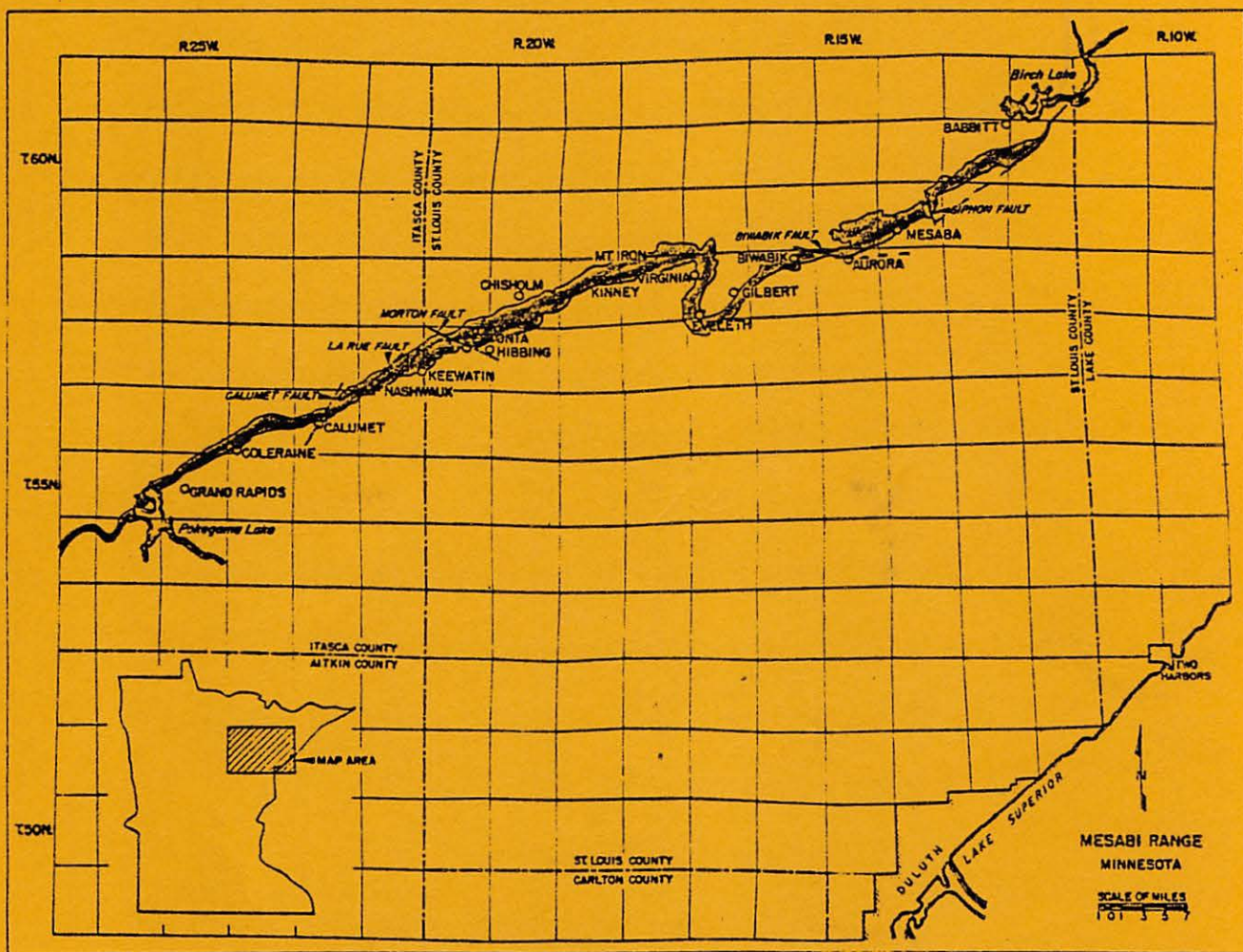


THE MESABI RANGE TRIP



MAY 12, 1979

ZZ
1815
.A1
c. 1
TECH
REPT

ZZ 1815 .A1 c. 1 TECH REPT

Plummer, Wayne L

The Mesabi Range Trip

**NATURAL RESOURCES RESEARCH INSTITUTE
LIBRARY
5013 MILLER TRUNK HIGHWAY
DULUTH, MN 55811**

Mesabi Range Trip

Wayne L. Plummer and Ralph W. Marsden

May 12, 1979

Leave Normandy Inn Hotel - - 8:00 A.M.

Travel via Minnesota #4 to Biwabik and on #169 to the Mary Ellen Mine road west of Biwabik.

Attached are maps showing the locations of iron ranges in the Lake Superior Region and the geology of the Virginia-Eveleth-Gilbert area (formerly termed districts by U.S.S.). The Virginia-Gilbert map is dated 1956 so the roads and some mine pits are not up-to-date. The geology is as shown and gives the general orientation for Stops 3 and 4 and the Minntac Mine.

Stop 1 - Mary Ellen Mine, Section 9 and 10 T58N R16W.

The Mary Ellen Mine was operated by the Stanley Mining Company 1924-1928 and 1948-1951, by the Pioneer Mining Company 1951-1961 and by the Pittsburgh Pacific Company 1962. Production totaled 4,574,973 long tons. Most of the ore produced required concentration.

The algal zone of the Upper Cherty member of the Biwabik Formation is well exposed near the top of the south pit wall. The algal zone forms a massive jaspery chert bed that was waste rock in the mine and forms a part of the rock on the waste rock dumps. Oxidized and partly leached Upper Cherty member of the Biwabik formation is exposed in the pit.

Stop 2 - Pillowed Greenstone - Leave Mary Ellen Mine and travel on Minnesota 169 to Gilbert, turn on Wisconsin Avenue to the pillowed greenstone outcrop north of the Gilbert School athletic field.

Stop 3 - Pokegama Formation - Leave greenstone outcrop, travel on Hwy 169 to U.S. 53 near Eveleth. The Pokegama Quartzite outcrop on the east side of U.S. 53 at the road junction is near the top of the formation. The hills to the northeast are on pre-Animikie rocks; the Biwabik formation is exposed in the road cut south of highway 169.

Stop 4 - Lower Precambrian - Outcrops of Lower Precambrian rocks are exposed on hills east of highway 53 between Eveleth and Midway Addition. These rocks are commonly termed Knife Lake Series, which includes a variety of meta-sedimentary, metavolcanic and intrusive rocks.

Stop 5 - Lunch - Alcott Park, Virginia.

Stop 6 - Minntac Mine and Plant - Mountain Iron, Minnesota. See accompanying description.

MINNTAC TACONITE

Ralph W. Marsden and Wayne L. Plummer

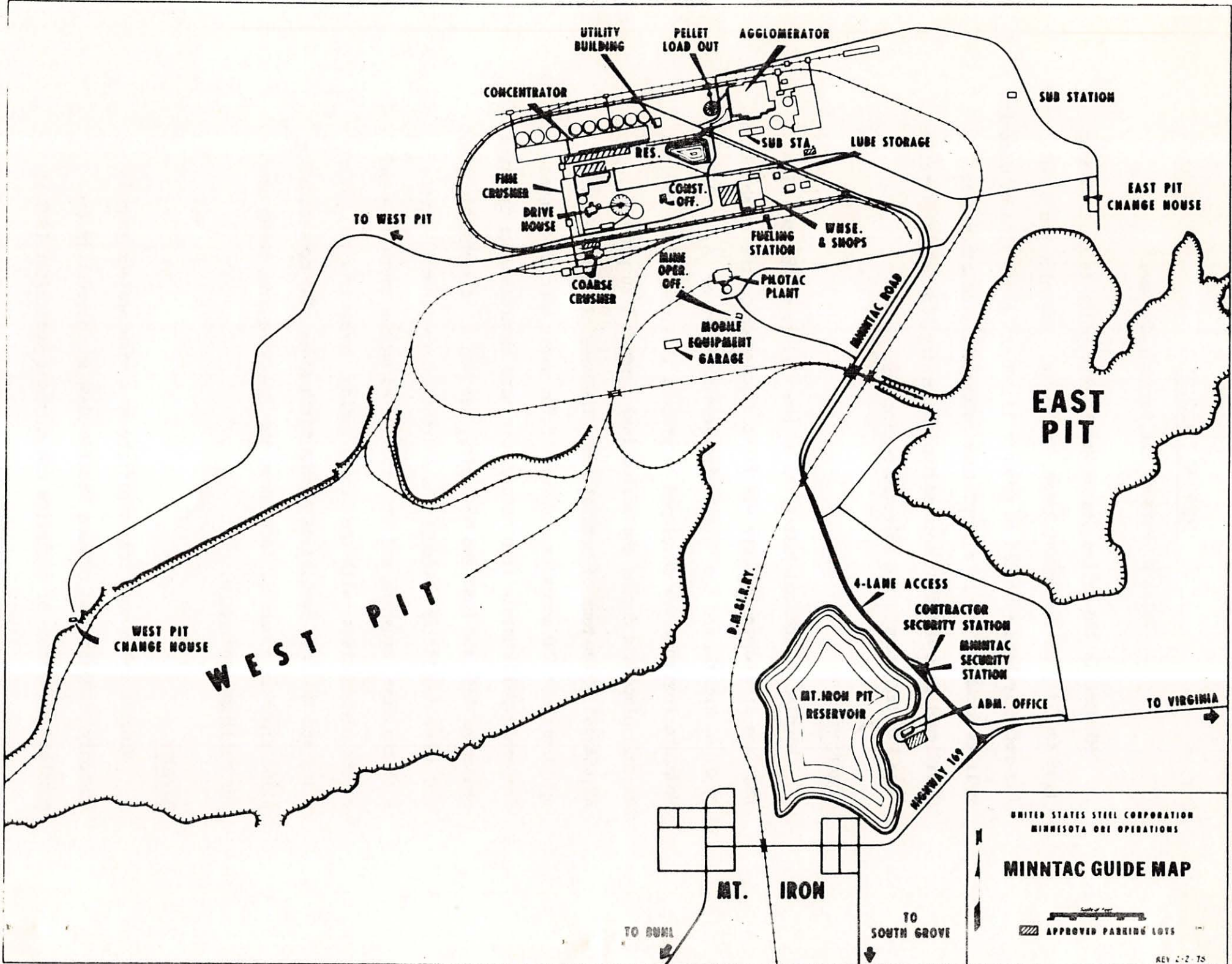
Minntac is the United States Steel Corporation taconite production facility on the Mesabi Range, Minnesota. The mine and plant has recently been expanded to produce 18,500,000 gross tons of taconite pellets annually and is a completely integrated production unit. Additional more detailed information concerning Minntac is given in "The Minntac Story", see selected references.

LOCATION

Minntac is located just north of the village of Mountain Iron near the site where iron ore was first discovered on the Mesabi Range by J. A. Nichols and the Merritt Brothers on November 16, 1890. The Mountain Iron mine was developed to produce the iron ore discovered at this place and during the period 1892 through 1956 produced 48,664,453 gross tons of natural ore. The mine pit which covers approximately 300 acres is a reservoir for water used at Minntac. The exhausted Mountain Iron natural ore mine separates the taconite ore areas into the East and West pits, see Map 1. The Minntac plant and other facilities straddle the Laurentian, continental divide with the mine, crushing and shop facilities on the south side and on the divide crest, with the fine grinding, concentrating, pelletizing and tailings facilities on the north side. The concentrating plant floor is about 255 feet above the low-lying area being used for tailings deposition.

HISTORY

Minntac has a much longer history as a mine project than is commonly recognized as company records show an interest in the possible production of magnetite concentrates soon after 1900 at



the time the United States Steel Corporation was created and lands were acquired to give a continuing long-term supply of iron ore. The threat of exhaustion of the natural ores on the Mesabi Range, that was recognized in the early 1940's stimulated research on the commercial processing of taconite. United States Steel, as well as many other companies and the Mines Experiment Station of the University of Minnesota, expanded studies and research on the processing of all types of potentially concentratable low grade iron formation materials. The most promising material was the magnetite taconites of the Mesabi Range. After sufficient laboratory work was completed, two prototype processing plants were constructed by United States Steel. The first, a taconite mine and concentrating plant with a rated annual capacity of approximately 500,000 gross tons of concentrates, was built north of Mountain Iron near the site of the present Minntac plant and was named "Pilotac". Construction of the plant started in 1951. This plant served to test commercial sized crushing, grinding, and concentrating equipment and to develop the best possible flow pattern for processing magnetite taconite. The Pilotac mine was used to test drilling, blasting and mine practice as well as to furnish ore to the processing plant. This plant, after many modifications and changes in equipment, has been used as a taconite research facility since about 1965 and is still operating as a production unit of Minntac producing about 800,000 gross tons of taconite concentrates annually.

The second plant termed "Extaca" was constructed in the NE-NE of Section 19, T58N., R17W. in the southwestern part of the city of Virginia, Minnesota. This location is also the site of the Rouchleau

crushing and screening plant. Extaca plant was used to test the agglomeration of taconite concentrates (and to some extent natural iron ore fines). The Extaca plant included full scale sintering and rotary kiln nodulizing facilities. This plant operated until 1967.

Meanwhile, the Reserve Mining Company began the commercial production of taconite pellets in 1956, and the Erie Mining Company began production in 1958. Construction began at Minntac in November, 1964 with the first shipment of iron ore pellets on October 25, 1967.

GEOLOGY

Commercial quality magnetite taconite occurs in the Lower Cherty, Lower Slaty and Upper Cherty members of the Biwabik iron-formation. The limits of ore quality taconite is determined by the magnetite content which is related to the stratigraphy, metamorphism, and by the extent of secondary oxidation. The relationship of taconite ore to stratigraphy in the Minntac area, is generally predictable with the central part of the Lower Cherty and much of the Lower Slaty members commonly of ore grade. The upper and lower boundaries of the Lower Cherty and Lower Slaty ore zones are determined by drilling as the margins of ore is gradational. The occurrence of taconite of ore grade in the Upper Cherty member is variable and must be determined by drilling. Oxidation of the Biwabik formation may be extensive in areas of fracturing such as near the natural ore deposit at the Mountain Iron mine. Several zones of oxidation occur in the Minntac mine area which has resulted in the development of hematite and goethite from iron silicates, iron carbonates and magnetite. Ordinarily magnetite is oxidized to martite. The extent and distribution of oxidized zones can be generally outlined by magnetic surveys accompanied

by drilling. The oxidized taconite material may be left in the mine or, if it is in the way of mining, removed to oxidized taconite dumps. These materials may be used at a later time when it is economically feasible to process hematitic and goethitic iron-formation.

The Biwabik formation dips 4° to 8° south in the Minntac area. The iron-formation varies somewhat in strike and dip along the about 7 mile length of the Minntac deposit. Minor local structures are present and include faults with relatively small displacement zones of fracturing and minor folds.

The Biwabik formation is about 625 feet thick in the Minntac area and is subdivided into four members; Upper Slaty, Upper Cherty, Lower Slaty and Lower Cherty. Each of the members are divided into sub-units for more detailed geological work related to the mining. The accompanying Table I gives a generalized description of the Biwabik formation in the Minntac area.

TACONITE ORE

Taconite ore commonly includes all material that contains in excess of about 14 percent magnetic iron or about 20 percent magnetite with the average mine-run ore containing about 33 percent magnetite or about 24 percent magnetic iron. As an average, about three tons of taconite ore is processed to yield one ton of pellets. The determination of ore quality requires that the magnetite can be liberated from other minerals at an acceptable grind, which is defined at Minntac, as at a grind with about 90 percent passing a 270 mesh screen. Presently about 75 percent of the ore comes from the lower cherty member and 25 percent from the lower slaty member.

In order to allow a uniform flow to the grinding and concentration sections of the plant, the crude ore is blended as it is mined to give continuously similar material in grindability, magnetic iron content, weight recovery and concentrate quality. Careful crude ore grade control requires detailed knowledge of the character and composition of the taconite ore as it occurs in the mine. This knowledge is obtained by closely spaced drilling on a 300 x 200 foot grid pattern. The grade control program uses computer assistance to program mining plans.

MINING

The Minntac mine includes two major open pit areas; the east and west pits, see Map 1. The west pit was opened during the Pilotac operation and now extends from near the plant site westward for about 3 miles with a maximum width of about 2000 feet and a maximum depth of 170 feet. The west pit is being extended westward and is expected to have an ultimate length of about 4.5 miles and a depth of about 500 feet. The east pit is being developed and will have an ultimate length of about 2.5 miles.

The glacial overburden and rock stripping are removed by a separate mining unit that uses 14 cubic yard shovels loading 120 ton trucks for haulage to stripping dump sites. Lean, taconite waste rock is segregated so it could be recovered if a change in processing systems or a change in costs will permit its use. The glacial overburden ranges in thickness from 5 to 50 feet and averages about 25 feet. Currently most of the rock stripping comes from the "Intermediate Slate" and the upper part (5B unit) of the lower cherty member with an average combined thickness of about 50 feet.

Crude taconite ore is drilled using large rotary drills with tungsten carbide insert bits. Jet piercer drills were tested at Pilotac and one jet drill is available for part time use. Blast drill holes with three diameters are used, 12-1/4" and 15" to permit the development of the most effective hole spacing and rock fragmentation.

Blasting is done using ammonium nitrate and fuel oil. Mine benches are 40 feet high with the benches generally running parallel to the strike of the iron-formation. Commonly blast drill holes are spaced on a 28 to 32 foot grid pattern with typical blasts breaking from 300,000 to 1,000,000 tons of taconite. In order to minimize blast noise and air vibrations, careful consideration is given to meteorological conditions before blasting. Small monitor blasts are used to check the suitability of atmospheric conditions before blasting.

Crude ore is loaded by shovels using from 6-1/2 to 14 cubic yard buckets into 40 to 50 cubic yard (70 to 90 ton) side dump cars with 9 or 10 cars per train. All ore haulage at Minntac to the plant is by rail. Trains use 1200 & 1500 HP diesel-electric locomotives which are remotely controlled by the operator so one man can handle the train and maintain complete, accurate control of the train during loading and unloading. The train operator dumps cars at the crusher using an on-board air dumping system. The present average haul from the west pit mine face to the crusher is about 3.5 miles which will increase somewhat as the west pit mine reaches its maximum development. The mine track system is changed as the mine faces are developed and are single track except in areas of heavy traffic which are double track. To aid in flexibility of operation, two track entrances

and exits are available from the west pit. The east pit is being developed and has a single track main line and mine track system.

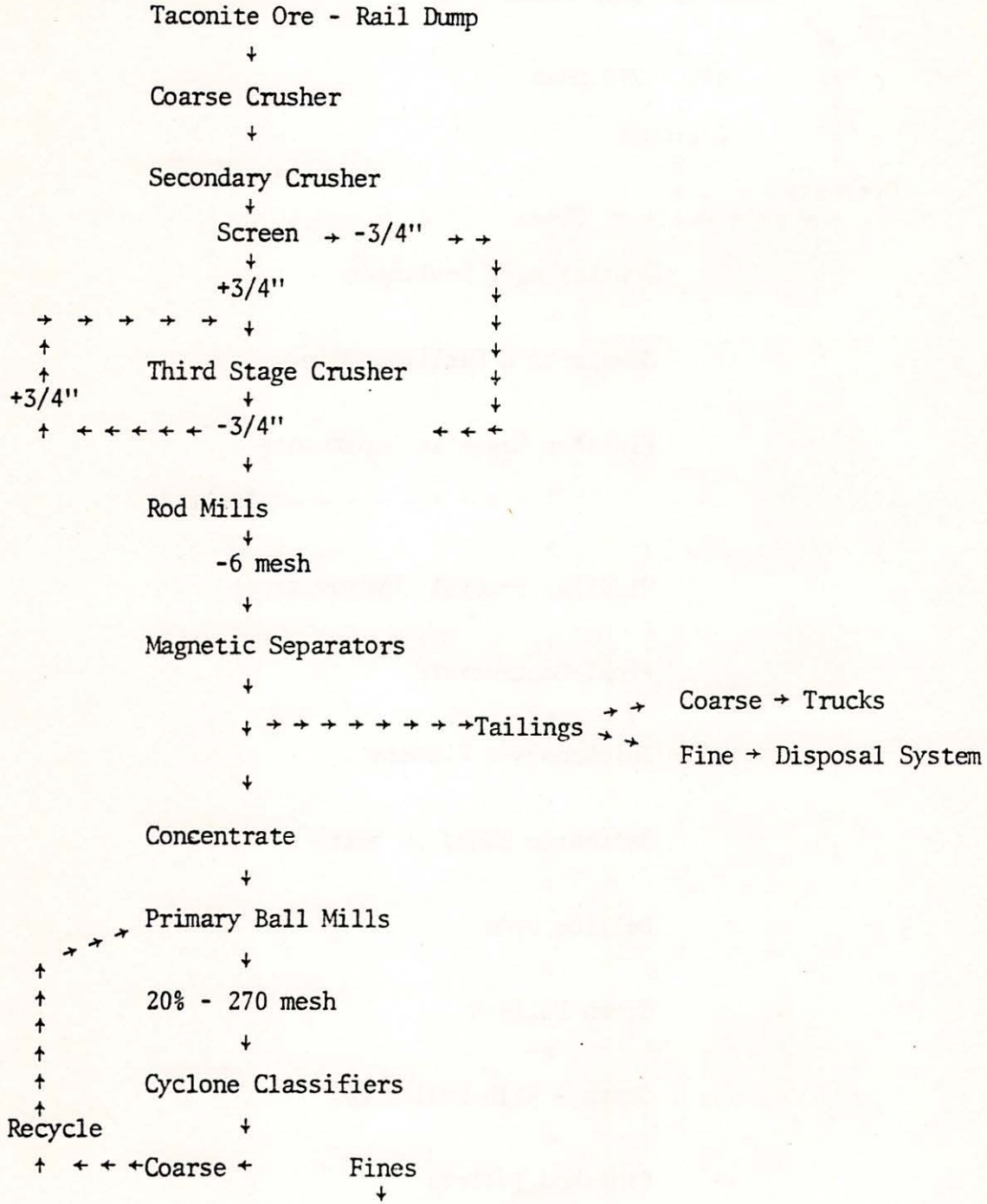
At the 18,500,000 gross ton level of pellet production, about 62,000,000 tons of crude taconite ore is delivered to the processing plant annually, with about 35,000,000 tons of waste rock and about 10,000,000 cubic yards of surface overburden removed during mining.

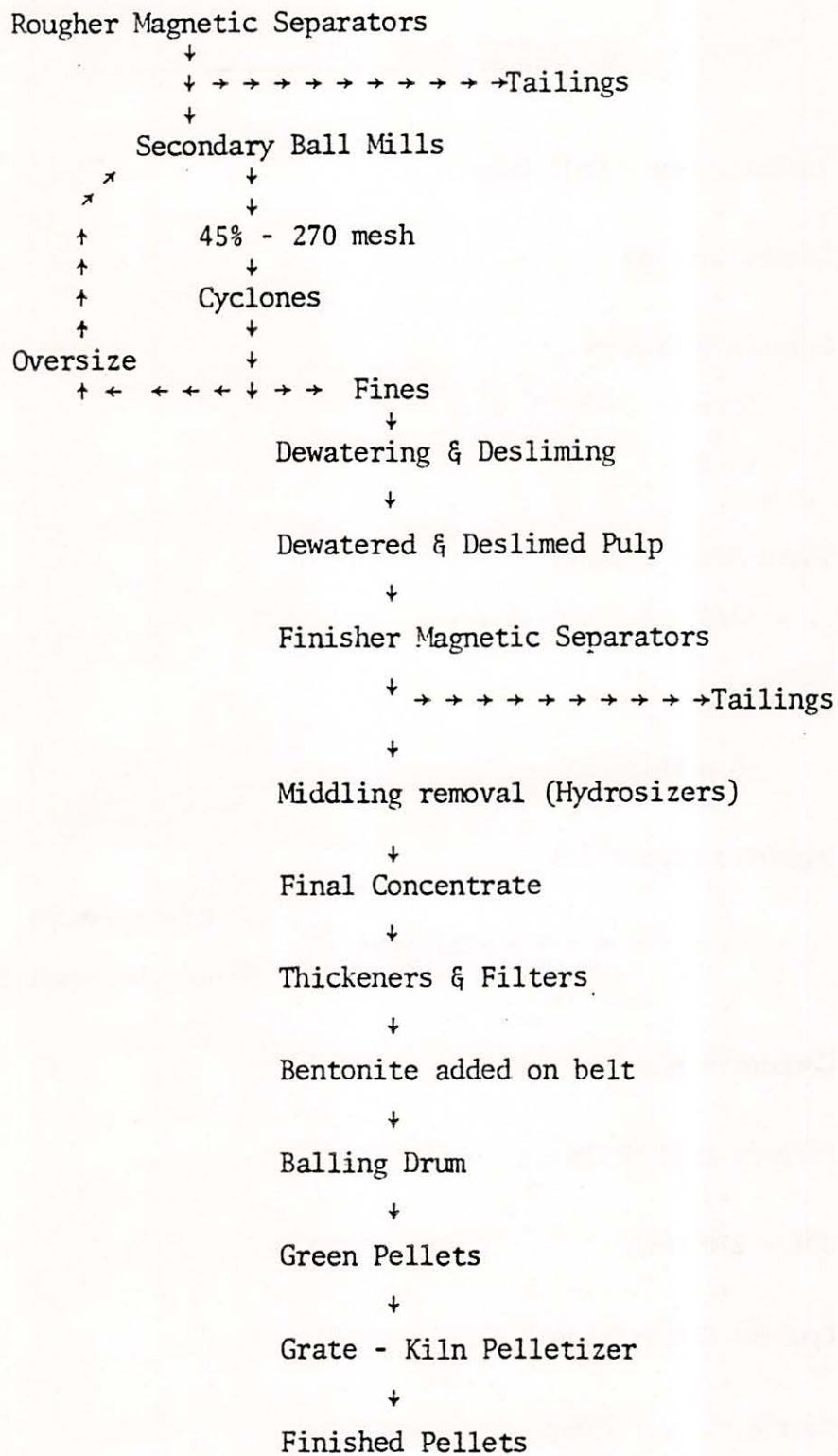
The mined ore is delivered to the processing plant in mine run sizes from a maximum of about 6 feet and is reduced in size to 90 to 92 percent minus 270 mesh before final processing is complete and the fine concentrate delivered to the pelletizing plant. The generalized flow pattern of the Minntac operation is shown on Figure 1 which includes all essential steps from primary crushing through the final pellet product. The Minntac plant is highly automated with centralized control and monitoring, modern safety and pollution control equipment.

CRUSHING

Taconite ore is crushed in 3 stages to 95 percent minus 3/4 inch which requires passing a 60'x110" gyratory crusher with an open side setting of 6"; and a 7' standard gyratory, secondary crusher that reduces the feed to minus 3 inch size. This crushed product from the secondary crusher is screened on double-deck vibrating screens to give a finished -3/4 inch product and a plus 3/4 inch product that is sent to the third stage, 7' shorthread crushers to produce a minus 3/4 inch product. After the third stage crushing, the product is screened in a closed circuit and the oversize is recycled. The under-size joins the minus 3/4 inch screen product from the secondary crusher screens and is transported by belt conveyers to the grinding section.

Figure 1- GENERALIZED FLOW SHEET - MINNTAC PLANT





Since crushing is a dry process, dust collectors are installed at each crushing station, primary, secondary and tertiary and at screening stations. The dust collectors remove essentially all particulate material in the air stream.

GRINDING

Product from the crushing section is delivered at 95 percent minus 3/4 inch to storage bins at the grinding and concentrating building.

The minus 3/4 inch material is fed to rod mills. The discharge of the rod mills, at about minus 10 mesh, flows by gravity to drum magnetic separators that produce a cobber concentrate and a coarse tailing product. The cobber concentrate is sent to primary ball mills where it is ground to about 40 percent minus 270 mesh. The coarse cobber rejects, which represent about 35 percent of the crude ore, are classified with the sand size material conveyed to a truck loading pocket and deposited in the coarse tailings disposal area and the fine tailings are routed to the tailings disposal system.

The cobber concentrate passes through the primary ball mills and cyclone classifiers. The oversize returns to the primary ball mills and the fines pass through a rougher magnetic separator where a second tailings is removed. The rougher concentrate passes to secondary ball mills that operate in a closed circuit with cyclone classifiers. The cyclone overflow passes to 30'x6' hydro-separators for dewatering and desliming. The high silica overflow is sent to the tailing circuit and the thickened pulp underflow is sent to three-drum finisher magnetic separators. The finisher products are a final magnetic concentrate and final tailings. The

finished concentrate average is 66% Fe and 5.2% SiO₂. The average weight recovery is about 30.5 percent on a dry basis.

The tailings from the finishing process pass to thickeners where water is recovered and returned to the plant water system and the fine tailings to a pump house from which they are discharged into the tailings basin. In the tailings basin, the fine material settles and is retained and the water recovered and returned to the plant for reuse. The Minntac tailings basin, on the north side of the continental divide presently covers an area of about 2800 acres. Plans are made to plant the surface of the tailings deposit as areas reach the final stage of development. No water is overflowed into surface drainages. Clear water is lost only through underground seepage and by evaporation. An annual average of approximately 8500 gallons per minute of new make-up water is required to maintain a circulating volume of about 36,000 gallons per minute at the 18,500,000 annual ton level of pellet production.

PELLETIZING

The fine magnetite concentrate is delivered to the pelletizing plant as a slurry with about 50 percent solids and is sent to 50'x20' thickeners, which produces a slurry containing from 62 to 68 percent solids. The thickened slurry passes through storage tanks and is then distributed to disc type filters. The filters produce a filter cake containing an optimum 9.8 percent moisture. The concentrate is monitored for Blaine surface and is maintained at a temperature of from 60°F to 70°F as filtration is affected by both size and temperature. Heat is added when needed by heating coils in the slurry tanks.

Filter cake is delivered by conveyor to balling drums. Bentonite at from 18 to 20 pounds per ton of concentrate is added on the conveyor belt and furnishes binder for the pelletizing process. Bentonite and concentrates are mixed in motor-driven reel-type blenders on the belt. The mixture together with recycled, undersized seed balls are fed to 10'x32' balling drums. The wet, green balls pass to a roll feeder and onto the 12'2" wide grate of the grate-kiln firing unit. The pellets are dried, pre-heated and when heated, partly hardened at about 1800°F, are discharged from the grate into a gas fired, refractory lined rotary kiln. The kiln rotates at about 78 revolutions per hour and is heated so the pellets attain a temperature of about 2450°F. The hot pellets are discharged into an annular cooler where forced air fans provide air to cool the pellets to about 250°F prior to dumping into a bin for transfer to a pellet storage area from which they are loaded into railroad cars for shipment. The final pellets are a nominal 1/2" in size and have a uniform chemical composition, that in 1971, averaged 65% Fe, 5.4% SiO₂, 0.01% P, 0.13% Mn, 0.17% Al₂O₃, and 1.9% moisture.

SELECTED REFERENCES

"The Minntac Story"

Part I - General - D. F. Widmayer

Part II - Mining - D. Hartley

Part III - Crushing and Concentrating - K. L. Prothero

Part IV - Agglomeration - D. V. Erickson

Minnesota Section, AIME - 1970; Thirty-first Annual Mining Symposium and Forty-third Annual Meeting of the Minnesota Section, AIME, University of Minnesota, p. 37-52.

GENERALIZED DESCRIPTION OF THE BIWABIK FORMATION, MINNTAC AREA

UPPER SLATY MEMBER - (80'-85'*) The Upper Slaty member is seldom observed in the drilling in the Minntac area as the outcrop zone of the Upper Slaty is about a mile south of the current mining activity. Because of the scanty information, only a limited description and a listing of the lithologies present is given.

The Upper Slaty member includes interlayered gray to greenish granule, chert silicate taconite, even-bedded and laminated, gray, ferruginous and calcareous argillite, black to dark green fine-grained chert, gray to white dolomitic limestone, and dark green chloritic layers. A few thin pyrite layers and seams occur. Locally within the dolomitic limestone, there are thin layers composed of fragments or nodules of dark flinty chert in a carbonate matrix. The Upper Slaty member has a gradational relationship to the Virginia argillite formation above and the Upper Cherty member below. The contact between the Upper Cherty and Upper Slaty members is usually made where the jaspery chert layers stop and the first argillaceous and calcareous beds occur.

UPPER CHERTY MEMBER - (185'±) The Upper Cherty member consists of interlayered units of granular, often jaspery, cherty taconite and even-bedded, laminated chert-silicate and chert-silicate-magnetite taconite. It is sub-divided into 6 units that are designated U.C.-11 through U.C.-16 with U.C.-16 at the top of the member.

U.C.-16 Granular Cherty Taconite- This unit is a granular to finely conglomeratic, jasper-chert-silicate-magnetite taconite as nodules and interlayers with even bedded, silicate-carbonate-chert-magnetite taconite. There does not seem to be a pattern to the relative quantities of each present. The relationship is not regular with separate units apparently lenticular. Some of the even bedded silicate-carbonate units are fissile and similar to parts of L.C.-13.

U.C.-15 Algal Chert- (Range 14'-60'; East pit - 50', West pit - 60')
The Algal unit includes a zone of cherty taconite that contains layers that are laminated, or contain stromatolite like laminated structures that are conveniently termed "algal structures". These structures have been observed over stratigraphic thickness of 182 feet which suggests the occurrence of a series of algal chert horizons within this thickness of the Biwabik formation. The associated taconite consists of conglomeratic beds with jasper and chert fragments and interbedded magnetite-silicate-chert taconite. Only the upper, commonly rather massive, algal and fragmental beds are recognized in other adjacent areas in the Upper Cherty member.

U.C.-14 Even bedded, silicate-chert-magnetite-taconite- which is interlayered with pinkish chert or jaspery conglomeratite layers.

U.C.-13 Silicate-carbonate-chert taconite- that is even bedded to fissile. This unit is commonly non-magnetic, dark green in color and classed as "slaty taconite". In section 8, T58N, R18W, this type of taconite occurs below L.C.-12 and represents the basal lithology of the Upper Cherty member and is classed as U.C.11.

U.C.-12 Fragmental, Cherty taconite- Throughout most of the Minntac area, the basal unit of the Upper Cherty member is a conglomeratic, with gray chert fragments in a magnetite-chert taconite matrix. Locally some algal chert occurs at or near the top of the unit.

U.C.-11 Silicate-carbonate-chert taconite- See description of L.C.-13.

LOWER SLATY MEMBER - (165'±) The Lower Slaty member consists, generally of interlayered, even-bedded, laminated and rather thick-bedded cherty beds with a series of lensing units of cherty and slaty taconite. The sub-units thicken and thin laterally with the exception of the lower sub-unit, the "Intermediate Slate". Five units are recognized that have gradation and sometimes vaguely defined contact relationships. The units from the bottom upward are numbered L.S.-6 through L.S.-10. In the Mountain Iron to Gilbert, Central Mesabi Range area, much of the Lower Slaty member contains sufficient magnetite to be mined and processed.

L.S.-10 Sandy Banded magnetite-taconite- This upper unit of the Lower Slaty member has a "sandy" appearing, fine-grained, granular texture which is commonly laminated. The unit is an even-bedded magnetite-taconite and has a small content, possibly 1 to 3 percent, alumina. The laminated beds contain common irregularly shaped, tabular lenses and nodules of granular cherty taconite.

L.S.-9 - This unit is an even, thick-bedded, rather massive yet even-bedded, chert-silicate-magnetite taconite with some hematite and pinkish chert. Dark colored silicate granules are common and finely conglomeratic layers with chert fragments occurs at the bottom of the

unit. The bottom beds of the unit may be wavy bedded.

L.S.-8 - Laminated and nodular, "sandy" textured, chert-silicate-magnetite, slaty taconite with minor hematite. This unit is similar to L.S.-9 but commonly is noticeably laminated.

L.S.-7 Cherty Taconite- This unit is commonly a cherty, wavy and thick-bedded, massive, granular chert-silicate-carbonate-magnetite taconite which may have a mottled texture or contain laminated beds. This unit is similar in appearance to the parts of the Lower Cherty 4 unit.

L.S.-6 "Intermediate Slate"- This basal unit of the Lower Slaty member has a gradational relationship with L.S.-7 with rather thick beds of chert-silicate-magnetite taconite interlayered with laminated and nodular silicate-carbonate, slaty taconite. Downward, the slaty taconite increases in amount and the rock becomes well laminated, fissile, and argillaceous. The fresh, unoxidized material is dark green to black and is carbonaceous. White to gray, fine grained chert and granular, silicate-taconite occurs as nodules and in thin layers up to about 2 inches thick. A dark gray to black, silicate-granule chert occurs at the bottom of the unit. The "Intermediate Slate" contains little magnetite and often is totally non-magnetic.

LOWER CHERTY MEMBER - (200'±) The Lower Cherty member is divided into 7 units (L.C.-1 to L.C.-5B) that includes a basal algal, clastic and conglomeratic unit. This member is characterized as a generally granular, cherty taconite with a considerable variation in mineralogy and in bedding characteristics that are the basis for subdivision into units.

Chert-Silicate Taconite - L.C.-5B (25'±) This unit consists of rather coarsely granular, wavy, thick bedded, silicate-chert-carbonate taconite with very minor magnetite interlayered with some dark green to black, even-bedded, carbonate-silicate-chert taconite in the upper part. The contacts with the overlying "Intermediate Slate" and the L.C.-5A unit below are often optional over a few feet of thickness.

Magnetite-Silicate Taconite - L.C.-5A (25'±) This unit is a coarsely granular and fragmental, silicate-rich, magnetite taconite which is massive and often is without bedding lamination or with minor, irregular laminations, silicate granules are common and give a green color to the rock. Fragmental zones that may be termed "intra-formational conglomerate" with common, disseminated magnetite, are characteristic of this unit. Minor pyrite, siderite and ankerite are present. Some bedding surfaces are coated with carbonaceous material or graphite. Some anthraxolite occurs locally.

Bedded, Magnetite-Taconite - L.C.-4 (55'±) This unit is a wavy and thick-bedded, granular, chert-magnetite taconite with common iron silicates and carbonate. The upper part of L.C.-4 is rather massive with mottles of ankerite in a dark colored, wavy and thick-bedded magnetite-chert-siderite taconite and a green, silicate taconite. The lower part of L.C.-4 contains laminated, magnetite-rich layers up to 1 inch thick, interlayered with gray, chert-silicate taconite with some mottled carbonate, layers near the base. Iron-silicate, (minnesotaite) occurs in small radiating bundles or clusters that gives a marked toughness to the rock. The general color is greenish to greenish-gray with some pinkish, carbonate-rich layers.

Wispy-bedded Magnetite Taconite - L.C.-3 (35'±) This unit is a wavy and thick-bedded, medium to coarse granule locally conglomeratic, magnetite-silicate-carbonate-chert taconite. Magnetite occurs as irregular, wispy seams and disseminated grains. Some beds contain carbonate mottles. Pyrite as seams and fracture fillings or as "balls" are common locally. Carbonaceous material (possibly graphite) is common on bedding surfaces. The upper part of the unit is usually greenish in color with a slightly higher silicate content than the lower gray-green portion. The L.C.-3 and L.C.-4 contact is gradational. The L.C.-3 unit is characterized by the absence of $\frac{1}{4}$ to $\frac{1}{2}$ inch magnetite-rich seams. The contact with the L.C.-2 unit is also gradational and is usually placed at the first prominent, hematite-rich beds. The bottom of L.C.-3 is commonly the base of commercial quality magnetite-taconite at Minntac.

Hematite-magnetite-chert taconite - L.C.-2 (30'±) This unit is characterized by the occurrence of hematite that is considered to be primary. It is commonly even-bedded, thick to massive, hematite-carbonate-chert taconite with variable amounts of magnetite and iron-silicates. The chert often is pink. Some beds are mottled, others may be laminated.

Argillaceous, Hematite-magnetite Taconite - L.C.-1 (28'±) This is a variable unit which in places includes the same lithologies as the L.C.-2 unit so that a separation into L.C.-2 and L.C.-1 is not made. Characteristically, L.C.-1 contains laminated, argillaceous hematitic layers that are wavy or massive or even-bedded and may be fissile or thick bedded. Magnetite-hematite-carbonate-silicate taconite,

magnetite-silicate-chert taconite and carbonate-silicate-chert taconite occurs. Locally, the unit may contain little hematite with most of the iron oxide as magnetite. Sometimes, layers are fragmental with quartz clasts and jasper fragments. The contact with the basal algal and clastic unit is drawn on the occurrence of algal or jaspery or common clastic layers.

Algal and Clastic Unit - This subdivision of the Lower Cherty member is of variable lithology but is characterized by the common occurrence of gray to jaspery algal chert, chert and vein quartz pebbles, and sandstone. Sandstone is generally thin, but locally in the Minntac area is up to several feet in thickness. The sandstone is commonly massive, red to greenish-gray, with quartz sand grains in a ferruginous, chloritic, possibly argillaceous matrix. Fragments that appear to be argillaceous occur as pebbles. Algal chert and jasper layers up to 2 or 3 inches thick are fairly common in the sandstone. Locally, the argillaceous sandstone is absent and there is an abrupt change from iron formation to quartzite with only a thin conglomerate present. This unit may be in contact with the Pokegama formation or rest upon Lower Precambrian greenstone or granite.

AVERAGE CHARACTERISTICS OF LAYERS

LAYER	AV. THICK.	CRUDE FE.	MAG. FE	AGGL.		GRIND INDEX
				WT.REC.	SiO ₂	
LS	165'	28.8	19.8	28.7	8.2	41.1
LC5B	20'	25.7	8.9	12.8	7.3	39.1
LC5A	25'	27.8	15.3	22.4	7.7	44.8
LC4	60'	31.6	21.8	31.9	5.0	44.8
LC3	30'	30.3	23.4	33.9	5.2	49.5