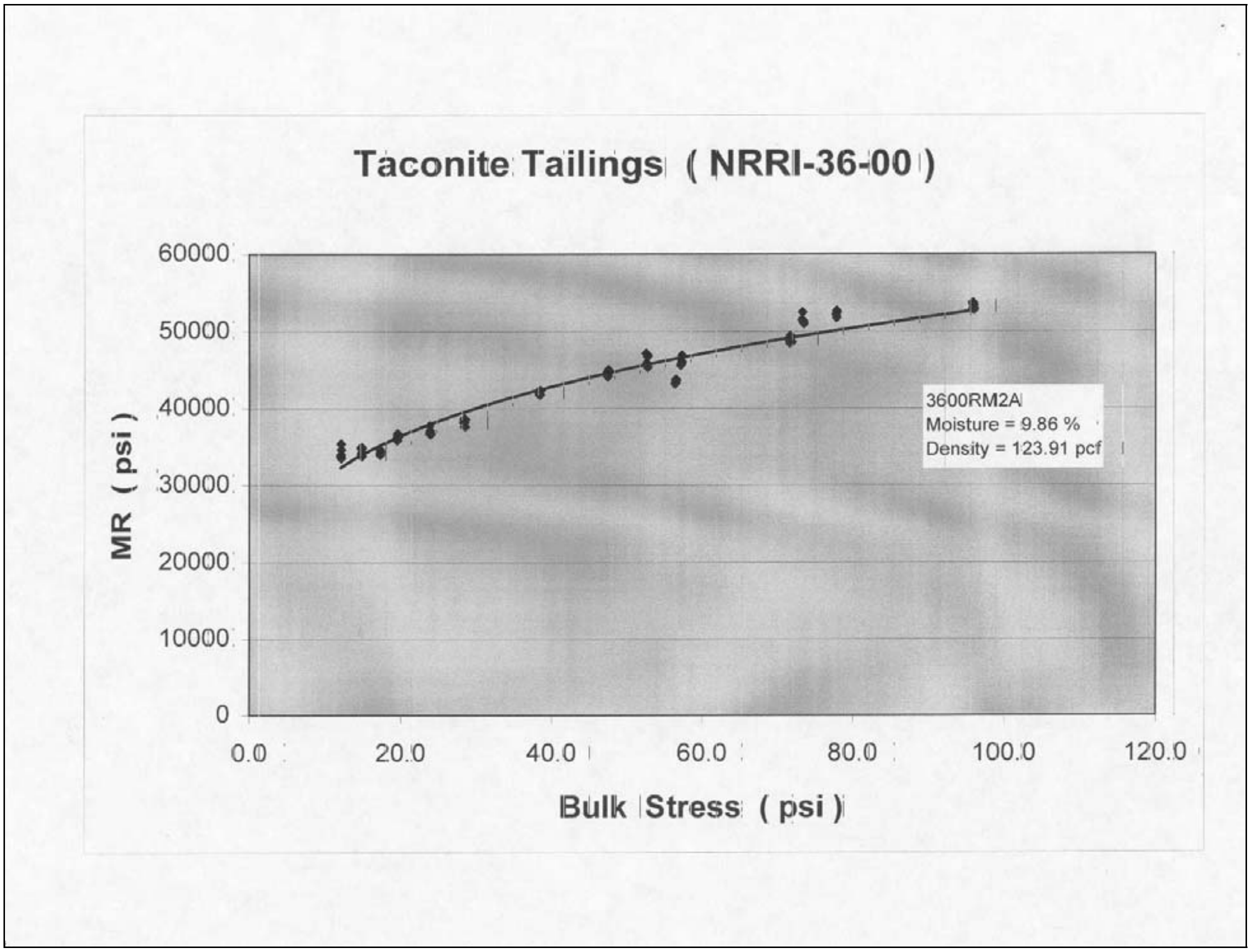


Figure 5.58 Mn/DOT MR graph: Hibtac sample NRRI 36-00 (3600RM2A).

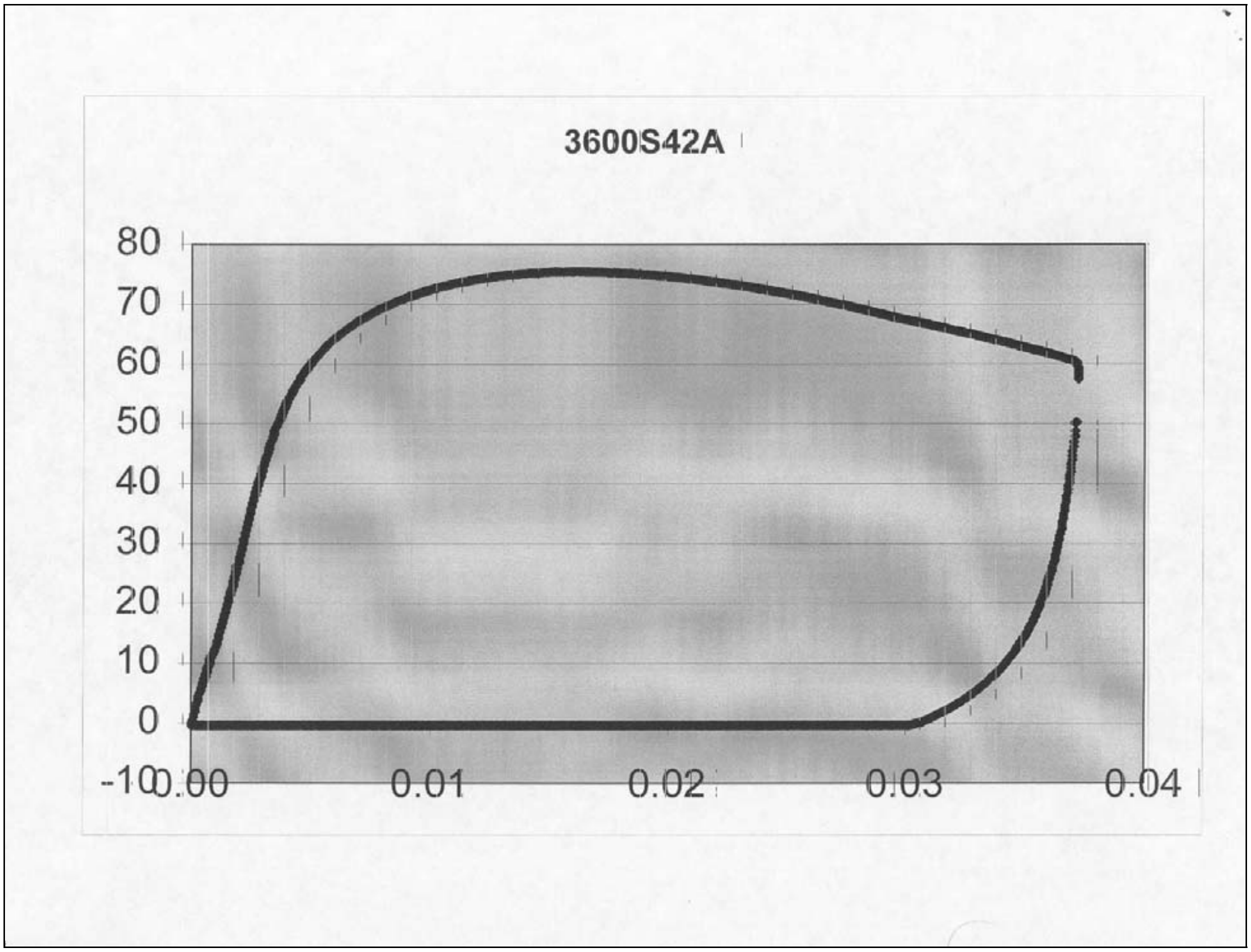


Figure 5.59 Mn/DOT stress/strain (shear) graph: Hibtac sample NRRI 36-00 (3600S42A).

State of Minnesota Department of Transportation
Aggregates Test Report

Sample ID CO-GS01-0022	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-11-01	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	94							
2.36mm (#8)	84							
2.00mm (#10)	82							
1.18mm (#16)	75							
600um (#30)	64							
425um (#40)	55							
300um (#50)	43							
150um (#100)	16							
75um (#200)	4.7							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value & Resilient Modulus results will be distributed on other reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

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Figure 5.60 Mn/DOT gradation test sheet: Hibtac sample NRRI 11-01.

MAY 18 2001

LAB NO SS01049

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINNTAC	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED 4/13/2001 FIELD ID NRRI-11-01

SAMPLE TAKEN FROM:

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	99.6	% SILT	
% PASSING #4	94.1	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	12.2
		MAX# DENSITY	118.4
		R-VALUE (240 psi)	59.7
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

REVIEWED BY

CHARGE OUT: [redacted] 1042 1056

Figure 5.61 Mn/DOT optimum moisture, maximum density, R-value test sheet: Hibtac sample NRRI 11-01.

Soil and Granular Material Compaction Data sheet

Sample No: SS01 - 1101RM1A	Sample Type:	Date:	5/29/01

Desired MC (%):	12.2	**Desired dry density (lbs/ft^3):**	118.4		
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735		
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829	**or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282	**or**	0.196344
No. of lifts:	6				

Hygroscopic MC

HMC wet wt of initial soil:	526.0
HMC dry wt of initial soil:	523.9
HMC tare wt:	189.9
Hygroscopic MC:	0.6

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs): 27.12162

2) Wt of water needed based on Mold Vol [Ww] (lbs): 3.308837

3) Total wt of oven dried soil needed [Ws+Was] (lbs) 28.22162 [add Was=1.1 lbs (500g) for MC determination]

4) Wt of hygroscopic water in sample (lbs): 0.177441

8) Calc. Wet density (lbs/ft^3) 132.8448

9) Desired compacted soil wt (lbs): 26.08325

5) Total wt of existing soil needed [Wad] (lbs) **28.39906** Lbs
12881.5 g

6) Wt of water needed to add in the existing soil [Waw] (lbs): **3.265596** Lbs.
1481.242 g

7) Wt of soil on each lift (lbs): **4.347208** Lbs
1971.85 g

Figure 5.62 Mn/DOT compaction data test sheet 1: Hibtac sample NRRI 11-01 (1101RM1A).

Taconite Tailings

Date 5/29/01

File Name 1101RM1A
Field I.D. NRRI-11-01
Lab I.D. SS01049

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	189.9	526.0	523.9	2.1	0.6%
Moisture + 24 hrs.				0	#DIV/0!
Moisture from lifts	809.3	1159.2	1121.8	37.4	12.0%
Moisture from leftovers	443.3	1785.8	1640.6	145.2	12.1%
Moisture from top 1/2	2692.1	7841.6	7465.9	375.7	7.9%
Moisture from bottom 1/2	2650.4	9053.6	8459.3	594.3	10.2%

12.5 "

12.20

Tare 32988 g

Wt. 1972.0 Vol.= 59.367 wt. den.= 126.39	(0.3 0.3 0.3 0.3) avg. in. = 0.3	44818.0 g
Wt. 1962.0 Vol.= 57.24675 wt. den.= 130.41	(2.4 2.3 2.4 2.5) avg. in. = 2.4	42846.0 g
Wt. 1983.0 Vol.= 56.54 wt. den.= 133.45	(4.5 4.4 4.4 4.4) avg. in. = 4.425	40884.0 g
Wt. 1972.0 Vol.= 57.9535 wt. den.= 129.47	(6.4 6.3 6.5 6.5) avg. in. = 6.425	38901.0 g
Wt. 1973.0 Vol.= 57.9535 wt. den.= 129.54	(8.3 8.6 8.6 8.4) avg. in. = 8.475	36929.0 g
Wt. 1968.0 Vol.= 55.83325 wt. den.= 134.12	(10.6 10.4 10.6 10.5) avg. in. = 10.525	34956.0 g

Wet Wt. = 11830.00 g
Vol.= 344.89 in.3
Moisture = 9.05%

Notes

Wet Density = 130.51
Dry Density = 119.68
Void Ratio = 0.4077
Degree of Saturation = 59.93%

Passing 3/4" = 100.0%
Passing 3/8" = 100.0%
Passing #4 = 94.0%
Passing # 10 = 82.0%
Passing # 30 = 64.0%
Passing # 40 = 55.0%
Passing # 50 = 43.0%
Passing # 100 = 16.0%
Passing # 200 = 4.7%

Percometer	Hard	Soft
Dielectric	13.1	11.0
Conductivity		

Shear Test
Rate = 0.03 in/sec
Time = 13 sec
Start @ = -0.98221
End @ = -0.59221

Figure 5.63 Mn/DOT compaction data test sheet 2: Hibtac sample NRRI 11-01 (1101RM1A).

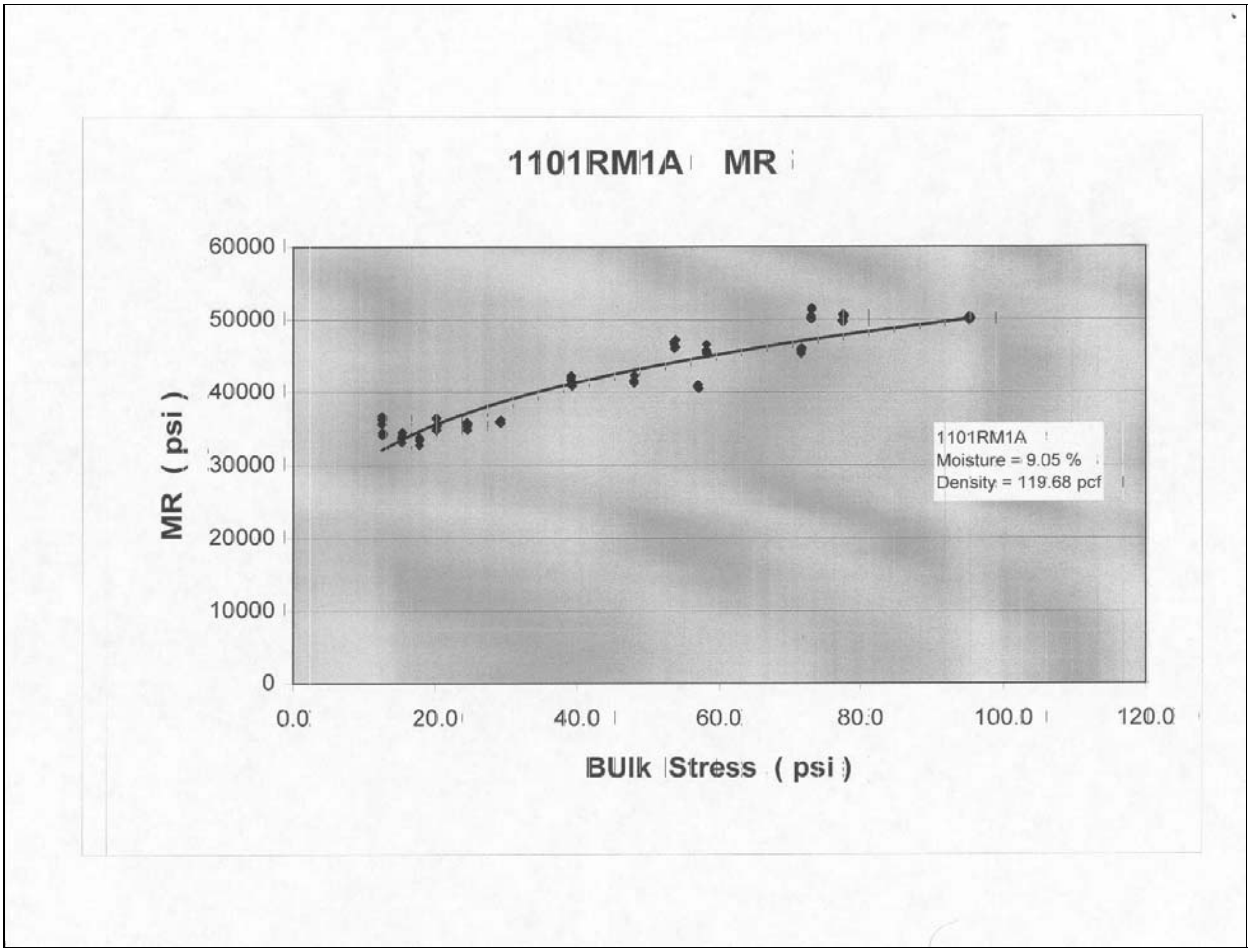


Figure 5.64 Mn/DOT MR graph: Hibtac sample NRRI 11-01 (1101RM1A).

Soil and Granular Material Compaction Data sheet

Sample No: SS01 - 1101RM2A	Sample Type:	Date:	5/30/01

Desired MC (%):	12.2	**Desired dry density (lbs/ft^3):**	118.4	
Mold dia (in):	6.0	**Sample Area (in^2):**	28.2735	
Mold ht (in):	14.0	**Mold Vol. (in^3 or ft^3):**	395.829 **or**	0.229068
Desired Sample ht (in):	12.0	**Sample Vol. (in^3 or ft^3)**	339.282 **or**	0.196344
No. of lifts:	6			

Hygroscopic MC

HMC wet wt of initial soil:	526.0
HMC dry wt of initial soil:	523.9
HMC tare wt:	189.9
Hygroscopic MC:	0.6

1) Wt of over dried soil needed base on Mold Vol [Ws] (lbs): 27.12162

2) Wt of water needed based on Mold Vol [Ww] (lbs): 3.308837

3) Total wt of oven dried soil needed [Ws+Was] (lbs): 28.22162 [add Was=1.1 lbs (500g) for MC determination]

4) Wt of hygroscopic water in sample (lbs): 0.177441

8) Calc. Wet density (lbs/ft^3): 132.8448

9) Desired compacted soil wt (lbs): 26.08325

5) Total wt of existing soil needed [Wad] (lbs): **28.39906** Lbs; **12881.5** g

6) Wt of water needed to add in the existing soil [Waw] (lbs): **3.265596** Lbs.; **1481.242** g

7) Wt of soil on each lift (lbs): **4.347208** Lbs; 1971.85 g

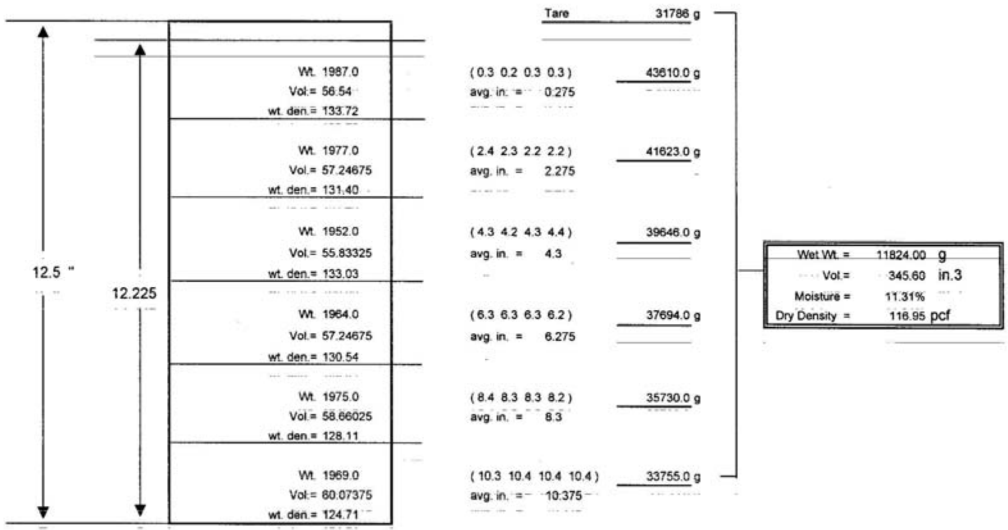
Figure 5.65 Mn/DOT compaction data test sheet 1: Hibtac sample NRRI 11-01 (1101RM2A).

Taconite Tailings

Date 5/30/01

File Name 1101RM2A
Field I.D. NRRI-11-01
Lab I.D. SS01049

Moistures	tare	wt	dry	wt - dry	%
Hygroscopic mc.	189.9	526.0	523.9	2.1	0.6%
Moisture + 24 hrs.				0	#DIV/0!
Moisture from lifts	189.8	537.9	500.7	37.2	12.0%
Moisture from leftovers	422.4	2272.3	2059.6	212.7	13.0%
Moisture from top 1/2	2503.2	8449.8	7924.1	525.7	9.7%
Moisture from bottom 1/2	2514.2	8306.8	7644	662.8	12.9%



Notes

Wet Density = 130.18 pcf
Dry Density = 116.95 pcf
Void Ratio = 0.4408
Degree of Saturation = 69.31%

Passing 3/4" = 100.0%
Passing 3/8" = 100.0%
Passing #4 = 94.0%
Passing # 10 = 82.0%
Passing # 30 = 64.0%
Passing # 40 = 55.0%
Passing # 50 = 43.0%
Passing # 100 = 16.0%
Passing # 200 = 4.7%

Percometer	Hard	Soft
Dielectric	9.5	7.6
Conductivity		

Shear Test
Rate = 0.03 in/sec
Time = 12 sec
Start @ = -1.11771
End @ = -0.75771

Figure 5.66 Mn/DOT compaction data test sheet 2: Hibtac sample NRRI 11-01 (1101RM2A).

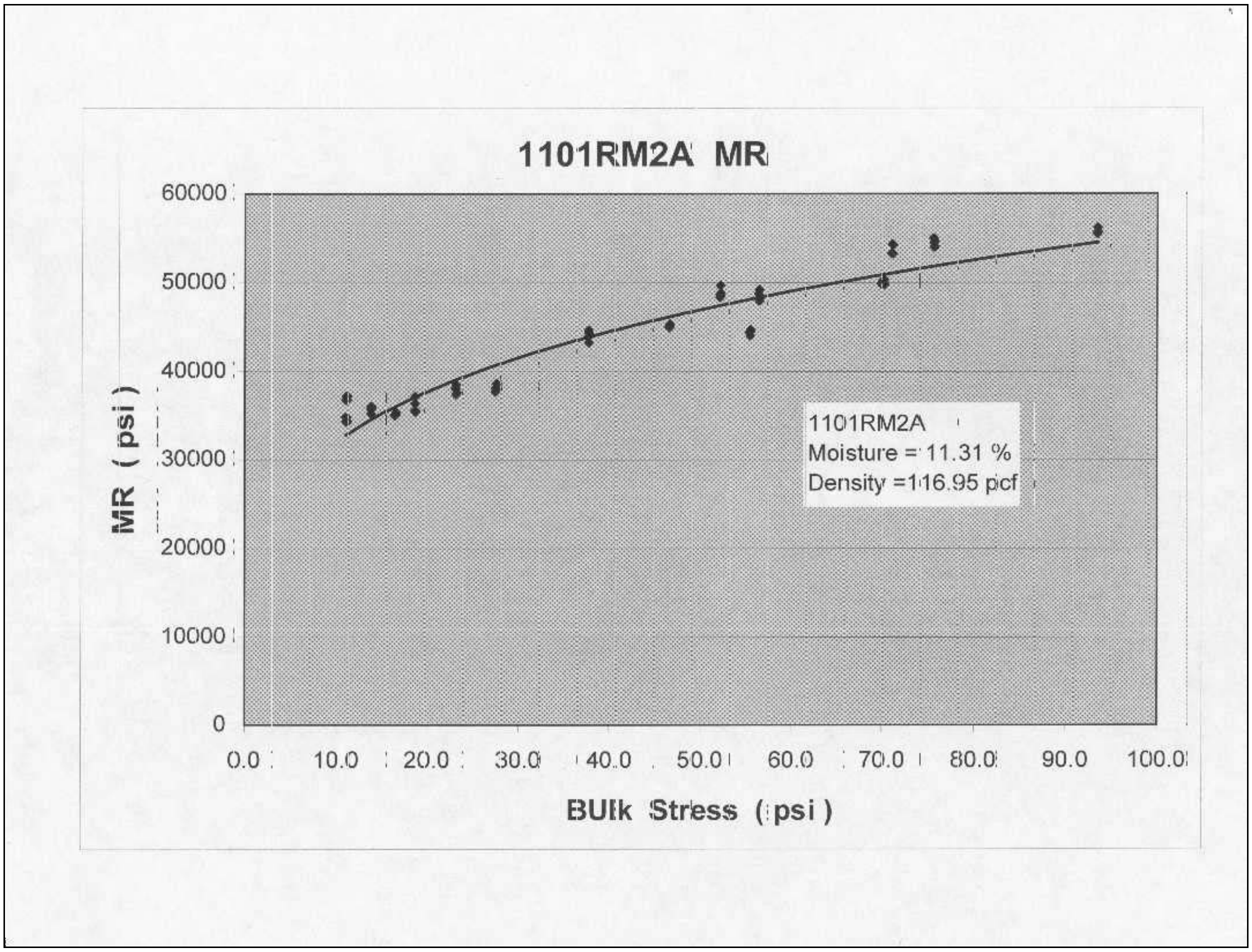


Figure 5.67 Mn/DOT MR graph: Hibtac sample NRRI 11-01 (1101RM2A).

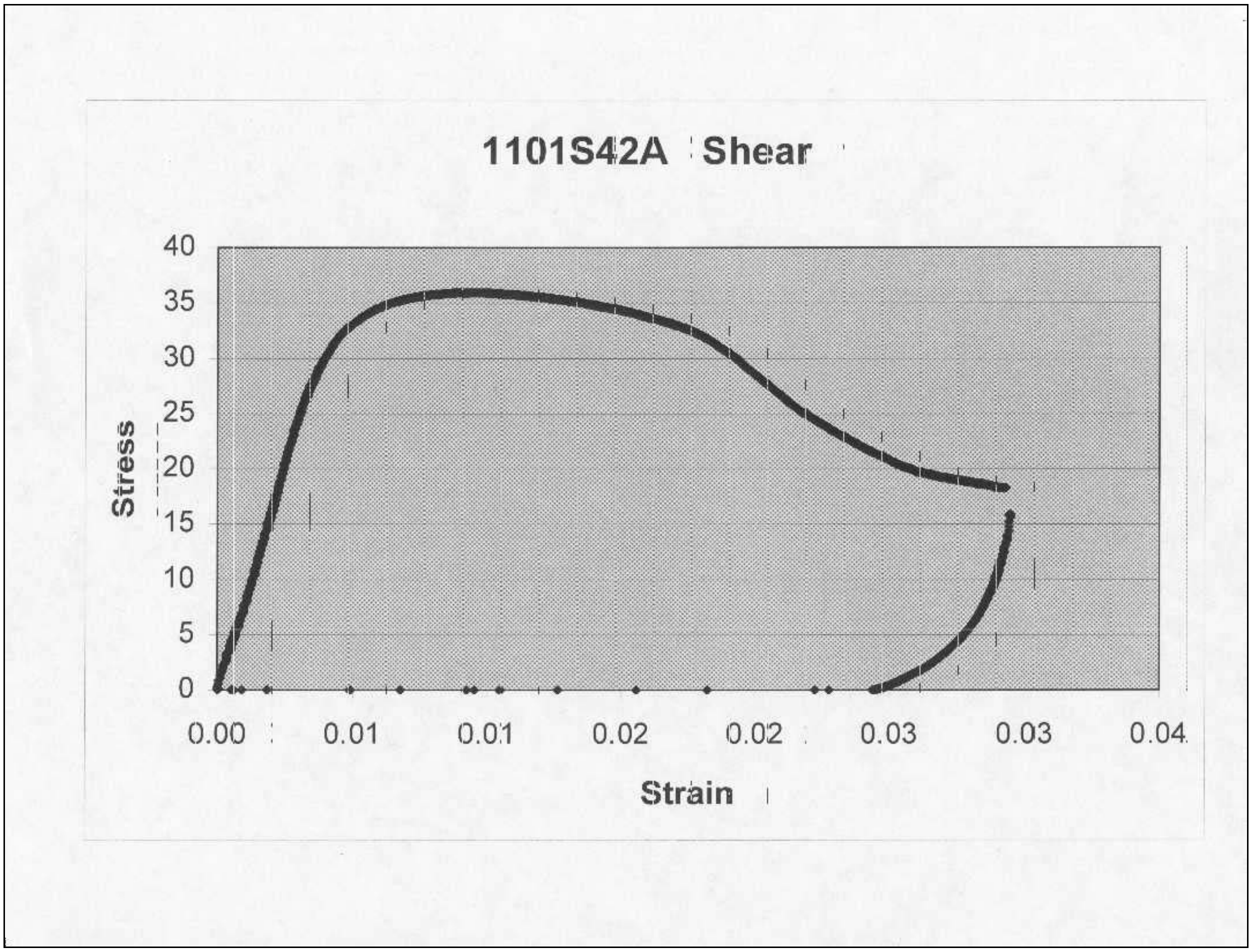


Figure 5.68 Mn/DOT stress/strain (shear) graph: Hibtac sample NRRI 11-01 (1101S42A).

Mn/DOT Testing Results – Minntac Samples

State of Minnesota Department of Transportation
Aggregates Test Report

MAY 01 2001

Sample ID CO-GS01-0021	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-37-00	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	99							
2.36mm (#8)	90							
2.00mm (#10)	85							
1.18mm (#16)	62							
600um (#30)	35							
425um (#40)	22							
300um (#50)	12							
150um (#100)	4							
75um (#200)	2.0							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value and Resilient Modulus results will come on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

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Figure 5.69 Mn/DOT gradation test sheet: Minntac sample NRRI 37-00.

MAY 18 2001

LAB NO SS01048

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

<u>TEST REPORT ON SAMPLE OF SUBSOIL</u>

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINNTAC	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-37-00
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	100.0	% SILT	
% PASSING #4	99.2	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	11.8
		MAX# DENSITY	109.1
		R-VALUE (240 psi)	53.7
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

REVIEWED BY

CHARGE OUT: [redacted] 1042 1056

Figure 5.70 Mn/DOT optimum moisture, maximum density, R-value test sheet: Minntac sample NRRI 37-00.

State of Minnesota Department of Transportation
Aggregates Test Report

Sample ID CO-GS01-0016
Field ID: NRRI-08-01
Date Sampled:
Date Received: 4/18/01
Usage: Special Study
Submitter: Nancy Whiting
Grad Spec:
Spec. Class:
Quality Spec:
T.H. Number

IAS Name:
Project No: OTH NRRI Study
Proj Eng:
County Number:
County Name:
City Number
City Name:
Bridge #:
Sampled From:
Pit #:
Pit Name:
Comment:

Sample ID
Field ID:
Date Sampled
Date Received
Usage:
Submitter:
Grad Spec:
Spec. Class:
Quality Spec:
T.H. Number

IAS Name:
Project No:
Proj Eng:
County Number:
County Name:
City Number
City Name
Bridge #:
Sampled From:
Pit #:
Pit Name:
Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
9.5mm (3/8")	100							
4.75mm (#4)	98							
2.36mm (#8)	85							
2.00mm (#10)	79							
1.18mm (#16)	55							
600um (#30)	27							
425um (#40)	16							
300um (#50)	8							
150um (#100)	3							
75um (#200)	1.5							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor & Resilient Modulus results will be on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

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Figure 5.71 Mn/DOT gradation test sheet: Minntac sample NRRI 08-01.

MAY 18 2001

LAB NO SS01043

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINNTAC	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-08-01
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	100.0	% SILT	
% PASSING #4	98.4	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	13.8
		MAX# DENSITY	111.2
		R-VALUE (240 psi)	60.3
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Patin
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.72 Mn/DOT optimum moisture, maximum density, R-value test sheet: Minntac sample NRRI 08-01.

AUG 14 2001

LAB NO SS01141

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH
TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	SP NRRI STUDY	DATE COMPLETED	8/14/2001
SOURCE	MINNTAC	DATE RECEIVED	7/13/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED		FIELD ID	NRRI-17-01
SAMPLE TAKEN FROM:			

% PASSING 2"		LIQUID LIMIT	
% PASSING 1"		PLASTIC LIMIT	
% PASSING 3/4"		PLASTICITY INDEX	
% PASSING 3/8"		% SILT	
% PASSING #4		% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	11.3
		MAX# DENSITY	114.5
		R-VALUE (240 psi)	60.0
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Paturi
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.73 Mn/DOT optimum moisture, maximum density, R-value test sheet: Minntac sample NRRI 17-01.

Mn/DOT Testing Results – Ispat Inland (Minorca) Samples

State of Minnesota Department of Transportation
Aggregates Test Report

Sample ID CO-GS01-0019	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-39-00	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	100							
2.36mm (#8)	95							
2.00mm (#10)	91							
1.18mm (#16)	72							
600um (#30)	43							
425um (#40)	29							
300um (#50)	18							
150um (#100)	6							
75um (#200)	2.8							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks: Proctor, R-Value and Resilient Modulus results will come on separate reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

☐ Meets Requirements
☐ Does Not Meet Requirement
☑ For Info Only

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Figure 5.74 Mn/DOT gradation test sheet: Ispat Inland (Minorca) sample NRRI 39-00.

MAY 18 2001

LAB NO SS01046

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINORCA	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-39-00
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	99.9	% SILT	
% PASSING #4	99.6	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	11.3
		MAX# DENSITY	113.9
		R-VALUE (240 psi)	52.8
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

REVIEWED BY

CHARGE OUT: [redacted] 1042 1056

Figure 5.75 Mn/DOT optimum moisture, maximum density, R-value test sheet: Ispat Inland (Minorca) sample NRRI 39-00.

State of Minnesota Department of Transportation
Aggregates Test Report

Sample ID CO-GS01-0017	IAS Name:	Sample ID	IAS Name:
Field ID: NRRI-09-01	Project No: OTH NRRI Study	Field ID:	Project No:
Date Sampled:	Proj Eng:	Date Sampled	Proj Eng:
Date Received: 4/18/01	County Number:	Date Received	County Number:
Usage: Special Study	County Name:	Usage:	County Name:
Submitter: Nancy Whiting	City Number	Submitter:	City Number
Grad Spec:	City Name:	Grad Spec:	City Name
Spec. Class:	Bridge #:	Spec. Class:	Bridge #:
Quality Spec:	Sampled From:	Quality Spec:	Sampled From:
T.H. Number	Pit #:	T.H. Number	Pit #:
	Pit Name:		Pit Name:
	Comment:		Comment:

% Passing Sieve:	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High	Lab Test	Field Test	Spec. Limits Low	Spec. Limits High
31.5mm (1 1/4")	100							
25.0mm (1")	100							
19.0mm (3/4")	100							
16.0mm (5/8")	100							
12.5mm (1/2")	100							
9.5mm (3/8")	100							
4.75mm (#4)	100							
2.36mm (#8)	95							
2.00mm (#10)	91							
1.18mm (#16)	73							
600um (#30)	47							
425um (#40)	34							
300um (#50)	22							
150um (#100)	6							
75um (#200)	2.6							

cc: N. Whiting
J. Zollars
R. Patrin
G. & B. Office

Approved By:

Charge: 1 - 1013

Remarks:
Proctor, R-Value & Resilient Modulus results will be distributed on other reports.

* Value does not meet Spec
** Value out of Field-Lab Tolerance
*** Trace (0.0045 - 0.044) Detected
% Shale in Sand N.C. = Trace

- [ ] Meets Requirements
- [ ] Does Not Meet Requirement
- [x] For Info Only

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Figure 5.76 Mn/DOT gradation test sheet: Ispat Inland (Minorca) sample NRRI 09-01.

MAY 18 2001

LAB NO SS01044

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH
TEST REPORT ON SAMPLE OF SUBSOIL

PROJECT NO.	TACONITE TAILINGS	DATE COMPLETED	5/18/2001
SOURCE	MINORCA(ISPAT)	DATE RECEIVED	4/27/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED	4/13/2001	FIELD ID	NRRI-09-01
SAMPLE TAKEN FROM:			

% PASSING 2"	100.0	LIQUID LIMIT	
% PASSING 1"	100.0	PLASTIC LIMIT	
% PASSING 3/4"	100.0	PLASTICITY INDEX	
% PASSING 3/8"	100.0	% SILT	
% PASSING #4	99.7	% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	12.8
		MAX# DENSITY	116
		R-VALUE (240 psi)	56.5
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Patin
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.77 Mn/DOT optimum moisture, maximum density, R-value test sheet: Ispat Inland (Minorca) sample NRRI 09-01.

AUG 14 2001

LAB NO SS01140

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING AND RESEARCH

<u>TEST REPORT ON SAMPLE OF SUBSOIL</u>

PROJECT NO.	SP NRRI STUDY	DATE COMPLETED	8/14/2001
SOURCE	MINORCA	DATE RECEIVED	7/13/2001
TESTS REQUIRED	P,R-V	SUBMITTED BY	NANCY WHITING
		PROJ. ENGINEER	

DATE SAMPLED		FIELD ID	NRRI-30-01
SAMPLE TAKEN FROM:			

% PASSING 2"		LIQUID LIMIT	
% PASSING 1"		PLASTIC LIMIT	
% PASSING 3/4"		PLASTICITY INDEX	
% PASSING 3/8"		% SILT	
% PASSING #4		% CLAY	
% PASSING #10		TEXTURAL CLASS	
% PASSING #20		AASHTO GROUP	
% PASSING #40		GROUP INDEX	
% PASSING #60		FIELD MOISTURE	
% PASSING #100		% ORGANIC	
% PASSING #200		OPT# MOISTURE	11.7
		MAX# DENSITY	113.7
		R-VALUE (240 psi)	63.3
		SPG	

TESTS METHODS: AASHTO T87 T88 T89 T90 T99 T100 T190

COMMENTS PROCTOR RESULTS ARE APPROXIMATE

COPIES TO NANCY WHITING
DAVE VAN DEUSEN

Rod Patun
REVIEWED BY

CHARGE OUT: [illegible] [illegible] [illegible] 1042 1056

Figure 5.78 Mn/DOT optimum moisture, maximum density, R-value test sheet: Ispat Inland (Minorca) sample NRRI 30-01.

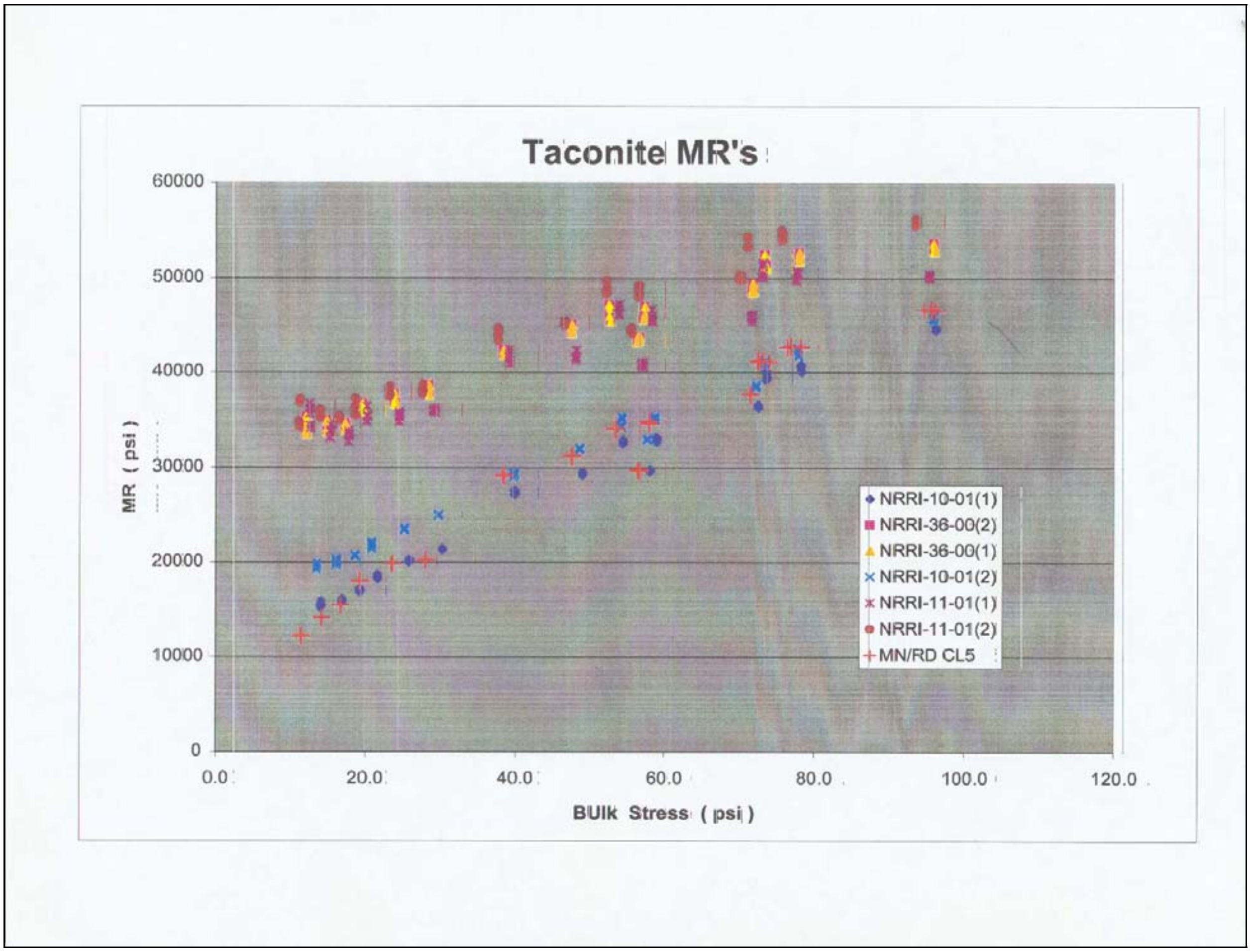

Figure 5.79 Mn/DOT taconite MR summary sheet.

AGGREGATE TESTING SUMMARY

So how do the coarse tailings stack up?

The aggregate tests show that coarse taconite tailings have several desirable characteristics that make them a viable source of fine aggregates for both bituminous, base, and fill applications.

A study conducted by Wu et al. concluded that the Micro-Deval and magnesium sulfate soundness tests provided the best correlations with field performance of asphalt concrete [13]. The study showed that losses of less than 18% for both tests appeared to separate good and fair from poor performers. All coarse taconite tailings samples tested well below the 18% mark for both tests. Individual Micro-Deval and magnesium sulfate soundness test values ranged from 8.4 to 15.8, and from 2.8 to 12.1, respectively.

Superpave also specifies uncompacted void contents (aka Fine Aggregate Angularity, or FAA) of at least 45 percent on high-volume roads (crushed manufactured fine aggregates generally have uncompacted void contents of at least 44.5 percent) [14]. As the FAA column in Table 5.2 shows, the average for each taconite company meets the 45 percent minimum. When an aggregate's FAA value exceeds 47 percent, care must be taken because it may result in a mixture with excess voids in the mineral aggregate (VMA), which can lead to a very high binder content. Based on the results, it appears that most of the coarse tailings samples have acceptable FAA values, with average values ranging from 45.28 to 47.23.

Sand equivalent, or SE, identifies the presence of clay in the fine aggregate. This is an important measurement, because the presence of undesirable quantities of adverse clay-like materials is usually detrimental to the performance of any aggregate [15]. This test is applied to the fraction of road base aggregates finer than 4.75 mm. It has been concluded that the quality of a pavement aggregate was always satisfactory if SE > 55, and almost always satisfactory if SE > 35. Given that the average SE for each sample ranges from 73.5 to 95.0, coarse taconite tailings easily satisfy the SE requirement.

Lightweight particles, i.e., particles having a low mass density like coal, in aggregate can be deleterious. However, the test results show that ***no*** lightweight particles were detected in any of the coarse tailings samples. This is not a surprising result, given the geologically uniform nature of the source material (hard rock taconite), and the closed nature of the taconite process.

Lastly, the hydraulic conductivity and R-value tests show that the tailings behave like free-draining sand, but may require some confinement for optimizing their use. Therefore, additional shear tests should be conducted on coarse tailings to determine their stability in saturated and unsaturated conditions. Because stability is largely dependent on gradation, and the gradation can vary in some tailing products (especially products obtained from tailings basins where a well controlled coarse/fine segregation has not been made), if it can be more precisely defined under what conditions certain materials fail, some coarse tailings products may be used as backslope fill or in other unconfined situations. Nonetheless, their free-draining properties and adequate R-values appear to make coarse tailings a good choice as a granular fill/base material that would minimize freezing effects. Volumetrically, granular fill applications would use the greatest amount of coarse tailings in road construction relative to other applications.

CHAPTER 6: CHEMICAL ANALYSES (WHOLE ROCK AND TRACE ELEMENT)

Chemical analyses were performed on the coarse tailings samples to assess their composition and to aid in quantifying their mineralogical makeup (Chapter 7). Analyses were done by CMRL and by ACME Analytical Laboratories, Inc., of Vancouver, British Columbia.

CMRL ANALYSES

The CMRL assayed head samples for total iron, ferrous iron (Fe^{2+}), magnetic iron by Satmagan magnetic balance, SiO_2, Al_2O_3, CaO, MgO, MnO, Na_2O, K_2O, CO_2, combined H_2O, P, S, and TiO_2.

- Total and ferrous iron are determined by dissolution and titration.

- SiO_2, Al_2O_3, CaO, MgO, MnO, Na_2O, K_2O, P, S, and TiO_2 are determined by dissolution and ICP analysis.

- CO_2 is determined by acid dissolution and measurement of evolved gas.

- Combined H_2O is determined by decomposition of hydrated oxides at 1100°C and weighing the evolved H_2O.

Table 6.1 summarizes CMRL's major oxide analyses. Total oxides have been normalized to 100%. SiO_2 is, by far, the dominant major oxide. Satmagan Mag Fe shows that only a small amount of magnetite remains in the coarse tailings samples. This is as expected, given that the mines are trying to recover magnetite from the taconite ore.

Table 6.1 CMRL major oxide chemical analyses.

Material	Sample Rec'd. No.	Property	Total Fe %	Satmagan MagFe %	Fe++ %	SiO_2 %	Al_2O_3 %	CaO %	MgO %	MnO %	CO_2 %	Na_2O %	K_2O %	Comb. H_2O %	S %	TiO_2 %	P %	Total Oxides %	Total Oxides (norm.) %
Coarse Tails	NRRI-40-00	EVTAC	18.4	2.92	7.46	63.07	0.250	1.25	2.63	0.517	5.22	0.017	0.072	1.65	0.041	0.020	0.019	100.9712	100
Coarse Tails	NRRI-10-01	EVTAC	19.4	5.23	5.15	63.68	0.340	1.06	2.69	0.455	3.19	0.017	0.063	1.42	0.036	0.026	0.018	102.6206	100
Coarse Tails	NRRI-31-01	EVTAC	19.7	1.92	11.86	58.27	0.496	0.97	3.28	0.797	7.70	0.059	0.125	1.70	0.064	0.039	0.026	103.3910	100
Coarse Tails	NRRI-49-01	EVTAC	15.3	1.86	7.27	64.95	0.330	1.66	3.44	0.553	6.42	0.080	0.114	1.55	0.038	0.011	0.015	97.9004	100
Coarse Tails	NRRI-36-00	Hibbtac	16.5	1.79	8.41	63.53	0.370	1.55	3.22	0.637	6.57	0.018	0.082	1.57	0.033	0.011	0.019	100.7224	100
Coarse Tails	NRRI-11-01	Hibbtac	17.5	1.54	8.28	61.79	0.360	1.60	2.78	0.710	7.10	0.011	0.073	1.68	0.025	0.009	0.019	102.5180	100
Coarse Tails	NRRI-42-01	Hibbtac	14.6	1.29	8.59	65.70	0.300	1.63	3.31	0.596	6.96	0.053	0.093	1.65	0.029	0.010	0.017	99.0176	100
Coarse Tails	NRRI-50-01	Hibbtac	17.3	2.84	7.49	63.82	0.220	1.65	2.63	0.634	5.60	0.052	0.044	1.60	0.048	0.019	0.013	101.0979	100
Coarse Tails	NRRI-37-00	Minntac	16.4	2.63	7.52	66.15	0.450	1.12	2.68	0.533	4.37	0.025	0.103	1.89	0.253	0.033	0.018	102.5916	100
Coarse Tails	NRRI-08-01	Minntac	15.8	2.72	8.67	65.46	0.900	1.45	2.77	0.689	5.24	0.031	0.126	1.69	0.194	0.070	0.026	101.4102	100
Coarse Tails	NRRI-17-01	Minntac	18.2	2.52	5.73	65.20	0.330	0.87	2.26	0.617	3.83	0.013	0.069	1.42	0.152	0.020	0.016	100.4236	100
Coarse Tails	NRRI-46-01	Minntac	20.3	2.94	4.77	61.62	0.390	1.61	1.96	0.773	3.54	0.019	0.110	1.42	0.170	0.025	0.020	103.4339	100
Coarse Tails	NRRI-39-00	Minorca	16.7	2.55	4.40	67.28	0.290	1.62	2.04	0.662	3.45	0.041	0.078	1.23	0.021	0.022	0.016	101.8418	100
Coarse Tails	NRRI-09-01	Minorca	13.3	1.80	4.95	70.72	0.270	1.11	3.27	0.646	4.04	0.022	0.081	1.48	0.022	0.013	0.013	102.9282	100
Coarse Tails	NRRI-30-01	Minorca	13.5	3.02	7.94	71.95	0.121	0.97	1.67	0.787	4.52	0.052	0.042	1.67	0.026	0.007	0.011	102.3856	100
Coarse Tails	NRRI-52-01	Minorca	17.0	2.35	8.89	65.53	0.200	1.33	2.57	0.733	4.77	0.043	0.036	1.68	0.042	0.016	0.014	103.8027	100
Coarse Tails	NRRI-37-01	NSPC	19.4	3.10	5.90	61.71	0.300	1.29	3.08	0.656	4.51	0.012	0.081	1.40	0.030	0.016	0.014	102.3873	100
Coarse Tails	NRRI-62-01	NSPC	20.6	2.57	5.36	59.11	0.320	1.59	3.31	0.660	4.49	0.014	0.074	1.67	0.041	0.015	0.014	100.2195	100

SUPPLEMENTAL WHOLE ROCK AND TRACE ELEMENT GEOCHEMISTRY

Additional geochemical analyses were performed to establish a more complete project database for potential end-users of the coarse tailings. However, not all samples were analyzed, as insufficient amounts of pulverized sample splits remained after the initial CMRL whole rock chemical analyses, X-ray diffraction work (Chapter 7), and specialized microscopic work (Chapter 8). Even so, at least two samples per mine were available. This analytical work was subcontracted to ACME Analytical Laboratories in Vancouver, BC. The whole rock analytical results are summarized Table 6.2, and the trace element results are summarized in Tables 6.3 and 6.4. Rare earth element (REE) analyses are presented in Table 6.3; heavy metals like Cu, Pb, Zn, and Cd are presented in Table 6.4. Trace element concentrations are generally given in parts-per-million (ppm), except for gold and mercury, which are reported in parts-per-billion (ppb).

None of the analyses reveal unusual levels of heavy metals or other elements in the coarse tailings samples; the concentrations appear to be comparable to other forms of aggregate.

Table 6.2 Supplemental whole rock chemical analyses: ACME Analytical Labs.

		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	Ba	Ni	Sc	LOI	TOT/C	TOT/S	S-/S	SO_4	SUM
SAMPLE	MINE SOURCE	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	%	%	%	%	%	%
NRRI-10-01	EVTAC	65.47	0.34	26.80	2.59	1.09	0.02	0.06	0.03	0.07	0.43	0.018	15	< 20	< 1	3.5	0.92	0.02	< .03	0.06	100.42
NRRI-31-01	EVTAC	59.69	0.53	27.21	3.25	1.05	0.03	0.12	0.04	0.09	0.76	0.012	16	< 20	1	7.7	2.23	0.05	< .03	0.17	100.49
NRRI-49-01	EVTAC	65.97	0.26	23.08	2.64	1.79	0.02	0.06	0.02	0.06	0.64	0.017	10	< 20	< 1	5.8	1.61	0.01	< .03	0.12	100.36
NRRI-49-01 (DUP)	EVTAC	66.06	0.25	22.95	2.62	1.76	0.01	0.05	0.02	0.05	0.63	0.014	12	< 20	< 1	5.9	1.61	< .01	< .03	0.15	100.32
NRRI-11-01	HIBTAC	62.70	0.36	24.56	2.72	1.50	0.02	0.08	0.01	0.07	0.73	0.011	19	< 20	< 1	7.7	2.06	0.02	< .03	0.09	100.46
NRRI-42-01	HIBTAC	67.06	0.35	19.67	3.27	1.67	0.02	0.09	0.01	0.05	0.56	0.014	18	< 20	< 1	7.7	2.04	0.01	< .03	0.09	100.46
NRRI-50-01	HIBTAC	66.41	0.44	20.31	3.55	1.79	0.02	0.12	0.01	0.06	0.53	0.014	17	< 20	< 1	7.3	1.99	< .01	< .03	0.09	100.56
NRRI-17-01	MINNTAC	66.57	0.34	25.02	2.24	1.02	0.01	0.08	0.02	0.04	0.58	0.015	43	< 20	< 1	4.5	1.15	0.15	< .03	0.44	100.44
NRRI-8-01	MINNTAC	66.80	0.91	21.28	2.72	1.51	0.02	0.13	0.08	0.09	0.66	0.016	65	< 20	2	6.3	1.67	0.21	0.03	0.52	100.52
NRRI-8-01 (DUP)	MINNTAC	66.69	0.92	21.27	2.70	1.52	0.04	0.12	0.08	0.06	0.66	0.018	67	< 20	2	6.4	1.67	0.19	0.03	0.49	100.48
NRRI-30-01	ISPAT/MINORCA	73.71	0.13	18.43	1.65	0.97	0.01	0.03	0.01	0.04	0.70	0.020	9	< 20	< 1	4.5	1.32	0.02	< .03	0.12	100.20
NRRI-9-01	ISPAT/MINORCA	72.87	0.26	17.41	3.18	1.18	0.02	0.08	0.01	0.05	0.61	0.014	15	< 20	< 1	4.7	1.25	< .01	< .03	< .03	100.39
NRRI-37-01	NSPC	63.61	0.33	26.12	2.92	1.20	< .01	0.07	0.01	0.04	0.60	0.011	20	< 20	< 1	5.5	1.36	0.01	< .03	0.03	100.41
NRRI-62-01	NSPC	61.56	0.32	27.56	3.09	1.49	0.02	0.09	0.02	0.05	0.63	0.008	24	< 20	< 1	5.6	1.41	< .01	< .03	0.03	100.44
14 NRRI-STD (BRICK CLAY)	STANDARD	50.73	21.41	12.52	1.28	0.23	0.17	2.71	0.96	0.15	0.21	0.017	446	44	23	9.5	0.11	0.01	< .03	0.03	99.95
STANDARD SO-17/CSB	STANDARD	61.32	14.44	5.96	2.35	4.70	4.06	1.41	0.61	0.97	0.54	0.421	404	28	23	3.4	2.40	5.31	0.16	15.45	100.23

Table 6.3 Supplemental trace element geochemistry - Part 1 (rare earth elements, etc.)

			Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
SAMPLE	DATE	MINE	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
NRRI-10-01	03-06-01	EVTAC	8.2	1.2	1.0	< .5	1.3	2.4	1.0	17.8	< .1	0.2	0.2	15	1	4.9	3.5	2.1	3.8	0.45	1.8	0.5	0.12	0.49	0.07	0.39	0.08	0.27	< .05	0.26	0.04
NRRI-31-01	06-13-01	EVTAC	10.8	1.7	1.9	< .5	1.5	4.3	< 1	26.2	< .1	0.4	0.1	20	< 1	6.8	5.1	3.7	6.4	0.78	3.2	0.5	0.21	0.77	0.12	0.60	0.13	0.37	0.07	0.37	0.05
NRRI-49-01	09-11-01	EVTAC	6.3	1.0	1.4	< .5	0.8	2.2	2.0	19.0	< .1	0.2	< .1	11	< 1	3.7	3.8	2.0	3.2	0.44	1.9	0.5	0.14	0.49	0.08	0.43	0.09	0.30	< .05	0.27	0.03
NRRI-49-01(Dup)	09-11-01	EVTAC	5.9	0.9	1.5	< .5	0.6	1.8	1.0	17.0	< .1	0.1	0.1	11	< 1	3.7	3.7	2.4	4.6	0.44	2.2	0.4	0.14	0.58	0.07	0.42	0.08	0.30	< .05	0.27	0.03
	EVTAC Average		8.4	1.3	1.5	< .5	1.2	2.9	na	20.7	< .1	0.3	0.1	15.3	na	5.1	4.1	2.7	4.7	0.56	2.4	0.5	0.16	0.60	0.09	0.47	0.10	0.31	na	0.30	0.04
NRRI-11-01	03-09-01	Hibtac	6.4	0.9	1.6	< .5	< .5	2.6	2.0	25.3	< .1	0.1	< .1	9	< 1	2.3	4.6	2.3	3.9	0.46	2.0	0.3	0.13	0.58	0.06	0.39	0.09	0.33	0.05	0.30	0.05
NRRI-42-01	07-24-01	Hibtac	5.1	1.0	1.7	< .5	< .5	2.7	2.0	31.1	< .1	0.3	0.1	7	< 1	2.4	3.5	2.9	4.2	0.36	1.7	0.3	0.12	0.41	0.05	0.29	0.07	0.26	< .05	0.24	0.03
NRRI-50-01	09-12-01	Hibtac	4.9	1.4	1.6	< .5	< .5	3.9	2.0	35.4	< .1	0.1	< .1	7	< 1	2.4	3.2	2.5	3.6	0.41	1.9	0.3	0.10	0.35	0.06	0.32	0.08	0.23	< .05	0.21	0.04
	Hibtac Average		5.5	1.1	1.6	< .5	< .5	3.1	2.0	30.6	< .1	0.2	0.1	7.7	< 1	2.4	3.8	2.6	3.9	0.41	1.9	0.3	0.12	0.45	0.06	0.33	0.08	0.27	na	0.25	0.04
NRRI-08-01	02-15-01	Minntac	15.4	1.8	2.8	< .5	2.6	4.3	< 1	29.7	0.2	0.6	0.2	22	1	11.3	5.1	5.0	10.0	1.11	4.3	0.8	0.25	0.81	0.12	0.67	0.14	0.42	0.06	0.38	0.07
NRRI-08-01(Dup)	02-15-01	Minntac	14.9	2.0	2.6	< .5	2.6	3.7	5.0	29.6	0.1	0.6	0.3	23	1	11.3	5.0	5.4	10.4	1.08	4.3	0.6	0.29	0.73	0.13	0.70	0.15	0.43	0.06	0.36	0.05
NRRI-17-01	05-07-01	Minntac	10.8	1.2	1.5	< .5	0.9	2.4	2.0	21.2	< .1	0.1	0.1	12	2	4.1	4.2	2.9	4.5	0.53	2.3	0.5	0.14	0.59	0.07	0.47	0.10	0.35	< .05	0.31	0.05
	Minntac Average		13.0	1.6	2.1	< .5	1.8	3.2	3.5	25.4	na	0.4	0.2	17.3	1.5	7.7	4.6	4.1	7.4	0.81	3.3	0.6	0.21	0.68	0.10	0.58	0.12	0.39	na	0.34	0.06
NRRI-09-01	03-01-01	Minorca	7.0	1.4	1.1	< .5	0.5	1.8	8.0	17.8	< .1	< .1	< .1	9	1	2.4	3.1	2.0	2.5	0.33	1.4	0.3	0.10	0.36	0.05	0.34	0.07	0.22	< .05	0.23	0.03
NRRI-30-01	06-11-01	Minorca	7.4	0.6	1.0	< .5	0.6	0.6	11.0	10.5	< .1	< .1	< .1	8	4	2.6	3.8	2.2	3.6	0.42	1.7	0.3	0.14	0.34	0.07	0.40	0.08	0.30	< .05	0.25	0.03
	Minorca Average		7.2	1.0	1.1	< .5	0.6	1.2	9.5	14.2	< .1	< .1	< .1	8.5	2.5	2.5	3.5	2.1	3.1	0.38	1.6	0.3	0.12	0.35	0.06	0.37	0.08	0.26	< .05	0.24	0.03
NRRI-37-01	07-09-01	NSPC	4.4	0.8	1.3	< .5	< .5	1.6	< 1	19.9	< .1	< .1	< .1	7	1	2.0	3.3	1.9	3.1	0.37	1.7	0.4	0.11	0.35	0.05	0.33	0.08	0.25	< .05	0.23	0.03
NRRI-62-01	10-01-01	NSPC	4.5	1.1	1.2	< .5	< .5	2.1	< 1	23.9	< .1	0.1	< .1	7	1	2.0	3.7	2.1	3.4	0.43	1.8	0.3	0.12	0.27	0.06	0.36	0.09	0.25	< .05	0.26	0.03
	NSPC Average		4.5	1.0	1.3	< .5	< .5	1.9	< 1	21.9	< .1	0.1	< .1	7.0	1.0	2.0	3.5	2.0	3.3	0.40	1.8	0.4	0.12	0.31	0.06	0.35	0.09	0.25	< .05	0.25	0.03
NRRI-STD (BRICK CLAY)			26.9	10.4	31.5	4.5	18.0	194.8	2.0	78.8	1.4	14.9	2.9	164	2	146.6	43.1	53.6	106.2	12.83	48.0	9.3	1.81	8.11	1.32	6.83	1.33	4.21	0.64	4.08	0.65
STANDARD SO-17			18.5	3.7	19.4	12.2	24.6	22.4	9.0	312.7	4.5	13.0	11.4	128	11	355.8	27.6	11.0	24.1	3.14	13.9	3.0	1.07	4.01	0.69	4.28	0.90	2.83	0.45	2.94	0.44

Table 6.4 Supplemental trace element geochemistry - Part 2 (heavy metals, etc.).

			Mo	Cu	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Hg	FeO	H_2O-	H_2O+
SAMPLE	DATE	MINE	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppb	%	%	%
NRRI-10-01	03-06-01	EVTAC	2.0	9.6	1.5	5	4.4	15.8	< .1	0.1	< .1	< .1	0.7	0.02	< .1	22.1	6.9	0.5	0.3
NRRI-31-01	06-13-01	EVTAC	2.1	11.8	1.6	14	3.5	23.5	< .1	0.1	< .1	< .1	< .5	0.03	< .1	39.7	15.4	0.4	0.6
NRRI-49-01	09-11-01	EVTAC	2.1	26.9	3.1	6	3.0	13.0	< .1	0.1	< .1	< .1	< .5	0.03	< .1	30.1	12.7	0.6	0.6
NRRI-49-01(Dup)	09-11-01	EVTAC	2.2	26.8	2.1	7	3.0	14.2	< .1	0.1	< .1	< .1	0.6	0.03	< .1	31.6	11.9	0.7	0.6
	EVTAC Average		2.1	16.1	1.9	8.5	3.6	17.6	< .1	0.1	< .1	< .1	0.6	0.03	< .1	30.9	11.5	0.5	0.5
NRRI-11-01	03-09-01	Hibtac	1.3	5.4	2.3	4	2.5	12.6	< .1	0.2	< .1	< .1	< .5	0.02	< .1	22.7	11.3	0.5	1.2
NRRI-42-01	07-24-01	Hibtac	1.3	4.2	4.6	3	2.3	9.9	< .1	0.3	< .1	< .1	1.6	0.01	< .1	19.8	11.7	0.2	1.4
NRRI-50-01	09-12-01	Hibtac	1.3	4.3	1.2	5	2.6	8.8	< .1	0.1	< .1	< .1	< .5	< .01	< .1	14.7	10.9	0.5	1.5
	Hibtac Average		1.3	4.6	2.7	4.0	2.5	10.4	< .1	0.2	< .1	< .1	1.6	0.02	< .1	19.1	11.3	0.4	1.4
NRRI-08-01	02-15-01	Minntac	2.0	15.8	4.7	15	7.3	37.6	< .1	0.3	< .1	< .1	< .5	0.06	0.1	67.9	10.5	0.3	1.6
NRRI-08-01(Dup)	02-15-01	Minntac	1.6	17.1	4.8	15	7.3	39.4	< .1	0.3	< .1	< .1	0.7	0.07	0.1	74.5	10.9	0.4	1.5
NRRI-17-01	05-07-01	Minntac	1.9	7.2	8.7	10	3.8	29.5	< .1	0.8	< .1	< .1	0.5	0.03	0.1	46.5	7.6	0.1	1.6
	Minntac Average		1.9	11.8	6.7	12.5	5.6	34.0	< .1	0.6	< .1	< .1	0.6	0.05	0.1	58.9	9.2	0.2	1.6
NRRI-09-01	03-01-01	Minorca	2.5	7.6	0.7	4	3.3	16.0	< .1	0.1	< .1	< .1	< .5	0.01	< .1	19.1	7.0	0.5	0.8
NRRI-30-01	06-11-01	Minorca	1.9	8.0	0.7	6	3.1	22.3	< .1	0.1	< .1	< .1	< .5	0.02	< .1	26.0	10.1	0.4	1.0
	Minorca Average		2.2	7.8	0.7	5.0	3.2	19.2	< .1	0.1	< .1	< .1	< .5	0.02	< .1	22.6	8.6	0.5	0.9
NRRI-37-01	07-09-01	NSPC	1.2	6.9	1.3	4	1.9	10.7	< .1	0.1	< .1	< .1	0.7	0.02	< .1	21.7	7.9	0.3	1.4
NRRI-62-01	10-01-01	NSPC	1.3	6.4	1.8	11	2.4	9.6	< .1	0.1	< .1	< .1	0.8	0.01	< .1	15.1	8.1	0.4	1.2
	NSPC Average		1.3	6.7	1.6	7.5	2.2	10.2	< .1	0.1	< .1	< .1	0.8	0.02	< .1	18.4	8.0	0.4	1.3
NRRI-STD (BRICK CLAY)			0.7	25.6	18.7	88	44.7	5.6	< .1	0.3	0.3	< .1	1.4	0.01	0.2	12.9	< .1	1.5	1.0
STANDARD SO-17			8.8	120.2	32.1	147	35.4	29.3	5.0	4.7	5.3	0.3	21.8	0.20	1.1	202.0	0.0	0.0	0.0

CHAPTER 7: QUANTITATIVE MINERALOGY

X-ray diffraction (XRD) is an analytical method used for identifying specific minerals in a rock or soil sample. Minerals will refract X-rays in diagnostic ways, depending on their crystal/molecular structure. By itself, the technique is qualitative, not quantitative, but it does a good job of identifying the major, minor, and trace minerals present in a sample.

X-ray diffraction patterns on the first nine tailing samples were run by NRRI Economic Geology Group (EGG) personnel on the Philips XRD machine in the UMD Geology Department. The last nine samples were run at the University of Minnesota Characterization Facility at the Shepherd Laboratories in Minneapolis. Figures 7.1 and 7.2 are examples of the XRD patterns produced at UMD and Shepherd Laboratories. The peaks in the patterns showed the presence of various combinations of minerals; again, this is the qualitative aspect of the technique. However, when the patterns were used with reference to the chemical analyses performed in Chapter 6, the percentage of each mineral in the sample was calculated; this is the quantitative aspect of the technique. XRD data for minerals in taconite are given in Table 7.1. The full compliment of XRD patterns is included at the end of this chapter.

MINERAL CALCULATIONS

Both XRD patterns and the chemical analyses of Chapter 6 were used in calculating mineral percentages. XRD determined which minerals were present in each sample, and chemistry determined the percentages. As each mineral was calculated, its chemical constituents were subtracted from the original analysis or from the residual percentage so that the latter was as near zero as possible and so that the total of the mineral percentages was at least within 0.5 percent of the total chemical percent (total oxides). Minerals were calculated as described below.

- Magnetite was determined by the Satmagan magnetic iron measurement.
- Stilpnomelane was calculated assuming all K_2O was present in this mineral.
- Apatite was assumed to be the only P_2O_5-bearing mineral.
- Ankerite and/or other Ca-bearing carbonates used all CaO.
- Siderite (and/or Rhodochrosite) used the remaining CO_2 and MnO.
- Minnesotaite, Talc, and Greenalite used the remaining MgO and FeO.
- Chamosite was calculated if Al_2O_3 residual was greater than 0.05 percent.
- Hematite (and Goethite) used remaining Fe_2O_3.
- Quartz was equal to the remaining SiO_2.
- Rutile equivalent equaled TiO_2 percent.
- Pyrite was calculated using all S.
- Carbon was total C minus carbon as CO_2.

The calculations were performed using macros developed by CMRL for Quattro Pro for Windows. Mineral chemistries used in the calculations are given in Table 7.2. The chemical compositions of the various minerals were determined from the following sources: [16]; [17]; [18]; [19]; [20].

XRD CARD FILE DATA for MINERALS in TACONITE (Cu Radiation)																
Mineral Name	File #	d-spacing	Int.	2-theta	d-spacing	Int.	2-theta	d-spacing	Int.	2-theta	d-spacing	Int.	2-theta	d-spacing	Int.	2-theta
Ankerite	410586	2.906	100	30.74	1.797	6	50.76	2.203	5	40.93						
Ankerite (ferroan Dolomite)	120088	2.899	100	30.82	2.199	6	41.01	1.812	6	50.31	1.792	6	50.91			
Calcite, manganoan	20714	2.95	100	30.27	1.85	80	49.21	1.81	70	50.37	2.24	50	40.22	2.04	40	44.37
Calcite, syn.	50586	3.04	100	29.35	2.29	20	39.31	2.1	20	43.03	1.91	20	47.57	1.88	20	48.37
Chamosite-1MIIb	211227	7.05	100	12.54	3.52	100	25.28	2.601	90	34.47	2.392	80	37.57	14.1	70	6.26
Dolomite	110078	2.886	100	30.96	2.192	30	41.15	1.783	30	51.19	1.804	20	50.55	2.015	15	44.95
Glauconite	90439	10.1	100	8.75	2.587	100	34.64	4.53	80	19.58	3.33	60	26.75	2.396	60	37.50
Goethite	290713	4.18	100	21.24	2.45	50	36.65	2.69	40	33.28	1.72	20	53.21	2.19	20	41.18
Greenalite	110265	2.59	100	34.6	2.2	90	40.99	7.21	70	12.27	1.602	60	57.48	1.819	50	50.1
Greenalite	21012	2.57	100	34.88	7.12	80	12.43	3.56	80	24.99						
Greenalite	230301	7.22	100	12.25	3.58	50	24.85	2.47	50	36.34	2.76	40	32.41	1.605	30	57.36
Greenalite-1M	390348	7.2	100	12.28	2.605	60	34.4	1.616	60	56.93	3.61	50	24.64	1.577	45	58.47
Greenalite-1T, syn	451353	7.16	100	12.35	2.56	70	35.02	3.57	70	24.92	2.18	30	41.38	1.59	20	57.95
Hematite	240072	2.703	100	33.15	2.519	70	35.6	1.697	36	53.88	3.686	33	24.12	1.843	31	49.41
Hematite	130534	2.69	100	33.28	1.69	60	54.23	2.51	50	35.74	1.838	40	49.55	1.484	35	62.53
Hematite	330664	2.7	100	33.15	2.519	70	35.61	1.694	45	54.09	1.841	40	49.47	3.684	30	24.14
Magnetite	190629	2.53	100	35.45	1.49	40	62.25	2.97	30	30.06						
Magnetite	30863	2.53	100	35.45	1.48	40	62.72	2.96	20	30.17	2.09	20	43.25	1.62	20	56.78
Magnetite	110614	2.53	100	35.45	1.61	85	57.16	1.48	85	62.72	2.966	70	30.1	2.096	70	43.12
Maghemite	40755	2.52	100	35.6	1.48	53	62.72	2.95	34	30.27						
Marcasite	30799	2.71	100	33.02	1.76	63	51.91	3.44	40	25.88	1.91	30	47.57	2.41	25	37.28
Minnesotaite	410594	9.54	100	9.26	3.18	50	28.03	2.528	45	35.48	2.655	35	33.73	2.405	32	37.36
Minnesotaite	170506	9.6	100	9.2	2.52	70	35.6	3.17	50	28.13	4.78	20	18.55	2.75	20	32.53
Pyrite	60710	1.633	100	56.29	2.71	85	33.02	2.423	65	37.07	2.212	50	40.76	1.916	40	47.41
Quartz	50490	3.34	100	26.67	4.26	35	20.83	1.82	17	50.08						
Quartz	331161	3.342	100	26.65	4.257	22	20.85	1.818	14	50.13	1.542	9	59.94	2.457	8	36.54
Rhodochrosite, syn.	70268	2.84	100	31.47	3.66	40	24.3	1.76	40	51.91	2.17	30	41.58	2	30	45.3
Siderite	120531	2.789	100	32.06	1.73	45	52.88	1.735	35	52.71	1.962	30	46.23	2.131	25	42.38
Siderite	80133	2.79	100	32.05	1.734	80	52.75	3.59	60	24.78	2.13	60	42.4	1.963	60	46.2
Stilpnomelane	170505	12.1	100	7.3	2.56	50	32.02	4.02	35	22.09	2.71	35	33.02	3.03	25	29.45
Stilpnomelane	180634	12.3	100	7.18	4.16	100	21.34	2.55	100	35.16	2.69	70	33.28	3.12	60	28.59
Stilpnomelane	250174	12.1	100	7.3	2.57	100	34.88	4.039	80	21.99	3.027	70	29.48	2.35	70	38.27
Stilpnomelane, Mg, Fe	451355	12.14	100	7.28	4.02	100	22.09	2.558	100	35.05	3.025	80	29.5	1.58	80	58.35
Talc-2M	291493	9.31	100	9.49	3.12	90	28.59	4.55	60	19.49	2.48	30	36.19	1.52	30	60.89
Talc-2M	190770	9.35	100	9.45	1.529	55	60.45	4.59	45	19.32	3.12	40	28.59	2.479	30	36.2

Table 7.1 Minerals in taconite for XRD analyses.

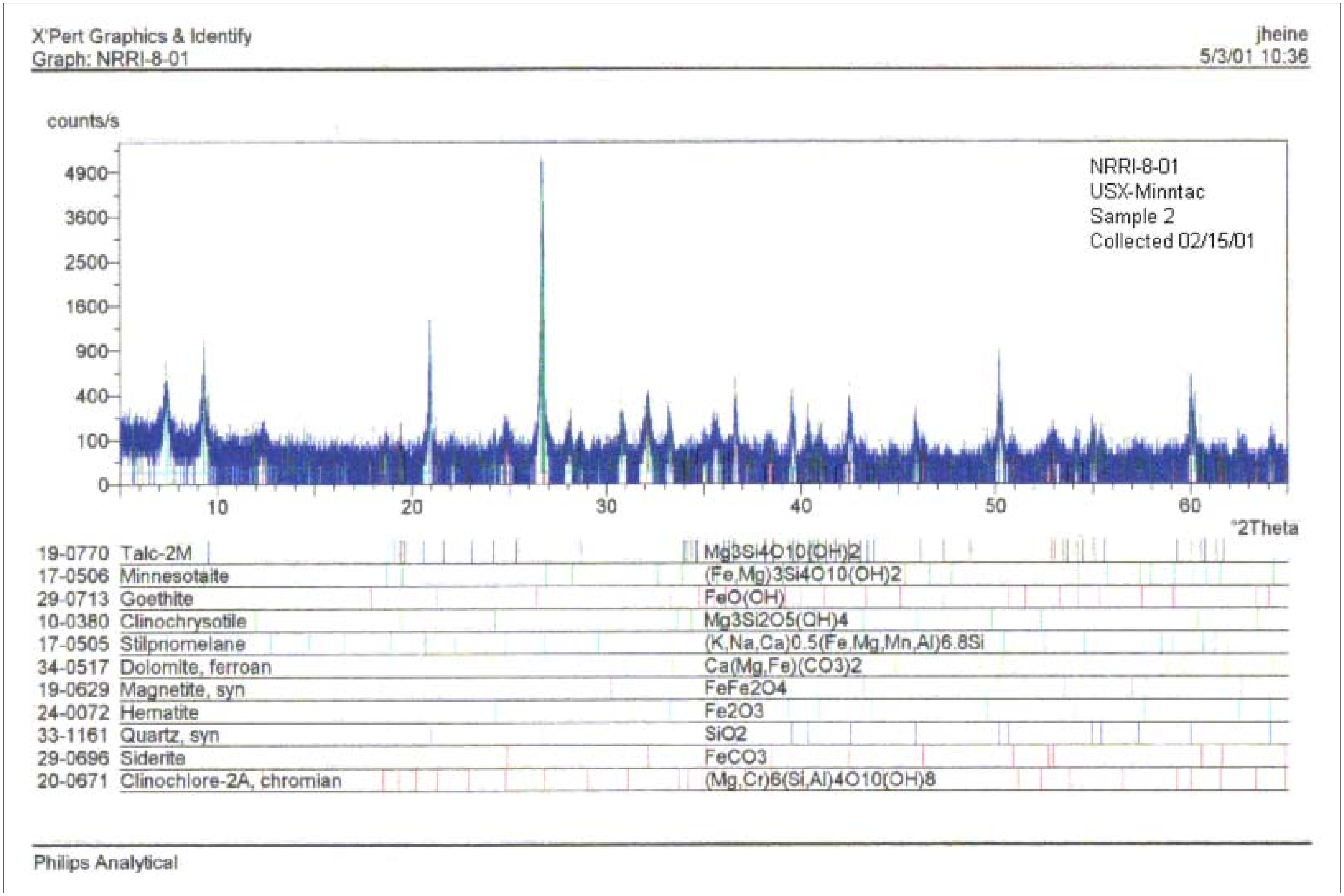

Figure 7.1 XRD trace of NRRI-8-01, USX Minntac Sample 2, collected 02/15/01: UMD

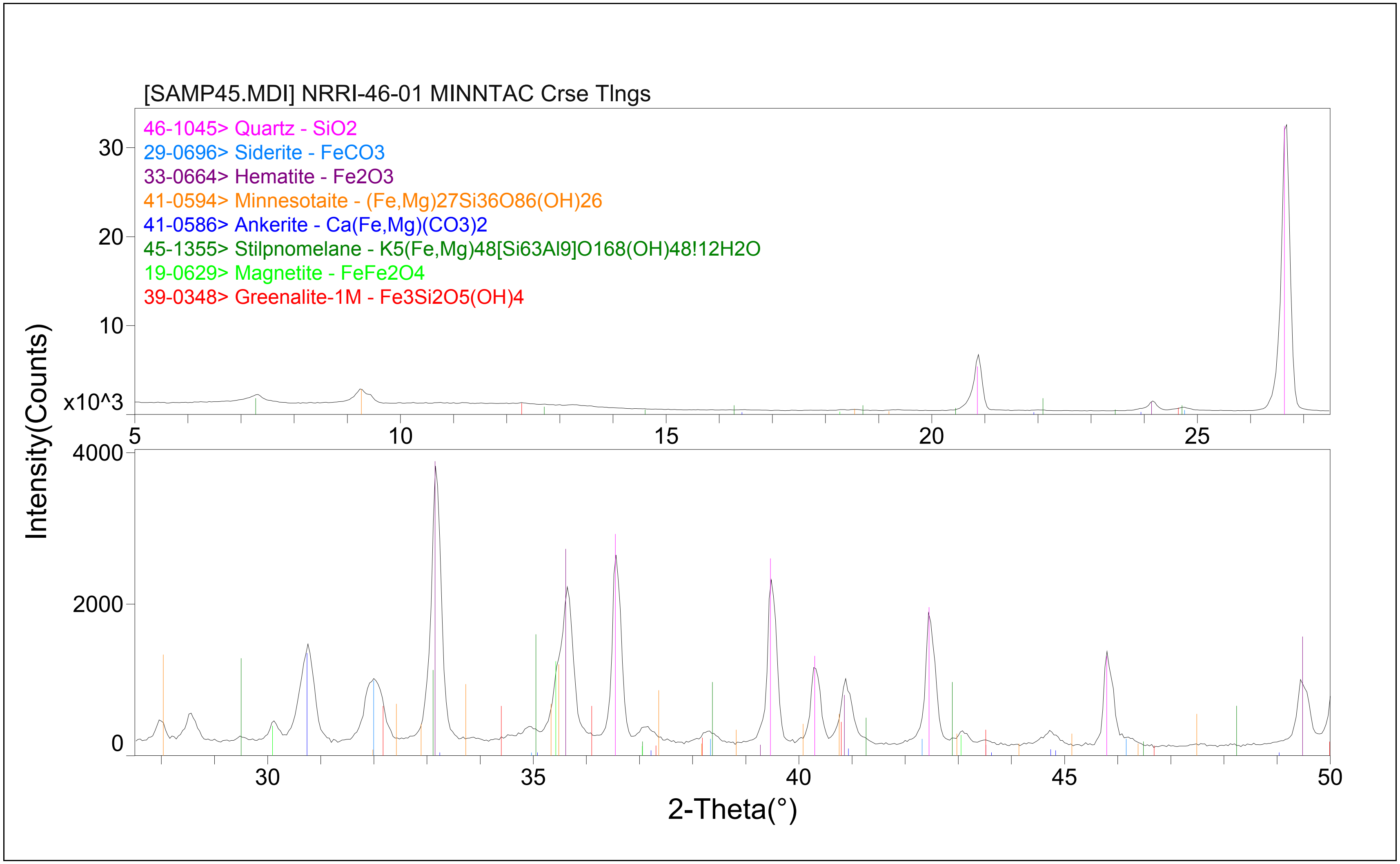

Figure 7.2 XRD trace of NRRI-46-01, USX Minntac Sample 4, collected 08/08/01: Shepherd Lab

Table 7.2 Mineral chemistries used for qualitative mineralogy calculations.

ASSUMED CHEMICAL COMPOSITIONS OF MINERALS															
	CHEMISTRY, percent														
Mineral	Tot. Fe	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	MnO	Na_2O	K_2O	CO_2	Comb. H_2O	P_2O_5	S	F
Ankerite	13.99	18.00				29.00	8.50	1.50			43.00				
Apatite, Carb-fluor						52.50		2.50			2.20	0.51	38.00		4.30
Calcite						56.03					43.97				
Chamosite	32.00	36.35	5.37	24.21	19.87		2.44					11.76			
Dolomite						30.41	21.86				47.73				
Fe-Dolomite	9.41	12.11				29.34	12.90	0.77			44.88				
Goethite	62.85		89.86									10.14			
Greenalite	39.48	46.31	5.00	35.59	1.00		2.31					9.79			
Greenalite	39.07	41.00	10.31	35.59	1.00		2.31					9.79			
Greenalite *	38.13	29.00	22.31	33.59	1.00		4.31					9.79			
Hematite	69.94		100.00												
Magnetite	72.36	31.03	68.97												
Minnesotaite	27.05	34.81	1.45	51.29	0.55		6.26					5.64			
Minnesotaite	27.05	34.81	2.00	51.29			6.26					5.64			
Pyrite	46.55													53.45	
Quartz				100.00											
Rhodochrosite, (MGS)	1.04	1.34				3.06	0.80	53.08			41.72				
Siderite	40.59	52.24					3.05	4.06			40.65				
Siderite *	36.08	46.44					8.85	4.06			40.65				
Siderite, SIDMN	38.75	48.70					2.60	8.50			40.20				
Siderite, SIDMN*	34.73	44.70					6.60	8.50			40.20				
Siderite, Hi-Mn (MGS)	34.15	43.95					2.72	13.59			39.74				
Siderite, VHi-Mn (MGS)	26.36	33.92					2.45	24.00			39.64				
Stilpnomelane	25.00	27.67	5.00	46.98	5.07		4.22	1.20	0.30	1.74		7.82			
Stilpnomelane	24.66	23.27	9.40	46.98	5.07		4.99	0.59	0.14	1.74		7.82			
Talc				62.35	1.00		31.35					5.30			

The average coarse tailings mineralogy for each mine is depicted in Figure 7.3; the composite mineralogy for all 18 samples is illustrated in Figure 7.4. Both figures show that quartz is the dominant mineral, comprising about 50 to 60 percent of each sample. Besides siderite and hematite (either of which can range up to 10 percent) the remaining minerals generally comprise less than 5 percent individually. Mineralogical summaries for each mine are presented in the next section.

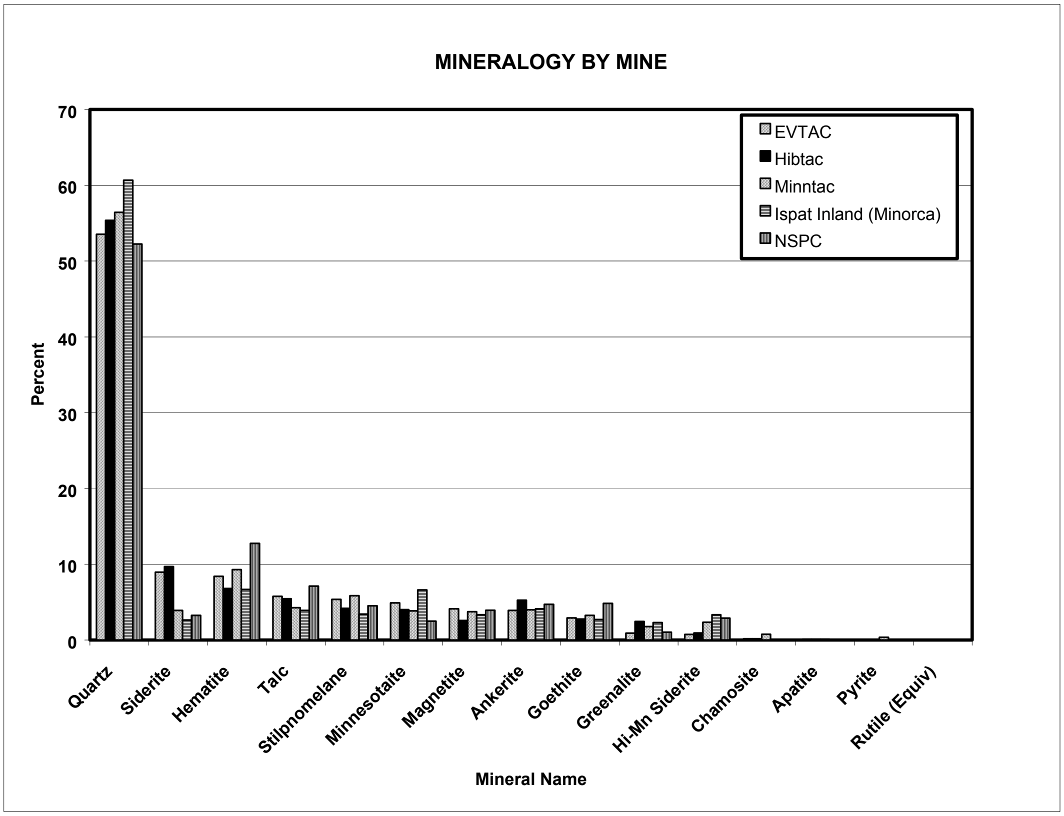

Figure 7.3 Average coarse tailings mineralogy by mine.

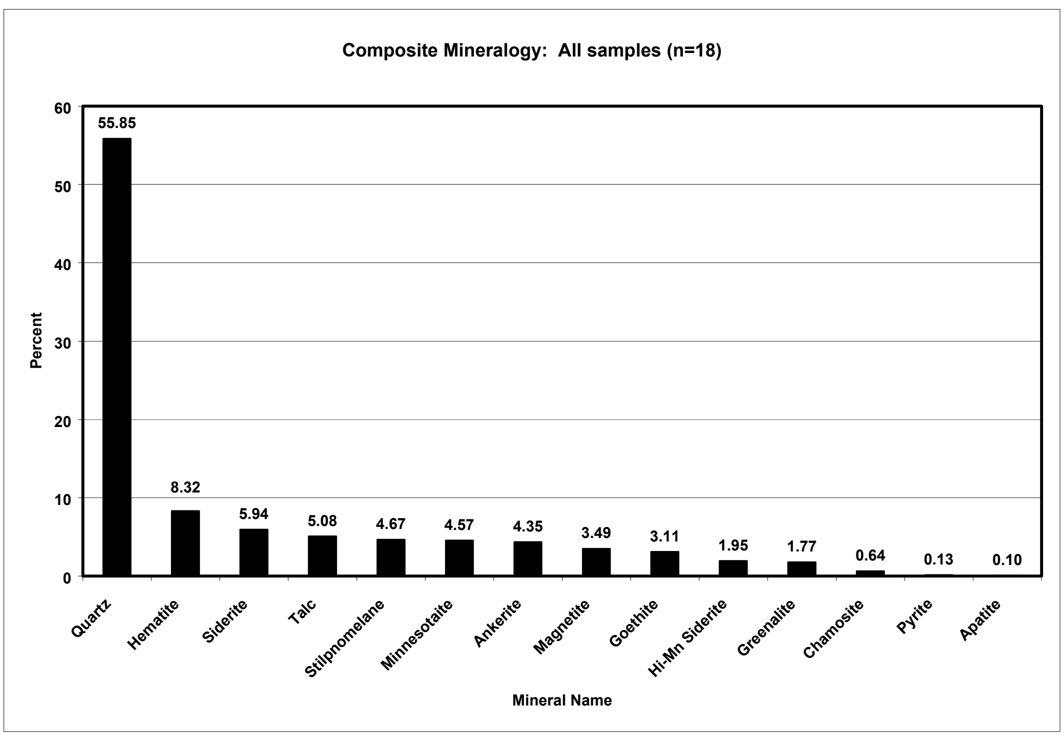

Figure 7.4 Composite mineralogy of all coarse tailings samples.

MINERALOGICAL RESULTS AND X-RAY DIFFRACTION TRACES, BY MINE

On the following pages, complete mineralogical data summaries are presented for each mine, including XRD traces.

EVTAC Mineralogical Results

The relative percentages of major minerals in all four EVTAC samples are summarized in Table 7.3. XRD traces for all samples are presented in Figures 7.5 to 7.8.

Table 7.3 EVTAC sample mineral percentages.

EVTAC				
	NRRI-40-00	NRRI-10-01	NRRI-31-01	NRRI-49-01
	12-13-00	03-06-01	06-13-01	09-11-01
Mineral	Mineral	Mineral	Mineral	Mineral
Name	percent	percent	percent	percent
Magnetite	4.0	7.2	2.7	2.6
Hematite	8.5	11.1	7.7	6.3
Goethite	4.1	4.1	0.5	3.0
Quartz	55.0	56.9	46.1	56.1
Minnesotaite	5.9	1.4	10.0	2.3
Stilpnomelane	4.1	3.6	7.2	6.6
Chamosite		0.4	0.3	
Greenalite	0.7	0.9	1.5	0.5
Talc	4.6	6.4	5.0	7.1
Ankerite	4.0	3.4	2.9	5.4
Siderite	8.0	2.3	15.5	10.0
Calcite	0.0	0.0	0.0	0.0
Hi-Mn Siderite	0.6	2.0	0.3	0.0
Rhodochrosite	0.0	0.0	0.0	0.0
Pyrite	0.077	0.067	0.120	0.071
Carbon	0.000	0.000	0.000	0.000
Apatite	0.115	0.109	0.157	0.090
Rutile (Equivalent)	0.020	0.026	0.039	0.011
Maghemite				
Dolomite	0.0	0.0	0.0	0.0
Fe-Dolomite	0.0	0.0	0.0	0.0

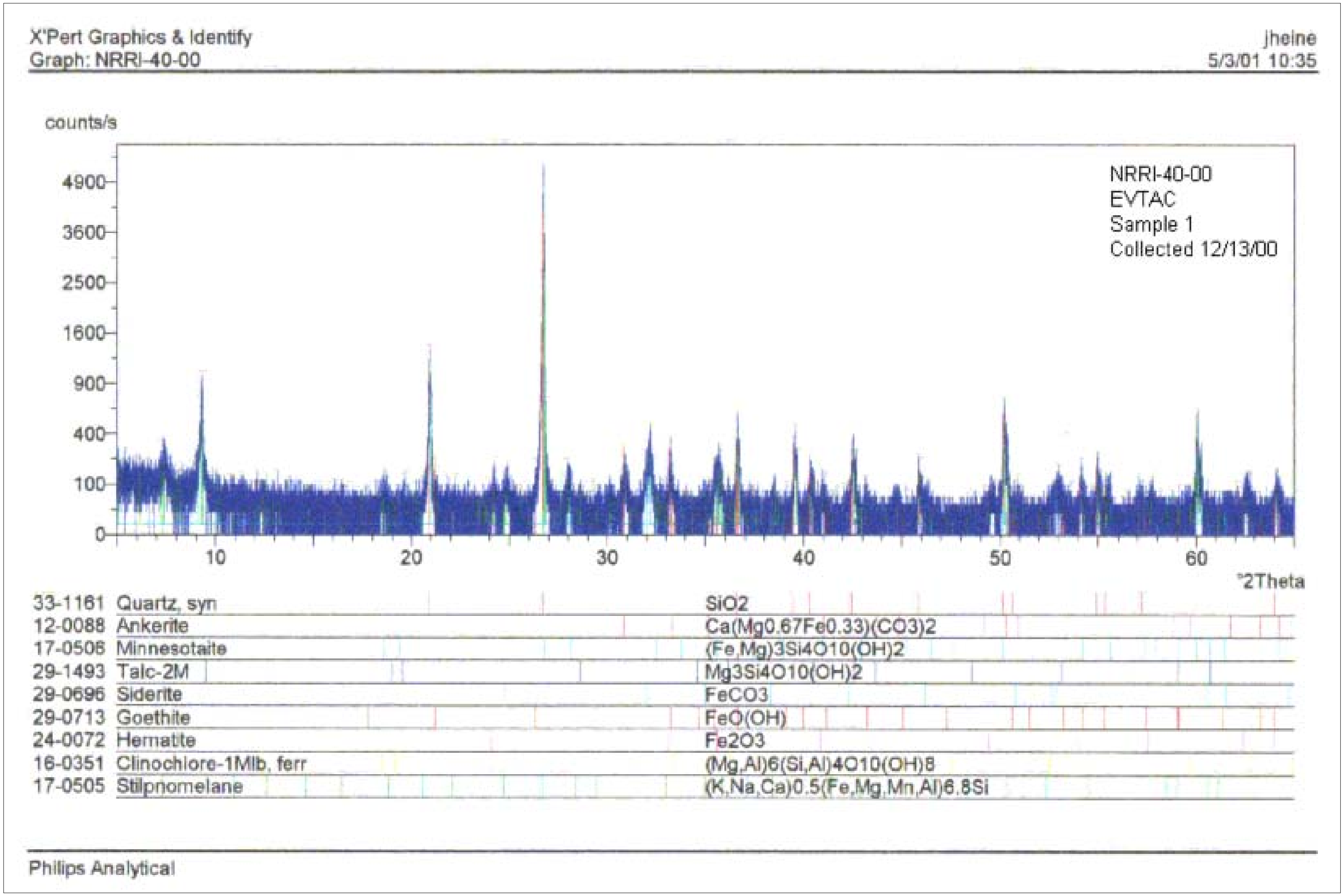

Figure 7.5 XRD trace of NRRI-40-00, EVTAC Sample 1, collected 12/13/00: UMD

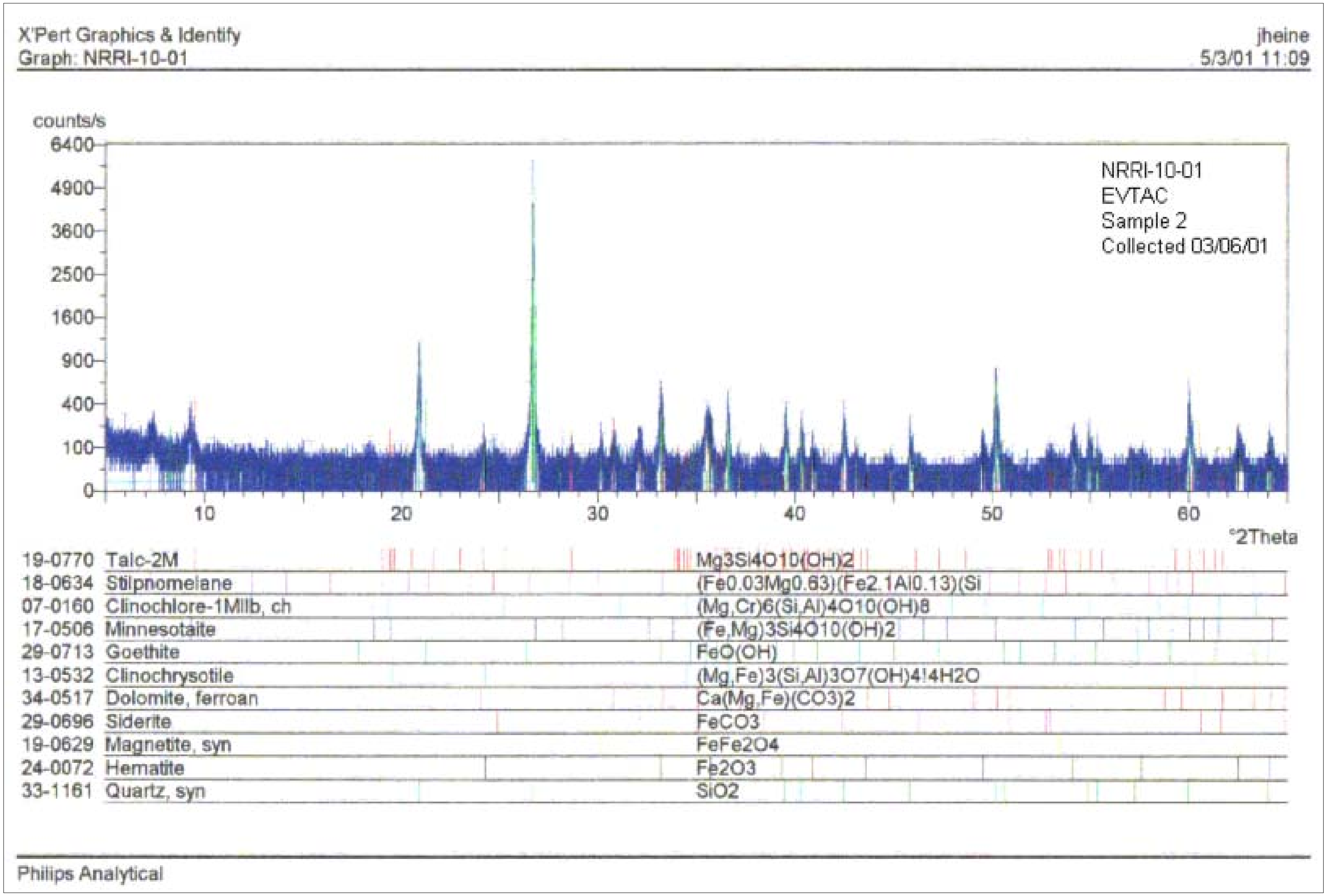

Figure 7.6 XRD trace of NRRI-10-01, EVTAC Sample 2, collected 3/6/01: UMD

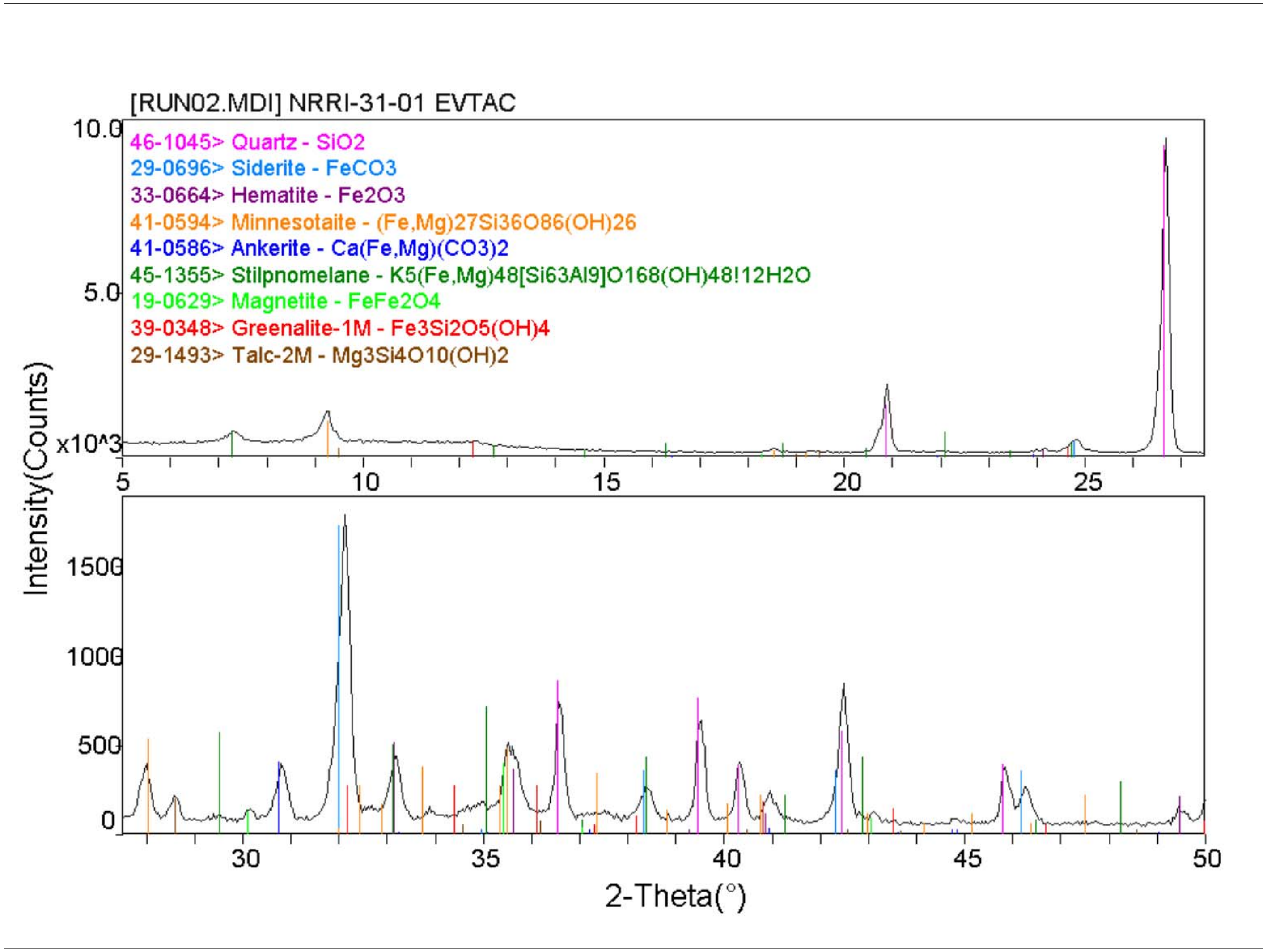

Figure 7.7 XRD trace of NRRI-31-01, EVTAC Sample 3, collected 6/13/01: Shepherd Lab

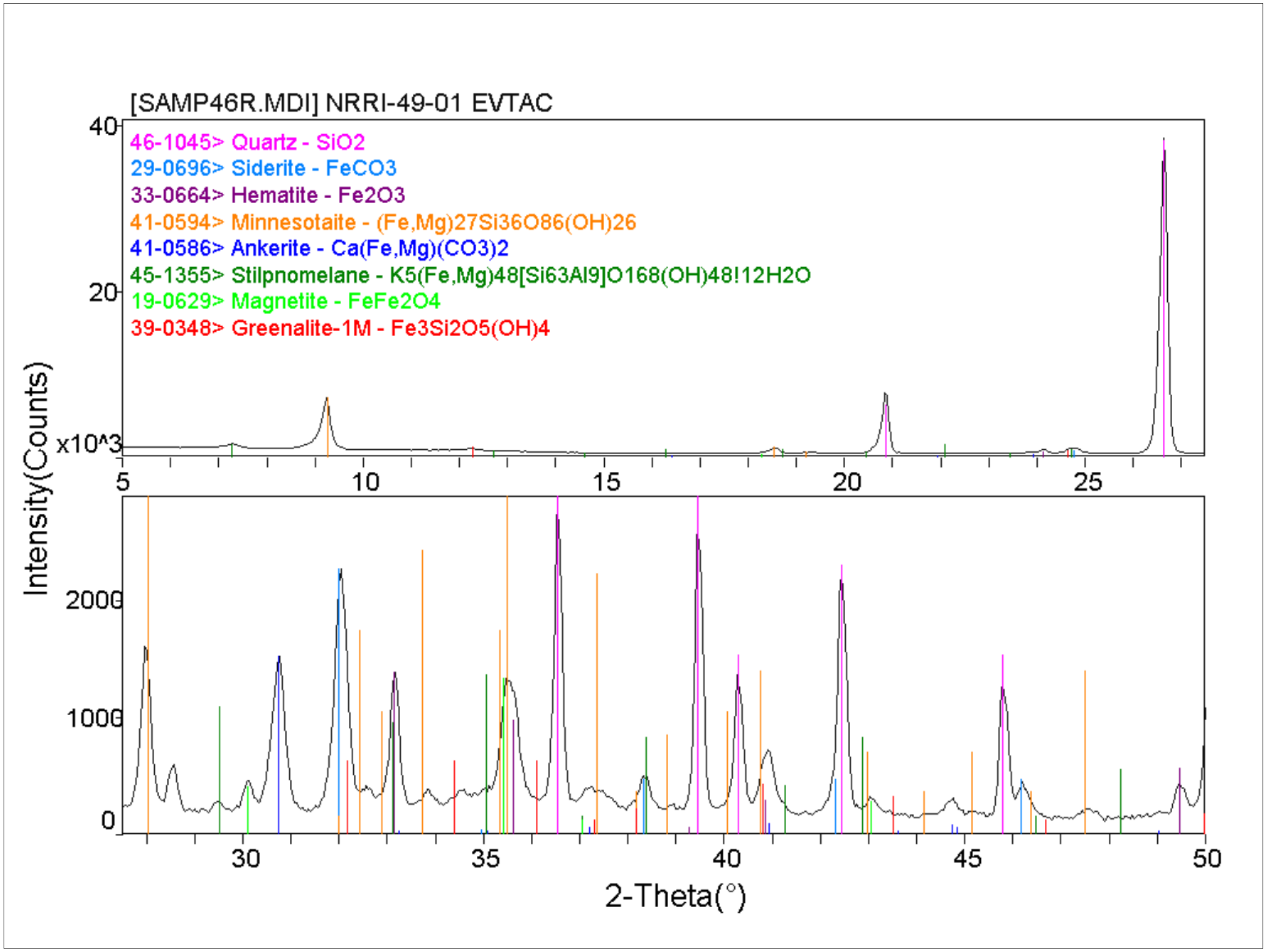

Figure 7.8 XRD trace of NRRI-49-01, EVTAC Sample 4, collected 9/11/01: Shepherd Lab

Hibtac Mineralogical Results

The relative percentages of major minerals in all four Hibtac samples are summarized in Table 7.4. XRD traces for all samples are presented in Figures 7.9 to 7.12.

Table 0.4 Hibtac sample mineral percentages.

Hibtac				
	NRRI-36-00	NRRI-11-01	NRRI-42-01	NRRI-50-01
	11-16-00	03-09-01	07-24-01	09-12-01
Mineral	Mineral	Mineral	Mineral	Mineral
Name	percent	percent	percent	percent
Magnetite	2.5	2.1	1.8	3.9
Hematite	7.4	7.1	4.5	8.2
Goethite	2.1	4.2	1.7	3.0
Quartz	54.4	54.1	56.4	56.6
Minnesotaite	4.7	4.3	3.6	3.5
Stilpnomelane	4.7	4.2	5.3	2.5
Chamosite	0.3	0.4		
Greenalite	1.7	1.4	3.3	3.5
Talc	6.2	4.7	6.1	4.8
Ankerite	5.0	5.2	5.3	5.5
Siderite	10.2	11.0	11.5	6.0
Calcite	0.0	0.0	0.0	0.0
Hi-Mn Siderite	0.7	1.0	0.0	2.0
Rhodochrosite	0.0	0.0	0.0	0.0
Pyrite	0.062	0.047	0.054	0.090
Carbon	0.000	0.000	0.000	0.000
Apatite	0.115	0.115	0.103	0.078
Rutile (Equivalent)	0.011	0.009	0.010	0.019
Maghemite				
Dolomite	0.0	0.0	0.0	0.0
Fe-Dolomite	0.0	0.0	0.0	0.0

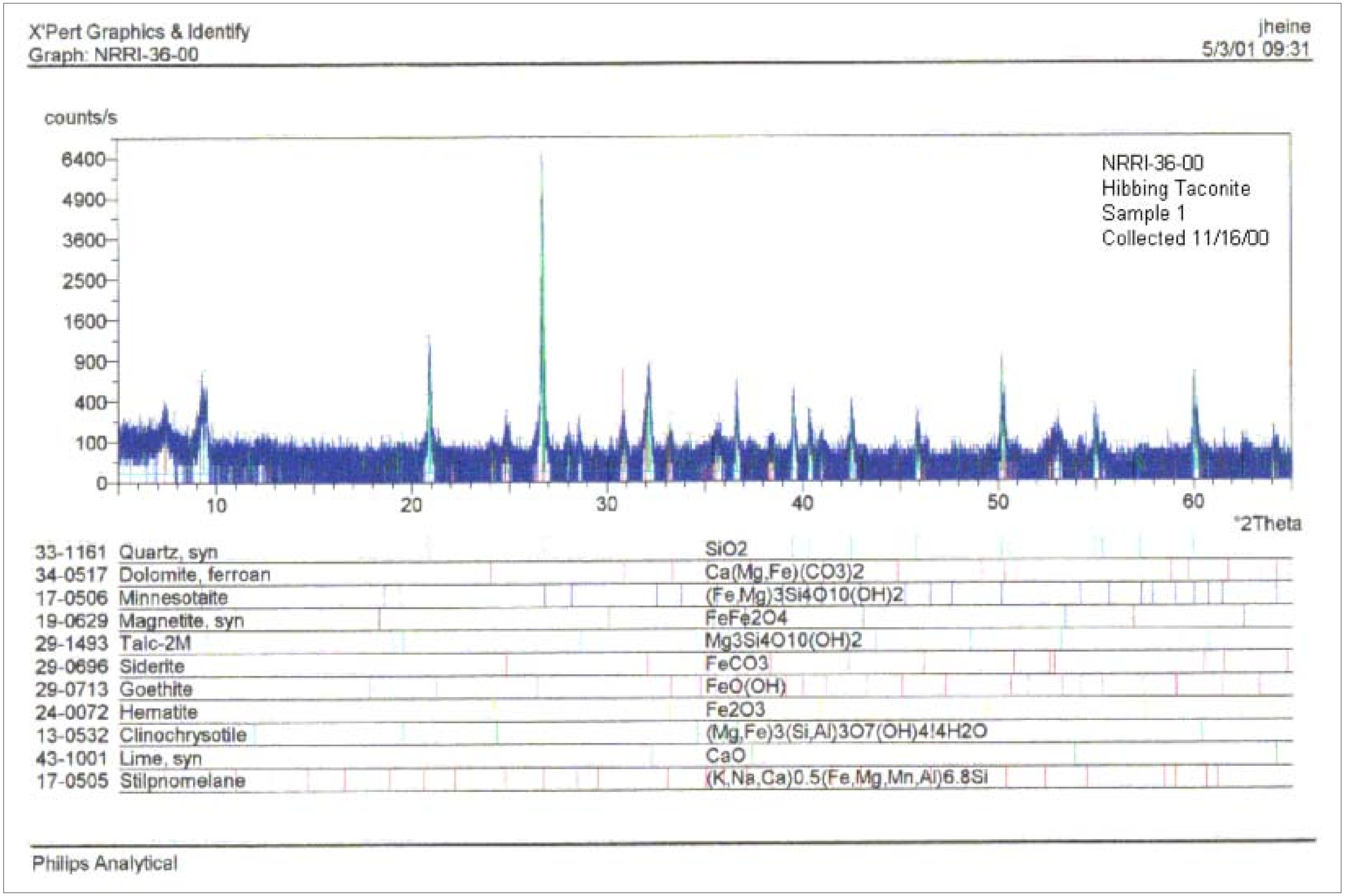

Figure 7.9 XRD trace of NRRI-36-01, Hibtac Sample 1, collected 11/16/00: UMD

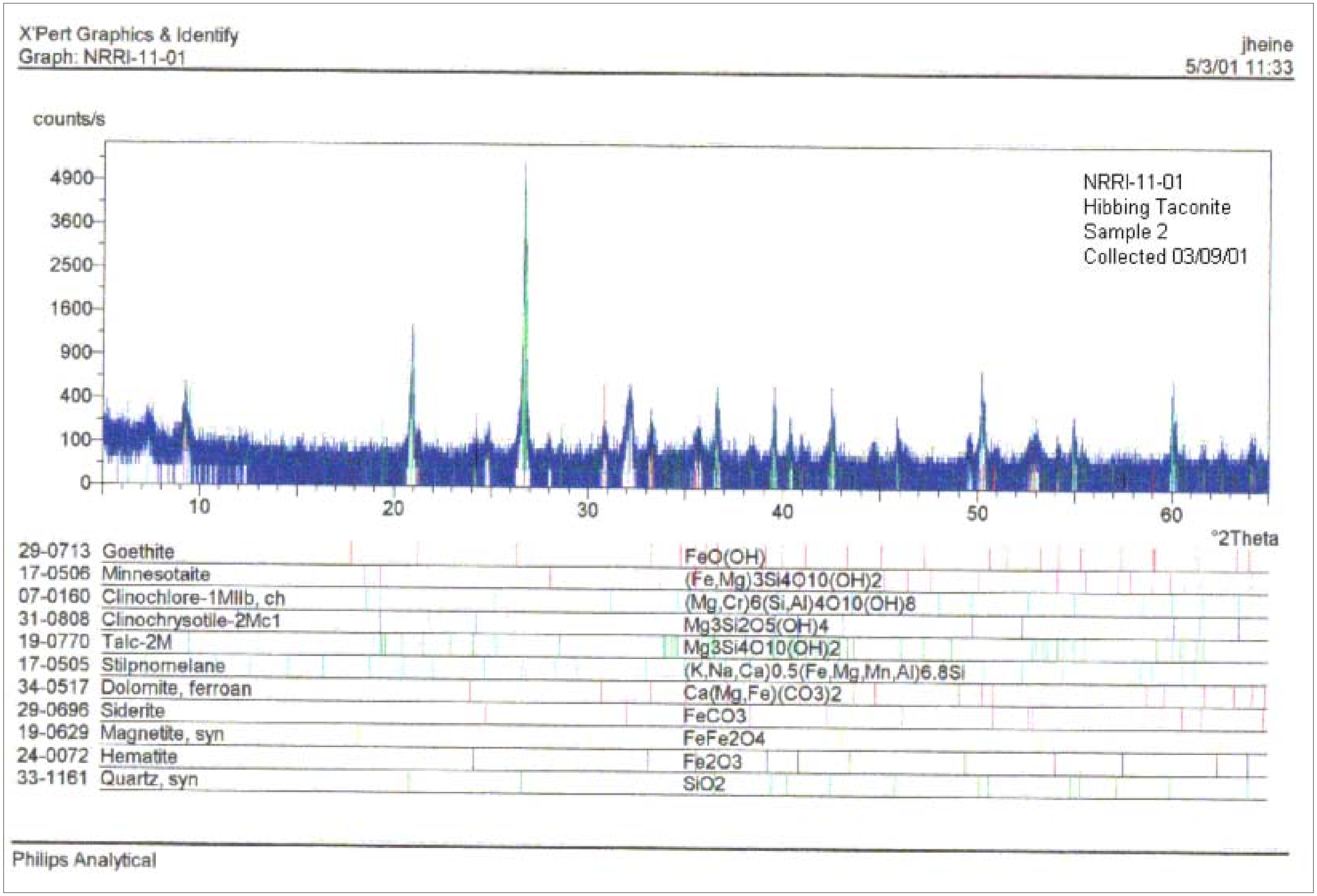

Figure 7.10 XRD trace of NRRI-11-01, Hibtac Sample 2, collected 3/9/01: UMD

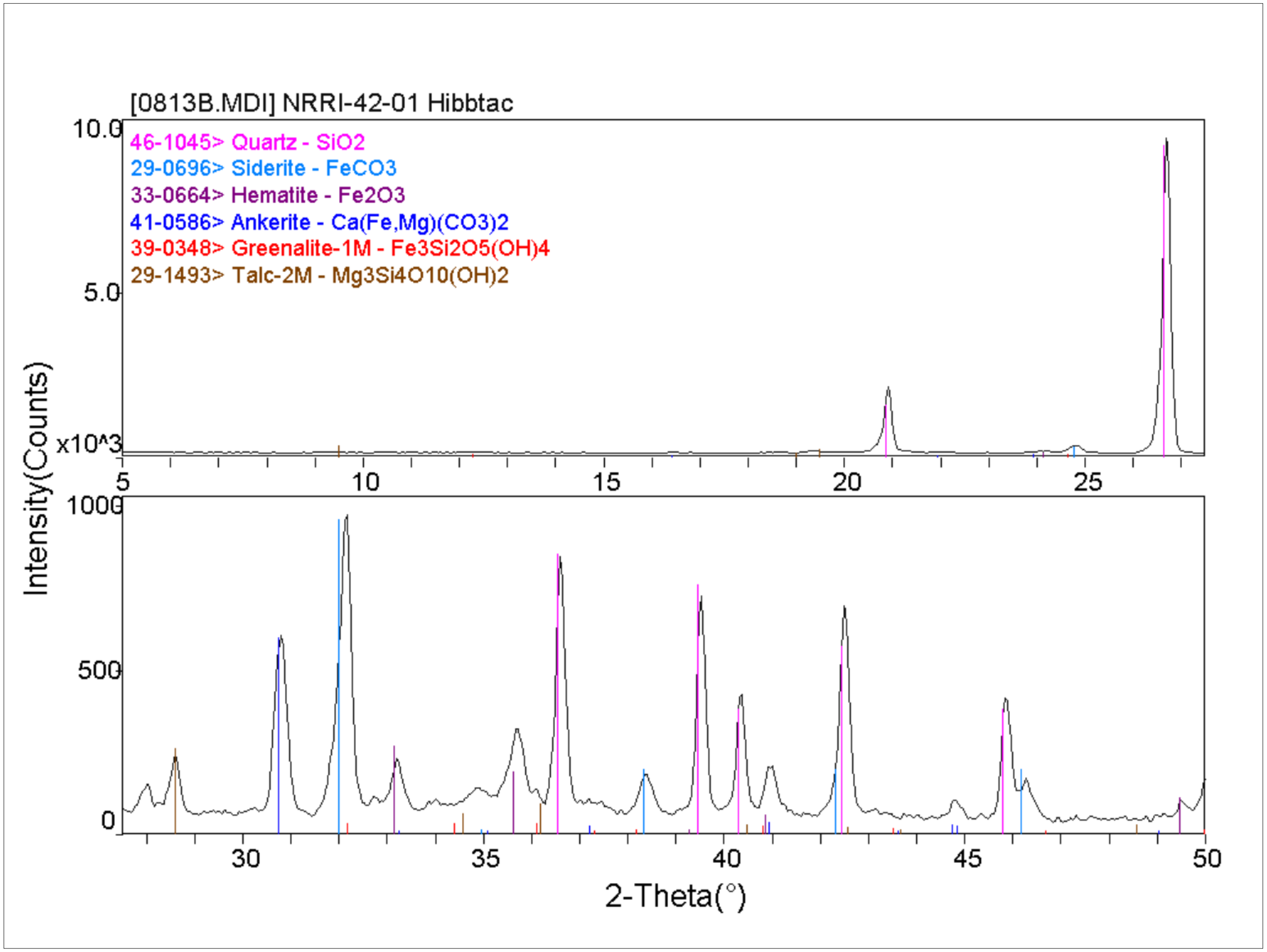

Figure 7.11 XRD trace of NRRI-42-01, Hibtac Sample 3, collected 7/24/01: Shepherd Lab

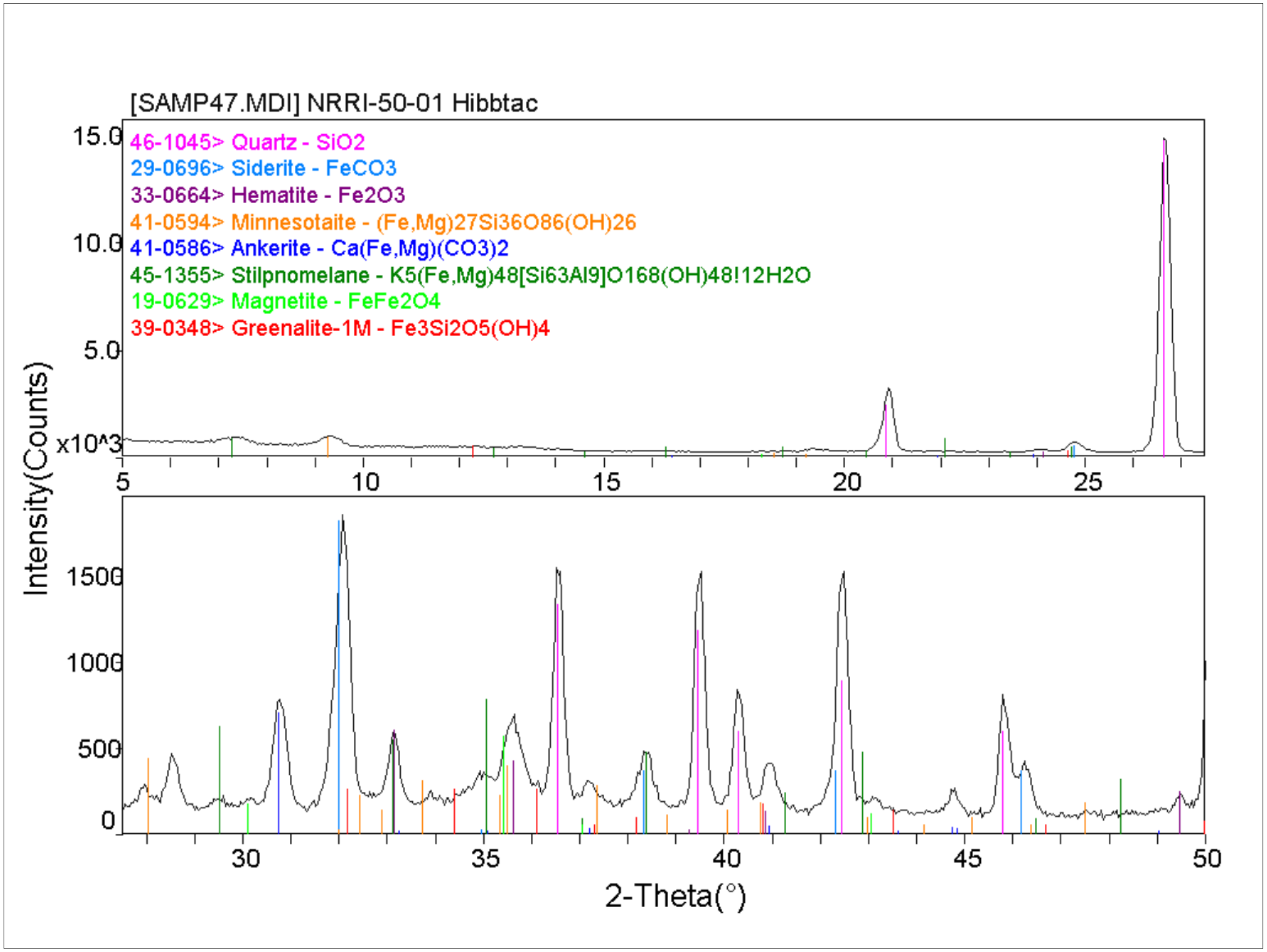

Figure 7.12 XRD trace of NRRI-50-01, Hibtac Sample 4, collected 9/12/01: Shepherd Lab

Ispat Inland (Minorca) Mineralogical Results

The relative percentages of major minerals in all four Ispat Inland (Minorca) samples are summarized in Table 7.5. XRD traces for all samples are presented in Figures 7.13 to 7.16.

Table 7.5 Ispat Inland (Minorca) sample mineral percentages.

Ispat-Inland (Minorca)				
	NRRI-39-00	NRRI-09-01	NRRI-30-01	NRRI-52-01
	12-08-00	03-01-01	06-11-01	09-18-01
Mineral	Mineral	Mineral	Mineral	Mineral
Name	percent	percent	percent	percent
Magnetite	3.5	2.5	4.2	3.2
Hematite	11.7	7.1	1.7	6.2
Goethite	3.3	2.6	1.9	3.0
Quartz	60.9	62.5	64.5	54.8
Minnesotaite	4.2	1.7	6.9	13.7
Stilpnomelane	4.5	4.7	2.4	2.1
Chamosite				
Greenalite	0.0	1.2	6.0	2.0
Talc	3.4	7.8	1.2	3.2
Ankerite	5.3	3.6	3.2	4.4
Siderite	0.0	3.4	3.7	3.5
Calcite	0.0	0.0	0.0	0.0
Hi-Mn Siderite	2.9	2.8	4.1	3.6
Rhodochrosite	0.0	0.0	0.0	0.0
Pyrite	0.039	0.041	0.049	0.079
Carbon	0.000	0.000	0.000	0.000
Apatite	0.096	0.078	0.066	0.084
Rutile (Equivalent)	0.022	0.013	0.007	0.016
Maghemite				
Dolomite	0.0	0.0	0.0	0.0
Fe-Dolomite	0.0	0.0	0.0	0.0

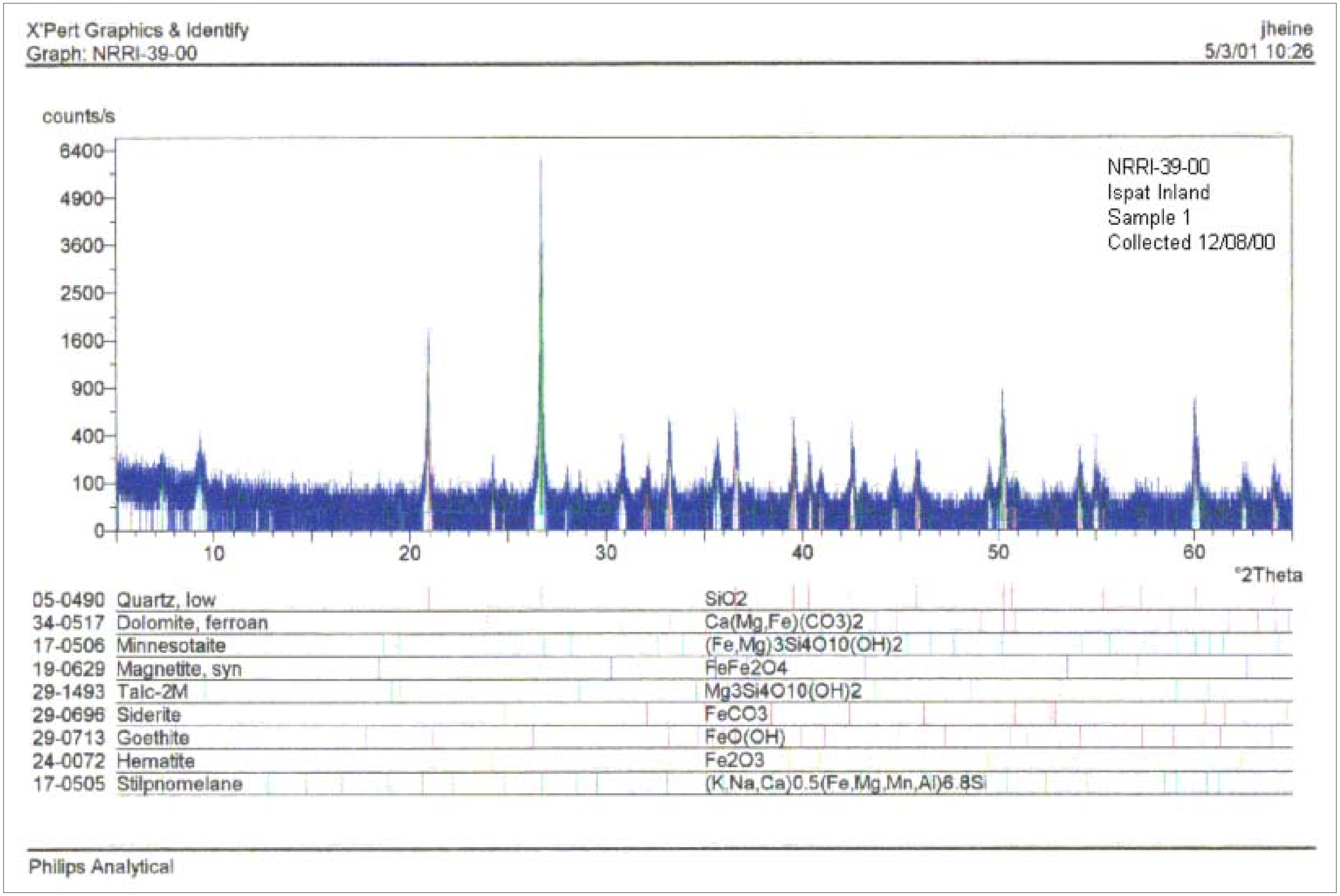

Figure 7.13 XRD trace of NRRI-39-00, Ispat Inland (Minorca) Sample 1, collected 12/8/00: UMD

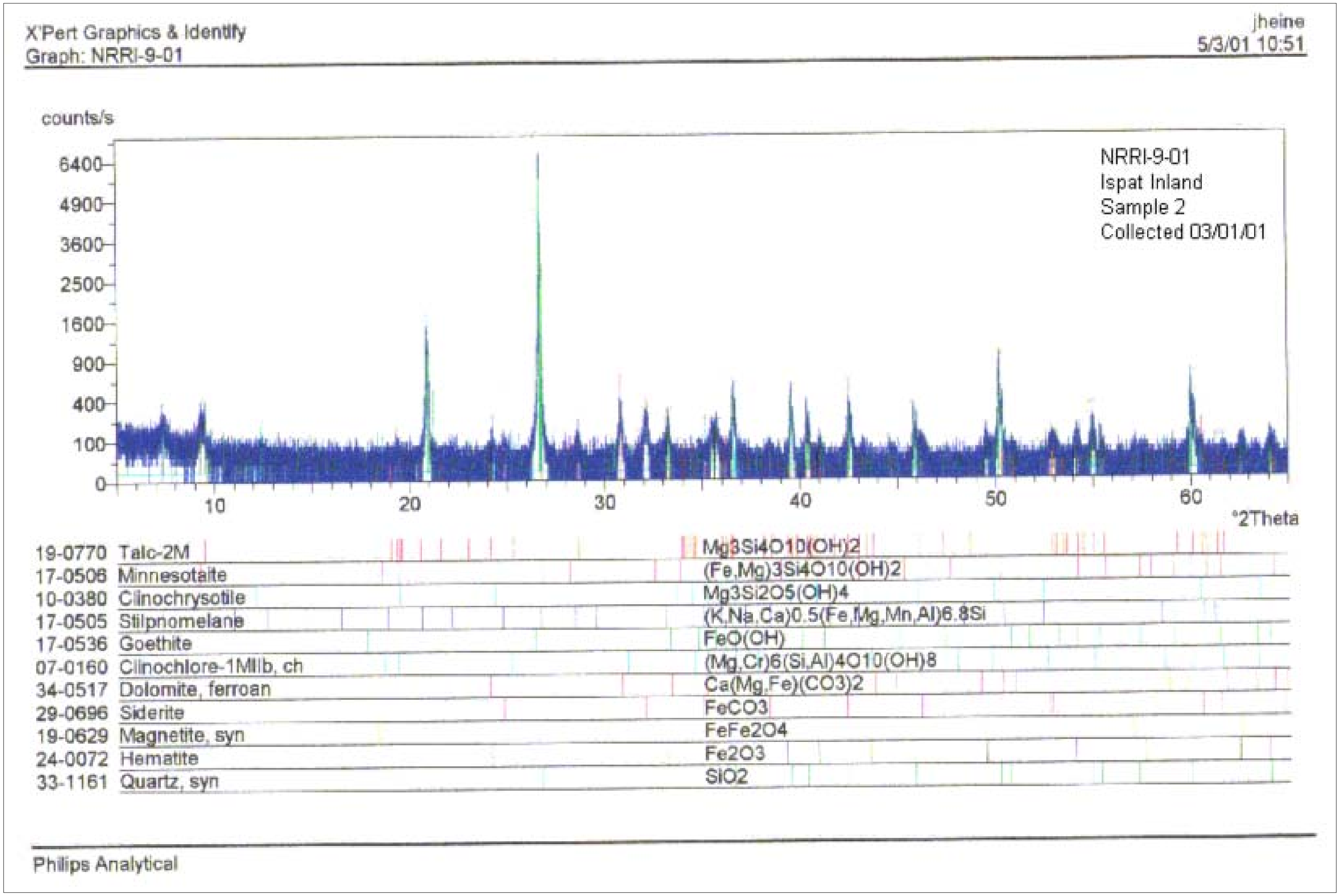

Figure 7.14 XRD trace of NRRI-09-01, Ispat Inland (Minorca) Sample 2, collected 3/1/01: UMD

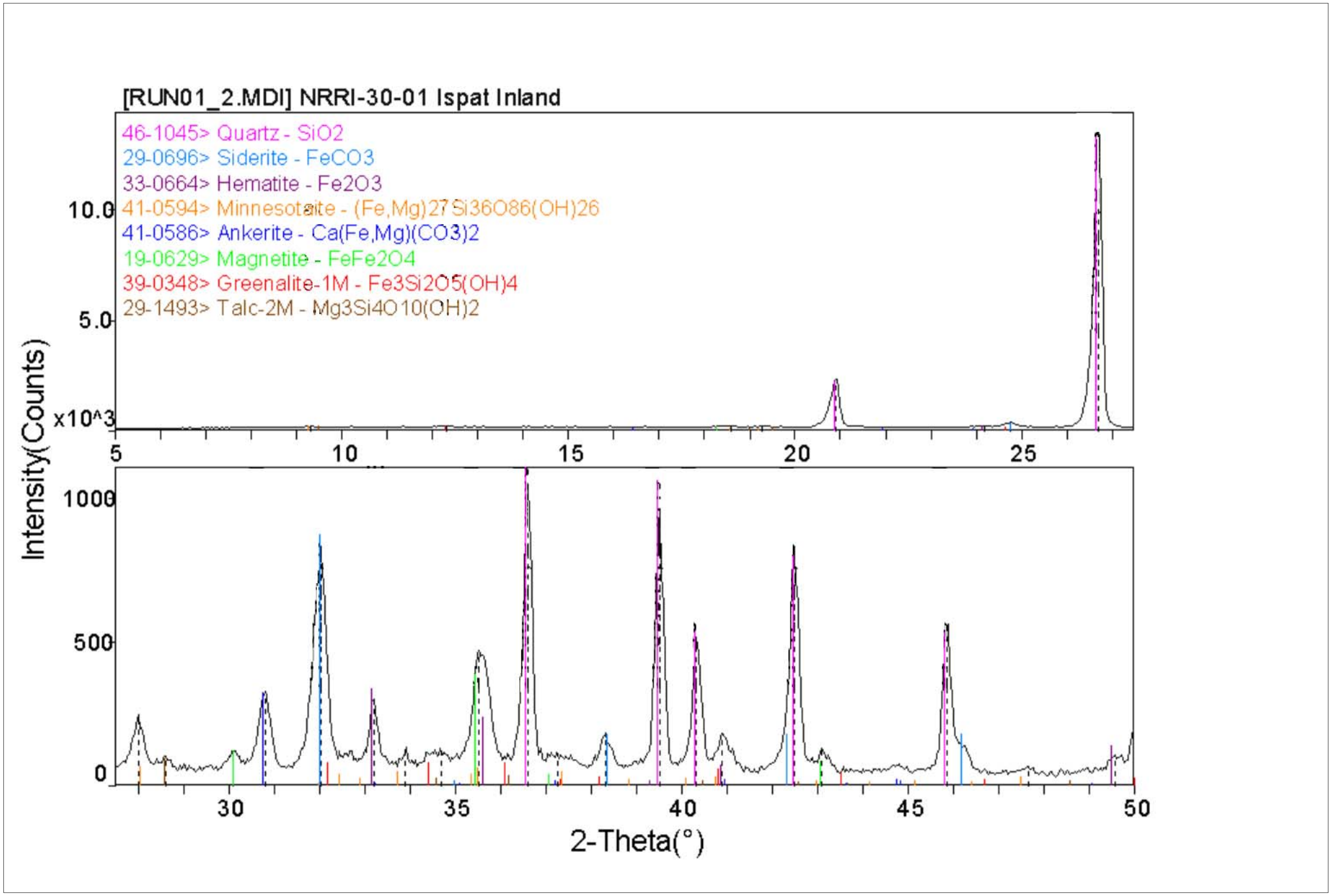

Figure 7.15 XRD trace of NRRI-30-01, Ispat Inland (Minorca) Sample 3, collected 6/11/01: Shepherd Lab

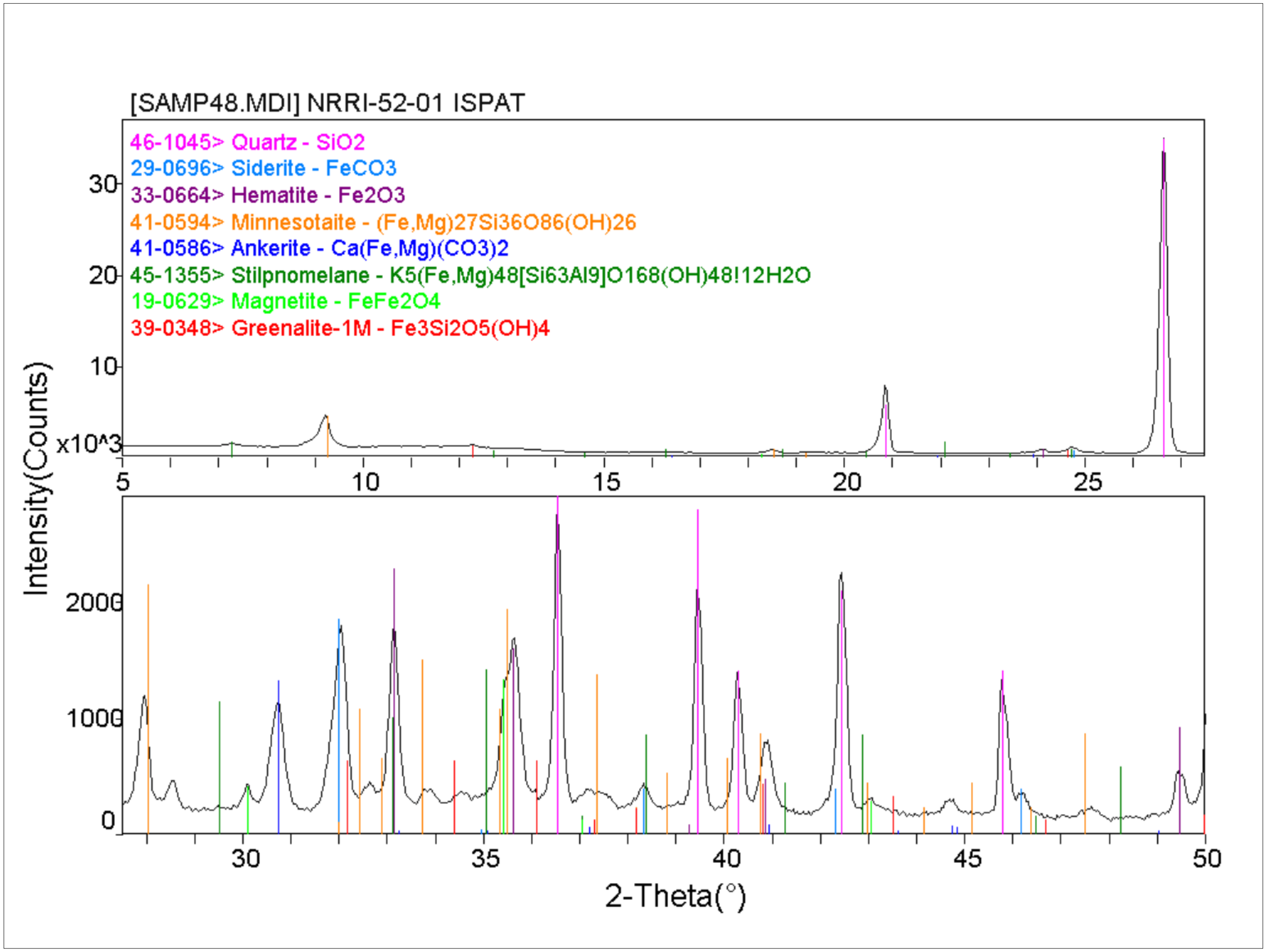

Figure 0.16 XRD trace of NRRI-52-01, Ispat Inland (Minorca) Sample 4, collected 9/18/01: Shepherd Lab

Minntac Mineralogical Results

The relative percentages of major minerals in all four Minntac samples are summarized in Table 7.6. XRD traces for all samples are presented in Figures 7.17 to 7.20.

Table 7.6 Minntac sample mineral percentages.

Minntac				
	NRRI-37-00	NRRI-08-01	NRRI-17-01	NRRI-46-01
	11-22-00	02-15-01	05-07-01	08-08-01
Mineral Name	Mineral percent	Mineral percent	Mineral percent	Mineral percent
Magnetite	3.6	3.8	3.5	4.1
Hematite	6.5	5.7	10.9	14.1
Goethite	3.1	0.7	4.0	5.2
Quartz	56.9	55.1	58.4	55.3
Minnesotaite	4.6	6.2	2.7	1.9
Stilpnomelane	5.9	7.2	4.0	6.3
Chamosite	0.4	2.4	0.3	
Greenalite	2.8	1.3	2.1	0.9
Talc	4.9	4.4	4.5	3.3
Ankerite	3.5	4.6	2.7	5.2
Siderite	5.7	6.0	3.9	0.0
Calcite	0.0	0.0	0.0	0.0
Hi-Mn Siderite	1.3	2.1	2.7	3.3
Rhodochrosite	0.0	0.0	0.0	0.0
Pyrite	0.473	0.363	0.284	0.318
Carbon	0.000	0.000	0.000	0.000
Apatite	0.109	0.157	0.096	0.121
Rutile (Equivalent)	0.033	0.070	0.020	0.025
Maghemite				
Dolomite	0.0	0.0	0.0	0.0
Fe-Dolomite	0.0	0.0	0.0	0.0

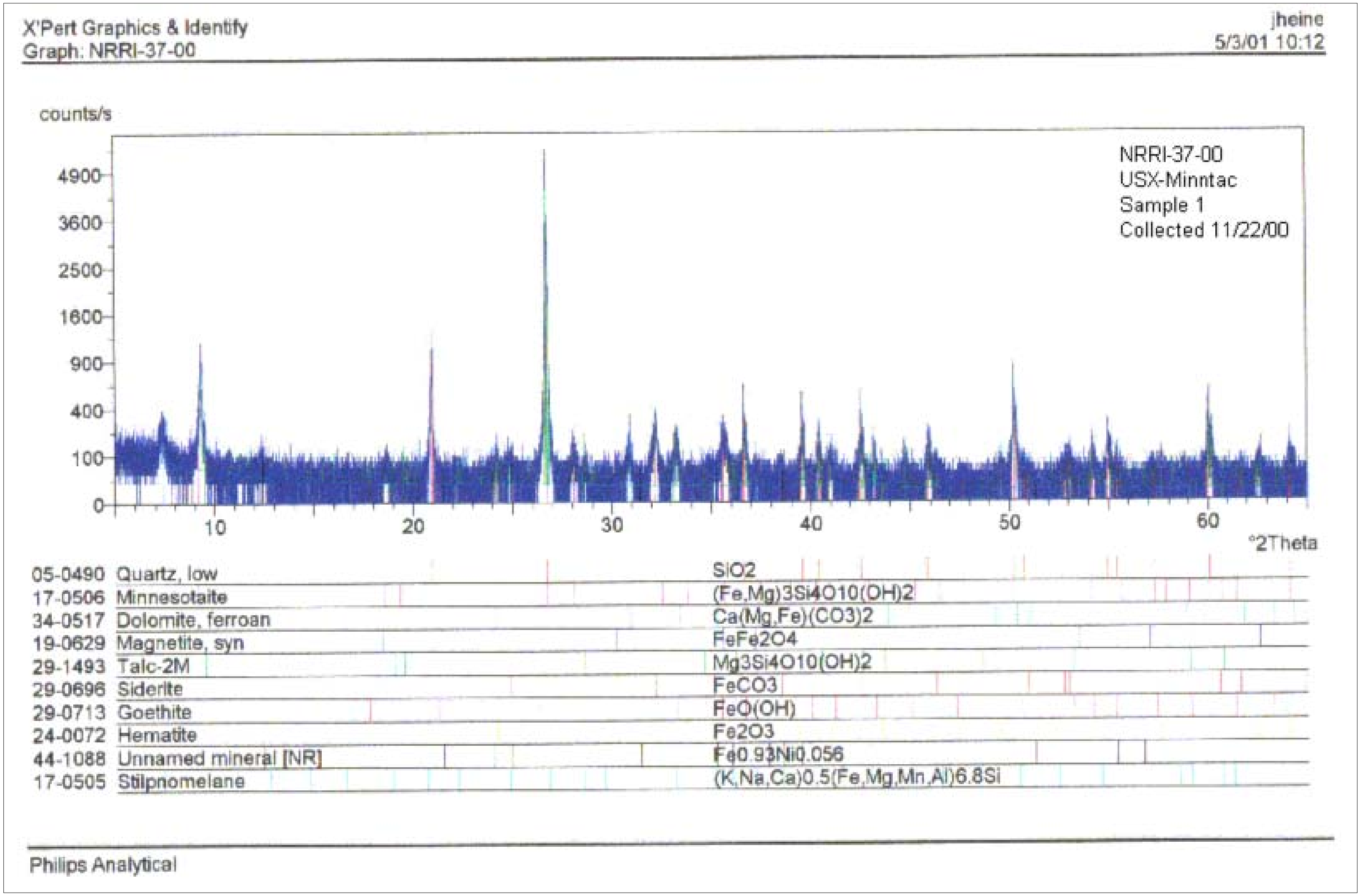

Figure 7.17 XRD trace of NRRI-37-00, Minntac Sample 1, collected 11/22/00: UMD

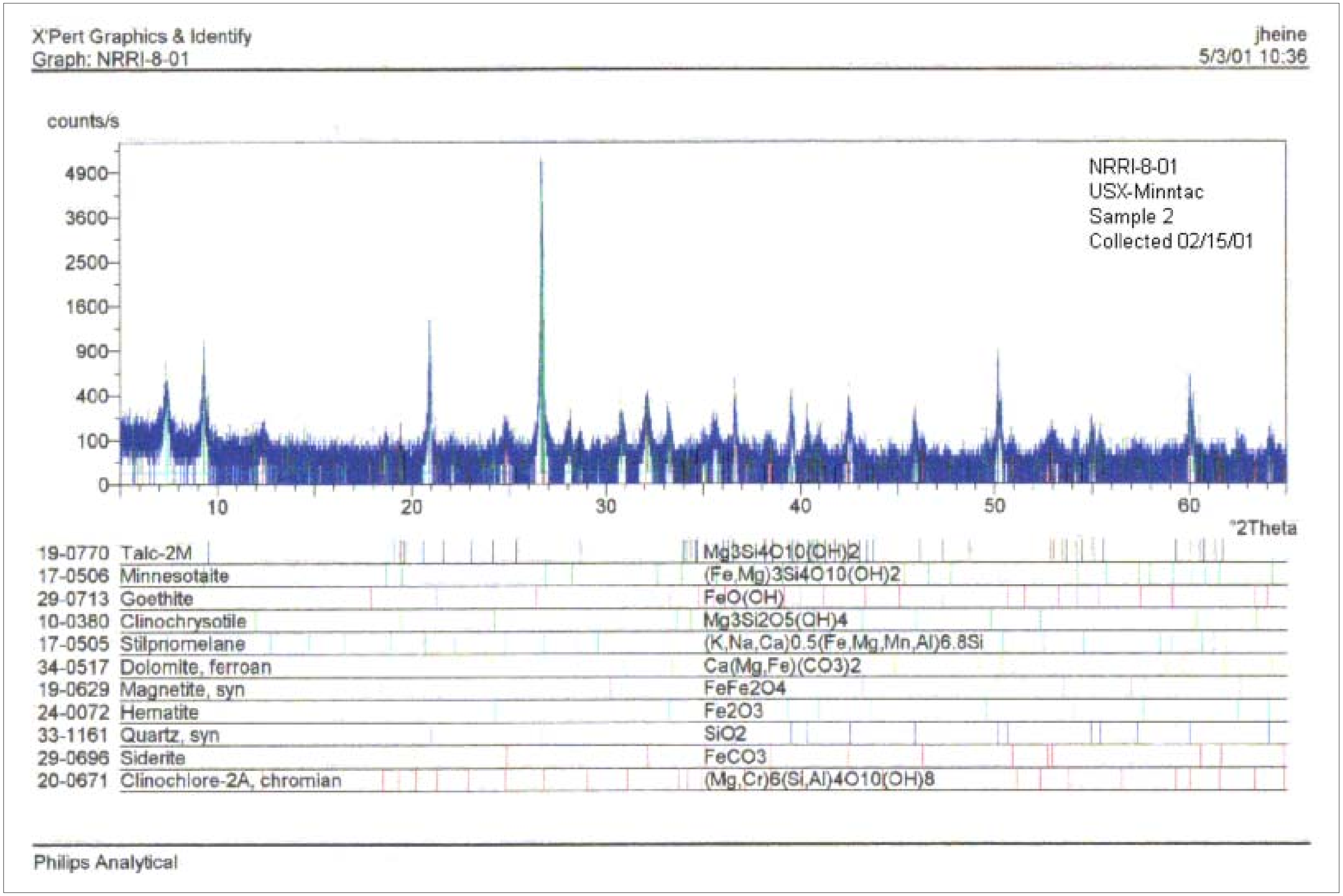

Figure 7.18 XRD trace of NRRI-08-01, Minntac Sample 2, collected 2/15/01: UMD

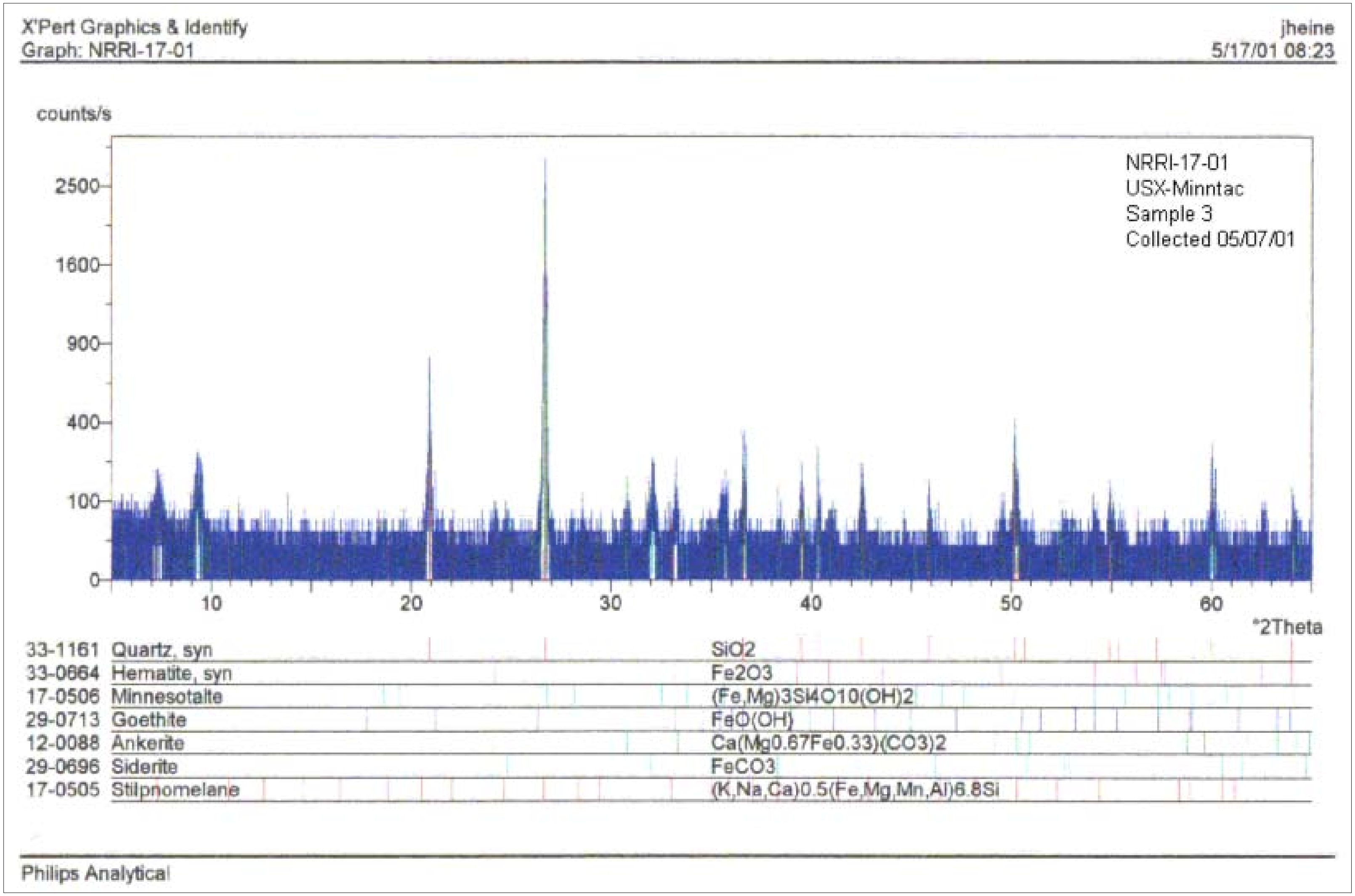

Figure 7.19 XRD trace of NRRI-17-01, Minntac Sample 3, collected 5/7/01: UMD

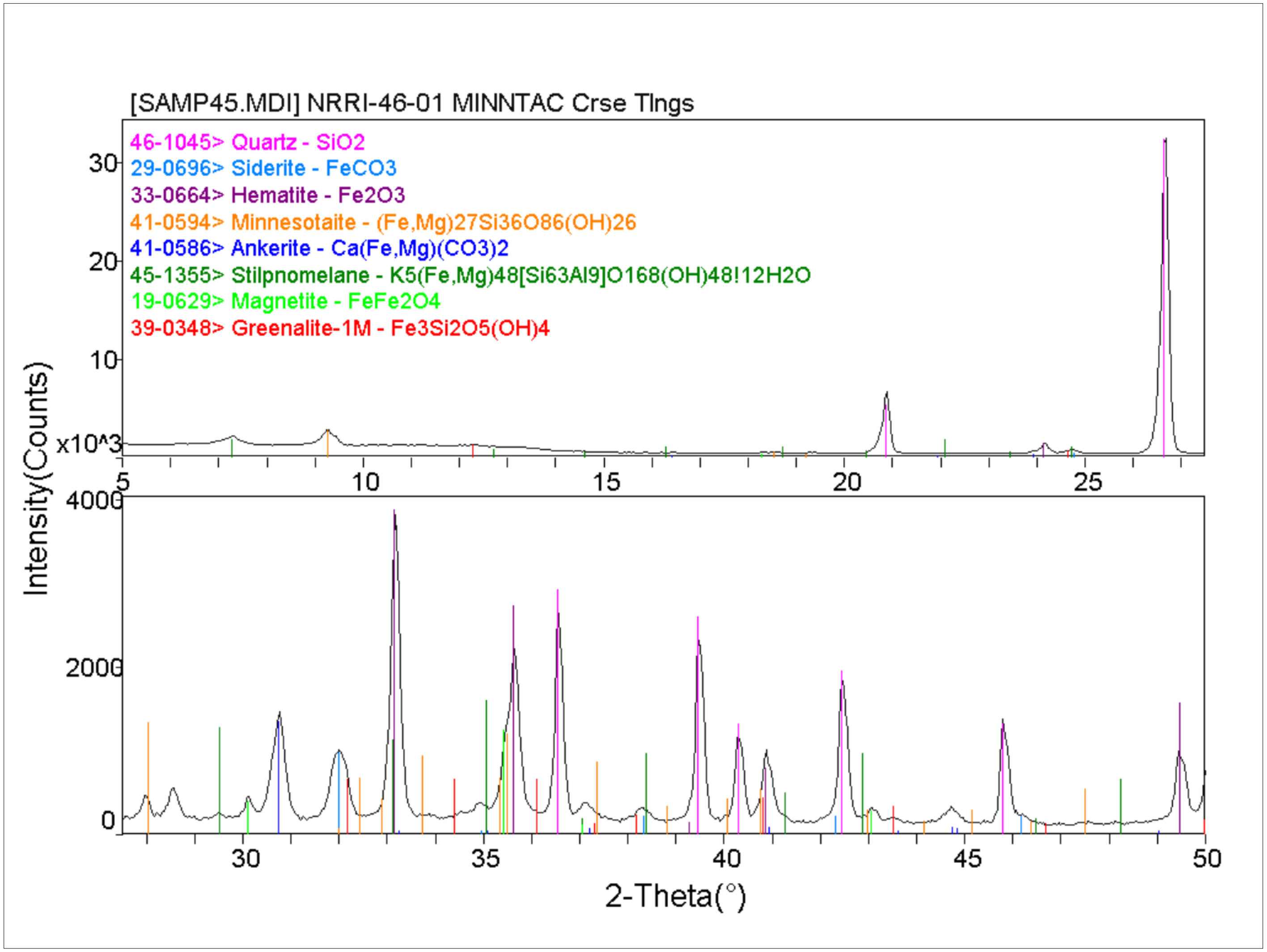

Figure 7.20 XRD trace of NRRI-46-01, Minntac Sample 4, collected 8/8/01: Shepherd Lab

NSPC Mineralogical Results

The relative percentages of major minerals in the two NSPC (now Keewatin Taconite) samples are summarized in Table 7.7. XRD traces for the samples are presented in Figures 7.21 and 7.22.

Table 7.7 NSPC sample mineral percentagaes.

NSPC		
	NRRI-37-01	NRRI-62-01
	07-09-01	10-01-01
Mineral	Mineral	Mineral
Name	percent	percent
Magnetite	4.3	3.6
Hematite	12.5	13.0
Goethite	3.5	6.2
Quartz	53.7	50.8
Minnesotaite	2.4	2.6
Stilpnomelane	4.7	4.3
Chamosite		
Greenalite	1.0	1.1
Talc	6.8	7.4
Ankerite	4.2	5.2
Siderite	4.0	2.5
Calcite	0.0	0.0
Hi-Mn Siderite	2.7	3.1
Rhodochrosite	0.0	0.0
Pyrite	0.056	0.077
Carbon	0.000	0.000
Apatite	0.084	0.084
Rutile (Equivalent)	0.016	0.015
Maghemite		
Dolomite	0.0	0.0
Fe-Dolomite	0.0	0.0

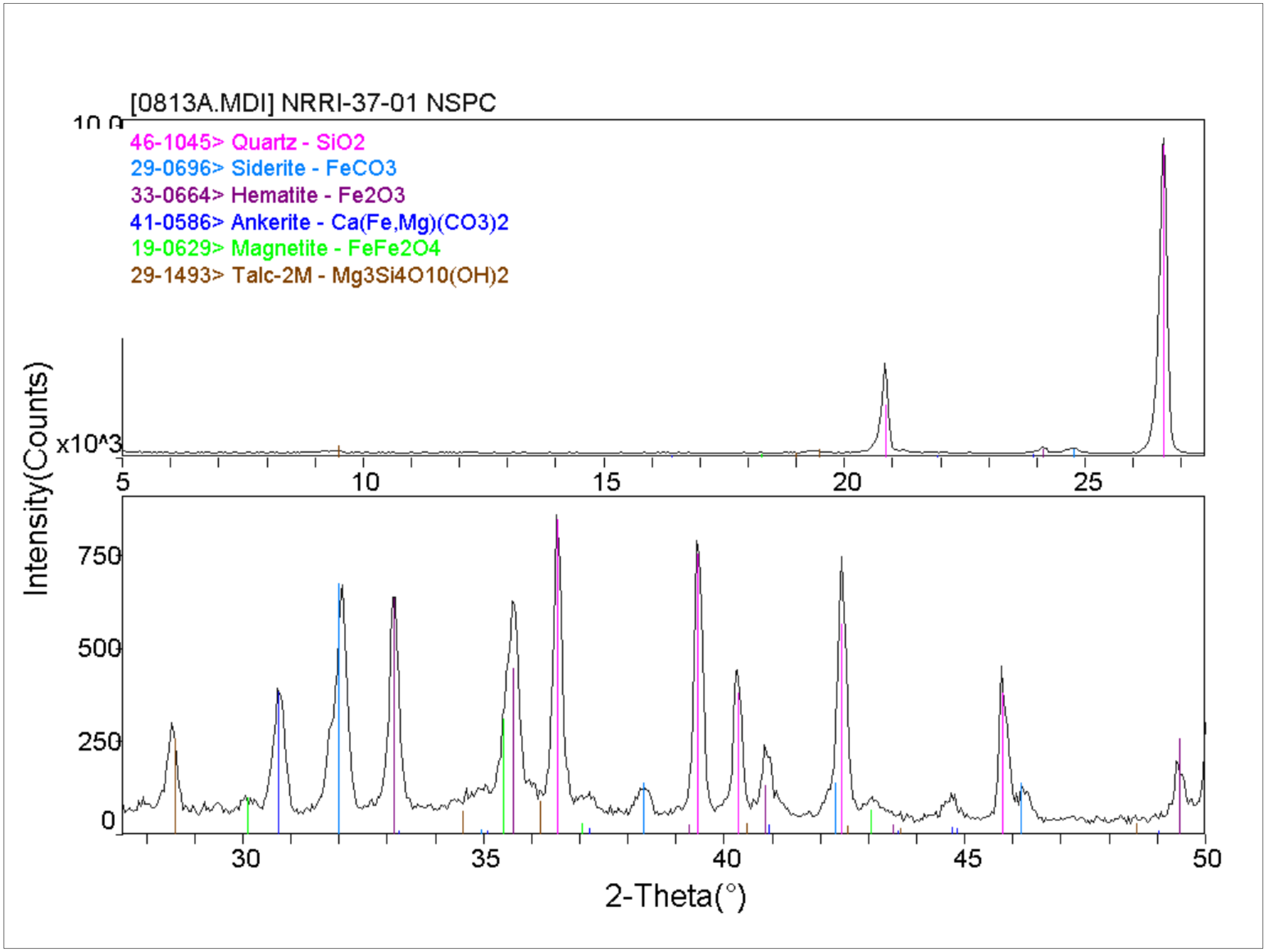

Figure 7.21 XRD trace of NRRI-37-01, NSPC Sample 3, collected 7/9/01: Shepherd Lab

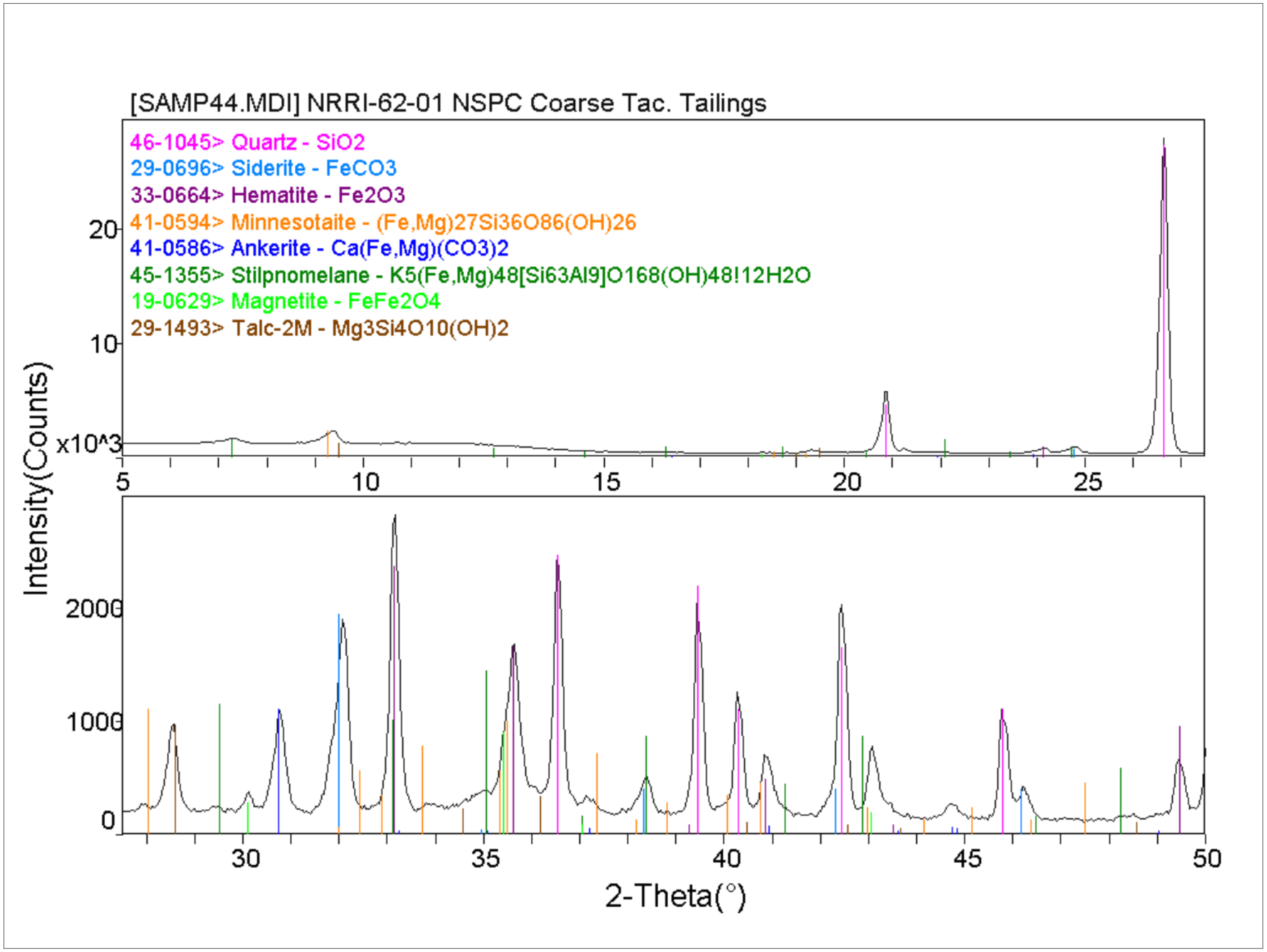

Figure 7.22 XRD trace of NRRI-62-01, NSPC Sample 4, collected 9/18/01: Shepherd Lab

CHAPTER 8: SPECIALIZED MICROSCOPY

Specialized microscopic work was subcontracted to the RJ Lee Group of Monroeville, PA. This work was done, in part, to address potential health concerns or questions that may arise in response to this project, specifically with regard to the "asbestiform" mineral issue. This issue has direct lineage to the Reserve Mining Co. trial of the 1970s, and to the mineralogy of the Biwabik Iron Formation at its eastern end. Bartlett provides useful detail and background on the issues surrounding the Reserve Mining case [21].

The iron-formation's eastern end was metamorphosed 1.1 billion years ago during the emplacement of a series of mafic igneous intrusions, collectively known as the Duluth Complex, and amphibole minerals were formed. The amphiboles are principally of the cummingtonite-grunerite series, and include some actinolite and hornblende [22]; [23]. These minerals first appear in the iron-formation midway through the former LTV Steel (now Cliffs Erie) property near Hoyt Lakes, as depicted by the diagonal lines in Figure 8.1. Some of their cleavage fragments can take on a morphology and an aspect ratio (length to width) of >3:1 (and greater than 5 microns in length) that has been called "asbestiform". The presence of amphibole minerals having these morphological characteristics was at the heart of the Reserve Mining Co. trial. However, they are *not* "asbestos".

The National Institute of Occupational Safety and Health (NIOSH) states: *"Asbestos" is a generic name given to a fibrous variety of six naturally occurring minerals that have been used for decades in the development of thousands of commercial products. The term "asbestos" is not a mineralogical definition but a commercial name given to a group of minerals that possess high tensile strength, flexibility, resistance to chemical and thermal degradation, and electrical resistance. These minerals have been used in many products, including insulation and fireproofing materials, automotive brakes and textile products, and cement and wallboard materials.*

The six regulated asbestos minerals are chrysotile (of the serpentine group of minerals), and tremolite, actinolite, amosite, anthophyllite, and crocidolite, which are in the amphibole group of minerals. However, cleavage fragments of non-asbestos minerals can have the same chemical composition as asbestos minerals. For example, cummingtonite shares its chemical formula with anthophyllite. Cummingtonite and anthophyllite are polymorphs, a situation where two minerals share the same chemistry but have different structures (poly=many, morphs=shapes). Diamond and graphite are classic examples of polymorphism. Cummingtonite and anthophyllite are often indistinguishable from other amphiboles without optical or X-ray diffraction tests.

All of the coarse tailings evaluated in this project came from taconite operations well to the west of the amphibole mineral area. Nevertheless, it was believed important to subject the samples to state-of-the-art analytical techniques and methods for detecting asbestos minerals and mineral cleavage fragments, because: 1) associations between "taconite tailings" and "asbestos" were still being made, regardless of where in the iron-formation the taconite ore and tailings originated; and 2) the potential use of coarse tailings and other taconite mining byproducts on a more widespread and significant basis inside and outside Minnesota would only generate more questions about those perceived associations. Therefore, the specialized microscopy work was performed to provide a factual and science-based evaluation and documentation of the mineralogical and physical nature of potentially respirable microscopic coarse tailings particles.

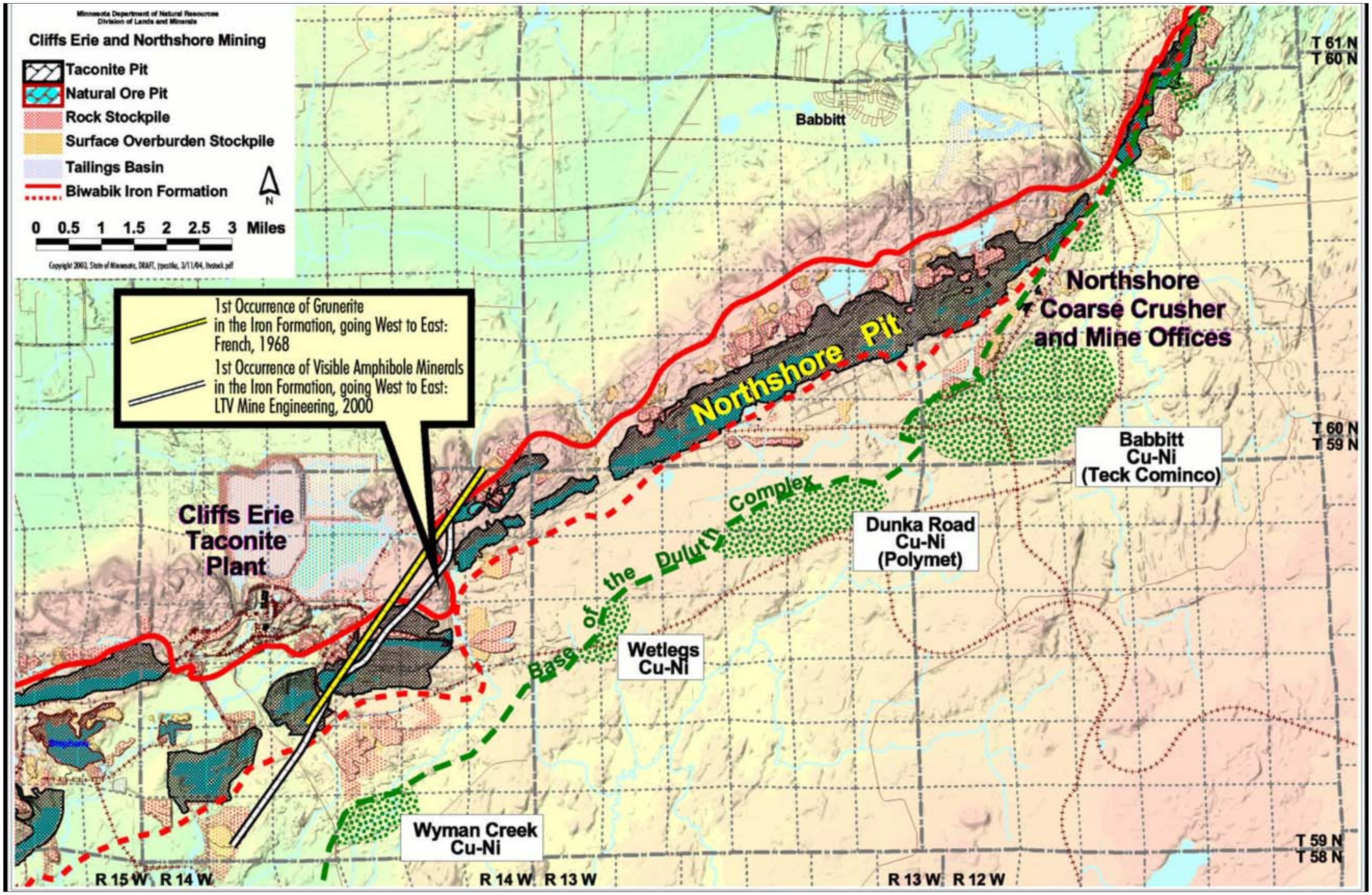

Figure 8.1 Map of Cliffs Erie (formerly LTV) and Northshore Mining Company properties showing line where grunerite and other amphibole minerals first appear at the eastern end of the BIF (map courtesy of Minnesota Department of Natural Resources, Division of Lands and Minerals, 2003).

ANALYTICAL TECHNIQUES

A combination of X-ray diffraction, polarized light microscopy (PLM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) was used to determine the size and shape characteristics of the minerals in the coarse tailings samples, and to determine if any asbestos minerals were present. Two sample types were submitted from each taconite operation: 1) composited, as-is, samples; and 2) composited samples pulverized to pass a 200 mesh screen. These composited samples were representative of the coarse tailings generated over a single production year at each mine.

A complete and detailed report was prepared by the RJ Lee Group on July 8, 2002, and is presented in Appendix A. Extracts and findings from that report are summarized and presented below. The summary reflects an update of the original (July 8, 2002) report's findings in which minnesotaite was incorrectly referred to as an "amphibole" in the XRD summary (minnesotaite is a layer silicate, not an amphibole), where some minnesotaite cleavage fragments found by the PLM analyses from Minntac and Minorca were also called amphiboles, and a structure found in one sample (#3030344 in the July, 2002, report) from EVTAC was reported as "actinolite/tremolite". Following discussions with Drew R. Van Orden, Senior Scientist at the RJ Lee Group, the samples in question were re-examined in April and May, 2003, and the findings were reported in a document received on May 7, 2003 (also presented in Appendix A in Section A.7). The re-examination showed that:

1) the Minntac and Ispat Inland (Minorca) fragments were minnesotaite; and
2) the "actinolite/tremolite" structure from EVTAC was really a talc fiber.

The follow-up review was requested because the authors did not want to publish potentially incorrect data, especially with an issue as sensitive as this. Even though we had previously discussed these discrepancies with the lab, and strongly suspected that the minerals were *not* amphiboles (based on the XRD analyses and our understanding of the mineralogy of the iron-formation), it was still important to re-examine these samples and verify their mineralogy. Suspicion is one thing; analytical confirmation is another.

The results indeed confirm that no amphiboles are present, and that no asbestos minerals are present in the coarse tailings samples.

SUMMARY OF RJ LEE GROUP REPORT FINDINGS

Samples of tailings from five taconite mines were received at RJ Lee Group for asbestos analysis. The tailings from each mine came in two forms - one "as-received" and the other pulverized to < 200 mesh (75 µm). The pulverized material and the < 200 mesh sieve fraction from the "as-received" sample have been analyzed by several techniques, which are summarized in the following sections. Full reports for the individual analytical tests are presented in Sections A.2 to A.7 of Appendix A.

X-Ray Powder Diffraction

A portion of each pulverized sample was ground in a mortar and pestle, mixed with fluorite (used as an internal standard), and backloaded into a standard XRD holder for analysis. The samples were processed using standard run parameters on a Philips XRD unit equipped with graphite monochromatized copper radiation. The analytical report and resulting XRD spectra are presented in Section A.2 of Appendix A.

The primary component of all samples is quartz, with varying amounts of hematite, magnetite, and siderite. The primary layer silicate mineral identified by XRD was Minnesotaite. (XRD cannot differentiate between fibrous and cleavage fragment varieties of minerals). No regulated amphibole was observed during these analyses.

Polarized Light Microscopy

Both the pulverized samples and the < 200 mesh fraction of the tailings were analyzed for asbestos content using polarized light microscopy (PLM) following the analytical procedures outlined in EPA/600/R-93/116, *Method for the Determination of Asbestos in Bulk Building Materials*. The non-asbestos materials, including cleavage fragments, were also identified and quantified during the PLM analysis. Quantitation of the sample was performed using a 1,000-point count procedure. Section A.3 of Appendix A also contains the analytical reports.

Trace levels of cleavage fragments were observed in the Minorca and Minntac samples by PLM. The cleavage fragments (four total in the entire PLM analyses) had moderate aspect ratios (> 3:1, length/width), but showed no evidence of fibular structure.

Based on the PLM analyses, no regulated asbestos minerals were detected.

Scanning Electron Microscopy

The pulverized samples and the < 200 mesh fraction of the as-received samples were analyzed using scanning electron microscopy (SEM) in general accordance with the methods outlined in ISO/DIS 14966 (Ambient Air: Measurement of inorganic fibrous particles - scanning electron microscopy method). A portion of each sample was weighed and placed in a beaker containing acetone. The suspension was shaken and an aliquot removed and deposited on a polycarbonate filter. A portion of the filter was placed on a carbon planchette and carbon coated (to reduce electrical charging on the particles).

The samples were analyzed in a SEM at an accelerating voltage of 20 KeV at a working distance of 15 - 17 mm. During the analyses, back-scattered electron images and energy dispersive spectroscopy (EDS) were used to evaluate the particles. Typical images and EDS spectra were acquired for major particle types, e.g., quartz, minnesotaite, talc, iron-oxides, and carbonates. Back-scattered electron images and EDS spectra were also obtained for particles that had a greater than 3:1 aspect ratio and were greater than 0.25 micrometers in diameter. Figures 8.2 to 8.7 are examples of images and spectra produced for the samples. Section A.4 of Appendix A contains the SEM count sheets, and all of the EDS spectra.

No asbestiform minerals were observed during the SEM analyses. Several cleavage fragments were observed in the < 200 mesh fraction that was sieved from the "as-received"

Minorca tailings; no cleavage fragments were observed in the pulverized Minorca sample. The chemistries for the cleavage fragments observed in the Minorca sample are consistent with minnesotaite and talc.

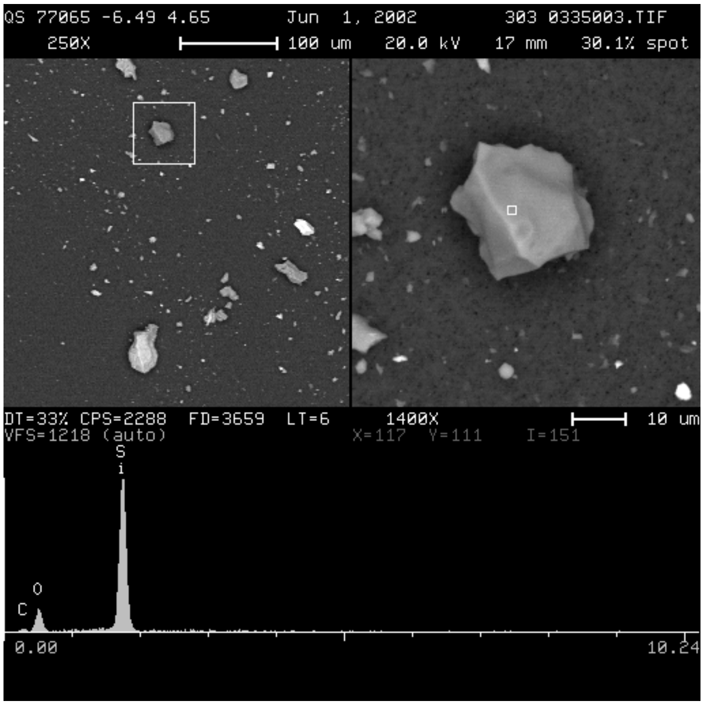

Figure 8.2 SEM image of quartz fragment: Ispat Inland (Minorca)

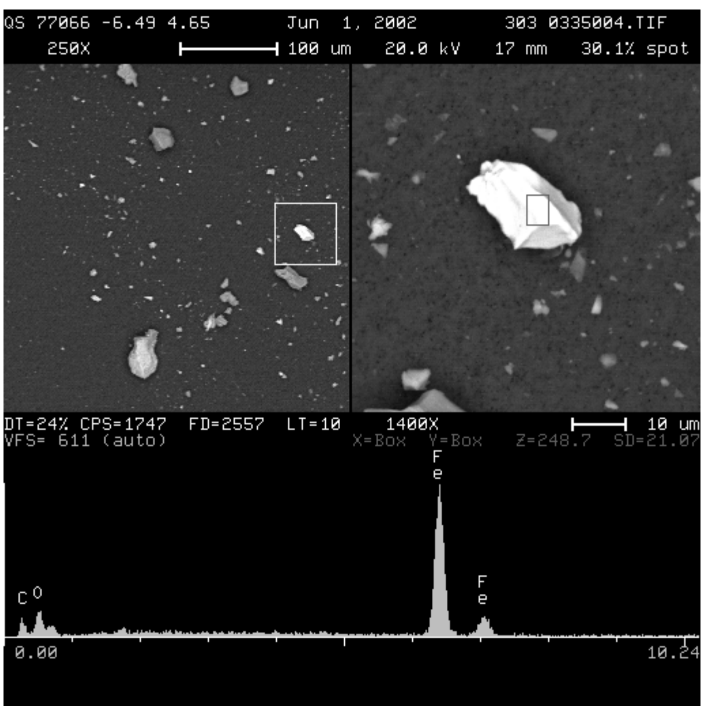

Figure 8.3 SEM image of iron-oxide fragment: Ispat Inland (Minorca)

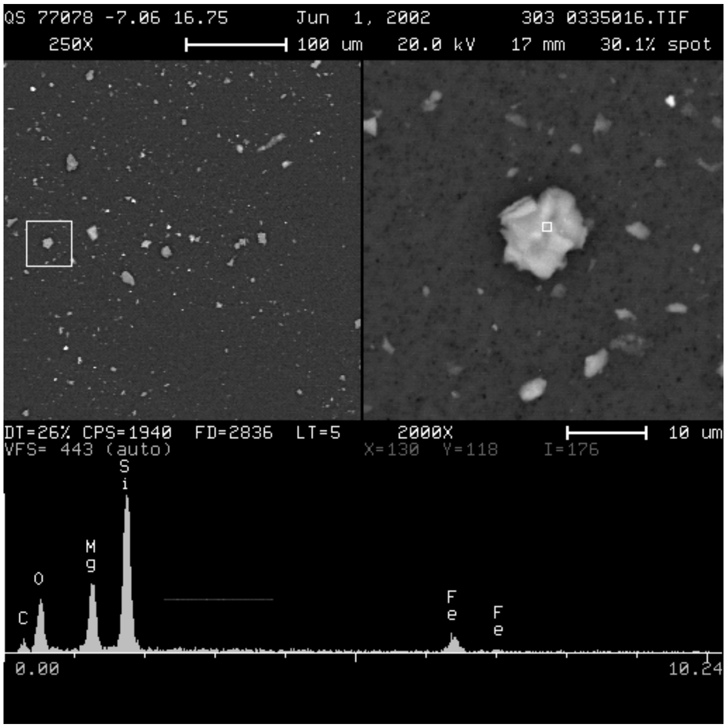

Figure 8.4 SEM image of talc fragment: Ispat Inland (Minorca)

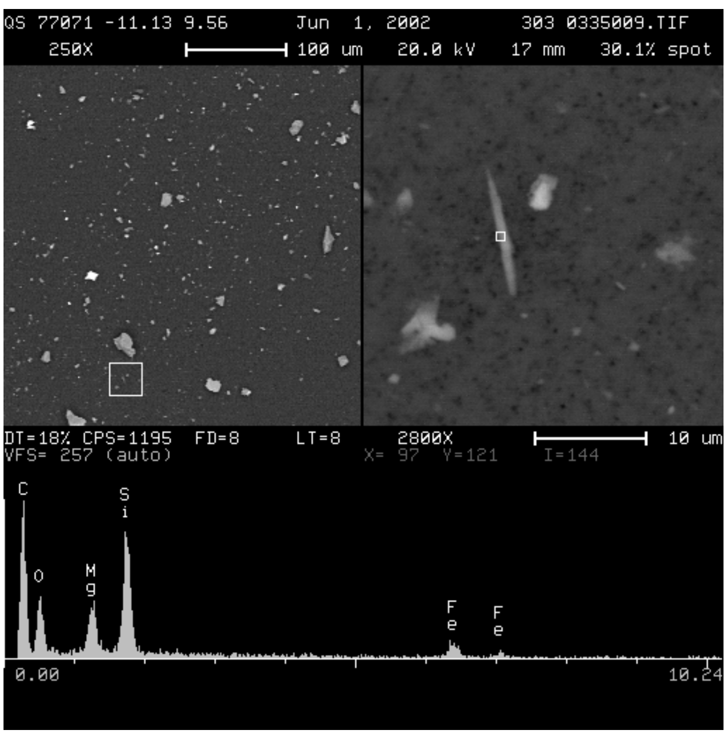

Figure 8.5 SEM image of talc cleavage fragment: Ispat Inland (Minorca)

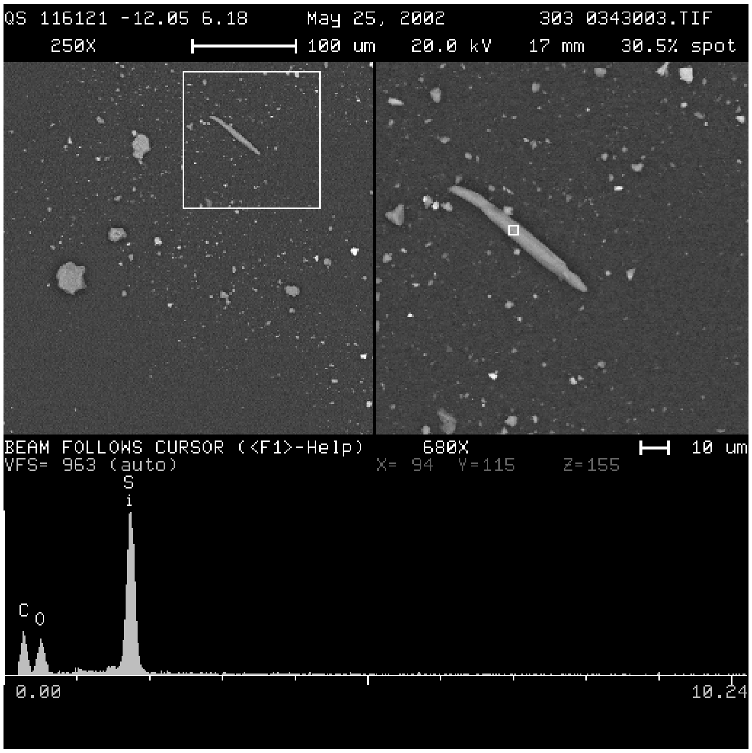

Figure 8.6 SEM image of silica-rich (quartz) cleavage fragment: EVTAC

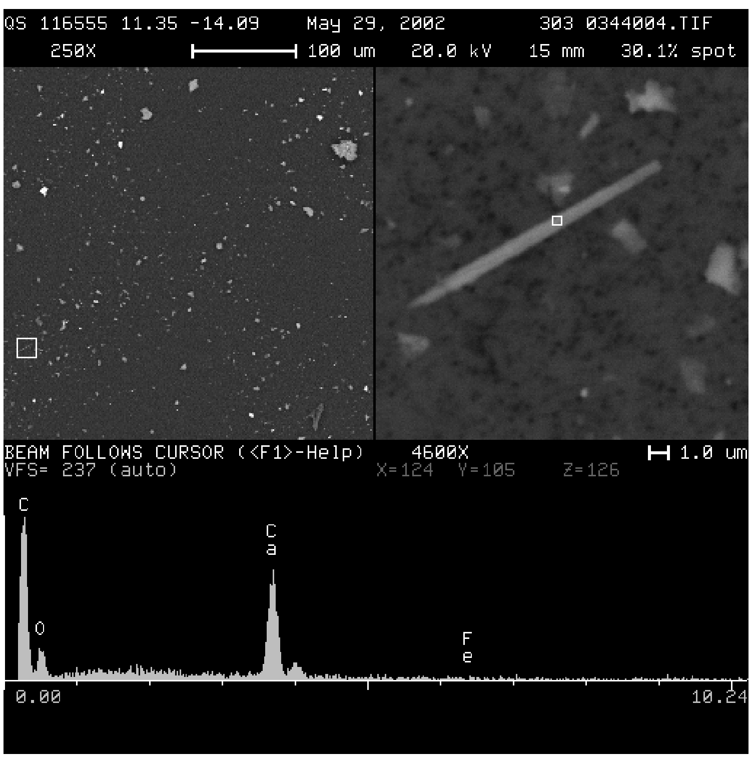

Figure 8.7 SEM image of calcium-rich (calcite?) cleavage fragment: EVTAC

Transmission Electron Microscopy

The tailing samples that were pulverized to < 200 mesh were analyzed by transmission electron microscopy (TEM) to determine the weight percent of asbestos and cleavage fragments. The analytical procedure used for the TEM analysis was in general accordance with the analytical portion of ASTM D 5756. A portion of each sample was weighed and placed in a beaker which was then filled to 100 ml with distilled water. The suspension was sonicated for 3 minutes, then allowed to settle for 2 minutes before an aliquot of the supernatant was removed and redeposited onto a 25 mm MCE filter. The filter was then prepared for analysis using direct preparation procedures. The TEM report and sample count sheets are attached in Section A.5 of Appendix A.

No asbestiform minerals or amphibole cleavage fragments were observed during the TEM weight percent analysis.

The "as-received" samples were analyzed using the *Superfund Method for the Determination of Releasable Asbestos in Soils and Bulk Materials*, EPA 540-R-97-028, as modified by Berman and Kolk [24]. The samples were sieved through a 1-mm screen (#18) and the two size fractions weighed. Seventy grams of the < 1 mm fraction was placed in the holder and tumbled as described in the method. Several filters of the elutriated sample were collected over varying times until one filter contained approximately 100 ug of samples. This filter from each sample was evaluated in the TEM for Protocol Fibers (fibers longer than 5 um and thinner than 0.5 um). The analytical data from these tests are included in Section A.6 of Appendix A.

No asbestiform fibers or cleavage mineral fragments were observed during the TEM analyses of the elutriated samples.

Based on these analyses, no asbestos minerals are present in these tailings.

Significance of Specialized Microscopy Results

Based on the combined results of the various tests, the RJ Lee Group concluded that no asbestos minerals were present in the tailings samples. The PLM and SEM analyses showed that some mineral cleavage fragments with an aspect ratio of >3:1 were present, but none were of the amphibole mineral group. Most of the cleavage fragments were consistent with minnesotaite or talc. As the previous mineralogical work has shown, both minnesotaite and talc are typical silicate minerals found on the western Mesabi Range. Interestingly, one of the cleavage fragments was silica-rich (quartz/chert?) (Fig. 8.6), and another was calcium-rich (calcite?) (Fig. 8.7). These findings suggest that mineral particles classified as "asbestiform" can be produced by crushing and grinding minerals that are neither amphiboles nor asbestos.

MSHA SAMPLING DATA

The fact that mineral fibers can be present in a variety of geological settings is shown in air sampling conducted by the Mine Safety and Health Administration (MSHA). Following news reports in 1999 that described serious health problems associated with amphibole asbestos-contaminated vermiculite mined at Libby, Montana, MSHA collected air samples from several mines and quarries in the United States between January 10, 2000, and March 25, 2002. The air sample data can be found at MSHA's web site: **www.msha.gov/asbestos/asbestos.htm** [25]. The purpose was to assess the air quality at operations where respirable mineral fibers could be generated, especially at other vermiculite mines.

The MSHA tests make no distinction as to mineral type, only to the total number of particles that meet the federal size and shape criteria to be classified as "fibers", i.e., >5 microns in length and <0.5 microns in width/diameter (EPA "protocol" fibers). The current MSHA personal exposure limit (PEL) is 2.0 fibers/cc for an 8-hour shift-weighted average. The Occupational Safety and Health Administration (OSHA) PEL is much more stringent at 0.1 fibers/cc for an 8-hour shift-weighted average. Figure 8.8 summarizes the MSHA air sampling findings by mine/quarry type for which at least six samples were available for averaging. The 0.1 fibers/cc OSHA standard is represented by the horizontal red line. The two bars for each mine/quarry type represent: 1) the average for samples that exceed the detection limit; and 2) the average for all samples, with those below the detection limit set equal to 0. Therefore, the first average will necessarily be greater than the second. Lastly, the data are taken in their entirety; no distinction is made between the various job categories for which air samples were collected.

The data (and graph) show Minnesota iron mines had an average PEL of 0.026 fibers/cc for an 8-hour shift-weighted average. This value is well below the OSHA standard, is comparable to the granite average, and is lower than the limestone average. For comparative purposes, samples taken in the 1970s at the Libby, Montana, vermiculite mine measured fiber levels at 18 fibers/cc.

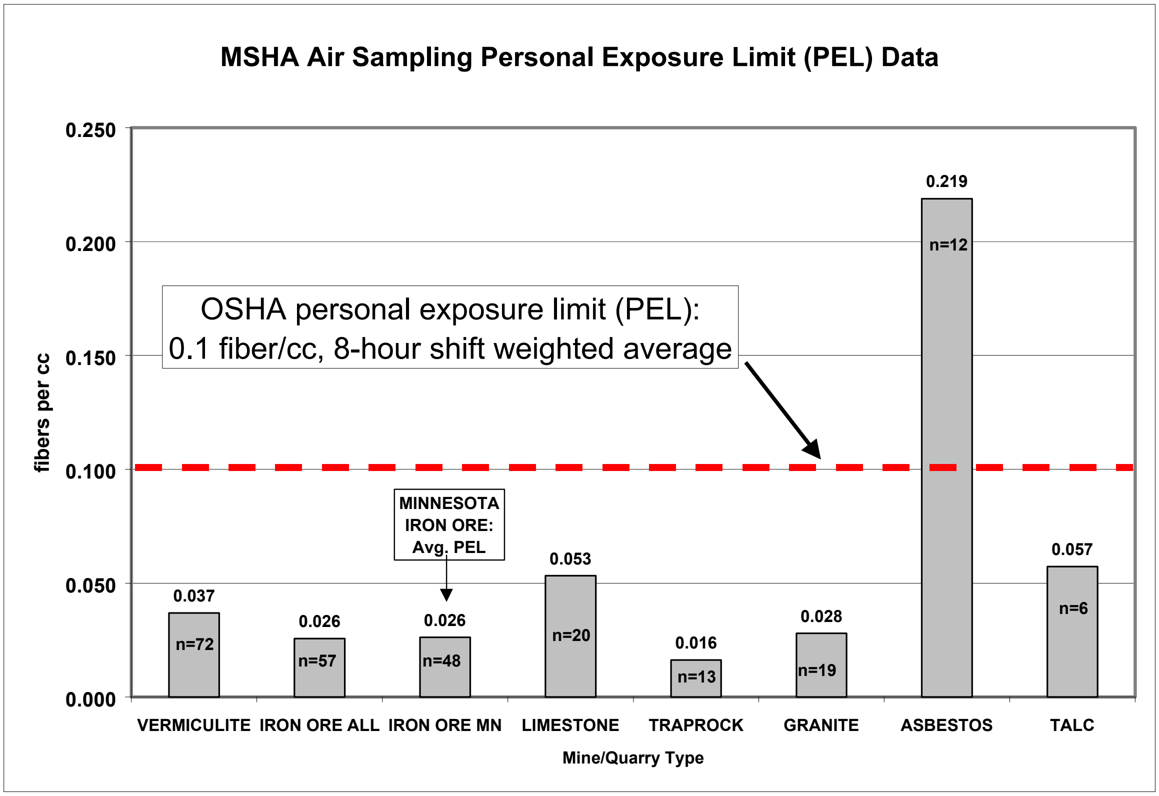

Figure 8.8 MSHA air sampling data and fiber counts.

Iron ore mines in Minnesota and Michigan were also sampled more thoroughly, not only in response to the Libby situation, but also to two Minnesota Department of Health (MDH) Minnesota Cancer Surveillance System (MCSS) reports published in 1997 (MCSS Epidemiology Report 97-1) and 1999 (MCSS Epidemiology Report 99-2) [26];[27]. The reports showed a higher rate (70% higher than expected) of the asbestos-related cancer, mesothelioma, occurring in males in a seven-county region of northeastern Minnesota.

Because some people ascribed the higher cancer rate to taconite dust exposure, the MDH conducted a follow-up study (MCSS Epidemiology Report 03:1) to look specifically at the incidence of mesothelioma in iron miners and possible sources of commercial asbestos exposure in the mining industry [28]. A summary of that study, presented as: "*Paper 6: Investigation of exposures to commercial asbestos in northeastern Minnesota iron miners who developed mesothelioma",* at the International Symposium on the Health Hazard Evaluation of Fibrous Particles Associated with Taconite and the Adjacent Duluth Complex, St. Paul, Minnesota, March 30-April 1, 2003, stated the following:

> *"Seventeen individuals (all men) diagnosed with mesothelioma in Minnesota between 1988 and 1996 were found to have worked in the iron mining industry. Of the 15 for whom adequate work histories were available, 14 had identifiable sources of exposure to commercial asbestos in jobs they held both inside and outside of the mining industry."*

These findings suggest that exposure to commercial asbestos products may have been a significant factor in the development of mesothelioma in the miners.

SPECIALIZED MICROSCOPY SUMMARY

Mineralogical and specialized microscopic analyses show that coarse taconite tailings sample composites from five western Mesabi Range taconite mines did not contain any of the six regulated asbestos minerals, nor did they contain amphibole minerals. A very small number of cleavage fragments/mineral fibers were detected by SEM, primarily minnesotaite.

Mineral cleavage fragments can also be generated from many rock types, not just taconite, as demonstrated by the Mine Safety and Health Administration's (MSHA) 2000 to 2002 air sampling data. Importantly, the *Superfund Method for the Determination of Releasable Asbestos in Soils and Bulk Materials*, EPA 540-R-97-028, as modified by Berman and Kolk and performed by the RJ Lee Group, failed to generate any protocol fibers from the coarse tailings samples [24].

The specialized microscopy analyses, coupled with the MSHA data and recent Minnesota Department of Health findings, should provide useful information to regulators and potential end-users about the nature of the dust that would be encountered when handling and using taconite mining byproducts like coarse tailings for construction aggregate purposes. The combined results show how geology, mineralogy, chemistry, physical properties, particle size, shape, and morphology, and intended end-uses must all be taken into account when working with any potential dust-generating aggregate, and should be viewed with proper context and perspective.

With respect to coarse taconite tailings, context and perspective includes the following points:

- most of the potentially respirable dust generated during the production of coarse tailings occurs at the mine sites;
- coarse tailings are a byproduct of typically wet mineral processing techniques, and are often transported as a slurry; they are, to varying degrees, a "washed" product;
- coarse tailings contain a small percentage of fines (-200 mesh), especially at operations that make a fine and coarse separation, where the percentage of fines is typically less than 2.5%;
- coarse tailings are hard and resist abrasion;
- coarse tailings are composed primarily of quartz; and
- coarse tailings would most likely be used in buried applications, such as granular fill, or encapsulated in bituminous asphalt or concrete mixes, thereby reducing the potential for post-construction dust exposure to negligible levels.

Therefore, coarse tailings and other taconite mining byproducts should be treated with the same common sense safety and industrial hygiene approach practiced for all mineral-based materials that have the potential to generate respirable dust, silica or otherwise.

CHAPTER 9: DATA ON MARKETS AND ECONOMICS

Technical suitability aside, any aggregate product is dependent on market conditions and costs, and coarse tailings are no exception. However, taconite mines that generate byproducts like coarse tailings have an inherently advantageous position relative to other aggregate producers for the following reasons:

1) The potential aggregate products they generate are largely incidental to their main business function of producing saleable iron units, typically in the form of taconite pellets;

2) Taconite mines are enormous, their byproduct output is enormous, and the mines are generally an accepted part of the landscape and culture of northern Minnesota. Conversely, many other "conventional" aggregate producers struggle with permitting issues and rampant NIMBYism, especially where their operations are near, or even within earshot of, residential developments.

Still, it is important to remember that taconite companies are in the business of mining and processing iron ore for making steel; the sale of taconite byproducts as aggregate products would only supplement - not replace – their main reason for existence.

To further address marketing and economic issues, a series of discussions took place with mining company representatives, Mn/DOT engineers, and contractors. Summaries of those discussions are presented on the following pages. Because low-cost rail haulage will be a key to more extensive taconite aggregate usage in the future, railroad information has also been compiled, and maps have been produced that show the proximity of the various rail lines to the taconite facilities.

MARKETING DISCUSSIONS

Discussions were held on-site at each of the five westernmost taconite producers: EVTAC, Hibtac, Ispat Inland (Minorca), Minntac, and NSPC. Topics covered included:

- products
- marketing issues
- progress to date (on marketing by-products)
- potential/goal (sales volumes and ultimate sales)
- directives for assistance (from agencies such as NRRI)

Similar discussions were held on-site with a private contractor, Terra Ferma Development, Inc. in Iron, MN, that handles outside sales of taconite tailings for Ispat Inland. Two other discussions took place with current and former Mn/DOT personnel - one at the Mn/DOT construction office in Virginia, MN, and the other at NRRI in Duluth. These two discussions centered on the actual use of taconite tailings in road construction. The following paragraphs and tables summarize the content of these discussions.

Products

A listing of products available for outside sales is presented in Table 9.1. EVTAC, Minntac, and Hibtac have expended the most effort in developing a line of taconite byproducts and have expressed the greatest interest in marketing their coarse taconite tailings. A private contractor handles outside sales of Ispat Inland's coarse tailings, which have been used for years in local road construction. While a small amount of NSPC's tailings are used locally in the Nashwauk and Keewatin area, most go into NSPC dike construction

Table 9.1 Product listing by producer.

EVTAC	Hibtac	Ispat Inland	Minntac	NSPC
Fine Aggregate (Coarse Tailings) Coarse Aggregate Magnetite Landscape Rock	Coarse Tailings ("Belt Filter Sand") Cobbing Rejects	Coarse Tailings	Coarse Tailings Ballast (100 % minus 2-in.) Ballast Fines (Class 5: minus 3/4-in.)	Coarse Tailings

Marketing Issues

Marketing issue discussions focused on placing value on taconite tailings as aggregate and moving them to new markets, particularly to the Twin Cities metropolitan area and the southeastern Minnesota / Rochester area. The value of taconite tailings stems from the fact that they are a dense, durable aggregate consisting of 100 % fractured faces (a Superpave requirement) formed as a byproduct in the production of taconite pellets. The energy required to produce the tailings has been expended in the processing of the crude ore. As a byproduct to this process, millions of tons of taconite tailings are stockpiled and available for use. However, they still cannot compete with local materials (gravel) price-wise.

Where discharged separately from the fine tailings, coarse tailings contain 0-3 % -200 mesh material. This provides open voids when used as fill, thus disallowing capillary action and guarding against frost-heave. Coarse taconite tailings are a higher-density product. This poses a problem in that current measure for payment by Mn/DOT specs is based on the lower specific gravity of common aggregates such as limestones, dolostones, granites, and quartzites. The higher specific gravity of taconite tailings produces a lesser yield, amounting to paying a penalty for use of tailings as aggregate. Easing of the specific gravity spec or, better yet, writing a new spec specifically for taconite tailings will remove a major obstacle in the path of marketing the tailings.

Tailings are cheap to get to Duluth. Moving them beyond and, particularly, breaking into the Twin Cities market, will require some effort. Primary movement would likely be by rail transport. This necessitates establishment of volume traffic, unit trains, minimal switching, back hauls, an unloading facility in or near the metropolitan area, and "do-able" rates. Burlington Northern Santa Fe (BNSF) railroad has direct links to the Twin Cities, Superior, WI, and Fargo, ND. Canadian National (CN) railroad runs straight through from Canada to the Gulf of Mexico via Wisconsin and Chicago, IL. The Duluth Missabe & Iron Range (DM&IR) railroad intercepts both BNSF and CN, and has direct access to Great Lakes shipping at ore dock facilities in Duluth and Two Harbors, MN. Other Lake Superior sites with rail access include Taconite Harbor (formerly used by LTV) and Northshore Mining Company's facility in Silver Bay.

Historically, the railroads have been difficult to deal with, and need to "get on line" with the taconite companies and others to make this work. Apparently this is starting to happen, as several of the producers have noted an increased willingness on the part of some railroads to work with the producers.

A facility in the Twin Cities or Rochester areas is necessary for unloading and loading. This involves locating a siding with a long rail spur. A 20-car lot would be ideal; a 10-car lot is needed at bare minimum. The "product" (coarse tailings) must be defined, as carrier rates are based on the value of the product hauled. A back haul must be established to gain profit above transport costs. Back haul possibilities include carbonate rock from the Rochester area and biomass fuels from the Twin Cities area.

Most recently, it was announced that Canadian National reached an agreement to acquire the railroad and related holdings of Great Lakes Transportation LLC [29]. The DM&IR will be part of that acquisition, as will Great Lakes Fleet, Inc. The latter has a fleet of eight bulk commodity vessels that sail the Great Lakes.

Progress To Date

<u>EVTAC</u>

EVTAC is currently moving product to the Twin Cities area, but feels the market potential is greater in the Rochester area due to less competition. The transportation issue for EVTAC appears to be working itself out. Rail rates are becoming reasonable and the DM&IR has been actively seeking new hauls in the last 1½ years.

EVTAC is moving landscape rock, which sells in the mid-$30 per ton range with a $10 per ton transport cost. However, the landscaping market is spotty, and landscape rock is a high-value/low-volume product that will grow slowly. Landscape rock from the iron-formation itself is starting to take off, but people still want the non-iron-formation boulders, i.e., granitic and gneissic boulders that are found in the glacial overburden. The higher value of landscape rock makes it less sensitive than coarse tailings to the high cost of transport.

In general, EVTAC is well-situated for movement of coarse tailings by rail. Rail track (DM&IR) runs right through the coarse tailings stockpile (Fig. 9.1). EVTAC has the advantage of being able to put rail cars on a siding where they're not in the way of pellet trains. Additionally, CN track runs along the eastern edge of EVTAC's tailings basin (Fig. 9.1), affording another potential sales outlet.

To promote the sale of its range of taconite byproducts, EVTAC has created a web-site: http://www.evtac.com. Locally, EVTAC coarse tailings are used in road construction projects, including the 2001 bituminous overlays on Highways 53 and 37, south of Virginia.

Hibtac

Hibtac has established contact with several of the major players in the aggregate industry of southeastern Minnesota. Hibtac's tailings lie adjacent to the BNSF rail line (Fig. 9.2); however, there is no siding. Cars must load/unload quickly to keep from interfering with pellet trains. Hibtac is working with a logistics agent to obtain better rail rates for moving their products, and has been actively working to create and build a market for their products in preparation of the expected aggregate shortage in southeastern Minnesota. BNSF provides Hibtac with a direct link to the Twin Cities metro area, Superior, WI, and Fargo, ND (Fig. 9.6).

Another mining byproduct at Hibtac is their cobber rejects, which were used in the construction of the precast concrete arch tunnels described earlier (see Fig. 3.2). Cobber rejects refer to that fraction of coarsely crushed (typically minus 1½-inch) crude ore that remains after the higher-grade and more magnetic fraction is sorted (cobbed) with magnetic separators. Coarse cobbing prevents excessive amounts of low-grade ore fragments from being processed further, which consumes valuable energy. These cobber rejects are currently undergoing testing by an outside testing lab to provide baseline aggregate data. This dry cob product has been described as the best concrete aggregate product on the Iron Range. Autogenous (rock-on-rock) grinding produces some rounded edges on this material.

Ispat Inland (Minorca)

Ispat Inland's outside sales of coarse taconite tailings has been handled by a private contractor, Terra Ferma Development, Inc., of Iron, MN, for the past five-plus years. A scale has been set up in the northwest corner of the Minorca pit to measure tonnages, and Ispat Inland receives a cut of the sales. For potential long-distance shipment of coarse tailings and other byproducts, Ispat Inland is serviced by the DM&IR rail line on a spur from the west off the CN rail line (Fig. 9.3).

Ispat Inland's coarse tailings are frequently used in road construction projects in the area, including the 2001 100 % taconite tailing bituminous overlays on Highway 53 in the Virginia area and Highway 135 from the Virginia garage to Aurora. The company's property is ideally situated for local distribution, with egress from three locations: 1) the entrance road to the west, which serves the City of Virginia, U.S. Highway 53 North and Trunk Highway 169 South; 2) the Laurentian Pit outlet to the southeast, which serves the cities of Gilbert and Biwabik, and MN Highway 135; and 3) County Road 304 to the north, off the northwest corner of the tailings dike, which serves Trunk Highway169 North.

Ispat Inland has historically separated its coarse and fine tailings, although options have been considered for commingling the two fractions and pumping both together into the Minorca pit. However, the capability to separately load out coarse tailings would be retained. More recent discussions (J. Holmes, pers. comm., 2003) suggest that coarse tailings will remain separate from fine tailings for the foreseeable future. Plans are forthcoming for the stockpiling of coarse tailings for a perimeter dam to be constructed on the south end of the Minorca Pit in 5 years.

As for generating a coarser aggregate, the company is producing all the pellets it can, and has no excess capacity in the crushing plant for making and sizing aggregate. Since there is no cobbing plant, Ispat Inland would need a contractor to crush material for road rock.

Minntac

Minntac is producing a video on using taconite tailings for pavements, base, and drainage. The company has most of the players in place for sending coarse tailings and ballast to the Twin Cities area. They are looking at a 50 - 75 car unit train that carries biomass fuel on the back haul. Their furnaces are equipped to run on biomass as an alternative fuel source, so this provides an ideal situation for them to acquire the necessary tonnages. Rail access to Minntac's coarse tailings is from the south via the DM&IR rail line (Fig. 9.4).

Minntac coarse tailings are used locally in road construction projects, including the 2002 reconstruction of T.H.169 between Virginia and Chisholm. The tailings were used as granular borrow, fine filter aggregate in edge drains, and bituminous aggregate. An independent contractor, Ulland Bros., of Mountain Iron, MN, produces railroad ballast out of Minntac's East Pit, with access to the Canadian National rail line on the east side of the Minntac property (Fig. 9.4).

NSPC

NSPC (now Keewatin Taconite) has not specifically looked to marketing their coarse tailings or other byproducts as aggregate, but has created niche markets for its pellets and concentrate. NSPC sells taconite pellets to Steffe's in North Dakota for use in high-density electric heat storage bricks. Concentrate is sold to farmers as a soil amendment and to companies as a fire retardant to put on coal. NSPC is serviced by the BNSF rail line (Fig. 9.5). Locally, NSPC tailings are used by the cities of Nashwauk and Keewatin and private individuals for road cover, water lines, basements, driveways, and garden drainage.

Potential/Goal

Each of the producers was asked to estimate the potential volume of coarse taconite tailings available per year for outside sale, and what their ultimate sales volume goal would be. These data are summarized in Table 9.2, and are reported as tons per year (TPY). Data for additional products are also included where provided.

Table 9.2 Potential and goal sales volumes of coarse taconite tailings, by producer.

Producer	Potential	Goal
EVTAC	Unlimited Coarse Tailings[1]	300K - 400K TPY Coarse Tailings[2]
Hibbing Taconite	Unlimited Coarse Tailings	375K TPY Coarse Tailings
Ispat Inland Steel	240K - 425K TPY Coarse Tailings	N.A.
USX Minntac	300K - 400K TPY Coarse Tailings	1M TPY by 2004 of all types of aggregate, the first being coarse tails (fine aggregate) and concrete aggregate.
NSPC	50K TPY Coarse Tailings	N.A.

[1] EVTAC has 37 years worth of coarse taconite tailings stored on site.
[2]Goal for 2002.

EVTAC's goal was to move 300K to 400K tons of coarse tailings from the Range to the Twin Cities in 2002. Hibtac's initial goal had been to sell 750K TPY of coarse tailings; however, their process has been altered and they will now be using half of this original amount in dike construction, etc. The volume potential listed for Ispat Inland is based on 1.2M - 1.7M TPY coarse tailings generated, of which 20-25 % go back to the pit for roads, etc. Ispat Inland's average sales of coarse tailings are 2K tons per month, or 24K TPY. The year 2001 saw this figure double to 48K TPY with several 100 % taconite tailings overlays being placed on area highways and 20,000 tons going to the Virginia Golf Course. Upcoming construction of an overpass north of Virginia, MN, on U.S. Highway 53 is projected to use 600K - 1M yds^3 of coarse tailings from Ispat Inland and Minntac. An independent contractor, Ulland Bros., of Mountain Iron, MN, is putting out 300K - 400K TPY of ballast on the CN rail line from the east end of Minntac's East Pit. This amounts to a 50 - 60 car train every day. NSPC generates 14M TPY of combined coarse and fine tailings, most of which are used for dike construction. One discharge line runs to the middle of the tailings pond, where it can be dug back.

Directives for Assistance

Table 9.3 presents directives from the taconite producers to NRRI and outside agencies to assist the process of moving taconite byproducts to market.

Table 9.3 Directives to outside agencies for assistance in bringing taconite byproducts to market.

American Engineering Testing
Compare tailings specs to existing specs for granular, fine aggregate, and select granular.
Define what products the Twin Cities market can potentially use (eg., $40-$60/T landscape rock).
Investigate electrical conductivity of crushed aggregate, particularly if used as railroad ballast.
Develop an ideal spec for taconite tailings so that plants can make adjustments within the operation to better meet specs.
Develop mix designs using taconite tailings with local material for the southeastern part of the state.
Develop special tailings high-wear pavements.
Develop specs requiring tailings in the mix.
Establish a price scale of, say, $0.50 - $0.75 - $1.00/T, increasing each year. Tie the cost to an index after the third year.
Evaluate and promote the safety aspect and performance of tailings, their longevity and safety features (eg., non-skid); more costly up front, but cheaper in the long run.
Investigate agricultural applications for taconite concentrate.
Investigate quarrying rather than mining taconite - the rock would be marketable all over the country (flagstones, retaining walls, facing stone).
Investigate seal coat specs.
Look at producing trap rock. All the mines could do this. It brings in $70.00/T in Chicago; can do it for $30.00/T shipped (vs. $2-$3/T for base material).
Promote a good road test. Hwy 7 from Forbes to Duluth used EVTAC tailings.
Sell the usage of taconite products. Get out the word on taconite products and why they should be used vs. what's available now.

Other Points of Discussion

Topics brought up in the discussions that have not been addressed elsewhere are presented below in Table 9.4.

Table 9.4 Additional topics of discussion relative to taconite mining byproducts.

Superior Minerals in Savage, MN, can handle a rail line; has Minnesota River access for barge.
Coarse tailings spec is a close match for septic system aggregate.
Potential issue of electrical conductivity with using tailings as ballast: can they affect switches?
Potential market for taconite tailings as roofing shingle aggregate.
There should be a good market for armor/shore stone around the Great Lakes, especially the Cleveland/Chicago markets (used to prevent shoreline erosion).
Forecast: coarse tails and Hibbing Taconite's cob tails have the best chance of being marketed in the near term; look for Class A aggregate in the long term.
Fee-holders are not covered for aggregate usage in some older leases. Waste materials are not covered under any royalty payment.
Twin Cities market works in terms of circles of influence. These circles will expand as the aggregate shortage increases.
Mine-specific advantages: ▪ Ispat Inland: tails load-out into trucks ▪ Minntac: can haul to set-up ▪ Hibtac: on BNSF line; will haul all cob rejects at one time to where they will be picked up ▪ EVTAC: tails load-out into trucks; loaders, shovels, and trucks available ▪ NSPC: on BNSF line
Cemstone was reportedly going to put in a railroad siding in north Minneapolis with bituminous and concrete plants.
Densities of Class 5 and taconite tailings are nearly the same; Class 5: ~128 lbs./ft^3, taconite tailings: ~130 lbs./ft^3.

Current Use of Coarse Tailings

Current coarse tailings usage as determined from the discussions is summarized in Table 9.5. This includes both on-site use and outside sales.

Table 9.5 Current coarse tailings usage.

Entity	Coarse Tailings Usage
EVTAC	Haul road construction. Dike construction.
Hibtac	Haul road construction. Dike construction.
Ispat Inland	Haul road construction: backfilled over as-shot waste rock. Dike/cell construction. Fill under concrete slabs and buildings.
Minntac	Haul road construction. Dike construction.
NSPC	Haul road construction. Dike construction.
Mn/DOT	Fill/base material: granular borrow, select granular, and Class 5 (coarser sizes: ballast (100% minus 1-inch). Sub-grade Bituminous aggregate Winter sand for snow and ice control.
Municipalities	Road construction/surfacing. Winter sand for snow and ice control.
Individuals	Basements Driveways Water lines Garden drainage

Local Mn/DOT Support For Taconite Tailings Usage in Road Construction

The Mn/DOT construction office in Virginia, MN, has been a strong proponent for the use of taconite tailings in road construction. Locally, coarse taconite tailings have been used as fill (granular borrow, select granular, and Class 5), sub-grade, backfill in subcuts, and fine filter material in edge drains. The Virginia beltline from 13th St. north to the last set of lights (ICO) was built on swamp. It was excavated and filled with taconite tailings. Up to 30 ft. of taconite tailings fill was placed at the ICO intersection on the north end. Ramps for Hwy 169 South (toward Hibbing) over Hwy 53 at Virginia were backfilled with taconite tailings.

Taconite tailings have been used locally in bituminous pavements and overlays. A 3/4-in. bituminous mat (plant seal mix with taconite tails) has replaced seal coating in the Virginia area. Tailings take the place of washed pea rock used in seal coating. A plant seal mix with taconite tailings designed for a 1-inch bituminous mat yields 15-20 years of service. In addition to extended road life, this mat improves the ride by leveling out the road and filling cracks. Taconite tailings used in bituminous yield a good constant product. Contractors are not required to do a trial mix, which can amount to $10,000 in savings. The depressed local job market on the eastern half of the Mesabi Range, brought about by the permanent closure of LTV Steel Mining Company, was buoyed by an increase in highway projects during the summer of 2001. These projects included 100 % taconite tailings bituminous overlays on large portions of U.S. Hwy 53 and MN highways 135 and 37 near Virginia, Eveleth, and Gilbert. Table 9.6 contains figures provided by Mn/DOT regarding tailings usage during the 2001 construction season.

Table 9.6 Estimate of tons of taconite tailings used in bituminous mixes during the 2001 construction season (*after Estimate of Bituminous Total Tons for 2001, provided by Mn/DOT-Virginia construction office).

Estimate of Taconite Tailings Used in Bituminous, 2001*				
Highway	Source	Mix Type	% Tailings	Tons
53	EVTAC	SPNW	26 %	5,742
53	EVTAC	SPWE	30 %	5,375
53	EVTAC	LV3WE	15 %	1,451
37	EVTAC?	MV3NW	30 %	1,821
37	EVTAC?	MV4WE	30 %	1,207
37	EVTAC?	HV5WE	100 %	4,377
37	EVTAC	MV3NW	15 %	9,880
53	Ispat Inland Steel	HV5WEB	100 %	40,757
53	Ispat Inland Steel	HV5WEE	100 %	7,424
135	Ispat Inland Steel	HV5WE	100 %	24,954
135	Ispat Inland Steel	LV4WE	31 %	9,202
135	Ispat Inland Steel	MV3NW	28 %	6,892
135	Ispat Inland Steel	LV3NW	27 %	10,117
1 & 169	Ispat Inland Steel	LV3WE	30 %	348
1 & 169	Ispat Inland Steel	MV4WE	15 %	1,040
53	Ispat Inland Steel	MV3WE	15 %	210
53	Ispat Inland Steel	MV3NW	15 %	158
53	Ispat Inland Steel	LV3NW	15 %	264
			Total Tons Taconite Tailings	131,221

Taconite tailings had commonly been used as winter sand prior to the Milepost 7 furor. Virginia has resumed using the tailings for snow and ice control in the past few years. The tailings are blended with washed concrete sand and a brine solution (granular calcite). The dark color of the tailings absorbs the sunlight, hastening melting.

According to Mn/DOT personnel, when taconite tailings are used as fill, it is necessary to place them using large amounts of water. The water causes the particles to flow together and interlock. The use of tailings as a base material requires a 3-in. gravel cap to prevent the tailings from drying out. When moisture is lost, the upper few inches of tailings become sugary and fluff up, damaging the road surface above.

Taconite tailing volumes for payment are determined by truck count, plant quantity, or stockpile cross-section. Taconite companies have apparently jointly set the price of taconite tailings at $1.00/yd^3$.

There is a downside to tailings and other taconite byproduct usage that Mn/DOT points out. Tailings are very abrasive on metal equipment. Coarser material (1-in. size) is hard on tires as it is very sharp. Tailings stockpiles dry out; they need to be watered more often to keep this fine aggregate from segregating. Tailings will scar if raked when placed as fill or bituminous pavements. Better aesthetics are achieved by just rolling.

TRANSPORTATION

Beyond demand and market acceptance, low-cost rail transportation will be key for expanded use of taconite mining byproducts like coarse tailings in markets beyond northeastern Minnesota. Low-value/high-volume industrial minerals like crushed aggregate are typically prisoners of geography. However, an extensive rail network is in place for hauling large amounts of pellets and carbonate rock (fluxstone) to and from the mines. As was mentioned previously, the Duluth-Misabbe & Iron Range (DM&IR), Burlington Northern Santa Fe (BNSF), and Canadian National (CN) have been the primary railroads servicing the Iron Range. But, now that Canadian National has reached an agreement to acquire the DM&IR and Great Lakes Fleet, Inc. (the latter of which has a fleet of eight bulk commodity vessels that sail the Great Lakes), the dynamics for moving large quantities of taconite aggregate products more efficiently might be more favorable.

Figures 9.1 to 9.5 show the rail line locations relative to each taconite operation; Figure 9.6 shows the overall rail network in the state of Minnesota [31]. The presence of two Class 1 carriers like BNSF and CN is important for the long-term prospect of moving large amounts of taconite aggregate to more distant markets. For example, CN now has a continuous rail route from the Canadian border to the Gulf of Mexico.

Distribution logistics will also be very important for the expanded use of taconite aggregate, and is something for which established aggregate producers and contractors could play a vital role. Consequently, partnerships or agreements with one or more aggregate producers and/or contractors would be the most likely scenario, especially at the delivered (market) end, simply because those entities are already in the business of aggregate sales and distribution. One or more aggregate terminals in the Metro Area would help in this regard.

Lastly, if a back-haul were part of the taconite aggregate transportation equation (for example, returning bio-mass to taconite facilities for use as fuel, or carbonate rock as a flux source for taconite pellet production), the overall economics could be improved, as suggested in a previous study by Zanko [30]. Interestingly, Wolters and Cassellius described taconite tailings being transported approximately 200 miles for bituminous paving usage [9]. This seems to suggest that at least 28 years ago, the conditions existed for economical movement of tailings as far as the Twin Cities. Perhaps we are approaching the same or similar conditions in 2003.

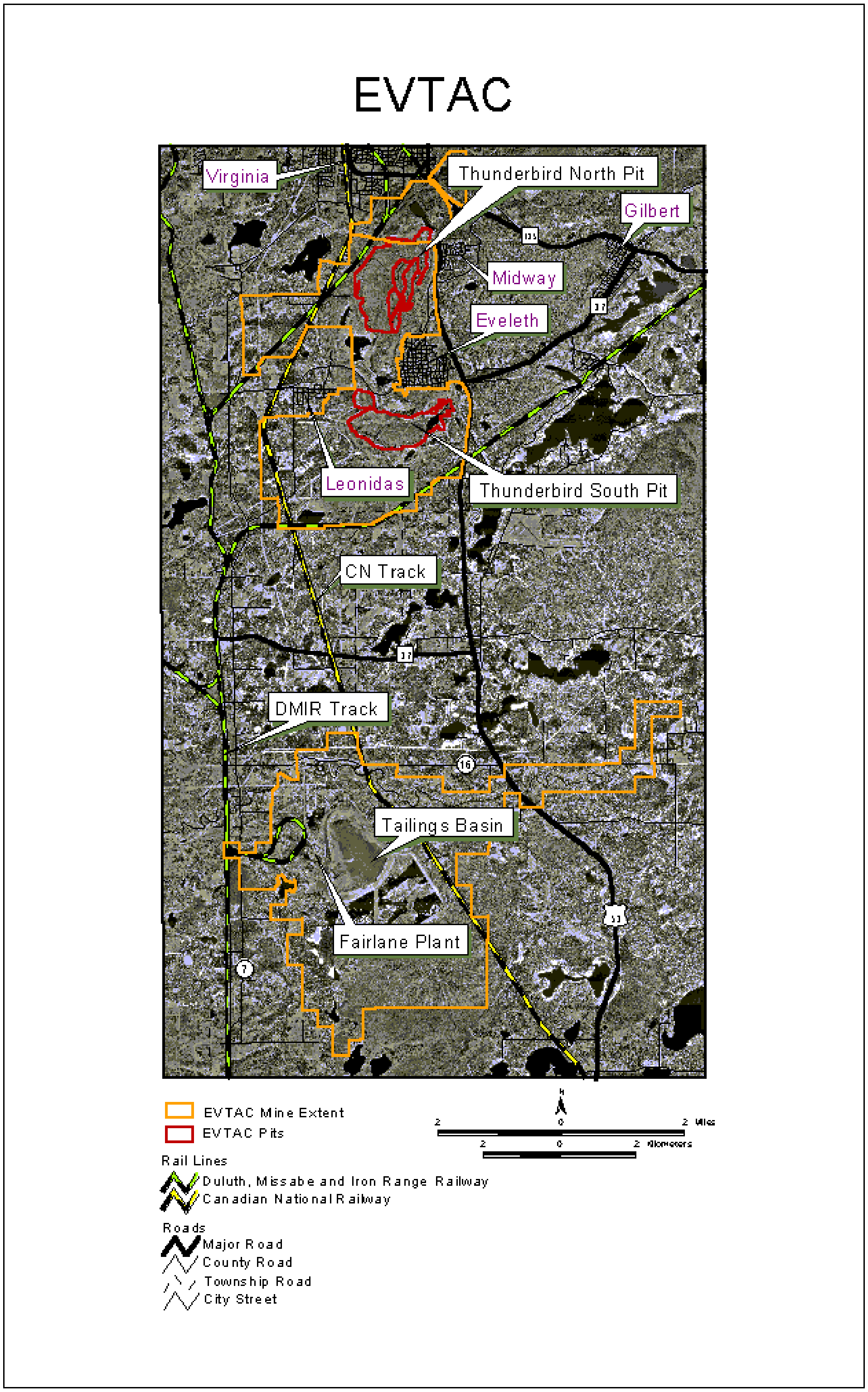

Figure 9.1 Rail lines relative to EVTAC.

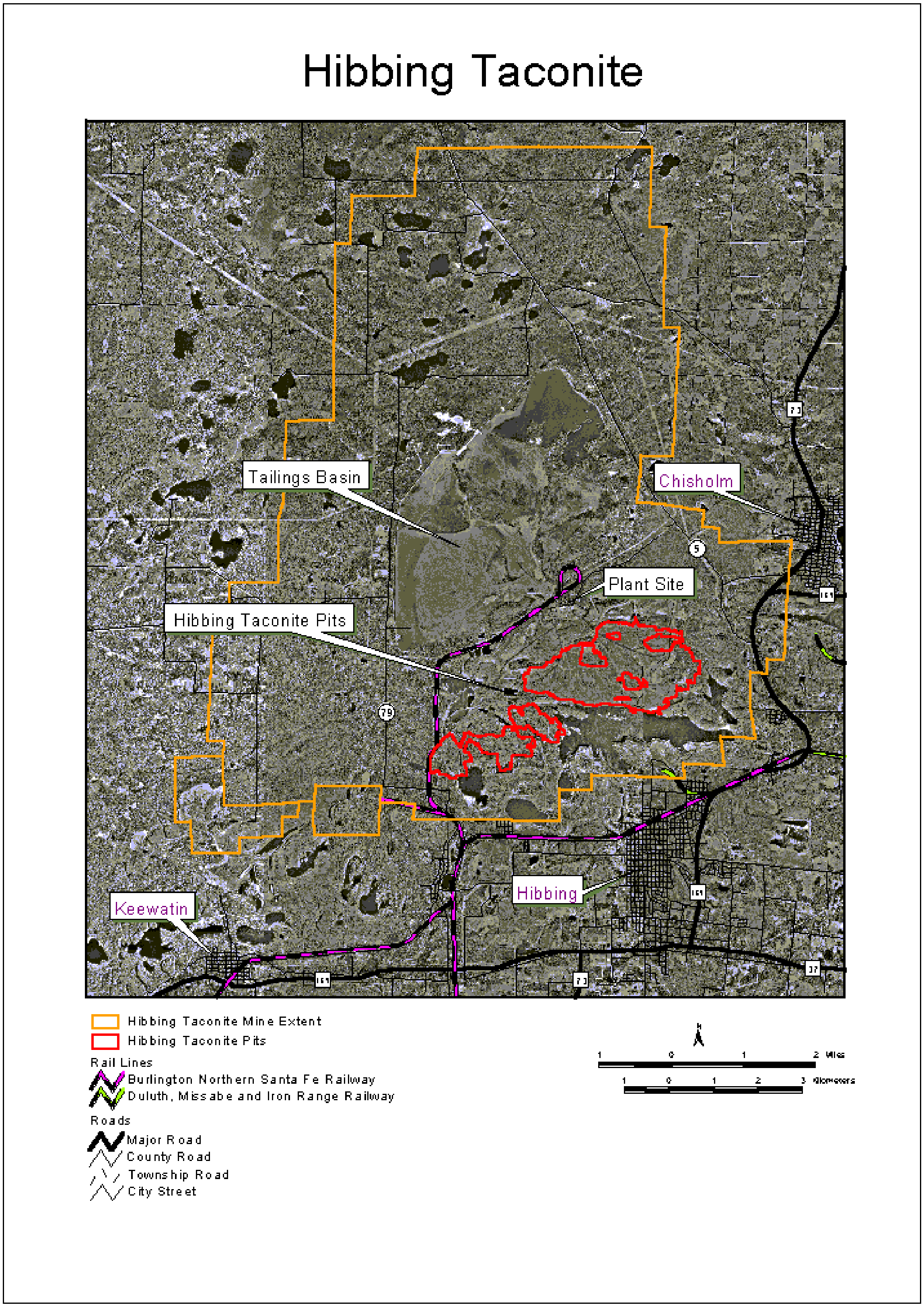

Figure 9.2 Rail lines relative to Hibtac.

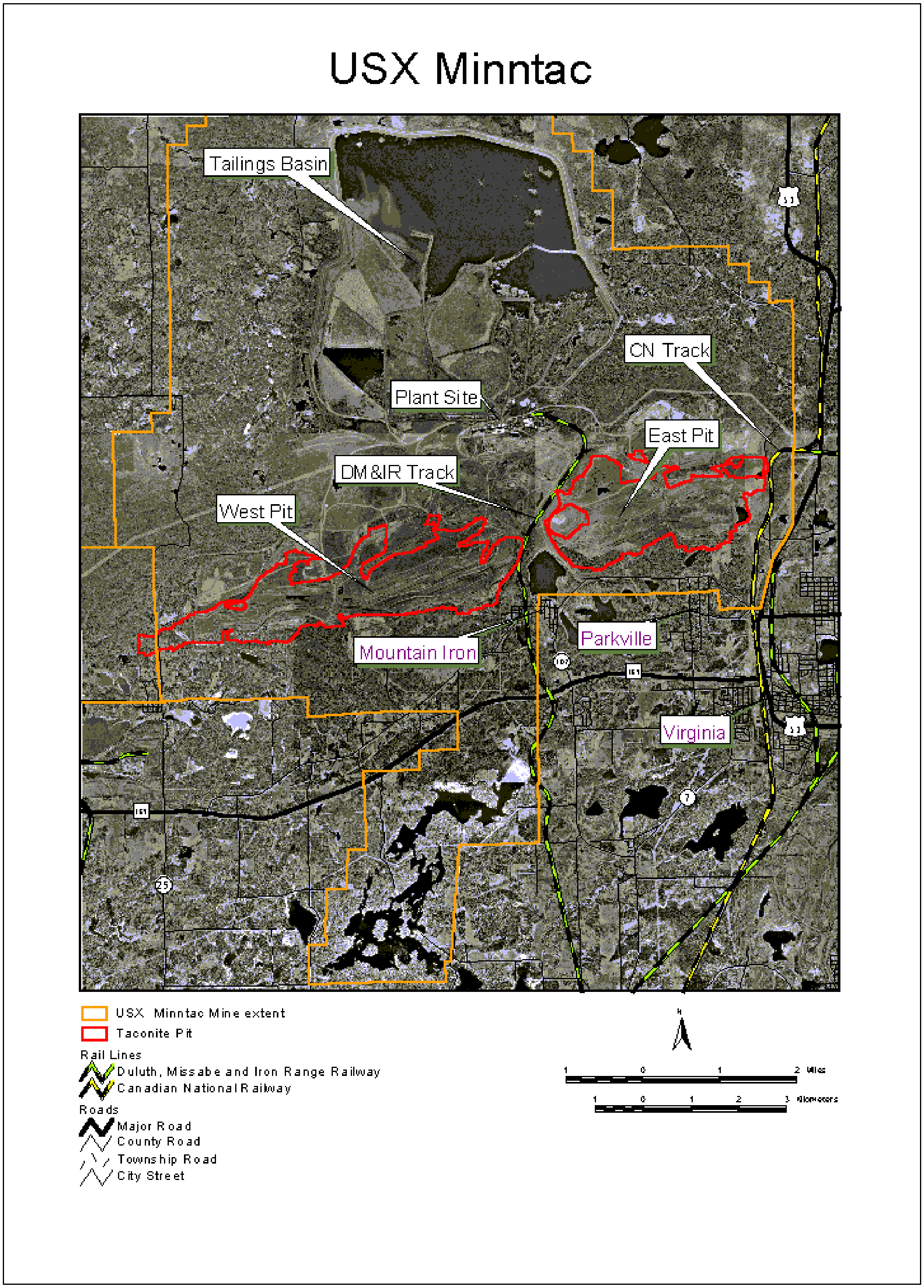

Figure 9.3 Rail lines relative to Minntac.

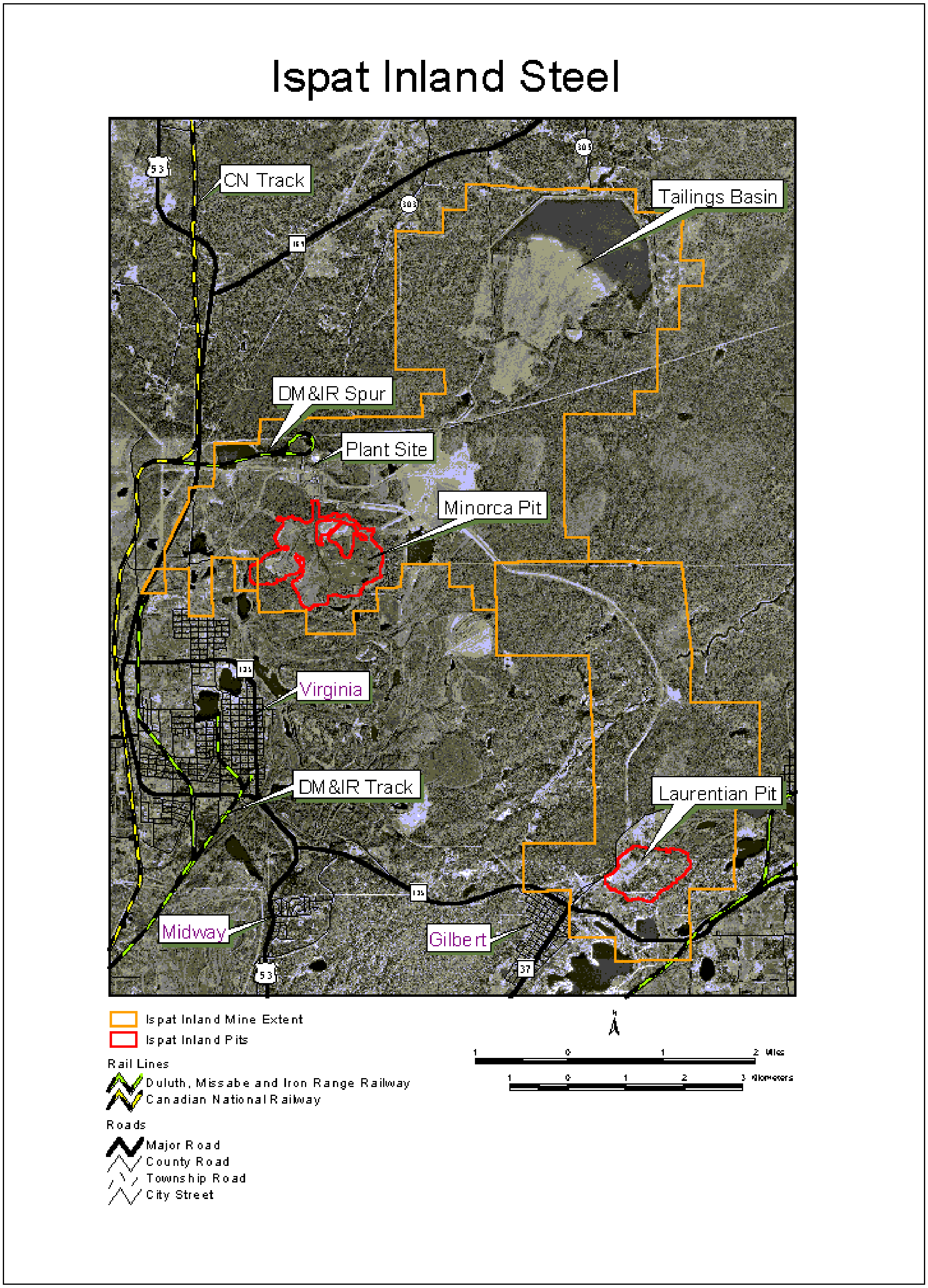

Figure 9.4 Rail lines relative to Ispat Inland (Minorca).

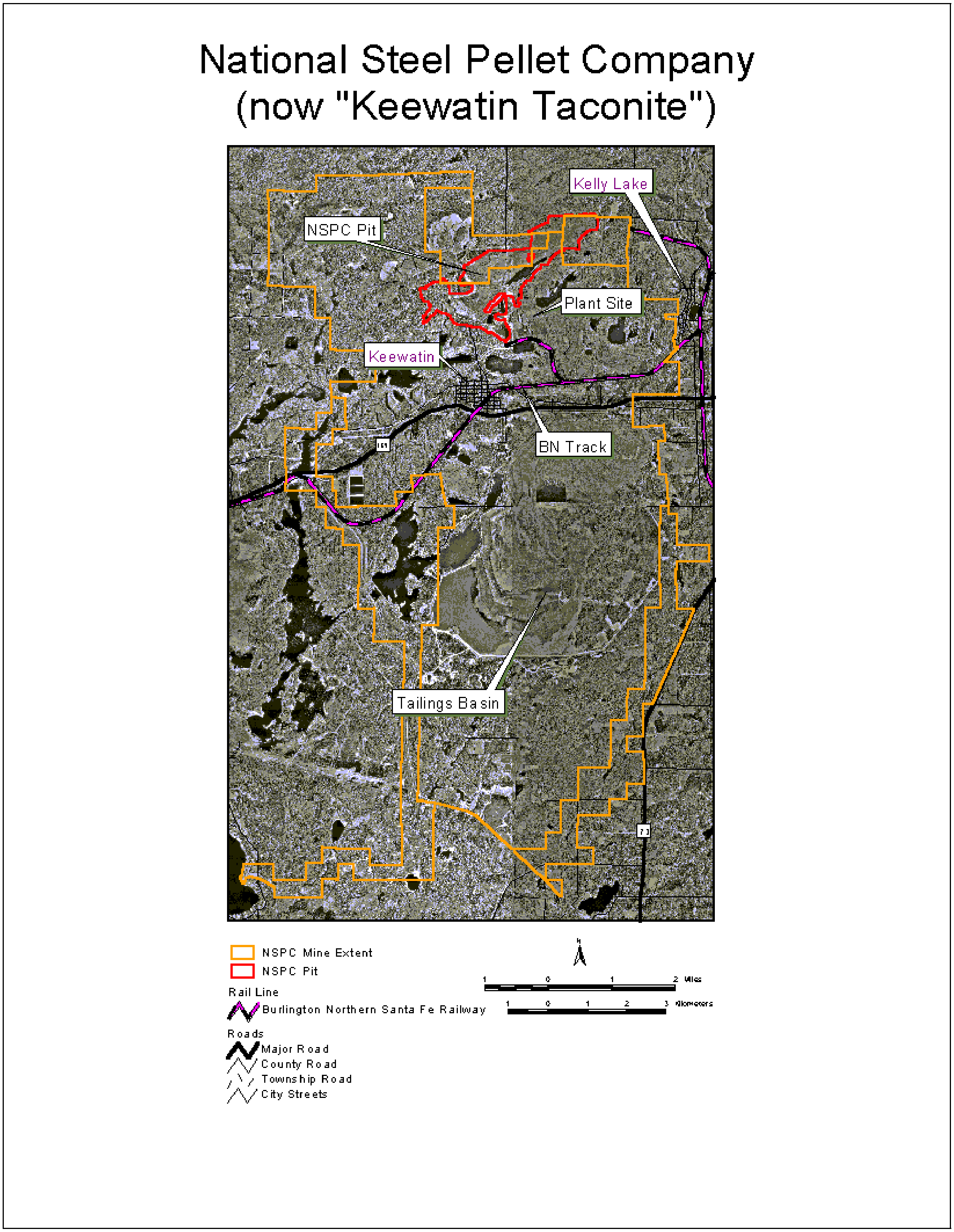

Figure 9.5 Rail lines relative to NSPC (now "Keewatin Taconite").

Figure 9.6 Minnesota railroad map, 2000 [31]

CHAPTER 10: DATA INTERPRETATION AND REPORTING

Data interpretation and reporting have taken place throughout the study. Final data interpretation is reflected in the various task discussions and summaries presented in each chapter. Project reporting has been accomplished via: 1) six Taconite Aggregate Project (TAP) meetings; 2) attendance at a Mine Safety and Health Administration (MSHA) public hearing held in Virginia, MN, on June 12, 2002; 3) formal presentations made at the April, 2002, and April, 2003, Society of Mining Engineers (SME) Annual Meeting in Duluth; 4) an informal presentation made at the *International Symposium on the Health Hazard Evaluation of Fibrous Particles Associated with Taconite and the Adjacent Duluth Complex*, St. Paul, Minnesota, on April 1, 2003; 5) poster presentation at the Fourteenth Annual Transportation Research Conference, St. Paul, Minnesota, on April 29, 2003; 6) e-mail communications; and 7) the production of this final report.

REPORTING DETAIL

TAP meetings

Five of the TAP meetings were held on November 22, 2000; June 7, 2001; March 25, 2002; July 12, 2002; and November 12, 2002. A sixth and final meeting took place on December 16, 2002, for feedback on the draft final report. All meetings were held at NRRI in Duluth, except for the June 7, 2001, meeting, which took place at the USX Minntac facility in Mountain Iron and included a tour of the mine and processing facility. The Minntac tour gave those TAP members who had never been to a taconite mine a sense of its scale, and a better idea of the type and amount of byproduct materials (like coarse tailings) that a taconite operation generates.

MSHA public hearing

On June 12, 2002, a public hearing, *"Measuring and Controlling Asbestos Exposure"*, was held by the United States Department of Labor - Mine Safety and Health Administration (MSHA) in Virginia, MN. The purpose of the hearing was to help MSHA evaluate five issues:

1) whether to lower MSHA's asbestos permissible exposure limit;
2) whether MSHA should replace its existing fiber analysis method referred to as phase contrast microscopy with a more sensitive method, which is transmission electron microscopy;
3) whether MSHA should implement safeguards to limit take-home exposure;
4) whether MSHA's field sampling methods were adequate and how their sampling results were being used; and
5) what would be the likely benefit and cost impact of any rulemaking action MSHA would take on these issues.

During the hearing, a brief presentation of the project's preliminary specialized microscopy results was made.

SME presentations

An overview of the project was presented in a talk and slide presentation, titled, *"Properties and Aggregate Potential of Course Taconite Tailings - An Evaluation of Five Minnesota Taconite Operations"*, at the 75th Annual Meeting of the Minnesota Section of SME and the 63rd Annual University of Minnesota Mining Symposium in April of 2002. In April of 2003, another presentation, titled, *"Properties and Aggregate Potential of Coarse Taconite Tailings from Five Minnesota Taconite Operations"*, was made at the 76th Annual Meeting of the Minnesota Section of SME and the 64th Annual University of Minnesota Mining Symposium.

The SME meeting and symposium is held annually at the Duluth Entertainment Convention Center (DECC) in Duluth, Minnesota, and is a gathering of industry professionals, equipment and technology vendors, consultants, and researchers that work in and with Minnesota's mining industry. The venue provides an excellent opportunity to disseminate information about the project.

Fibrous Particle Symposium

An informal presentation was made at the *International Symposium on the Health Hazard Evaluation of Fibrous Particles Associated with Taconite and the Adjacent Duluth Complex*, St. Paul, Minnesota, on April 1, 2003. This was an opportunity to present and discuss some of the testing results from the project related to mineralogy and "fibrous" particles. The symposium hosted world experts in the fields of analytics, health and risk studies, and geology and mineralogy. It also included State of Minnesota officials from the Department of Health (MDH), the Pollution Control Agency (MPCA), and the Department of Natural Resources (MDNR); and Federal representatives from the Environmental Protection Agency (EPA) and the Mine Safety and Health Administration (MSHA).

A request has been made by the symposium organizers to this project's authors to submit a paper for possible inclusion in a peer review publication of the symposium proceedings. The paper would focus on the mineralogy and microscopy aspects of the project.

Transportation Research Conference

An overview of the project was made via a poster presentation at the Fourteenth Annual Transportation Research Conference in St. Paul on April 29, 2003.

E-mail communications

Communicating and reporting by e-mail played an important role in the project. Several testing and logistical questions were answered, data were transferred and shared, and meetings were arranged.

PROJECT FINDINGS AND RECOMMENDATIONS

This report stands as a major technical reference for coarse taconite tailings. It provides well-documented baseline data that can be used by the taconite companies, transportation officials, highway engineers, contractors, aggregate producers, and the public for making rational decisions about the use of taconite mining byproducts like coarse tailings to supplement current and future aggregate requirements, not only on the Iron Range, but in other areas of the state, and beyond. Furthermore, making greater use of materials that have long been considered "waste" byproducts makes environmental sense because it maximizes the use of a resource that has already been mined and crushed, and could reduce the pressure to expand existing (or develop new) "natural" aggregate sources.

Project Findings

- A significant source of fine aggregate (coarse taconite tailings) is available at each of the taconite operations assessed in this study. Nearly one ton of coarse tailings are generated for every ton of finished taconite pellets produced on the Iron Range. The mines use a large fraction of their coarse tailings on-site, but considerable excess is available.

- Operations that make an in-plant separation of coarse and fine tailings, e.g., Ispat Inland, EVTAC, and Minntac, produce a more consistent size gradation and a minimal (less than 2.5%) amount of fines (-200 mesh material), compared to the two operations that do not segregate fine and coarse tailings, Hibtac and NSPC. Even so, suitably sized material can be obtained relatively easily at Hibtac and NSPC.

- The series of aggregate tests performed on all samples clearly demonstrates the suitability of coarse tailings for use in road construction applications, e.g., as a superior draining, granular-fill material when confined, and as a durable, Superpave bituminous surface component. For example, coarse tailings have been successfully used in bituminous surfaces for several highway projects on the Iron Range, such as comprising 100% of the wear surface on Highway 53 south of Virginia.

- Mineralogical and chemical analyses are available for all five taconite operations. Quartz is, by far, the dominant mineral in all samples (typically 55% to 60%), followed by hematite (8% to 12%), and iron-bearing carbonates like siderite and ankerite, silicates like stilpnomelane, minnesotaite, and talc, and minor magnetite (much less than 10% each). Trace element concentrations of heavy metals are typical for these materials, and are comparable to other forms of aggregate.

- Specialized mineralogical analyses, using state-of-the-art testing and analytical methods like scanning and transmission electron microscopy (SEM and TEM), show that neither amphibole minerals nor asbestos minerals are present in any of the tailings samples.

- Coarse tailings and other taconite mining byproducts should be treated with the same common sense safety and industrial hygiene approach practiced for all mineral-based materials that have the potential to generate respirable dust.

- Low-cost transportation and workable distribution logistics will be key for expanded use of taconite mining byproducts like coarse tailings in markets beyond northeastern Minnesota. The extensive rail network that services the Iron Range is well positioned to do just that. Other transportation options like trucking, barge, and Great Lakes shipping are also available. A back-haul component of any transportation option would help keep costs down.

Project Recommendations

Based on the project's findings, the following recommendations are made for future lines of research:

- Evaluate the market potential (and market acceptance) of taconite aggregates beyond northern Minnesota; investigate the economics and logistics of rail transport; and develop a plan (preferably with the private sector) for making it a cost-effective option for moving large volumes of taconite aggregate to new markets, both inside and outside Minnesota.

- Conduct a field evaluation of, and collect historical technical information for construction projects (past and present) in which taconite aggregates have been used. The goal would be to assess and document quality and performance over time.

- Perform a full-cost accounting comparison between aggregates that are byproducts of taconite mining and "conventionally produced" aggregates, with an emphasis on the energy differential.

- Develop modified or new aggregate specifications and/or bituminous formulations that encourage the use of coarse tailings. The highest value for coarse taconite tailings reuse is in bituminous mixtures since they add durability and skid resistance. Then, evaluate the modifications with laboratory testing and by conducting field trials, e.g., at the MnRoad test facility.

- Compile and generate baseline technical information on coarser (>3/8 in.) taconite aggregate. For example, the inclusion of coarser materials, such as 3/4 in. rejects, in mix designs would add to the marketability of the <3/8 in. coarse tailings. Furthermore, coarser aggregates typically have a higher unit value than finer aggregates.

- Conduct additional shear tests on coarse tailings to determine their stability in saturated and unsaturated conditions. Because stability is largely dependent on gradation, and the gradation can vary in some tailing products (especially products obtained from tailings basins where a well controlled coarse/fine segregation has not been made), if it can be more precisely defined under what conditions certain materials fail, some coarse tailings products may be used as backslope fill or in other unconfined situations.

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APPENDIX A: RJ LEE GROUP SPECIALIZED MICROSCOPY REPORTS AND RESULTS

The specialized microscopy work conducted on the coarse tailings samples (and summarized in Chapter 8) was performed by the RJ Lee Group of Monroeville, PA. Results for that work were provided by the RJ Lee Group in hard copy form and as corresponding .pdf files. For convenience, those files are referenced as individual sections to this Appendix on the following pages, and are included on the accompanying CD within the folder *Appendix A RJLee Microscopy Reports*.

SECTION A.1: OVERALL REPORT

Appendix A Section A.1 Overall Report Summary.pdf (in folder *Report_pdf*)

RJ Lee*Group*, Inc.

350 Hochberg Road
Monroeville, PA 15146
Tel: (724) 325-1776
Fax: (724) 733-1799

The Materials Characterization Specialists

July 8, 2002

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

RE: Taconite Samples
RJ Lee Group Project LSH204780

Dear Mr. Zanko:

Samples of tailings from five taconite mines were received at RJ Lee Group for asbestos analysis. The tailings from each mine came in two forms – one "as-received" and the other pulverized to < 200 mesh (75 μm). The pulverized material and the < 200 mesh sieve fraction from the "as-received" sample have been analyzed by several techniques. This report summarizes the procedures and findings; complete analytical reports can be found in the Appendices.

X-Ray Powder Diffraction

A portion of each pulverized sample was ground in a mortar and pestle, mixed with fluorite (used as an internal standard), and was back-loaded into a standard XRD holder for analysis. The samples were processed using standard run parameters on a Philips XRD unit with graphite monochromatized copper radiation. The analytical report and XRD spectra are attached as Appendix A.

The primary component of all samples is quartz, with varying amounts of hematite, magnetite, and siderite. The primary amphibole mineral identified by XRD was Minnesotaite. [XRD cannot differentiate between fibrous and cleavage fragments varieties of minerals.] No regulated amphibole was observed during these analyses.

Polarized Light Microscopy

Both the pulverized samples and the < 200 mesh fraction of the tailings were analyzed for asbestos content using polarized light microscopy (PLM) following the analytical procedures outlined in EPA/600/R-93/116, Method for the Determination of Asbestos in Bulk Building Materials. The non-asbestos materials, including cleavage fragments, were also identified and quantified during the PLM analysis. Quantitation of the sample was performed using a 1000-point count procedure. Appendix B contains the analytical reports.

Trace levels of cleavage amphibole fragments, observed in the Minorca and Minntac samples, were identified as "tremolite/actinolite". The cleavage fragments (four total in the entire PLM analyses) had moderate aspect ratios (> 3:1, length/width), but showed no evidence of fibril structure.

Based on the PLM analyses, no regulated asbestos minerals were detected.

Scanning Electron Microscopy

The pulverized samples and the < 200 mesh fraction of the as-received samples were analyzed using scanning electron microscopy (SEM) in general accordance with the methods outlined in ISO/DIS 14966 (Ambient Air: Measurement of inorganic fibrous particles – scanning electron microscopy method). A portion of each sample was weighed and placed in a beaker containing acetone. The suspension was shaken and an aliquot removed and deposited on a polycarbonate filter. A portion of the filter was placed on a carbon planchette and carbon coated (to reduce electrical charging on the deposited particles).

The samples were analyzed in a SEM at an accelerating voltage of 20 KeV at a working distance of 15 – 17 mm. During the analyses, back-scattered electron images and energy dispersive spectroscopy was used to evaluate the particles. Typical images and EDS spectra were acquired for major particle types. Back-scattered electron images and EDS spectra were also obtained for particles that had a greater than 3:1 aspect ratio and were greater than 0.25 micrometers in diameter. Appendix C contains the SEM count sheets, images, and EDS spectra.

No asbestiform minerals were observed during the SEM analyses. Several cleavage fragments (see Appendix C) were observed in the < 200 mesh fraction that was sieved from the Minorca tailings; no cleavage fragments were observed in the pulverized Minorca sample. The chemistries for the cleavage fragments observed in the Minorca sample are consistent with the Minnesotaite.

Transmission Electron Microscopy

The tailing samples that were pulverized to < 200 mesh were analyzed by transmission electron microscopy (TEM) to determine the weight percent of asbestos and cleavage fragments. The analytical procedure used for the TEM analysis was in general accordance with the analytical portion of ASTM D 5756. A portion of each sample was weighed and placed in a beaker which was then filled to 100 ml with distilled water. The suspension was sonicated for 3 minutes, allowed to settle for 2 minutes before an aliquot of the supernatant was removed and redeposited onto a 25 mm MCE filter. The filter was then prepared for analysis using direct preparation procedures. The TEM report and sample count sheets are attached in Appendix D.

No asbestiform minerals or amphibole cleavage fragments were observed during the TEM weight percent analysis.

The "as-received" samples were analyzed using the Superfund Method for the Determination of Releasable Asbestos in Soils and Bulk Materials, EPA 540-R-97-028, as modified by Berman and Kolk[1]. The samples were sieved through a 1-cm screen (18 mesh) and the two size fraction weighed. Seventy grams of the < 1 cm fraction was placed in the holder and tumbled as described in the method. Several filters of the elutriated sample were collected over varying times until one filter contained approximately 100 μg of samples. This filter from each sample was evaluated in the TEM for Protocol Fibers (fibers longer than 5 μm and thinner than 0.5 μm). The analytical data from these tests are included in Appendix E.

No asbestiform fibers or cleavage mineral fragments were observed during the TEM analyses of the elutriated samples.

Based on these analyses, no asbestos minerals are present in these tailings. If you have any questions regarding this report, please feel free to call either Keith Rickabaugh or me.

Sincerely,

Drew R. Van Orden

Drew R. Van Orden, PE
Senior Scientist

Attachments

[1] D. W. Berman and A. Kolk (2000). "Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Material", May 23, 2000, Revision 1.

SECTION A.2: X-RAY POWDER DIFFRACTION

Appendix A Section A.2 XRD results.pdf (in folder *Report_pdf*)

350 Hochberg Road
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The Materials Characterization Specialists

LABORATORY REPORT
RJ Lee Group Project No. LSH204780

ANALYSIS: X-ray Diffraction for Crystalline Phases

A portion of each sample was ground, mixed with fluorite (CaF_2) as an internal standard, and backloaded into a standard XRD holder for analysis. The samples were run using standard run parameters on a Philips XRD unit equipped with graphite monochromatized copper radiation. The XRD patterns are included. The patterns are labeled according to the following scheme: stilpnomelane (Se), minnesotaite (M), talc (Ta), kaolinite (K), quartz (Q), goethite (Go), siderite (Si), magnetite (Mt), ankerite (Ak), hematite (He), and fluorite (St). Aluminum (Al) is due to the sample holder and is not a part of the samples. Concentrations are based on pure mineral standards mixed with fluorite.

Client Sample Identification: Minorca Coarse Tails (< 200 mesh)
RJ Lee Group Sample No: 3030327

Phase Name	Composition	Concentration (Wt. %)
Quartz	SiO_2	60.7
Hematite	Fe_2O_3	7.9
Magnetite	Fe_3O_4	4.2
Siderite	$FeCO_3$	3.4
Ankerite	$CaFe(CO_3)_2$	2.1
Minnesotaite	$(Fe,Mg)_{27}Si_{36}O_{86}(OH)_{26}$	Minor
Talc	$Mg_3Si_4O_{10}(OH)_2$	Trace
Kaolinite	$Al_2Si_2O_5(OH)_4$	Trace

Client Sample Identification: Hibbing Coarse Tails (< 200 mesh)
RJ Lee Group Sample No: 3030339

Phase Name	Composition	Concentration (Wt. %)
Quartz	SiO_2	55.7
Siderite	$FeCO_3$	7.3
Hematite	Fe_2O_3	5.2
Ankerite	$CaFe(CO_3)_2$	4.0
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.9
Magnetite	Fe_3O_4	1.6
Stilpnomelane	$Ca_4Fe_{47}Si_{72}O_{180}(OH)_{36} \bullet xH_2O$	Minor
Minnesotaite	$(Fe,Mg)_{27}Si_{36}O_{86}(OH)_{26}$	Minor
Talc	$Mg_3Si_4O_{10}(OH)_2$	Trace
Kaolinite	$Al_2Si_2O_5(OH)_4$	Trace
Goethite	FeOOH	Trace

Client Sample Identification: Minntac Coarse Tails (< 200 mesh)
RJ Lee Group Sample No: 3030341

Phase Name	Composition	Concentration (Wt. %)
Quartz	SiO_2	59.3
Hematite	Fe_2O_3	9.9
Magnetite	Fe_3O_4	4.2
Siderite	$FeCO_3$	3.8
Ankerite	$CaFe(CO_3)_2$	2.4
Minnesotaite	$(Fe,Mg)_{27}Si_{36}O_{86}(OH)_{26}$	Minor
Stilpnomelane	$Ca_4Fe_{47}Si_{72}O_{180}(OH)_{36} \bullet xH_2O$	Minor
Talc	$Mg_3Si_4O_{10}(OH)_2$	Trace
Kaolinite	$Al_2Si_2O_5(OH)_4$	Trace

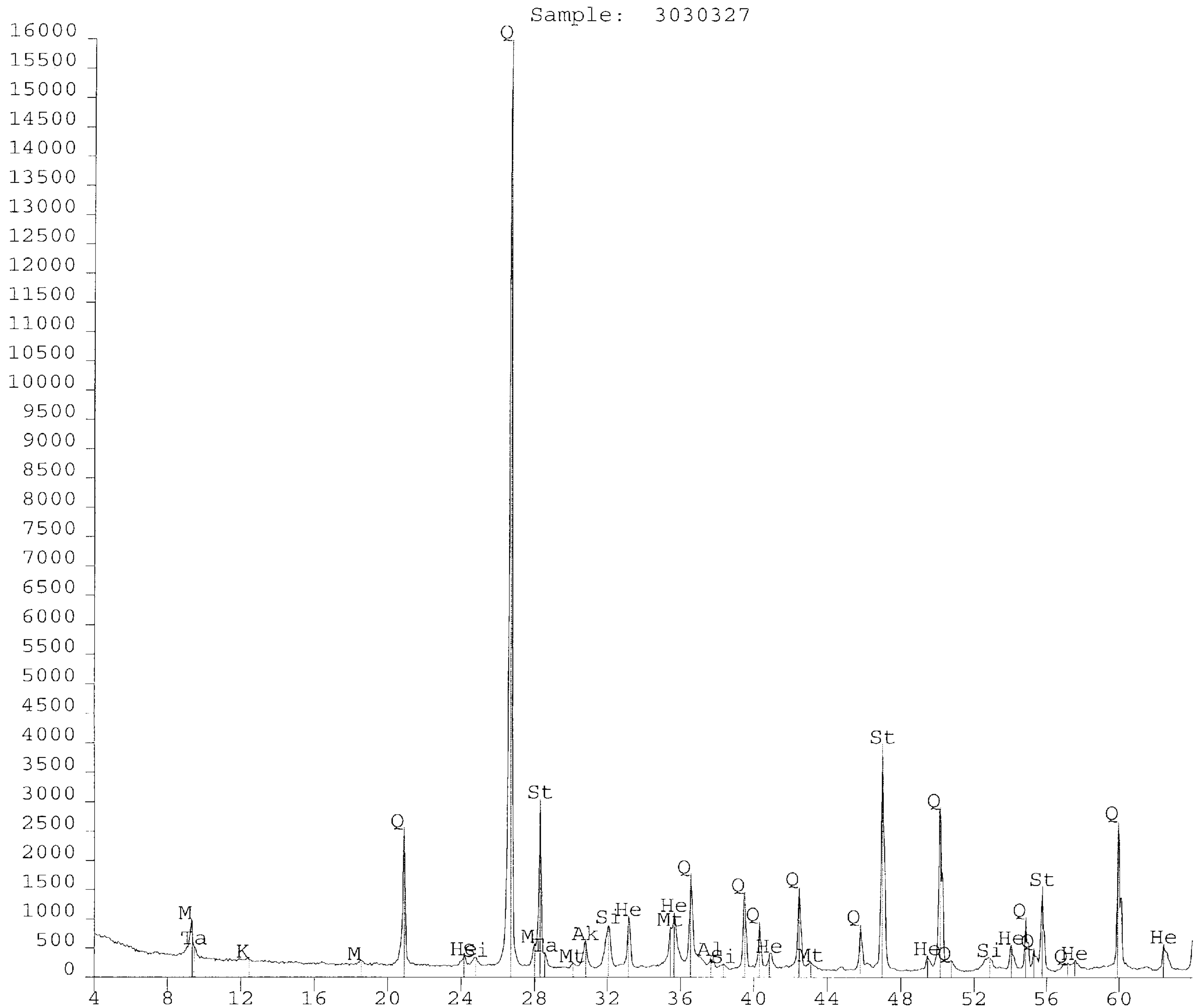
Client Sample Identification: EVTAC Coarse Tails (< 200 mesh)
RJ Lee Group Sample No: 3030343

Phase Name	Composition	Concentration (Wt. %)
Quartz	SiO_2	56.3
Hematite	Fe_2O_3	9.1
Siderite	$FeCO_3$	5.2
Magnetite	Fe_3O_4	5.0
Kaolinite	$Al_2Si_2O_5(OH)_4$	3.2
Ankerite	$CaFe(CO_3)_2$	2.0
Minnesotaite	$(Fe,Mg)_{27}Si_{36}O_{86}(OH)_{26}$	Minor
Stilpnomelane	$Ca_4Fe_{47}Si_{72}O_{180}(OH)_{36} \bullet xH_2O$	Minor
Talc	$Mg_3Si_4O_{10}(OH)_2$	Trace
Kaolinite	$Al_2Si_2O_5(OH)_4$	Trace

Client Sample Identification: NSPC Coarse Tails (< 200 mesh)
RJ Lee Group Sample No: 3030345

Phase Name	Composition	Concentration (Wt. %)
Quartz	SiO_2	64.9
Hematite	Fe_2O_3	13.8
Siderite	$FeCO_3$	5.3
Magnetite	Fe_3O_4	3.4
Ankerite	$CaFe(CO_3)_2$	1.9
Minnesotaite	$(Fe,Mg)_{27}Si_{36}O_{86}(OH)_{26}$	Trace
Stilpnomelane	$Ca_4Fe_{47}Si_{72}O_{180}(OH)_{36} \bullet xH_2O$	Trace
Talc	$Mg_3Si_4O_{10}(OH)_2$	Trace
Kaolinite	$Al_2Si_2O_5(OH)_4$	Trace
Goethite	FeOOH	Trace

Authorized Signature ______________________ Date ________
Stephen A. Brown
Manager, X-ray Diffraction Group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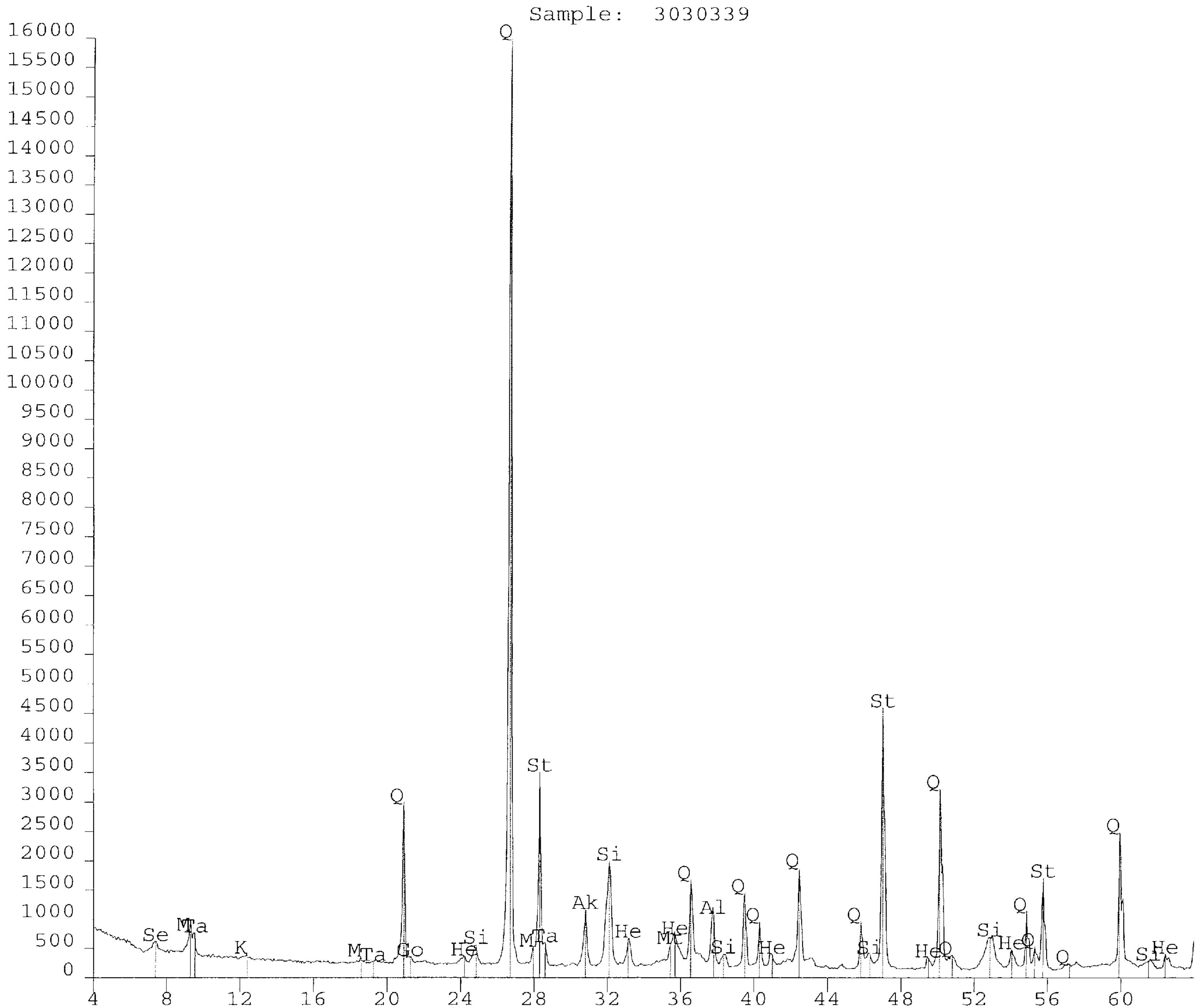

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8000
7500
7000
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3500
3000
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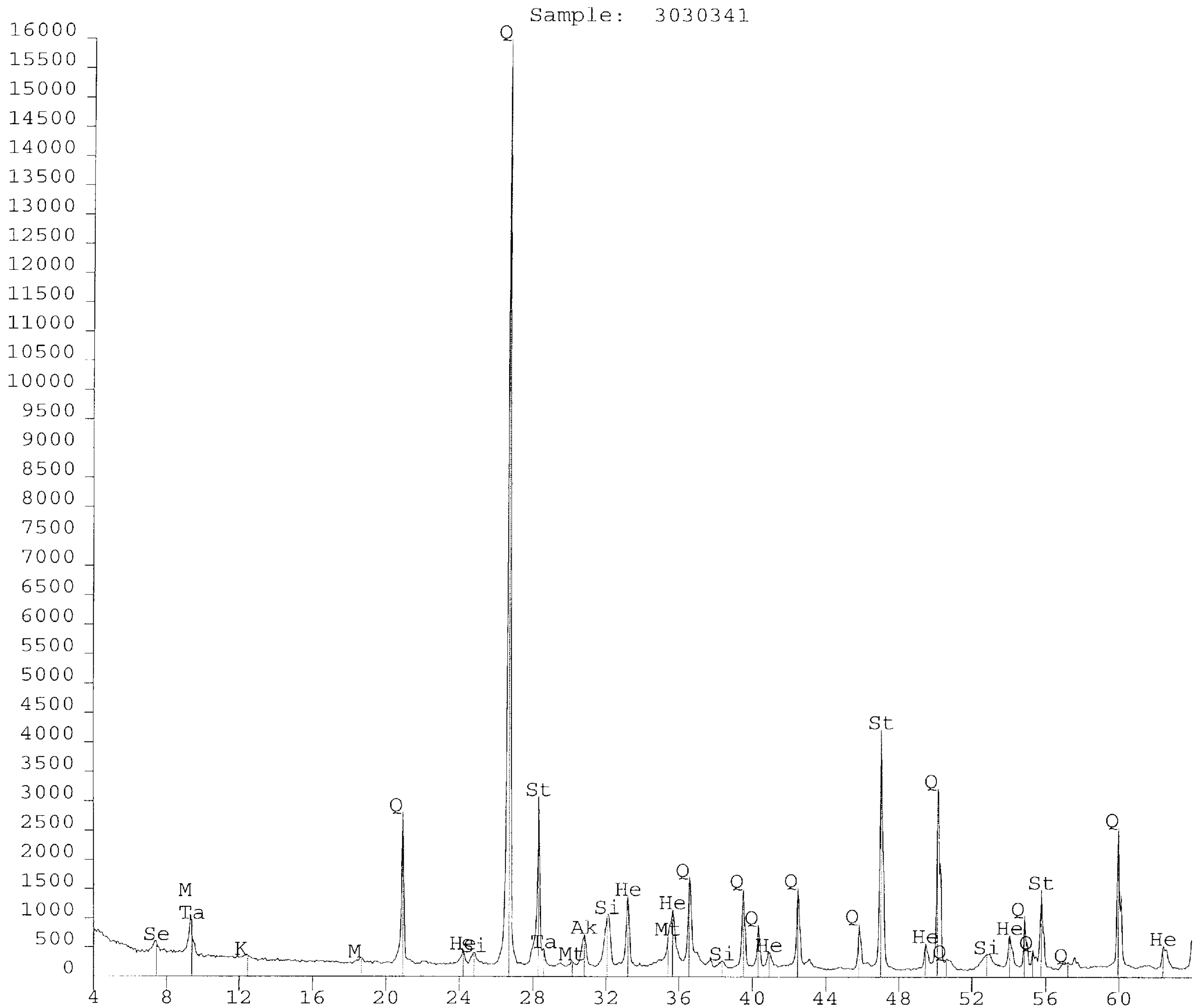

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8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
Q
St
Q
St
Q
Q
Q
Q
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Si
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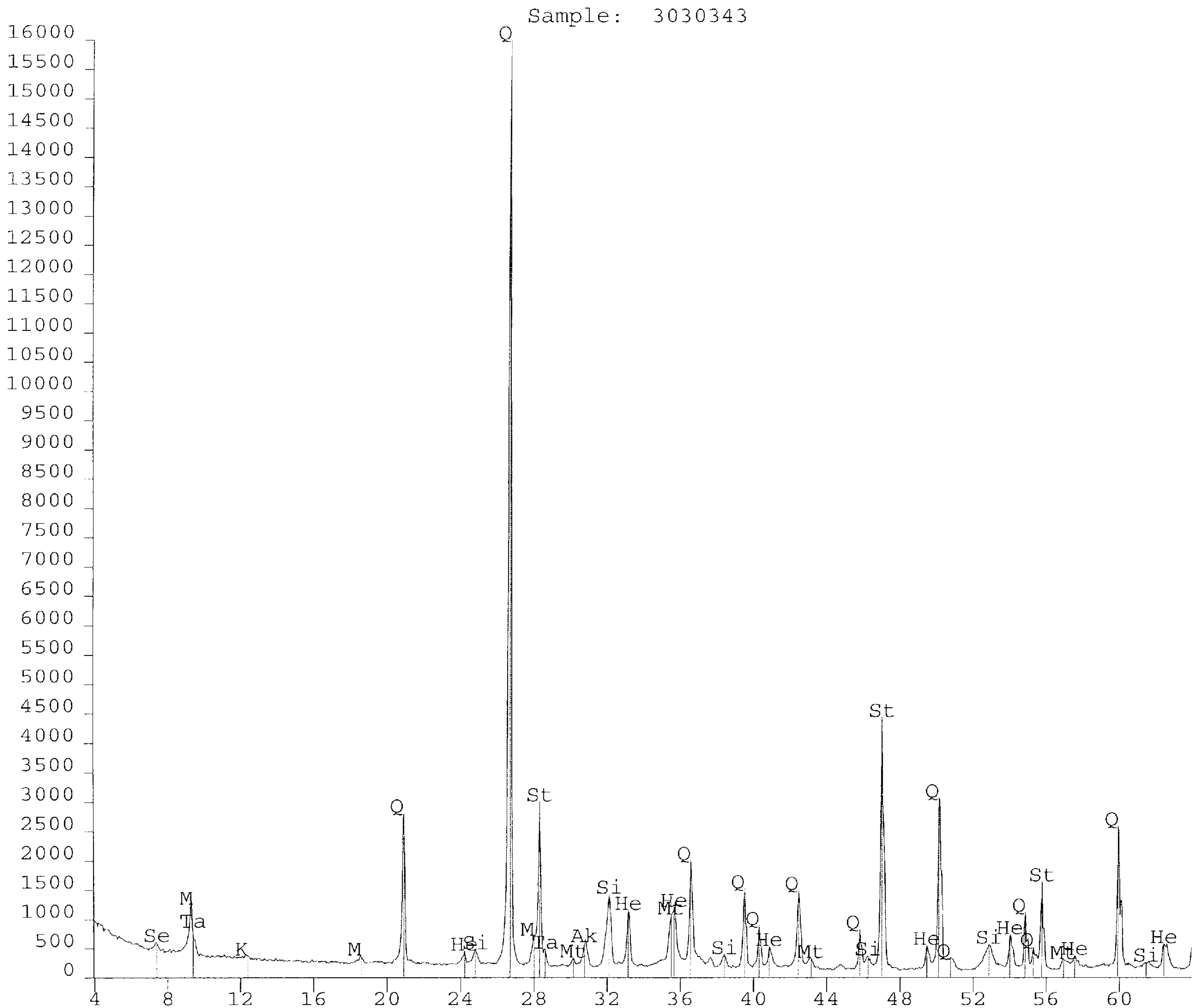
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9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
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3000
2500
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1500
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500
0
4
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12
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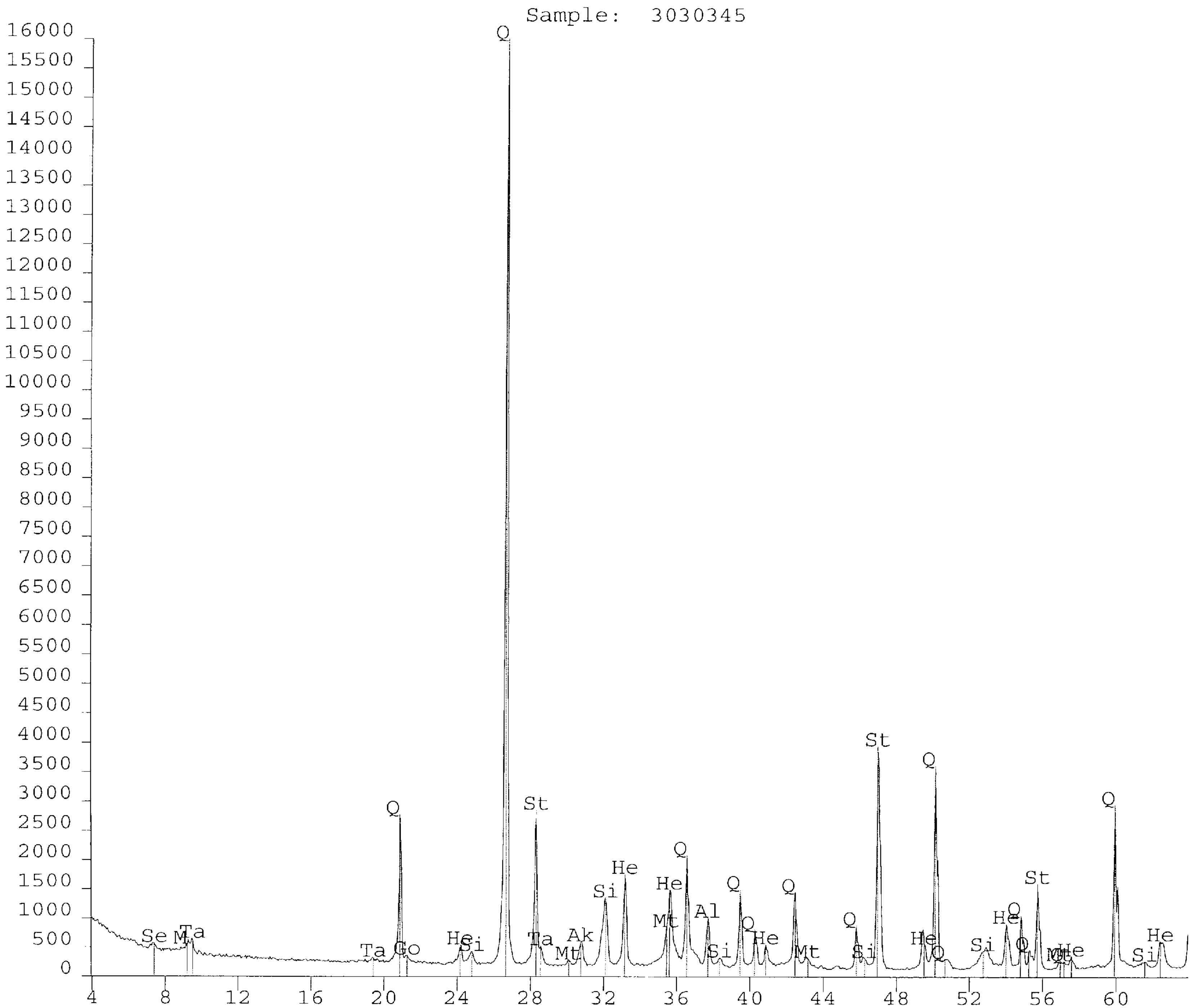

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14000
13500
13000
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12000
11500
11000
10500
10000
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9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
Q
St
He
Si
Mt
Al
Ta
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Se

SECTION A.3: POLARIZED LIGHT MICROSCOPY

Appendix A Section A.3 PLM results.pdf (in folder *Report_pdf*)

and

Appendix A Section A.3 revised PLM results.pdf (in folder *Report_pdf*)

Analyst: WHP

Analysis of Taconite, Contract No. 187-55037073 for The University of Minnesota

Sample ID	RJ Lee Group Sample ID	Non-Asbestos Components		Asbestos Content	Comments
Minorca Coarse Tails < 200M	3030327	Quartz Opaques Calcite Others	45 - 55 % 30 - 40 % 5 - 10 % 5 - 10 %	None Detected	Gray powder Cleavage Amphibole (0.1%)
Minorca Coarse Tails > 200M	3030335	Quartz Opaques Calcite Others	45 - 55 % 30 - 40 % 5 - 10 % 5 - 10 %	None Detected	Gray powder Cleavage Amphibole (0.2%)
Hibbing Coarse Tails < 200M	3030339	Quartz Opaques Calcite Others	45 - 55 % 20 - 30 % 10 - 15 % 10 - 15 %	None Detected	Gray powder
Hibbing Coarse Tails > 200M	3030340	Quartz Opaques Calcite Others	45 - 55 % 20 - 30 % 10 - 15 % 10 - 15 %	None Detected	Gray powder
Minntac Coarse Tails < 200M	3030341	Quartz Opaques Others Calcite	50 - 60 % 25 - 35 % 10 - 15 % 2 - 5 %	None Detected	Gray powder
Minntac Coarse Tails > 200M	3030342	Quartz Opaques Others Calcite	50 - 60 % 25 - 35 % 10 - 15 % 2 - 5 %	None Detected	Gray powder Cleavage Amphibole (0.1%)
EVTAC Coarse Tails < 200M	3030343	Quartz Opaques Others Calcite	40 - 50 % 25 - 35 % 15 - 25 % 5 - 7 %	None Detected	Gray powder

Appendix B. Polarized Light Microscopy (PLM) Results, EPA/600/R-93/116 Method
RJ Lee Group Project No. LSH204780

Analyst: WHP

Analysis of Taconite, Contract No. 187-55037073 for The University of Minnesota

Sample ID	RJ Lee Group Sample ID	Non-Asbestos Components		Asbestos Content	Comments
EVTAC Coarse Tails > 200M	3030344	Quartz Opaques Others Calcite	40 - 50 % 25 - 35 % 15 - 25 % 5 - 7 %	None Detected	Gray powder
NSPC Coarse Tails < 200M	3030345	Quartz Opaques Others Calcite	40 - 50 % 30 - 40 % 15 - 20 % 2 - 5 %	None Detected	Gray powder
NSPC Coarse Tails > 200M	3030346	Quartz Opaques Others Calcite	40 - 50 % 30 - 40 % 15 - 20 % 2 - 5 %	None Detected	Gray powder

Appendix B. Polarized Light Microscopy (PLM) Results, EPA/600/R-93/116 Method
RJ Lee Group Project No. LSH204780

Analyst: WHP

Analysis of Taconite, Contract No. 187-55037073 for The University of Minnesota

Sample ID	RJ Lee Group Sample ID	Non-Asbestos Components		Asbestos Content	Comments
Minorca Coarse Tails < 200M	3030327	Quartz Opaques Calcite Others	45 - 55 % 30 - 40 % 5 - 10 % 5 - 10 %	None Detected	Gray powder
Minorca Coarse Tails > 200M	3030335	Quartz Opaques Calcite Others	45 - 55 % 30 - 40 % 5 - 10 % 5 - 10 %	None Detected	Gray powder
Hibbing Coarse Tails < 200M	3030339	Quartz Opaques Calcite Others	45 - 55 % 20 - 30 % 10 - 15 % 10 - 15 %	None Detected	Gray powder
Hibbing Coarse Tails > 200M	3030340	Quartz Opaques Calcite Others	45 - 55 % 20 - 30 % 10 - 15 % 10 - 15 %	None Detected	Gray powder
Minntac Coarse Tails < 200M	3030341	Quartz Opaques Others Calcite	50 - 60 % 25 - 35 % 10 - 15 % 2 - 5 %	None Detected	Gray powder
Minntac Coarse Tails > 200M	3030342	Quartz Opaques Others Calcite	50 - 60 % 25 - 35 % 10 - 15 % 2 - 5 %	None Detected	Gray powder

Analysis of Taconite, Contract No. 187-55037073 for The University of Minnesota

Sample ID	RJ Lee Group Sample ID	Non-Asbestos Components		Asbestos Content	Comments
EVTAC Coarse Tails < 200M	3030343	Quartz Opaques Others Calcite	40 - 50 % 25 - 35 % 15 - 25 % 5 - 7 %	None Detected	Gray powder
EVTAC Coarse Tails > 200M	3030344	Quartz Opaques Others Calcite	40 - 50 % 25 - 35 % 15 - 25 % 5 - 7 %	None Detected	Gray powder
NSPC Coarse Tails < 200M	3030345	Quartz Opaques Others Calcite	40 - 50 % 30 - 40 % 15 - 20 % 2 - 5 %	None Detected	Gray powder
NSPC Coarse Tails > 200M	3030346	Quartz Opaques Others Calcite	40 - 50 % 30 - 40 % 15 - 20 % 2 - 5 %	None Detected	Gray powder

SECTION A.4: SCANNING ELECTRON MICROSCOPY

Appendix A Section A.4 SEM Count Sheets.pdf (in folder *Report_pdf*)

and

Appendix A Section A.4 SEM 3030344, revised Count Sheet.pdf (in folder *Report_pdf*)

Followed by:

MSEM Images folders (within folder *MSEM Images*)

3030327	3030339	3030341	3030343	3030345
3030335	3030340	3030342	3030344	3030346

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.:	3030327
Description:	Minorca Coarse Tails -200M Crushed
Date Analyzed:	5/22/02
Analyst:	AS

Calc. Wt% Asbestos in Fines: 0.00%

Mass of Original Filter - fines (mg):	51.3
Redeposit Fraction:	0.001
Effective Area of Filter (sq. mm):	385
Basis Field Magnification:	250
No. Fields Analyzed:	100
Area Analyzed (sq. mm):	12.64514

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
27	1	1	7	0.3	Clvg Fr.	Si-rich		327008

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.: 3030335
Description: Minorca Coarse Tails (<200M, Wet-sieve)
Date Analyzed: 6/1/02
Analyst: AS

Mass of Entire Starting Sample (mg): 217543.8
Mass of Original Filter - fines (mg): 1853.3
Redeposit Fraction: 2.25E-05
Effective Area of Filter (sq. mm): 385
Basis Field Magnification: 250
No. Fields Analyzed: 100
Area Analyzed (sq. mm): 12.64514

Wt % Fraction of Fines (<75 um): 0.85%
Calc. Wt% Asbestos in Fines (< 75 um): 0.0000%
Calc. Wt% Asbestos Fines (Sample): 0.000000%

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
4	1	1	9	0.9	Clvg Fr.	Talc		335005
17	2	1	9	0.4	Clvg Fr.	Ca-rich		335006
23	3	1	15	1	Clvg Fr.	Talc		335007
32	4	1	11	0.9	Clvg Fr.	Talc		335009
42	5	1	9.5	0.7	Clvg Fr.	Talc		335010
45	6	1	22	0.9	Clvg Fr.	Talc		335011
58	7	1	15	0.5	B	Talc		335012
62	8	1	16	0.25	B	Talc		335013
79	9	1	12	1.3	Clvg Fr.	Fe-rich		335014
93	10	1	11	0.8	Clvg Fr.	Fe-rich		

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.:	3030339	Mass of Original Filter - fines (mg):	45.3
Description:	Hibbing Coarse Tails -200M Crushed	Redeposit Fraction:	0.001
Date Analyzed:	5/25/02	Effective Area of Filter (sq. mm):	385
Analyst:	AS	Basis Field Magnification:	250
		No. Fields Analyzed:	100
Calc. Wt% Asbestos in Fines:	0.00%	Area Analyzed (sq. mm):	12.64514

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
89	1	1	5.89	0.5	Clvg. Fr.	Fe-rich		339008

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.: 3030340
Description: Hibbing Coarse Tails (<200M Wet-Sieve)
Date Analyzed: 5/29/02
Analyst: AS

Mass of Entire Starting Sample (mg):	218007.1
Mass of Original Filter - fines (mg):	2116.2
Redeposit Fraction:	3.48E-05
Effective Area of Filter (sq. mm):	385
Basis Field Magnification:	250
No. Fields Analyzed:	100
Area Analyzed (sq. mm):	12.64514

Wt % Fraction of Fines (<75 um):	0.97%
Calc. Wt% Asbestos in Fines (< 75 um):	0.00%
Calc. Wt% Asbestos Fines (Sample):	0.000000%

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id

* None Detected *

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.:	3030341	Mass of Original Filter - fines (mg):	59.1
Description:	Minntac Coarse Tails -200M Crushed	Redeposit Fraction:	0.001
Date Analyzed:	5/25/02	Effective Area of Filter (sq. mm):	385
Analyst:	AS	Basis Field Magnification:	250
		No. Fields Analyzed:	100
Calc. Wt% Asbestos in Fines:	0.00%	Area Analyzed (sq. mm):	12.6451

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id

- None Detected -

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.: 3030342
Description: Minntac Coarse Tails (<200M Wet-Sieve)
Date Analyzed: 5/29/02
Analyst: AS

Wt % Fraction of Fines (<75 um): 0.76%
Calc. Wt% Asbestos in Fines (< 75 um): 0.00%
Calc. Wt% Asbestos Fines (Sample): 0.000000%

Mass of Entire Starting Sample (mg): 221149.9
Mass of Original Filter - fines (mg): 1678
Redeposit Fraction: 5.13E-05
Effective Area of Filter (sq. mm): 385
Basis Field Magnification: 250
No. Fields Analyzed: 100
Area Analyzed (sq. mm): 12.64514

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
79	1	1	6	0.5	Clvg. Fr.	Fe-rich		342004

SEM Count Sheet

Sample No.: 3030343
Description: EVTAC Coarse Tails -200M Crushed
Date Analyzed: 5/25/02
Analyst: AS

Mass of Original Filter - fines (mg): 45.8
Redeposit Fraction: 0.001
Effective Area of Filter (sq. mm): 385
Basis Field Magnification: 250
No. Fields Analyzed: 100
Area Analyzed (sq. mm): 12.64514

Calc. Wt% Asbestos in Fines: 0.00%

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
6	1	1	40	5	Clvg. Fr.	Si - rich		343003

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.: 3030344
Description: EVTAC Coarse Tails (<200M Wet-Sieve)
Date Analyzed: 5/29/02
Analyst: AS

Mass of Entire Starting Sample (mg): 211325
Mass of Original Filter - fines (mg): 1890.6
Redeposit Fraction: 3.4E-05
Effective Area of Filter (sq. mm): 385
Basis Field Magnification: 250
No. Fields Analyzed: 100
Area Analyzed (sq. mm): 12.6451

Wt % Fraction of Fines (<75 um): 0.89%
Calc. Wt% Asbestos in Fines (< 75 um): 0.0000%
Calc. Wt% Asbestos Fines (Sample): 0.000000%

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
14	1	1	12	0.75	Clvg. Fr.	Ca-rich		344004
21	2	1	13	1	Clvg. Fr.	Si-rich		344005
24	3	1	12	0.6	Clvg. Fr.	Act/Trem		344006
32	4	1	12	0.5	Clvg. Fr.	Ca-rich		
37	5	1	9	1	Clvg. Fr.	Ca-rich		344007
53	6	1	10	0.75	Clvg. Fr.	Ca-rich		
57	7	1	11	0.9	B	Talc		344008
62	8	1	10	2	Clvg. Fr.	Ca-rich		
75	9	1	9	0.5	Clvg. Fr.	Ca-rich		
95	10	1	9	0.75	Clvg. Fr.	Ca-rich		

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.: 3030345
Description: NSPC Coarse Tails -200M Crushed
Date Analyzed: 5/25/02
Analyst: AS

Calc. Wt% Asbestos in Fines: 0.00%

Mass of Original Filter - fines (mg): 56.3
Redeposit Fraction: 0.001
Effective Area of Filter (sq. mm): 385
Basis Field Magnification: 250
No. Fields Analyzed: 100
Area Analyzed (sq. mm): 12.64514

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id
12	1	1	8	0.75	Clvg Fr.	Si - rich		345003
58	2	1	10	1	Clvg Fr.	Si/Na-rich		345004

LSH204780 - Taconite, Contract No. 187-55037073
SEM Count Sheet

Sample No.:	3030346
Description:	NSPC Coarse Tails (<200M Wet-Sieve)
Date Analyzed:	5/29/02
Analyst:	AS

Mass of Entire Starting Sample (mg):	254394.5
Mass of Original Filter - fines (mg):	15405
Redeposit Fraction:	5.58E-06
Effective Area of Filter (sq. mm):	385
Basis Field Magnification:	250
No. Fields Analyzed:	100
Area Analyzed (sq. mm):	12.64514

Wt % Fraction of Fines (<75 um):	6.06%
Calc. Wt% Asbestos in Fines (< 75 um):	0.00%
Calc. Wt% Asbestos Fines (Sample):	0.000000%

Field No.	Fiber No.	Fiber Fraction	Length (um)	Width (um)	Morphology	Class	Mass (ng)	Tiff Id

* None Detected *

SECTION A.5: TRANSMISSION ELECTRON MICROSCOPY

Appendix A Section A.5 TEM results.pdf (in folder *Report_pdf*)

Table I

Transmission Electron Microscopy (TEM) Results

Asbestos Structures ≥ 0.5 µm - < 5 µm in Length
5:1 Aspect Ratio
20,000X Magnification
RJ Lee Group, Inc. Job No. LSH204780-1
University of MN Project: Taconite, Contract No. 187-55037073

RJ Lee Group Sample #	Client Sample #	Asbestos Count: Chrysotile	Asbestos Count: Amphibole	Area Analyzed mm^2	Dilution Factor	Effective Filter Area mm^2
0127460HTP2	Minorea Coarse Tails	0	0	0.0927	0.001	385
0127461HTP2	Hibbing Coarse Tails	0	0	0.0927	0.001	385
0127462HTP2	Minntac Coarse Tails	0	0	0.0927	0.001	385
0127463HTP2	EVTAC Coarse Tails	0	0	0.0927	0.001	385
0127464HTP2	NSPC Coarse Tails	0	0	0.0927	0.001	385

Table II

Transmission Electron Microscopy (TEM) Results

Asbestos Structures ≥ 5 µm in Length
5:1 Aspect Ratio
20,000X and 10,000X Magnification
RJ Lee Group, Inc. Job No. LSH204780-1
University of MN Project: Taconite, Contract No. 187-55037073

RJ Lee Group Sample #	Client Sample #	-------------Asbestos Count------------ Chrysotile	Amphibole	Area Analyzed mm^2	Dilution Factor	Effective Filter Area mm^2
0127460HTP2/L	Minorea Coarse Tails	0	0	0.3245	0.001	385
0127461HTP2/L	Hibbing Coarse Tails	0	0	0.3245	0.001	385
0127462HTP2/L	Minntac Coarse Tails	0	0	0.3245	0.001	385
0127463HTP2/L	EVTAC Coarse Tails	0	0	0.3245	0.001	385
0127464HTP2/L	NSPC Coarse Tails	0	0	0.3245	0.001	385

Table III

Transmission Electron Microscopy (TEM) Results
RJ Lee Group, Inc. Job No. LSH204780-1
University of MN Project: Taconite, Contract No. 187-55037073

RJ Lee Group Sample #	Client Sample #	Sample Type	Material Used g	Analytical Sensitivity Weight %	Asbestos Concentration Weight %
0127460HTP2/L	Minorea Coarse Tails	Bulk	0.2047	$2.00 * 10^{-5}$	$<2.00 * 10^{-5}$††
0127461HTP2/L	Hibbing Coarse Tails	Bulk	0.2033	$2.01 * 10^{-5}$	$<2.01 * 10^{-5}$††
0127462HTP2/L	Minntac Coarse Tails	Bulk	0.2071	$1.97 * 10^{-5}$	$<1.97 * 10^{-5}$††
0127463HTP2/L	EVTAC Coarse Tails	Bulk	0.1992	$2.05 * 10^{-5}$	$<2.05 * 10^{-5}$††
0127464HTP2/L	NSPC Coarse Tails	Bulk	0.2033	$2.01 * 10^{-5}$	$<2.01 * 10^{-5}$††

††Less Than Analytical Sensitivity.

Authorized Signature: Drew Van Orden

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Headquarters

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May 24, 2002
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RJ Lee *Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127460HTP2**	**Grid Openings**	10
Client Sample #	MINOREA COARSE TAILS-200M/30:	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	21000 X	**Volume**	.0 Liters
Analyst	LH	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127460HTP2L**	**Grid Openings**	25
Client Sample #	MINOREA COARSE TAILS-200M/303	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	.0 Liters
Analyst	LH	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127461HTP2**	**Grid Openings**	10
Client Sample #	HIBBING COARSE TAILS-200M/303(	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	21000 X	**Volume**	.0 Liters
Analyst	LH	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127461HTP2L**	**Grid Openings**	25
Client Sample #	HIBBING COARSE TAILS-200M/303	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	.0 Liters
Analyst	LH	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127462HTP2**	**Grid Openings**	10
Client Sample #	MINNTAC COARSE TAILS-200M/30:	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	21000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	University Of Minnesota		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127462HTP2L**	**Grid Openings**	25
Client Sample #	MINNTAC COARSE TAILS-200M/30:	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127463HTP2**	**Grid Openings**	10
Client Sample #	EVTAC COARSE TAILS-200M/30303‹	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	21000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127463HTP2L**	**Grid Openings**	25
Client Sample #	EVTAC COARSE TAILS-200M/30303‹	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**University Of Minnesota**		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127464HTP2**	**Grid Openings**	10
Client Sample #	NSPC COARSE TAILS-200M/303034:	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	21000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc

Count Sheet

Client Name	University Of Minnesota		
Project Number	**LSH204780-1**	**RJL QA Number**	HQ20681
RJL Sample #	**0127464HTP2L**	**Grid Openings**	25
Client Sample #	NSPC COARSE TAILS-200M/303034:	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	.0 Liters
Analyst	TWS	**Grid Opening Area**	0.0093 mm^2
EDS Disk		**Dilution Factor**	0.001

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						

NSD - No Structures Detected

SECTION A.6: EPA SUPERFUND METHOD

Appendix A Section A.6 Superfund Method.pdf (in folder *Report_pdf*)

and

Appendix A Section A.6 Superfund Method2.pdf (in folder *Report_pdf*)

Appendix E.

Summary of Modified Elutriator Samples for Protocol Fibers

Client Sample #	RJLG Sample #	Deposited Mass, µg	Area Analyzed, mm^2	Protocol Structures	Analytical Sensitivity, s/µg	Concentration, s/µg
Minorca Coarse Tails	3030335	100	1.2805	0	3.007	< 3.007
Hibbing Coarse Tails	3030340	94	1.3617	0	3.008	< 3.008
Minntac Coarse Tails	3030342	93	1.3797	0	3.001	< 3.001
EVTAC Coarse Tails	3030344	92	1.3526	0	3.094	< 3.094
NSPC Coarse Tails	3030346	97	1.3256	0	2.994	< 2.994

Test Report

Total Asbestos Structure Concentration
Modified Elutrator Method for Protocol Structures
Project LSH204780

RJ Lee Group Sample Number	Client Sample Number	Filter Area (sq mm)	Volume ‡ (Liters)	Area Analyzed (sq mm)	Structures Chr	Structures Amp	Analytical Sensitivity † (S/sq. mm)	Analytical Sensitivity † (S/cc)	Concentration (S/sq. mm)	Concentration (S/cc)	Analysis Date
0127247HT	335-16/3030335	385	22.88	1.2805	0	0	7.8x10^-1	0.0131	<7.8x10^-1*	<0.0131*	7/3/2
0127248HT	340-17/3030340	385	22.88	1.3617	0	0	7.3x10^-1	0.0124	<7.3x10^-1*	<0.0124*	7/3/2
0127249HT	342-16/3030342	385	22.88	1.3797	0	0	7.2x10^-1	0.0122	<7.2x10^-1*	<0.0122*	7/3/2
0127250HT	344-16/3030344	385	17.16	1.3526	0	0	7.4x10^-1	0.0166	<7.4x10^-1*	<0.0166*	7/4/2
0127251HT	346-16/3030346	385	17.16	1.3256	0	0	7.5x10^-1	0.0169	<7.5x10^-1*	<0.0169*	7/4/2

‡ Volumes provided by RJ Lee Group, Inc. were used to calculate analytical results and sensitivities.
†Analytical sensitivity is the calculated concentration based on one structure in the area analyzed.

Chr - Chrysotile, Amp - Amphibole
Samples received on: Tuesday, May 7, 2002
* Results Less Than Analytical Sensitivity.

Authorized Signature
Kimberly A. Allison, Manager-TEM Analysis
Date Date Friday, July 5, 2002

RJ Lee Group, Inc.
Headquarters

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RJ Lee *Group*, Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**	**RJL QA Number**	HQ20635
Project Number	**LSH204780**	**Grid Openings**	142
RJL Sample #	**0127247HT**	**Total Asbestos**	0
Client Sample #	335-16/3030335	**Total Non-Asbestos**	0
Microscope	2000 FX	**Filter**	PC 385 mm^2
Accelerating Volt	120 **Kv**	**Volume**	22.9 Liters
Magnification	10000 X	**Grid Opening Area**	0.009 mm^2
Analyst	LH	**Dilution Factor**	1
EDS Disk			

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						
26	0			NSD						
27	0			NSD						
28	0			NSD						
29	0			NSD						
30	0			NSD						
31	0			NSD						
32	0			NSD						
33	0			NSD						
34	0			NSD						
35	0			NSD						
36	0			NSD						
37	0			NSD						
38	0			NSD						
39	0			NSD						
40	0			NSD						
41	0			NSD						
42	0			NSD						
43	0			NSD						
44	0			NSD						

NSD - No Structures Detected

RJ Lee *Group*, Inc
Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127247HT**	**Grid Openings**	142
Client Sample #	335-16/3030335	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
45	0			NSD						
46	0			NSD						
47	0			NSD						
48	0			NSD						
49	0			NSD						
50	0			NSD						
51	0			NSD						
52	0			NSD						
53	0			NSD						
54	0			NSD						
55	0			NSD						
56	0			NSD						
57	0			NSD						
58	0			NSD						
59	0			NSD						
60	0			NSD						
61	0			NSD						
62	0			NSD						
63	0			NSD						
64	0			NSD						
65	0			NSD						
66	0			NSD						
67	0			NSD						
68	0			NSD						
69	0			NSD						
70	0			NSD						
71	0			NSD						
72	0			NSD						
73	0			NSD						
74	0			NSD						
75	0			NSD						
76	0			NSD						
77	0			NSD						
78	0			NSD						
79	0			NSD						
80	0			NSD						
81	0			NSD						
82	0			NSD						
83	0			NSD						
84	0			NSD						
85	0			NSD						
86	0			NSD						
87	0			NSD						
88	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127247HT**	**Grid Openings**	142
Client Sample #	335-16/3030335	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
89	0			NSD						
90	0			NSD						
91	0			NSD						
92	0			NSD						
93	0			NSD						
94	0			NSD						
95	0			NSD						
96	0			NSD						
97	0			NSD						
98	0			NSD						
99	0			NSD						
100	0			NSD						
101	0			NSD						
102	0			NSD						
103	0			NSD						
104	0			NSD						
105	0			NSD						
106	0			NSD						
107	0			NSD						
108	0			NSD						
109	0			NSD						
110	0			NSD						
111	0			NSD						
112	0			NSD						
113	0			NSD						
114	0			NSD						
115	0			NSD						
116	0			NSD						
117	0			NSD						
118	0			NSD						
119	0			NSD						
120	0			NSD						
121	0			NSD						
122	0			NSD						
123	0			NSD						
124	0			NSD						
125	0			NSD						
126	0			NSD						
127	0			NSD						
128	0			NSD						
129	0			NSD						
130	0			NSD						
131	0			NSD						
132	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127247HT**	**Grid Openings**	142
Client Sample #	335-16/3030335	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
133	0			NSD						
134	0			NSD						
135	0			NSD						
136	0			NSD						
137	0			NSD						
138	0			NSD						
139	0			NSD						
140	0			NSD						
141	0			NSD						
142	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127248HT**	**Grid Openings**	151
Client Sample #	340-17/3030340	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						
26	0			NSD						
27	0			NSD						
28	0			NSD						
29	0			NSD						
30	0			NSD						
31	0			NSD						
32	0			NSD						
33	0			NSD						
34	0			NSD						
35	0			NSD						
36	0			NSD						
37	0			NSD						
38	0			NSD						
39	0			NSD						
40	0			NSD						
41	0			NSD						
42	0			NSD						
43	0			NSD						
44	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc
Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127248HT**	**Grid Openings**	151
Client Sample #	340-17/3030340	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
45	0			NSD						
46	0			NSD						
47	0			NSD						
48	0			NSD						
49	0			NSD						
50	0			NSD						
51	0			NSD						
52	0			NSD						
53	0			NSD						
54	0			NSD						
55	0			NSD						
56	0			NSD						
57	0			NSD						
58	0			NSD						
59	0			NSD						
60	0			NSD						
61	0			NSD						
62	0			NSD						
63	0			NSD						
64	0			NSD						
65	0			NSD						
66	0			NSD						
67	0			NSD						
68	0			NSD						
69	0			NSD						
70	0			NSD						
71	0			NSD						
72	0			NSD						
73	0			NSD						
74	0			NSD						
75	0			NSD						
76	0			NSD						
77	0			NSD						
78	0			NSD						
79	0			NSD						
80	0			NSD						
81	0			NSD						
82	0			NSD						
83	0			NSD						
84	0			NSD						
85	0			NSD						
86	0			NSD						
87	0			NSD						
88	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127248HT**	**Grid Openings**	151
Client Sample #	340-17/3030340	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
89	0			NSD						
90	0			NSD						
91	0			NSD						
92	0			NSD						
93	0			NSD						
94	0			NSD						
95	0			NSD						
96	0			NSD						
97	0			NSD						
98	0			NSD						
99	0			NSD						
100	0			NSD						
101	0			NSD						
102	0			NSD						
103	0			NSD						
104	0			NSD						
105	0			NSD						
106	0			NSD						
107	0			NSD						
108	0			NSD						
109	0			NSD						
110	0			NSD						
111	0			NSD						
112	0			NSD						
113	0			NSD						
114	0			NSD						
115	0			NSD						
116	0			NSD						
117	0			NSD						
118	0			NSD						
119	0			NSD						
120	0			NSD						
121	0			NSD						
122	0			NSD						
123	0			NSD						
124	0			NSD						
125	0			NSD						
126	0			NSD						
127	0			NSD						
128	0			NSD						
129	0			NSD						
130	0			NSD						
131	0			NSD						
132	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127248HT**	**Grid Openings**	151
Client Sample #	340-17/3030340	**Total Asbestos**	0
Microscope	2000 FX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	LH	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
133	0			NSD						
134	0			NSD						
135	0			NSD						
136	0			NSD						
137	0			NSD						
138	0			NSD						
139	0			NSD						
140	0			NSD						
141	0			NSD						
142	0			NSD						
143	0			NSD						
144	0			NSD						
145	0			NSD						
146	0			NSD						
147	0			NSD						
148	0			NSD						
149	0			NSD						
150	0			NSD						
151	0			NSD						

NSD - No Structures Detected

RJ Lee *Group*, Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127249HT**	**Grid Openings**	153
Client Sample #	342-16/3030342	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						
26	0			NSD						
27	0			NSD						
28	0			NSD						
29	0			NSD						
30	0			NSD						
31	0			NSD						
32	0			NSD						
33	0			NSD						
34	0			NSD						
35	0			NSD						
36	0			NSD						
37	0			NSD						
38	0			NSD						
39	0			NSD						
40	0			NSD						
41	0			NSD						
42	0			NSD						
43	0			NSD						
44	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127249HT**	**Grid Openings**	153
Client Sample #	342-16/3030342	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
45	0			NSD						
46	0			NSD						
47	0			NSD						
48	0			NSD						
49	0			NSD						
50	0			NSD						
51	0			NSD						
52	0			NSD						
53	0			NSD						
54	0			NSD						
55	0			NSD						
56	0			NSD						
57	0			NSD						
58	0			NSD						
59	0			NSD						
60	0			NSD						
61	0			NSD						
62	0			NSD						
63	0			NSD						
64	0			NSD						
65	0			NSD						
66	0			NSD						
67	0			NSD						
68	0			NSD						
69	0			NSD						
70	0			NSD						
71	0			NSD						
72	0			NSD						
73	0			NSD						
74	0			NSD						
75	0			NSD						
76	0			NSD						
77	0			NSD						
78	0			NSD						
79	0			NSD						
80	0			NSD						
81	0			NSD						
82	0			NSD						
83	0			NSD						
84	0			NSD						
85	0			NSD						
86	0			NSD						
87	0			NSD						
88	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127249HT**	**Grid Openings**	153
Client Sample #	342-16/3030342	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
89	0			NSD						
90	0			NSD						
91	0			NSD						
92	0			NSD						
93	0			NSD						
94	0			NSD						
95	0			NSD						
96	0			NSD						
97	0			NSD						
98	0			NSD						
99	0			NSD						
100	0			NSD						
101	0			NSD						
102	0			NSD						
103	0			NSD						
104	0			NSD						
105	0			NSD						
106	0			NSD						
107	0			NSD						
108	0			NSD						
109	0			NSD						
110	0			NSD						
111	0			NSD						
112	0			NSD						
113	0			NSD						
114	0			NSD						
115	0			NSD						
116	0			NSD						
117	0			NSD						
118	0			NSD						
119	0			NSD						
120	0			NSD						
121	0			NSD						
122	0			NSD						
123	0			NSD						
124	0			NSD						
125	0			NSD						
126	0			NSD						
127	0			NSD						
128	0			NSD						
129	0			NSD						
130	0			NSD						
131	0			NSD						
132	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127249HT**	**Grid Openings**	153
Client Sample #	342-16/3030342	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	22.9 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
133	0			NSD						
134	0			NSD						
135	0			NSD						
136	0			NSD						
137	0			NSD						
138	0			NSD						
139	0			NSD						
140	0			NSD						
141	0			NSD						
142	0			NSD						
143	0			NSD						
144	0			NSD						
145	0			NSD						
146	0			NSD						
147	0			NSD						
148	0			NSD						
149	0			NSD						
150	0			NSD						
151	0			NSD						
152	0			NSD						
153	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127250HT**	**Grid Openings**	150
Client Sample #	344-16/3030344	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						
26	0			NSD						
27	0			NSD						
28	0			NSD						
29	0			NSD						
30	0			NSD						
31	0			NSD						
32	0			NSD						
33	0			NSD						
34	0			NSD						
35	0			NSD						
36	0			NSD						
37	0			NSD						
38	0			NSD						
39	0			NSD						
40	0			NSD						
41	0			NSD						
42	0			NSD						
43	0			NSD						
44	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127250HT**	**Grid Openings**	150
Client Sample #	344-16/3030344	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
45	0			NSD						
46	0			NSD						
47	0			NSD						
48	0			NSD						
49	0			NSD						
50	0			NSD						
51	0			NSD						
52	0			NSD						
53	0			NSD						
54	0			NSD						
55	0			NSD						
56	0			NSD						
57	0			NSD						
58	0			NSD						
59	0			NSD						
60	0			NSD						
61	0			NSD						
62	0			NSD						
63	0			NSD						
64	0			NSD						
65	0			NSD						
66	0			NSD						
67	0			NSD						
68	0			NSD						
69	0			NSD						
70	0			NSD						
71	0			NSD						
72	0			NSD						
73	0			NSD						
74	0			NSD						
75	0			NSD						
76	0			NSD						
77	0			NSD						
78	0			NSD						
79	0			NSD						
80	0			NSD						
81	0			NSD						
82	0			NSD						
83	0			NSD						
84	0			NSD						
85	0			NSD						
86	0			NSD						
87	0			NSD						
88	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127250HT**	**Grid Openings**	150
Client Sample #	344-16/3030344	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
89	0			NSD						
90	0			NSD						
91	0			NSD						
92	0			NSD						
93	0			NSD						
94	0			NSD						
95	0			NSD						
96	0			NSD						
97	0			NSD						
98	0			NSD						
99	0			NSD						
100	0			NSD						
101	0			NSD						
102	0			NSD						
103	0			NSD						
104	0			NSD						
105	0			NSD						
106	0			NSD						
107	0			NSD						
108	0			NSD						
109	0			NSD						
110	0			NSD						
111	0			NSD						
112	0			NSD						
113	0			NSD						
114	0			NSD						
115	0			NSD						
116	0			NSD						
117	0			NSD						
118	0			NSD						
119	0			NSD						
120	0			NSD						
121	0			NSD						
122	0			NSD						
123	0			NSD						
124	0			NSD						
125	0			NSD						
126	0			NSD						
127	0			NSD						
128	0			NSD						
129	0			NSD						
130	0			NSD						
131	0			NSD						
132	0			NSD						

NSD - No Structures Detected

RJ Lee *Group*, Inc
Count Sheet

Client Name	RJ Lee Group, Inc.		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127250HT**	**Grid Openings**	150
Client Sample #	344-16/3030344	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 Kv	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
133	0			NSD						
134	0			NSD						
135	0			NSD						
136	0			NSD						
137	0			NSD						
138	0			NSD						
139	0			NSD						
140	0			NSD						
141	0			NSD						
142	0			NSD						
143	0			NSD						
144	0			NSD						
145	0			NSD						
146	0			NSD						
147	0			NSD						
148	0			NSD						
149	0			NSD						
150	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc
Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127251HT**	**Grid Openings**	147
Client Sample #	346-16/3030346	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
1	0			NSD						
2	0			NSD						
3	0			NSD						
4	0			NSD						
5	0			NSD						
6	0			NSD						
7	0			NSD						
8	0			NSD						
9	0			NSD						
10	0			NSD						
11	0			NSD						
12	0			NSD						
13	0			NSD						
14	0			NSD						
15	0			NSD						
16	0			NSD						
17	0			NSD						
18	0			NSD						
19	0			NSD						
20	0			NSD						
21	0			NSD						
22	0			NSD						
23	0			NSD						
24	0			NSD						
25	0			NSD						
26	0			NSD						
27	0			NSD						
28	0			NSD						
29	0			NSD						
30	0			NSD						
31	0			NSD						
32	0			NSD						
33	0			NSD						
34	0			NSD						
35	0			NSD						
36	0			NSD						
37	0			NSD						
38	0			NSD						
39	0			NSD						
40	0			NSD						
41	0			NSD						
42	0			NSD						
43	0			NSD						
44	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127251HT**	**Grid Openings**	147
Client Sample #	346-16/3030346	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
45	0			NSD						
46	0			NSD						
47	0			NSD						
48	0			NSD						
49	0			NSD						
50	0			NSD						
51	0			NSD						
52	0			NSD						
53	0			NSD						
54	0			NSD						
55	0			NSD						
56	0			NSD						
57	0			NSD						
58	0			NSD						
59	0			NSD						
60	0			NSD						
61	0			NSD						
62	0			NSD						
63	0			NSD						
64	0			NSD						
65	0			NSD						
66	0			NSD						
67	0			NSD						
68	0			NSD						
69	0			NSD						
70	0			NSD						
71	0			NSD						
72	0			NSD						
73	0			NSD						
74	0			NSD						
75	0			NSD						
76	0			NSD						
77	0			NSD						
78	0			NSD						
79	0			NSD						
80	0			NSD						
81	0			NSD						
82	0			NSD						
83	0			NSD						
84	0			NSD						
85	0			NSD						
86	0			NSD						
87	0			NSD						
88	0			NSD						

NSD - No Structures Detected

RJ Lee *Group* , Inc
Count Sheet

Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127251HT**	**Grid Openings**	147
Client Sample #	346-16/3030346	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
89	0			NSD						
90	0			NSD						
91	0			NSD						
92	0			NSD						
93	0			NSD						
94	0			NSD						
95	0			NSD						
96	0			NSD						
97	0			NSD						
98	0			NSD						
99	0			NSD						
100	0			NSD						
101	0			NSD						
102	0			NSD						
103	0			NSD						
104	0			NSD						
105	0			NSD						
106	0			NSD						
107	0			NSD						
108	0			NSD						
109	0			NSD						
110	0			NSD						
111	0			NSD						
112	0			NSD						
113	0			NSD						
114	0			NSD						
115	0			NSD						
116	0			NSD						
117	0			NSD						
118	0			NSD						
119	0			NSD						
120	0			NSD						
121	0			NSD						
122	0			NSD						
123	0			NSD						
124	0			NSD						
125	0			NSD						
126	0			NSD						
127	0			NSD						
128	0			NSD						
129	0			NSD						
130	0			NSD						
131	0			NSD						
132	0			NSD						

NSD - No Structures Detected

RJ Lee*Group* , Inc

Count Sheet

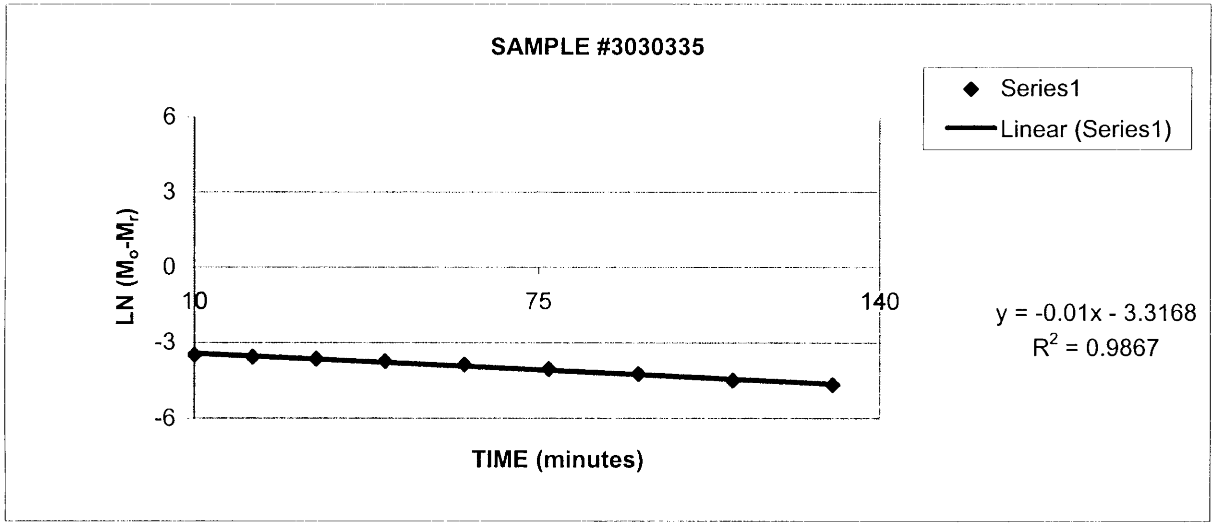
Client Name	**RJ Lee Group, Inc.**		
Project Number	**LSH204780**	**RJL QA Number**	HQ20635
RJL Sample #	**0127251HT**	**Grid Openings**	147
Client Sample #	346-16/3030346	**Total Asbestos**	0
Microscope	1200 EX	**Total Non-Asbestos**	0
Accelerating Volt	120 **Kv**	**Filter**	PC 385 mm^2
Magnification	10000 X	**Volume**	17.2 Liters
Analyst	RBG	**Grid Opening Area**	0.009 mm^2
EDS Disk		**Dilution Factor**	1

Field	Fiber	Length µm	Width µm	Structure Type	Morph	EDS	Photo	SAED	Amphibole Type	Comment
133	0			NSD						
134	0			NSD						
135	0			NSD						
136	0			NSD						
137	0			NSD						
138	0			NSD						
139	0			NSD						
140	0			NSD						
141	0			NSD						
142	0			NSD						
143	0			NSD						
144	0			NSD						
145	0			NSD						
146	0			NSD						
147	0			NSD						

NSD - No Structures Detected

PERCENT RESPIRABLE DUST

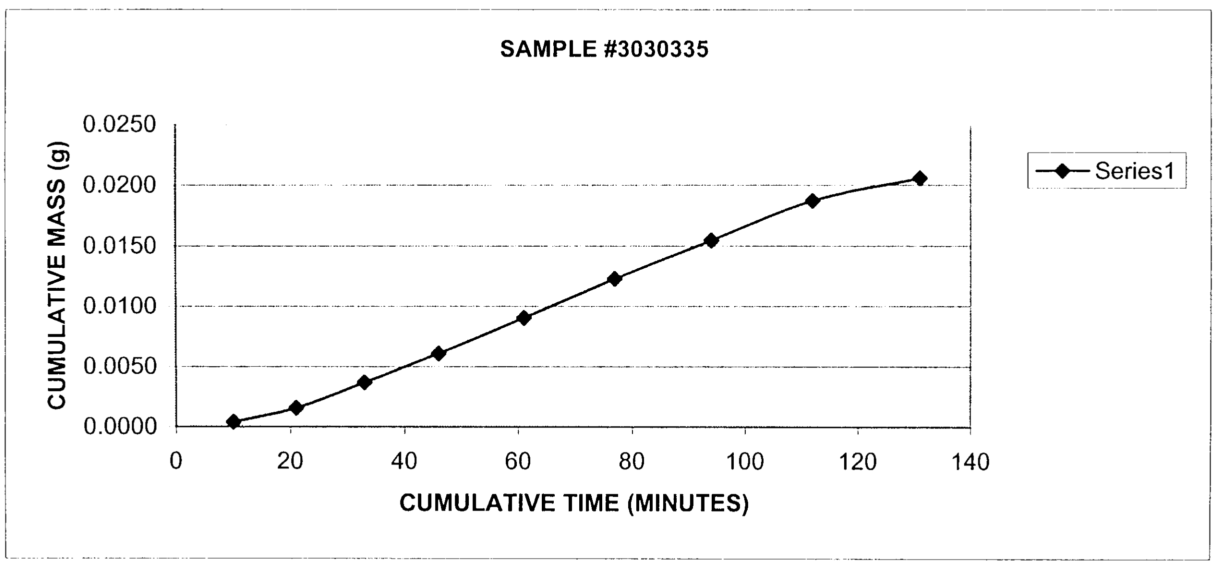
Sample	sec	Time, min	Initial weight	Final weight	Mass, g	Mr, g	Cum Time	Cum Mass	Mo, g	LN(Mo-Mr)	Ln(Mr)
335-05	600	10	0.0240	0.0244	0.0004	0.0004	10	0.0004	0.03	-3.4825635	-7.7730678
335-06	660	11	0.0239	0.0250	0.0011	0.0012	21	0.0016	0.03	-3.5606076	-6.4513119
335-07	720	12	0.0236	0.0256	0.0020	0.0021	33	0.0037	0.03	-3.6375421	-5.6040141
335-08	780	13	0.0235	0.0258	0.0023	0.0024	46	0.0061	0.03	-3.7340166	-5.0989191
335-09	900	15	0.0240	0.0268	0.0028	0.0029	61	0.0090	0.03	-3.8656061	-4.7050148
335-10	960	16	0.0242	0.0273	0.0031	0.0033	77	0.0123	0.03	-4.0348637	-4.3971882
335-11	1020	17	0.0237	0.0267	0.0030	0.0032	94	0.0155	0.03	-4.2314579	-4.1689295
335-12	1080	18	0.0241	0.0272	0.0031	0.0033	112	0.0187	0.03	-4.4856944	-3.9775786
335-13	1140	19	0.0282	0.0300	0.0018	0.0019	131	0.0206	0.03	-4.6697172	-3.8812475



Intercept	-3.3167947	-6.937917
Slope	-0.0100016	0.02800681
R2	0.9867403	0.80923911

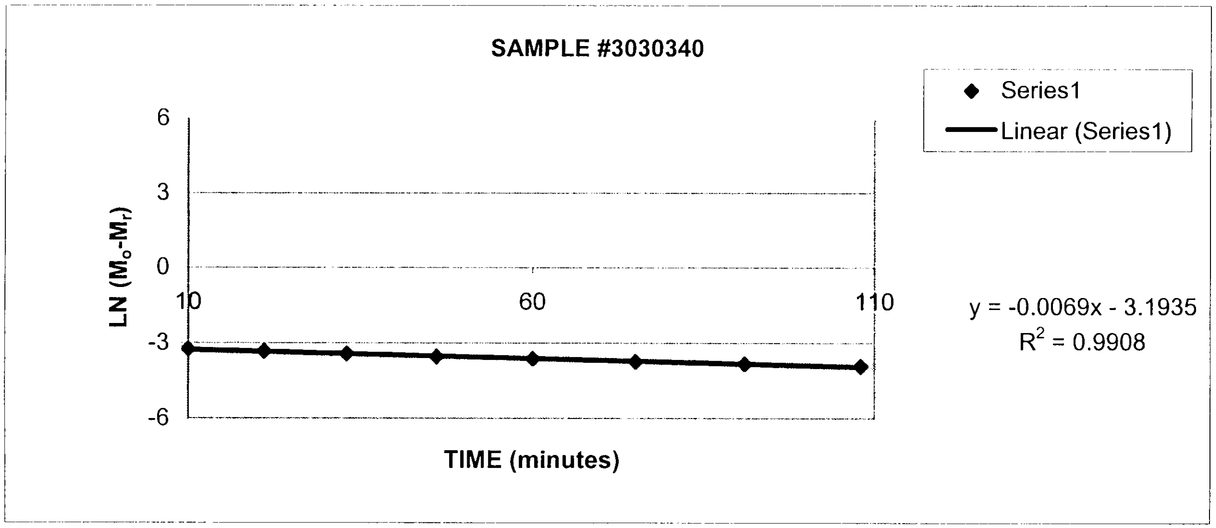
0.04 %RD

mass submitted, ug	100
size of grid opening, mm2	0.009018
go to be scanned	142



M⁻IFIED ⁻TRI⁻R ME⁻OD　　/IPLI 030:　　I IEC SH2 0
PERCENT RESPIRABLE DUST

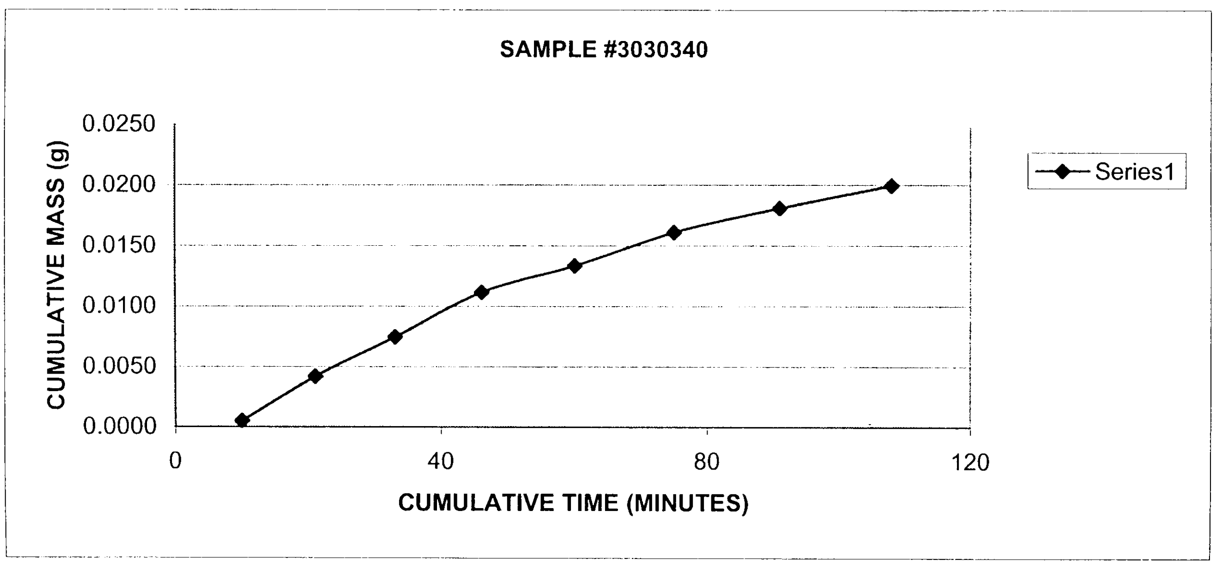
Sample	sec	Time, min	Initial weight	Final weight	Mass, g	Mr, g	Cum Time	Cum Mass	Mo, g	LN(Mo-Mr)	Ln(Mr)
340-05	600	10	0.0238	0.0243	0.0005	0.0005	10	0.0005	0.04	-3.2332607	-7.54992421
340-06	660	11	0.0235	0.0270	0.0035	0.0037	21	0.0042	0.04	-3.3300644	-5.47048267
340-07	720	12	0.0234	0.0265	0.0031	0.0033	33	0.0075	0.04	-3.4256334	-4.89668225
340-08	780	13	0.0233	0.0268	0.0035	0.0037	46	0.0112	0.04	-3.5457971	-4.49592303
340-09	840	14	0.0240	0.0261	0.0021	0.0022	60	0.0134	0.04	-3.6254995	-4.31517504
340-10	900	15	0.0235	0.0261	0.0026	0.0027	75	0.0161	0.04	-3.7338848	-4.12892421
340-11	960	16	0.0239	0.0258	0.0019	0.0020	91	0.0181	0.04	-3.8212486	-4.01186765
340-12	1020	17	0.0277	0.0295	0.0018	0.0019	108	0.0200	0.04	-3.9117081	-3.91233806



Intercept	-3.1934818	-6.44000931
Slope	-0.0069352	0.028690895
R2	0.99079342	0.668405131

0.06 %RD

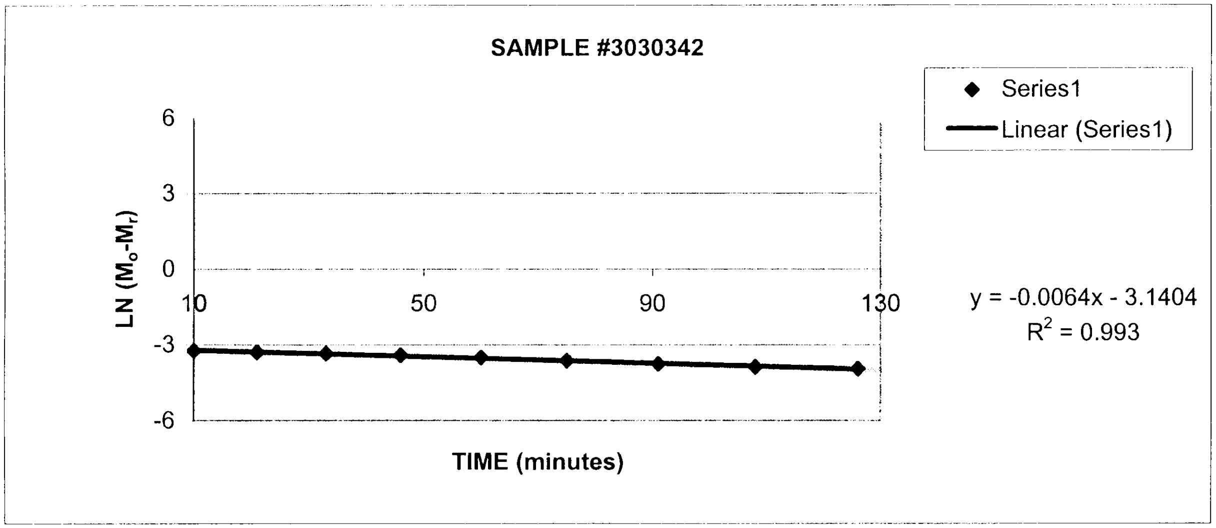
mass submitted, ug	94
size of grid opening, mm2	0.009018
go to be scanned	151



M[illegible]IED [illegible]TRI[illegible]R ME[illegible]D [illegible]MPL[illegible] [illegible]303[illegible] P[illegible]ECT [illegible]SH20[illegible]

PERCENT RESPIRABLE DUST

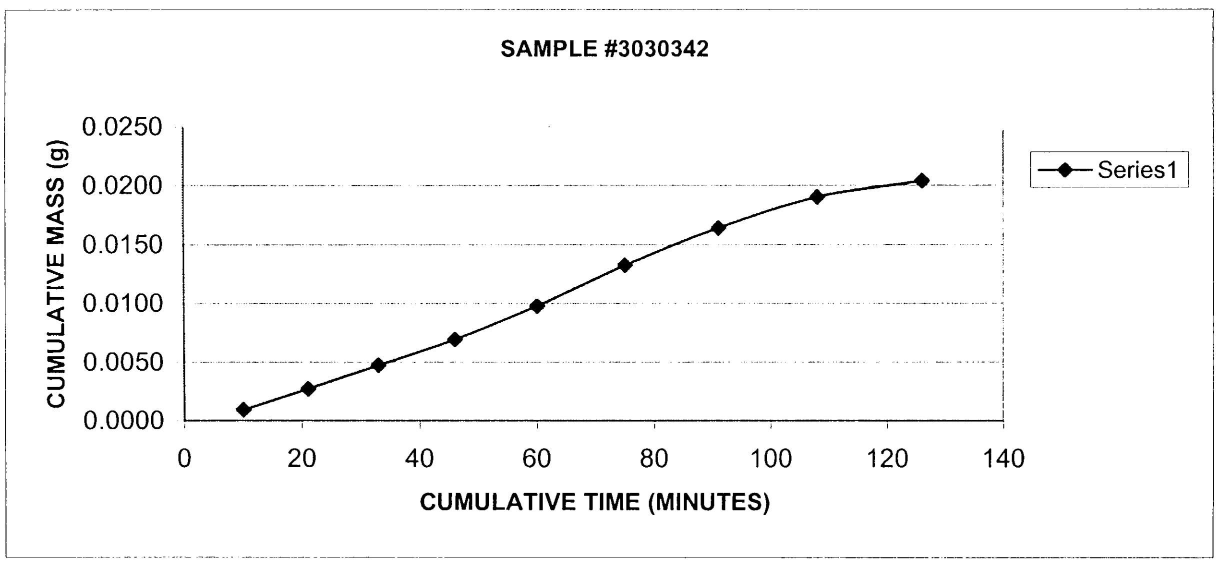
Sample	sec	Time, min	Initial weight	Final weight	Mass, g	Mr, g	Cum Time	Cum Mass	Mo, g	LN(Mo-Mr)	Ln(Mr)
342-05	600	10	0.0239	0.0248	0.0009	0.0009	10	0.0009	0.04	-3.2222057	-6.9621375
342-06	660	11	0.0221	0.0238	0.0017	0.0018	21	0.0027	0.04	-3.289727	-5.9012656
342-07	720	12	0.0202	0.0221	0.0019	0.0020	33	0.0047	0.04	-3.3448742	-5.3526996
342-08	780	13	0.0234	0.0255	0.0021	0.0022	46	0.0069	0.04	-3.4095879	-4.9697074
342-09	840	14	0.0240	0.0267	0.0027	0.0028	60	0.0098	0.04	-3.4994628	-4.6267626
342-10	900	15	0.0244	0.0277	0.0033	0.0035	75	0.0133	0.04	-3.6215566	-4.3230802
342-11	960	16	0.0229	0.0259	0.0030	0.0032	91	0.0164	0.04	-3.7471817	-4.1095061
342-12	1020	17	0.0236	0.0261	0.0025	0.0026	108	0.0190	0.04	-3.8654558	-3.9608651
342-13	1080	18	0.0236	0.0249	0.0013	0.0014	126	0.0204	0.04	-3.9329719	-3.891504



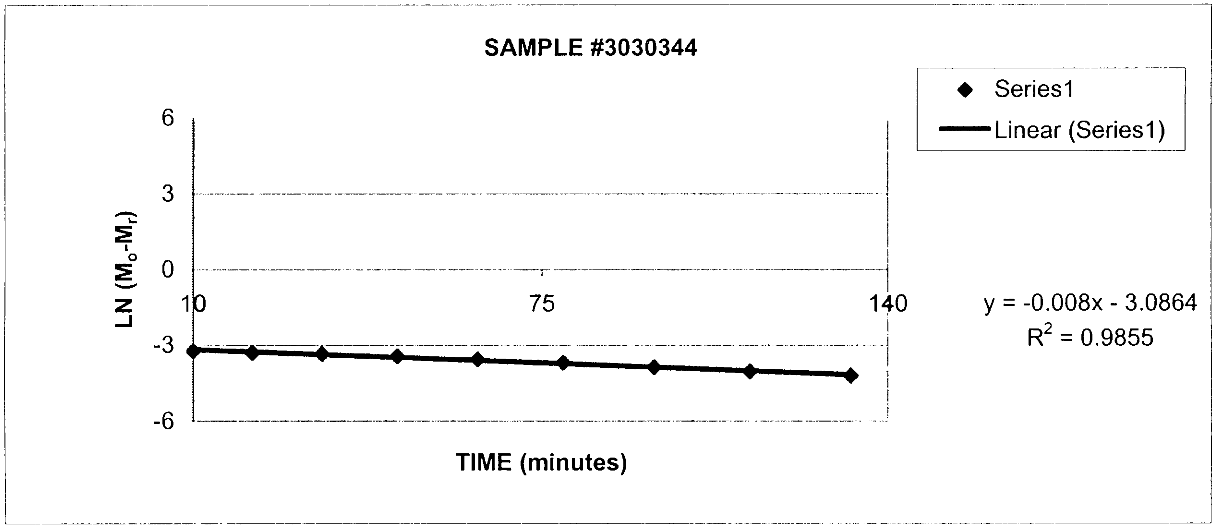
Intercept	-3.1404035	-6.3974554
Slope	-0.0064375	0.02364837
R2	0.99300157	0.84538025

0.06 %RD

mass submitted, ug	93
size of grid opening, mm2	0.009018
go to be scanned	153



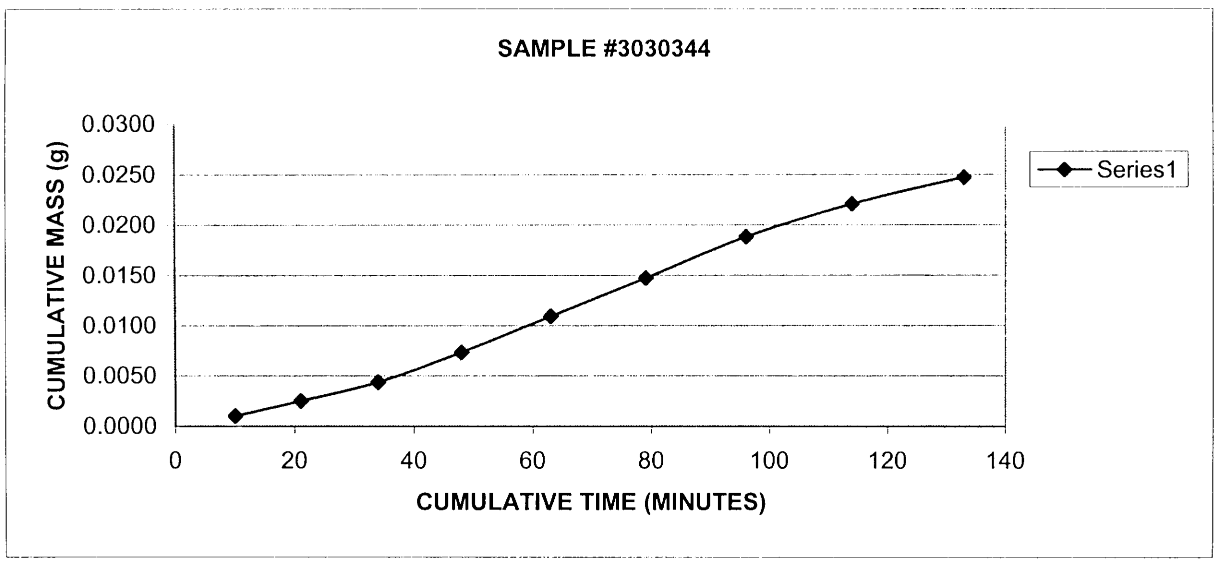
Sample	sec	Time, min	Initial weight	Final weight	Mass, g	Mr, g	Cum Time	Cum Mass	Mo, g	LN(Mo-Mr)	Ln(Mr)
344-05	600	10	0.0233	0.0243	0.0010	0.0011	10	0.0011	0.04	-3.2291585	-6.856777
344-06	660	11	0.0240	0.0254	0.0014	0.0015	21	0.0025	0.04	-3.2840951	-5.9813083
344-07	780	13	0.0233	0.0251	0.0018	0.0019	34	0.0044	0.04	-3.335962	-5.4216925
344-08	840	14	0.0234	0.0262	0.0028	0.0029	48	0.0074	0.04	-3.4224037	-4.9108669
344-09	900	15	0.0170	0.0204	0.0034	0.0036	63	0.0109	0.04	-3.5385275	-4.5149712
344-10	960	16	0.0233	0.0269	0.0036	0.0038	79	0.0147	0.04	-3.6782244	-4.2177197
344-11	1020	17	0.0204	0.0243	0.0039	0.0041	96	0.0188	0.04	-3.8554617	-3.9719763
344-12	1080	18	0.0234	0.0265	0.0031	0.0033	114	0.0221	0.04	-4.0228596	-3.8122546
344-13	1140	19	0.0244	0.0269	0.0025	0.0026	133	0.0247	0.04	-4.1818029	-3.6997766



Intercept	-3.0864215	-6.4058525
Slope	-0.0079778	0.0238551
R2	0.9854707	0.8785934

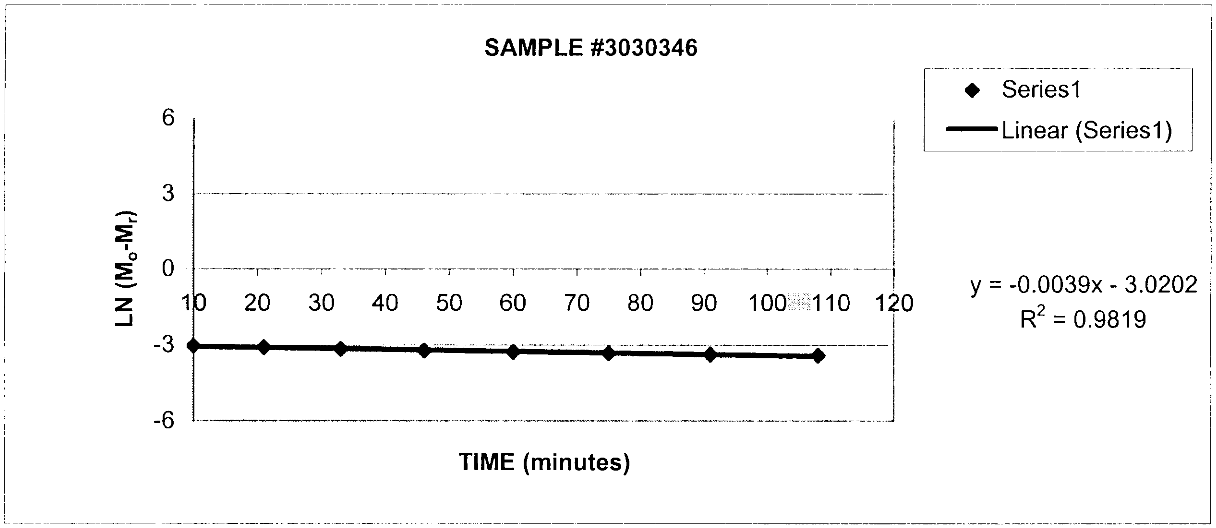
0.06 %RD

mass submitted, ug	92
size of grid opening, mm:	0.009018
go to be scanned	155



MODIFIED ELUTRIATOR METHOD   SAMPLE #3030346   PROJECT # SH20[illegible]
PERCENT RESPIRABLE DUST

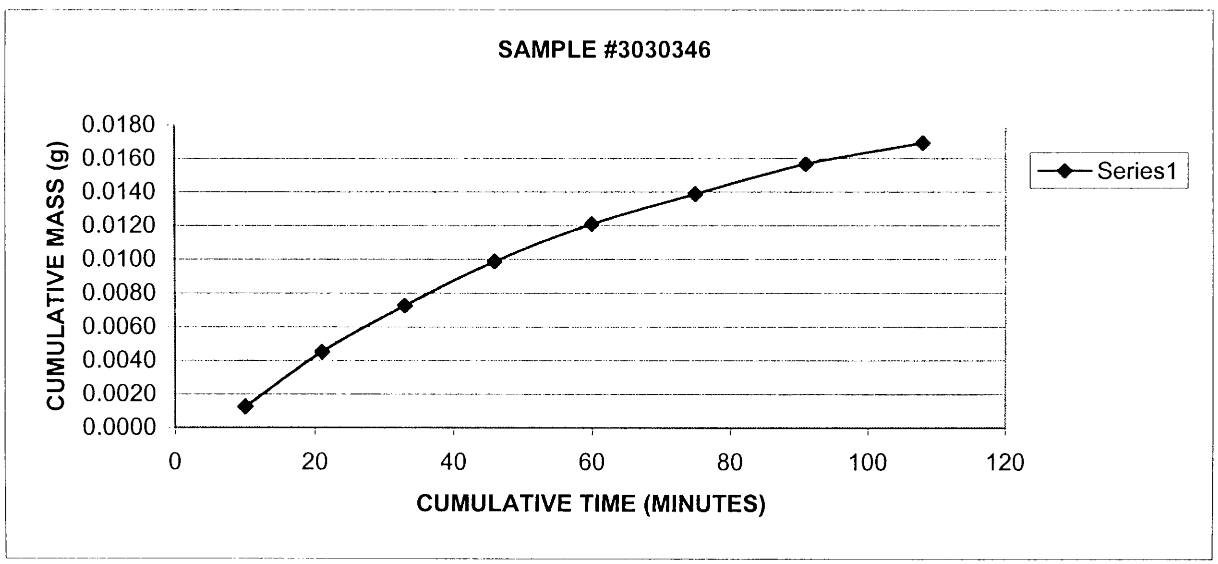
Sample	sec	Time, min	Initial weight	Final weight	Mass, g	Mr, g	Cum Time	Cum Mass	Mo, g	LN(Mo-Mr)	Ln(Mr)
346-05	600	10	0.0237	0.0249	0.0012	0.0013	10	0.0013	0.05	-3.037417	-6.67446
346-06	660	11	0.0268	0.0299	0.0031	0.0033	21	0.0045	0.05	-3.09059	-5.39816
346-07	720	12	0.0234	0.0260	0.0026	0.0027	33	0.0073	0.05	-3.15264	-4.92526
346-08	780	13	0.0205	0.0230	0.0025	0.0026	46	0.0099	0.05	-3.21617	-4.61607
346-09	840	14	0.0235	0.0256	0.0021	0.0022	60	0.0121	0.05	-3.272842	-4.41443
346-10	900	15	0.0242	0.0259	0.0017	0.0018	75	0.0139	0.05	-3.321195	-4.27656
346-11	960	16	0.0244	0.0261	0.0017	0.0018	91	0.0157	0.05	-3.372006	-4.15542
346-12	1020	17	0.0244	0.0256	0.0012	0.0013	108	0.0169	0.05	-3.409493	-4.07796



Intercept	-3.020202	-6.02286
Slope	-0.003853	0.021722
R2	0.981853	0.739679

0.07 %RD

mass submitted, ug	97
size of grid opening, n	0.009018
go to be scanned	147



SECTION A.7: MAY 2003 REVISIONS

Appendix A Section A.7 Revised Report Summary.pdf (in folder *Report_pdf*)

RJ Lee*Group*, Inc.

350 Hochberg Road
Monroeville, PA 15146
Tel: (724) 325-1776
Fax: (724) 733-1799

The Materials Characterization Specialists

May 6, 2003

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

RE: Taconite Samples
RJ Lee Group Project LSH204780, revised

Dear Mr. Zanko:

Samples of tailings from five taconite mines were received at RJ Lee Group for asbestos analysis. The original report of analyses was issued on July 8, 2002. Based on discussions held at the recent *International Symposium on the Health Hazard Evaluation of Fibrous Particles Associated with Taconite and the Adjacent Duluth Complex* (March 30-April 1, 2003), RJ Lee Group re-examined samples of Coarse tailings from Minorca, Minntac, and EVTAC. These samples had previously been identified as containing trace levels of cleavage amphibole particles.

Appendix B of the July report showed the Minntac and Minorca tails to contain trace amounts of cleavage amphiboles. These samples were re-examined and the previously identified amphiboles were correctly identified as Minnesotaite, a talc mineral in which iron has replaced the magnesium commonly found in talc. Minnesotaite is a common mineral in the iron formations in Minnesota. The optical properties of these minerals are very similar (minnesotaite – α = 1.580-1.592, γ = 1.615-1.632; tremolite/actinolite – α = 1.581-1.600, γ = 1.602-1.627[1]). The primary optical differences between these minerals is the birefringence, inclination (extinction angle), and project cleavage planes. Revised pages for Appendix B are attached to this letter. The identified minnesotaite is incorporated in the "Others" shown in the table.

In Appendix C of the July report, a structure was reported as "Act/Trem" in sample 3030344 (EVTAC Coarse Tails). A re-analysis of this particle indicates it is a talc fiber. In addition, particle number 7 was identified as a bundle of talc. The image is clearly of a single particle, not a bundle. The count sheet has been modified to note these changes and is also attached to this letter.

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[1] M. Fleischer, R. E. Wilcox, and J. J. Matzko (1984). Microscopic Determination of the Nonopaque Minerals, U. S. Geological Survey Bulletin 1627, p. 239-245.

Based on these analyses, no asbestos minerals are present in these tailings. If you have any questions regarding this report, please feel free to call either Keith Rickabaugh or me.

Sincerely,

Drew R Van Orden

Drew R. Van Orden, PE
Senior Scientist

Attachments