THIS LEASE, made this ________ day of ______________, 1963, by and between DOUGLAS COUNTY, a body politic and corporate of the State of Oregon, party of the first part, hereinafter sometimes called "Lessor" and THE HANNA MINING COMPANY, a corporation duly organized and existing under and by virtue of the laws of the State of Delaware, party of the second party, hereinafter sometimes called "Lessee",

W I T N E S S E T H :

WHEREAS, Lessor is the owner in fee of the following described mineral rights on lands located in the County of Douglas, State of Oregon:

> All of the mines, minerals, ores and valuable substances (excluding timber) in, on or under the West half of the Southeast quarter of Section 18; Northeast quarter of the Northeast quarter of Section 19; West half of the Northwest quarter of Section 20; and Northwest quarter of the Southwest quarter of Section 20, all in Township 30 South, Range 6 West, Willamette Meridian,

hereinafter referred to as the "mineral rights"; and

WHEREAS, in accordance with Chapter 271, Oregon Revised Statutes, the County Court of Douglas County, Oregon, has determined that the mineral rights on the above-described property are not needed for public use and has further determined that the public interest would be furthered by leasing the mineral rights to the Lessee for the term and for the purpose hereinafter set forth and that the execution of this lease has been authorized by order of the County Court of Douglas County, Oregon, duly entered in its journal and dated ____________________, 1963, and

WHEREAS, it is expressly understood that the Lessor has deeded the rights to timber and other rights in and to said premises to the Roseburg Lumber Company as more particularly set forth in deed to Roseburg Lumber Company dated May 6, 1959, recorded in Vol. 284, page 223 and 228, Deed Records, Douglas County, Oregon, subject to all minerals and mineral rights in and to the same, said minerals and mineral rights having been retained by Douglas County.

NOW THEREFORE, in consideration of the sum of one dollar ($1) to it in hand paid, and in consideration of the agreements hereinafter set forth to be kept and performed by Lessee, Lessor has let, leased and demised and by these presents hereby does let, lease and demise to the Lessee the mineral rights for such period of time and upon such terms and conditions as are hereinafter set forth.

1. The term of this lease shall be ten (10) years from and after the date hereof, provided, however, that the Lessee shall have the sole and exclusive option to renew this lease for five (5) year periods for the next thirty-five (35) years by giving the Lessor written notice of its desire for each respective renewal at least thirty (30) days prior to the first day of such renewal period, and provided further, however, that Lessee shall have the right at any time to terminate this lease or any renewal thereof as a whole by giving sixty (60) days' written notice to the Lessor of its intention so to do. On the expiration of said sixty days, this lease shall terminate and all liabilities of the Lessee under this agreement, except such liabilities as shall have then accrued, whether or not then payable, shall cease and terminate.

2. The Lessee desires to acquire the rights of said Roseburg Lumber Company in and to the said above described premises in order that it may use the surface of the above described premises for roadways, power lines, pipe lines, stockpiles, and for any other uses and purposes which shall be necessary or convenient in connection with its mining and treating operations in or on other properties.

3. The mineral rights are leased to Lessee for the purpose of enabling the Lessee to construct, maintain and use on the above described premises any or all of the facilities described in Section 2 hereof.

4. While the parties hereto expect that there is not contained in the mineral rights, a merchantable ore body, it is the desire of the Lessor that the Lessee shall verify the non-existence of a merchantable ore body in the manner hereinafter set forth prior to the use of the mineral rights by the Lessee for the construction and use of facilities on the surface thereof. The geological representatives of the Lessee, as soon as possible after the execution and delivery of this agreement, shall submit to the State Geologist of the State of Oregon, a proposed program for the exploration of the mineral rights, and when the Lessee shall have obtained the approval of said State Geologist to such proposed program, it shall cause such exploration program to be carried out. During the course of such exploration, geological representatives of the Lessee shall confer with the said State Geologist with respect to the results being obtained,

and at the completion of the exploration program, the geological representatives of the Lessee and the said State Geologist shall agree as to the existence or non-existence of a merchantable ore body on the mineral rights. The State Geologist shall thereupon make a report of such agreement to the Lessor, furnishing a copy of such report to the Lessee, and if such report shall indicate there is contained no merchantable ore body on the mineral rights, the Lessee shall thereafter, during the term of this lease or any renewal thereof, have the sole and exclusive right to use the mineral rights for the purposes herein set forth. If such report shall indicate that there is contained on the mineral rights a merchantable ore body, the said report shall also indicate the area covered by such merchantable ore body, and such area shall thereafter be excluded from the operation of this lease without any further action on the part of the parties hereto, but the Lessee shall thereafter during the term of this lease or any renewal thereof, have the sole and exclusive right to use all of the mineral rights, except the area so excluded, for the purposes herein set forth. The Lessee shall pay all costs and expenses incurred in connection with such exploration. For all purposes of this lease, a merchantable ore body shall be understood to be a concentration of minerals which could be mined and sold or mined, treated and sold on the market by the Lessee in the year in which such exploration is made.

5. In the event that the Lessor shall acquire at any time during the term of this lease or any renewal thereof, any interest or interests in the above described premises in addition to its ownership of the mineral or mineral rights therein, such additional interest or interests shall be automatically included herein and covered hereby with the same force and effect as if such interest or interests had been included herein on the date hereof.

6. Beginning with the date hereof and during the period this lease or any renewal thereof continues in force and effect, Lessee covenants and agrees to pay to Lessor, an annual rental, payable annually in advance, of the sum of twenty-five cents (25¢) for each acre of mineral rights covered by this lease at the time of each respective payment of rental.

7. The Lessor agrees that Lessee shall have the right to sub-lease the mineral rights or any part thereof and to contract with others to use the mineral rights or any part thereof for the purposes herein specified with the

and required of the Lessee.

8. The Lessee agrees during the term of this lease to pay any and all taxes of every kind and all assessments duly and lawfully made against all improvements or use of the premises as may be provided by the laws and statutes of the State of Oregon and which may be levied against that part of the mineral rights covered by this lease at the time of each levy of said taxes and assessments (excluding all of the surface thereof except that part used by the Lessee in its operations) and any and all taxes which may be assessed against the improvements placed by Lessee thereon, provided that the Lessee shall have the right to bond, in the manner provided by law, any assessments levied against any such leased property for local improvements and to pay the same in installments in the manner provided by law; provided further that only such installments of any such assessments as shall become due during the lease term shall be paid by the Lessee; PROVIDED, however, the Lessee shall always have the right to contest in the courts, or otherwise, the validity of any such tax or assessment in case it shall deem the same unlawful, unjust, unequal, or excessive, before it shall be required to pay or discharge it, or any part thereof; but all such taxes and assessments, or so much thereof as shall not have been cancelled or set aside, shall be paid by Lessee in time to prevent any sale of the mineral rights, or property or any part thereof, for said taxes and assessments.

9. The use and occupancy of the above described premises by the Lessee, and all of its operations hereunder shall be conducted in strict compliance with all laws applicable thereto, and with all rules and regulations promulgated, adopted and published by any commission or other governmental body having jurisdiction in the matter.

10. Lessor reserves and shall have a lien upon all machinery, implements and personal property of Lessee that may be on mineral rights as security for the payment of any annual rental that may have accrued under this lease, and for all unpaid taxes and assessments on the mineral rights and for any and all liabilities of Lessee. Any such unpaid annual rental or taxes or liabilities shall be deemed to be and be treated as a balance or balances of unpaid accounts under this lease, and such lien thereof may be enforced under the laws of the State of

Oregon by action or otherwise. Such lien, however, shall not follow any of said property after it has been shipped or removed from within the boundaries of the State of Oregon, and nothing herein contained shall prevent the removal of any or all of said property at any time when the Lessee shall not be in default hereunder, and the above referred to lien shall not, in case of sale of such property to third parties, be deemed to follow the same as against said third parties.

11. The grants of Lessor as contained herein are subject, however, to the express condition, that in case, and as often as Lessee shall make default in the performance, or by the violation of, any of the several agreements expressed herein to be kept and performed on its part, and such default shall continue uncorrected or unsatisfied for the period of ninety (90) days after written notice specifying the default complained of shall be given to Lessee by Lessor, then and in such case Lessor shall have the right to enter in and upon the mineral rights and to have and possess them again as of its first and former estate, and to exclude Lessee and all parties claiming under it.

12. The Lessor hereby represents and covenants to and with the Lessee that, at the time of the execution hereof, it owns the mineral rights in fee simple, and that the same are free and clear from all encumbrances and that (the Lessee keeping, performing and carrying out all of the covenants, promises and agreements, on its part to be kept, performed and carried out) the Lessor will, during the term aforesaid or until the termination of this lease as herein provided, warrant and defend the Lessee in the quiet and peaceable possession of the mineral rights and privileges herein granted, against all persons and corporations whomsoever, and the Lessor further covenants that at the beginning of the term hereunder, it will turn over and deliver the mineral rights to the Lessee in such condition that nothing therein or thereon shall constitute a continuing nuisance, or a continuing menace to adjacent property.

13. Lessee agrees that whenever this lease is terminated, Lessee shall peacefully surrender the mineral rights to Lessor, provided that Lessee shall be entitled and permitted to remove within ninety (90) days after such termination all buildings, structures (including milling and treatment plants), engines, tools, machinery, railroad tracks, pipe and power lines, improvements, and other property

Lessee shall leave all roads, complete with culverts and bridges necessary for their usefulness intact for the use of the Lessor upon expiration or termination of this lease.

Lessee further agrees to peaceably surrender the leased premises or the governmental descriptions affected thereby, as the case may be to the Lessor with all caves and openings properly fenced, filled or protected as may be required by any laws or proper regulations of any duly constituted governmental authority then in effect and in good order and condition, ordinary wear and tear in use and deterioration from and damage by the elements excepted.

Lessee agrees that when this lease terminates it will, at the request of Lessor, enter or cause to be entered a certificate of that fact upon the proper books of record in said Douglas County, Oregon, provided this lease shall have been recorded there.

14. Any difference or controversy which may arise between Lessor and Lessee, as to the construction or carrying out of this lease, or the rights of Lessor or Lessee under it, shall not interrupt or suspend Lessee's right to use the mineral rights for the purposes herein set forth, provided Lessee shall duly pay the annual rental herein provided for at the time or times and in the manner stated in this lease.

15. It is mutually covenanted and agreed that in case any controversy or disagreement shall arise between the Lessor and the Lessee relative to the due observance and fulfillment of the terms and obligations hereof by either party, then such controversy or disagreement shall be determined by arbitration in the manner herein specified. Either Lessor or Lessee may within thirty (30) days after such controversy or disagreement arises demand [illegible] party or parties making such demand shall in writing to be served upon the other in the manner herein specified for the service of notice, specify the matter to be submitted to arbitration, and at the same time choose and nominate some competent and wholly disinterested person to act as an arbitrator; thereupon within ten (10) days after the receipt of such written notice, the other shall in writing choose and nominate a competent and wholly disinterested arbitrator, and the two arbitrators

so chosen shall forthwith select a third arbitrator giving written notice to Lessor and Lessee of the choice so made and fixing a place and time for a meeting not later than ten (10) days thereafter, at which Lessor and Lessee may appear and be heard touching such controversy or disagreement. The arbitrators shall then make a decision as to the controversy or disagreement within thirty (30) days, which decision of said arbitrators shall be made in writing, and when signed by a majority of them, shall be final and conclusive upon all parties and the award so made shall be forthwith complied with. In case either Lessor or Lessee shall fail to choose and nominate an arbitrator, after notice as aforesaid from the other party, or in case the first two arbitrators selected fail to agree upon a third arbitrator within ten (10) days, then such arbitrator or arbitrators may, upon application made by either Lessor or Lessee, after ten (10) days written notice thereof given to the other, be appointed by any judge of the federal court having jurisdiction within the federal judicial district in which the mine is located. The expense of any such arbitration, including reasonable compensation for the arbitrators, shall be paid by the party against which the award shall be made, unless otherwise provided in the award of the arbitrators.

16. Any request or notice which either party may desire to give hereunder shall be properly served on the other party or parties only when reduced to writing placed in an envelope, sealed, stamped, registered and deposited in any United States Post Office addressed as follows, to wit:

County Court, Douglas County
County Courthouse
Roseburg, Oregon

Hanna Mining Company
1300 Leader Building
Cleveland 14, Ohio

Either party hereto may upon written notice to the other party (which shall be served as herein provided for service of notices generally) change the address to which notices to such party may be sent, or designate a new party with the same or a different address to which such notices may be sent.

17. In the event Lessor, in any instance, shall waive any default by Lessee or waive any provision hereof, such waiver shall not constitute a waiver by Lessor of any other default or, as to any other instance, of any provision hereof.

If any provision of this Lease or the application of such provision to any circumstance shall be held unlawful, the remainder of this lease shall not be affected thereby.

18. It is further agreed that the covenants, terms and conditions of this Lease shall both bind and benefit the heirs, executors, administrators, successors and assigns of the Lessor and the Lessee.

IN WITNESS WHEREOF, the parties hereto have executed or cause this agreement to be duly executed as of the day and year first above written.

DOUGLAS COUNTY

By ______________________
County Judge

____
County Commissioner

____
County Commissioner

____
County Clerk

THE HANNA MINING COMPANY

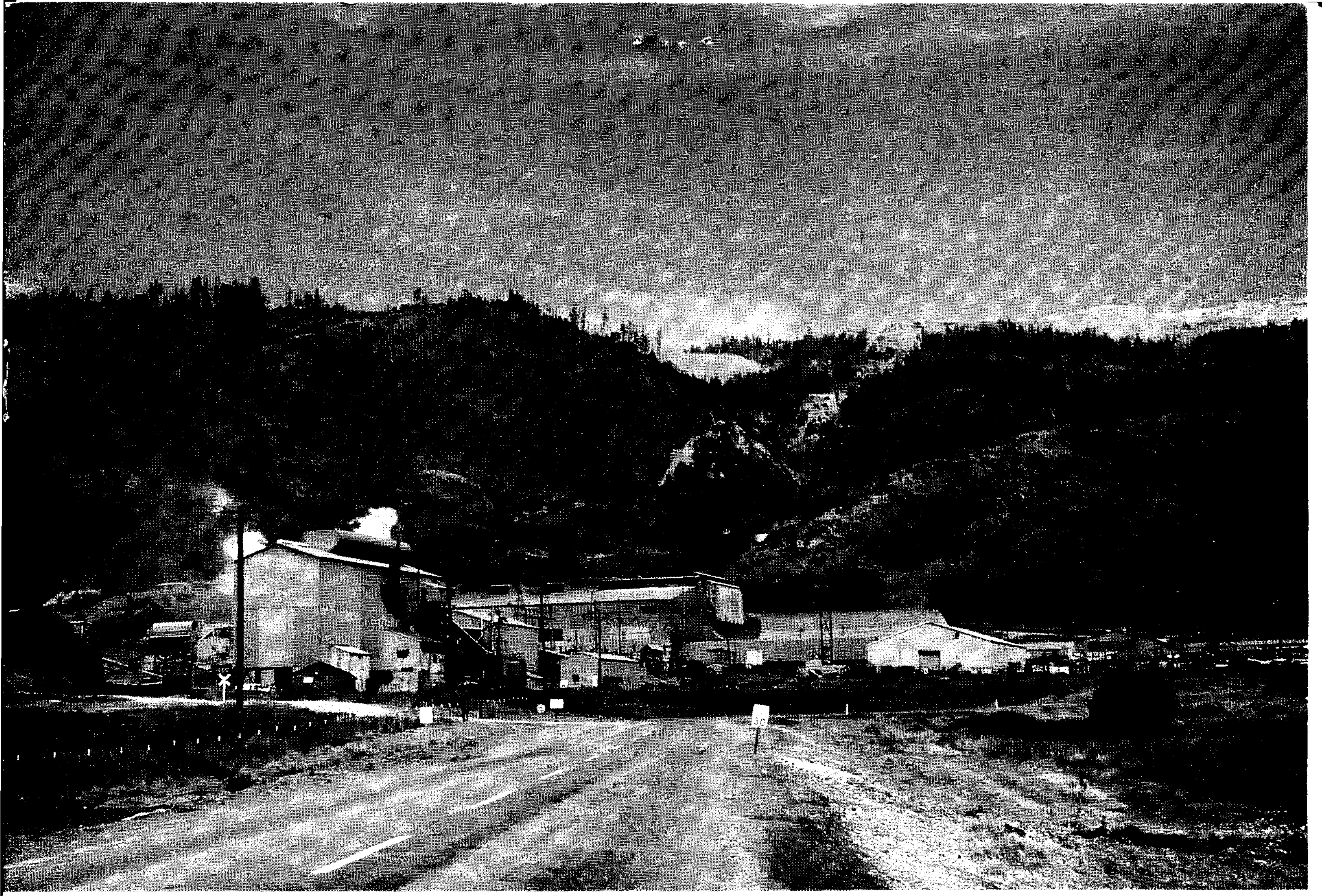
By ______________________
President

____
Secretary

Form 5K

Signed, sealed, ~~and acknowledged~~
in the presence of:

____



The Hanna Nickel Operation

Nickel Mountain is located in southwestern Douglas County, Oregon, four miles west of the town of Riddle. The deposit was discovered in 1864 by local settlers, but it was not until 1881 that the ore was recognized to contain nickel, rather than copper as originally assumed. Subsequent to 1881, much prospecting and preliminary development work was done, but no ore was processed, other than for testing purposes, until the present mining operation began.

The Hanna Mining Company and Hanna Nickel Smelting Company began production of ferronickel (a combination of iron and nickel), the first to be produced in the United States from domestic ores, in July, 1954. The companies have operated on an around-the-clock schedule since that time and provided steady, year-around work for approximately 600 employees.

Mine

Geology

The deposit is made up of six major areas, covering approximately 600 acres. Ten percent of the nickel-bearing mineral (garnierite) is found filling voids in fractured rock. The majority of nickel ore occurs in weathered rock. Average nickel grade in the crude ore presently under active development is approximately 1.0%.

Grade Control

Overall chemistry, as well as nickel content of ore delivered to the smelter stockpile, must be maintained as uniform as possible to produce the maximum amount of ferronickel. This is somewhat difficult due to the wide, inconsistent variations in ore type and nickel content throughout the deposit. Twenty-foot bench heights, narrow shovel cuts, bank samples, drill hole samples, geologic interpretations, mobile grade control trucks, slice maps and visual classification, combined with widely spaced daily cuts, make up the grade control pattern.

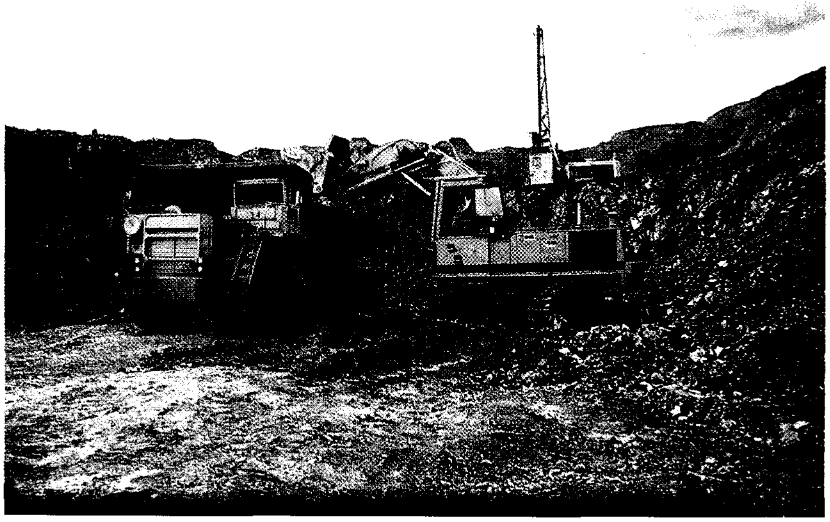
Development

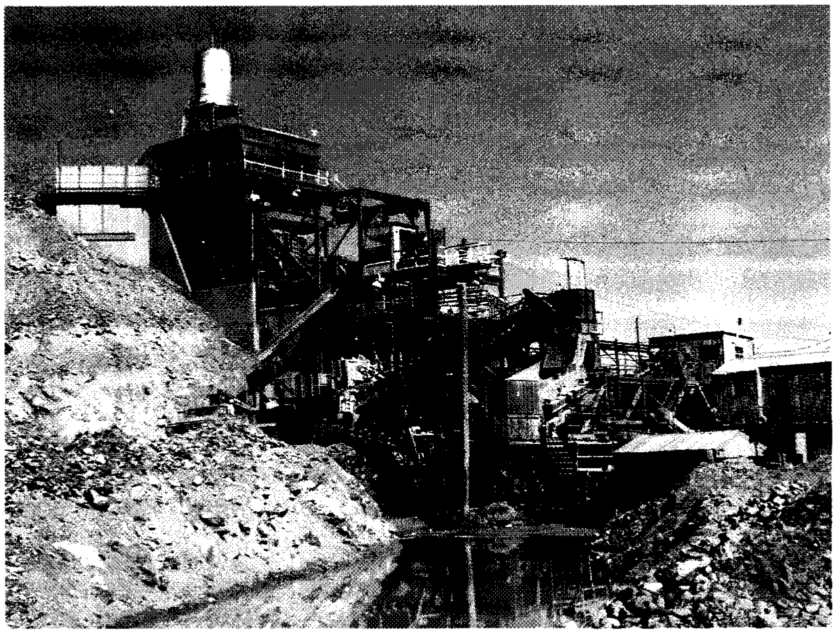
Open-cut methods are utilized. The lay of the land is ideal for the development of level mining benches at 20-foot vertical intervals. This interval was chosen for grade control purposes. Benches, a minimum of 50 feet wide, extend to the limits of the deposit, and main haulage roads, 60 feet wide, traverse the area.

Mining and Hauling

Up to 80 percent of the ore can be dug without blasting. When blasting is necessary, however, a hole is drilled and filled with an explosive and set off.

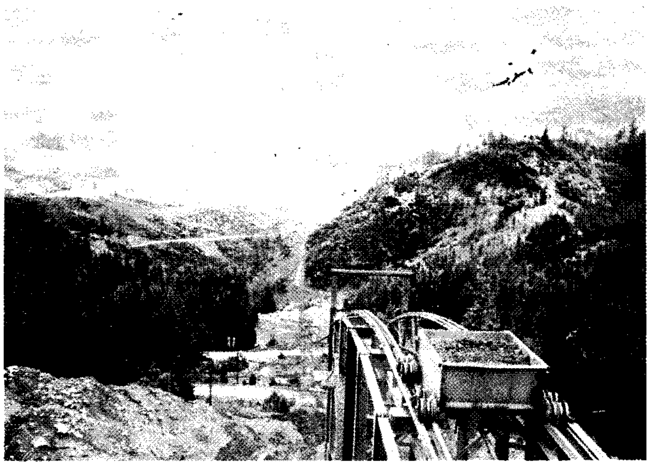
Loading crude ore is accomplished with diesel shovels. Large boulders, called pit rejects, are separated from the ore by the shovel operator and ultimately deposited on waste dumps, as they have low amounts of nickel in them. The ore is loaded into 60-ton diesel trucks and hauled to the screening plant.





Screening and Crushing

The ore is deposited directly into the screening plant feed hopper. A separation is made according to the size of the material, with the smaller going directly to the tramway and the larger to the crusher. After crushing, the material is visually classified and directed to the ore product or the reject stockpile.



Tramway

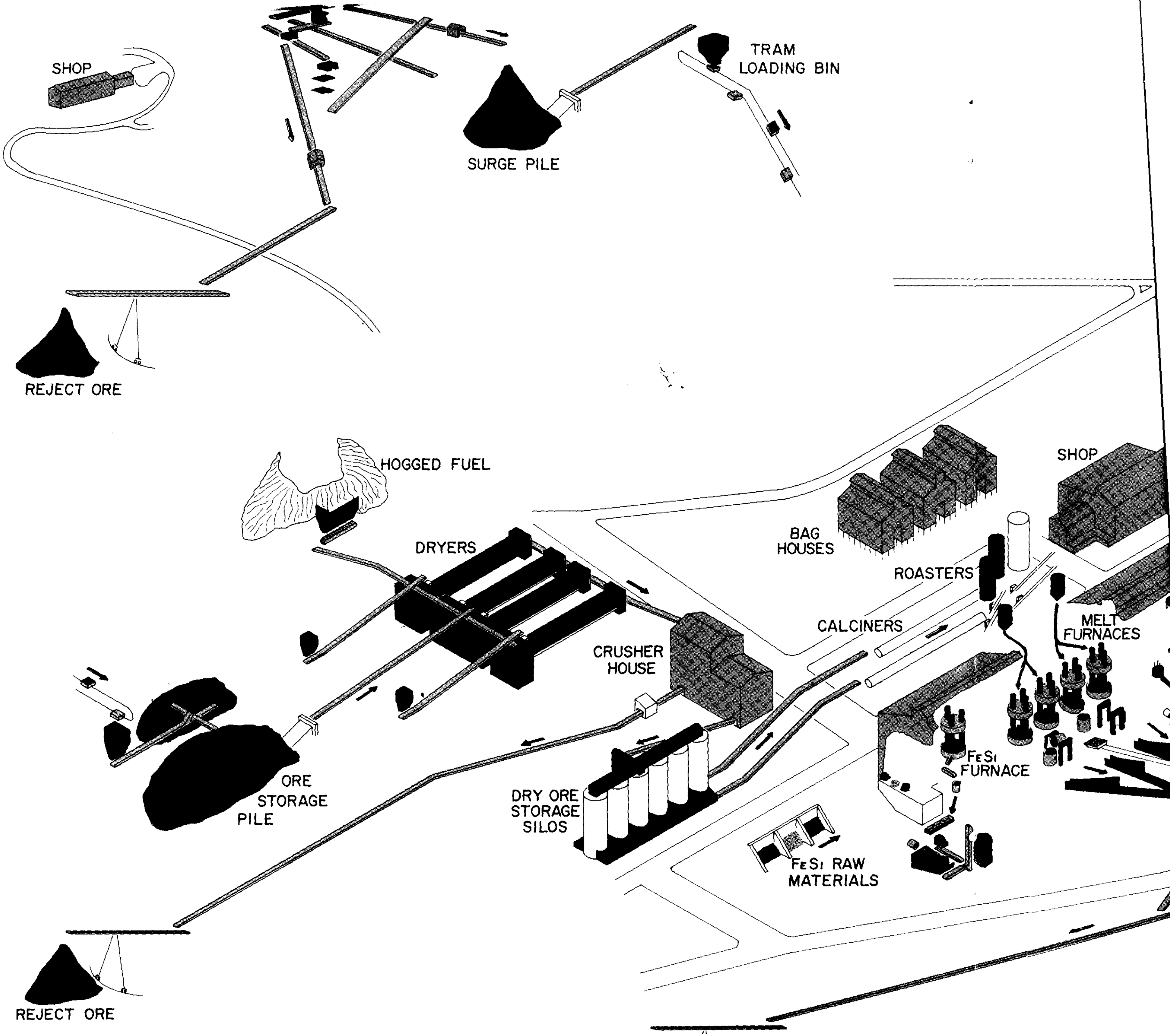
At the tramway the ore is fed to the loading terminal where it is loaded automatically into 50-cubic foot tram cars. It is conveyed downhill to the smelter storage stockpile.

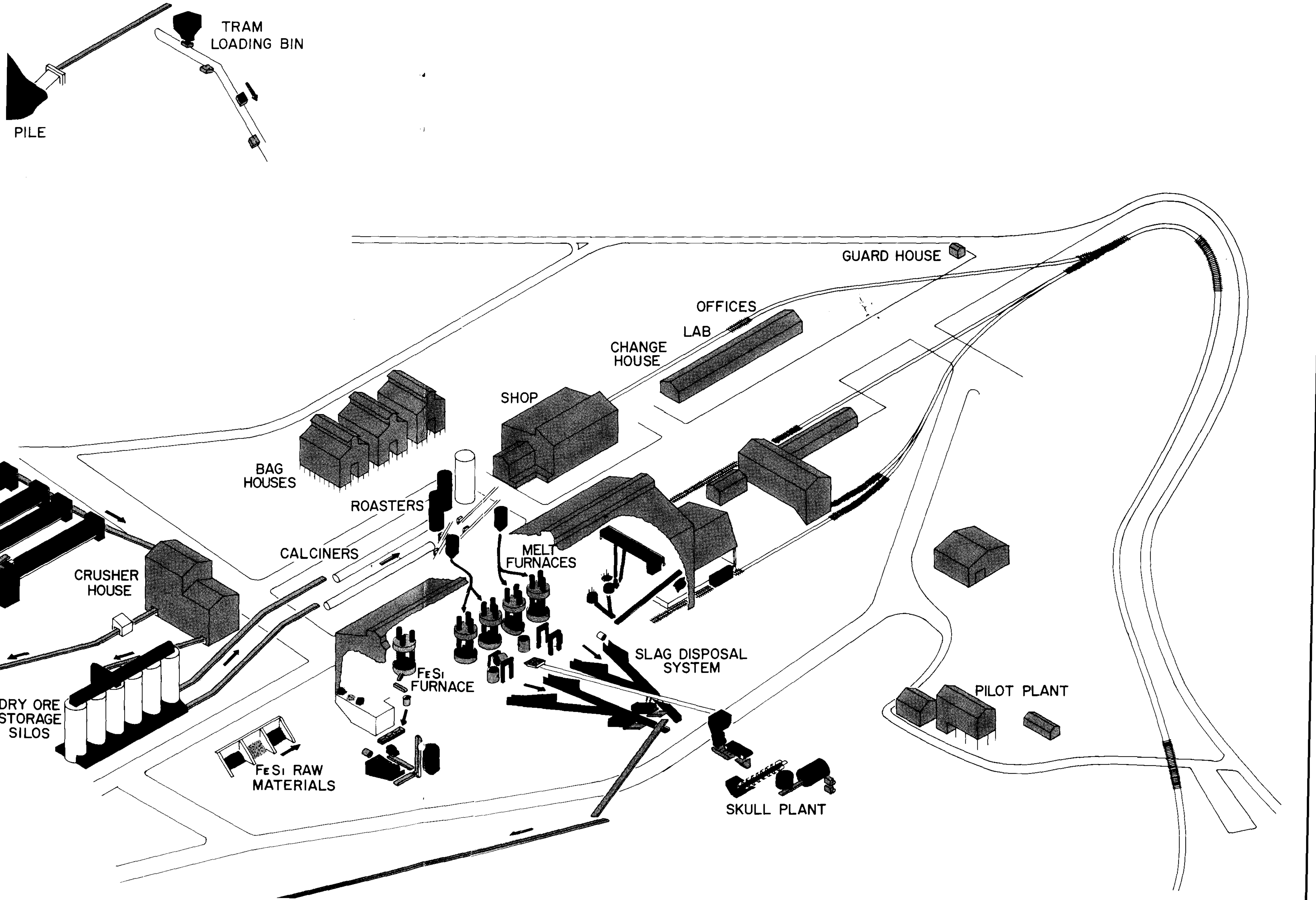
The tramway runs continuously, carrying ore in the upright tram cars and returning the empty cars in an inverted position. The ore is discharged by inverting the cars at the lower end of the tramway where it is stockpiled. A speed of 600 feet per minute is maintained by the braking action of the two 300-horsepower generators driven by the weight of the loaded tram cars. The braking action of the generators produces approximately 500 horsepower, which is used in the generating of electricity for the operation of the mine facilities.

The tramway is 8,300 feet long and drops a vertical distance of 2,000 feet in its length.

Smelter

Ore from the stockpile is processed at the smelter to produce ferronickel, containing approximately 50 percent nickel. Steps in the process include reclaiming ore, drying, fines screening, rejection of lean rock by screening, crushing, sampling, calcining, melting, reducing to ferronickel, refining, casting, and skull metallics recovery.


SHOP
TRAM LOADING BIN
SURGE PILE
REJECT ORE
HOGGED FUEL
DRYERS
BAG HOUSES
SHOP
ROASTERS
CALCINERS
MELT FURNACES
CRUSHER HOUSE
ORE STORAGE PILE
DRY ORE STORAGE SILOS
FeSi FURNACE
FeSi RAW MATERIALS
REJECT ORE


TRAM
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BAG
HOUSES
ROASTERS
CALCINERS
CRUSHER
HOUSE
MELT
FURNACES
SLAG DISPOSAL
SYSTEM
FeSi
FURNACE
DRY ORE
STORAGE
SILOS
FeSi RAW
MATERIALS
PILOT PLANT
SKULL PLANT

Form PR. 1-W

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

State OREGON

(Corps area or engineer division)

Nickel Mountain Mine
(Army reservation or defense industry site)

Project No. DA-RM-27

PROJECT STATEMENT

DEFENSE HIGHWAY ACT OF 1941

THE COMMISSIONER OF PUBLIC ROADS,
Washington, D. C.

Date December 30, 1942

Sir: War Production Board

The ~~Secretary of Wa~~r having indicated that the construction or improvement of access roads to the Nickel Mountain Mine is important to the national defense, the undersigned considers that the project described below as to general character of road work (including bridges thereon) and delineated as to location and termini in diagrammatic form on the accompanying sketch map, will provide a reasonable access road improvement for the above-named establishment, and recommends the construction thereof, under the provisions of the Defense Highway Act of 1941.

1. Description: Nickel Mountain Road from county road to the summit vicinity of Nickel Mountain
(Local name of road and points of beginning and ending)

2. Length in miles 8.0

3. General character of improvement Grading, draining and surfacing.

4. Preliminary estimate of cost: Total, $12,000.00

Respectfully submitted,

W. H. LYNCH
District Engineer, P. R. A.
By
L. J. Caufield, Sr. Highway Engineer

Approval recommended:

(Title *)

* Corps area commander or his representative for stations under corps area control, U. S. Division Engineer for Industrial Establishments, and military stations exempt from corps area control.

16—24602-2 U. S. GOVERNMENT PRINTING OFFICE

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STATE DEPT. OF GEOLOGY
& MINERAL INDS.

MONTHLY REPORT OF PURCHASES

Machinery, Supplies, Maintenance Items and Repairs under Preference Rating Order P-56

NAME OF MINE OPERATOR OR AUTHORIZED AGENT FOR SUCH OPERATOR Freeport Sulphur Co.

ADDRESS Box 160, Riddle, Oregon MINE SERIAL NO. 33-65

PURCHASES MADE IN MONTH OF December, 19 42.

I. PURCHASES TO WHICH RATING A-8 HAS BEEN APPLIED DURING MONTH:
Material None
Quantity W.P.B. Authorization No.
Supplier

II. PURCHASES TO WHICH RATING A-3 HAS BEEN APPLIED DURING MONTH:
Material None
Quantity W.P.B. Authorization No.
Supplier

III. PURCHASES TO WHICH RATING A-1-c HAS BEEN APPLIED DURING MONTH:
Material None
Quantity W.P.B. Authorization No.
Supplier

IV. PURCHASES TO WHICH RATING A-1-a HAS BEEN APPLIED DURING MONTH:
Material 3/4-ton pull lift chain hoist; solid rubber stoppers; 12-inch stroke drilling jars
Quantity 1; 1 pound; 1 set W. P. B. Authorization No.
Supplier Rogue River Hdwre, Grants Pass; Braun-Knecht-Heimann Co., San Francisco; Star Drilling Machine Co., Portland

V. PURCHASES TO WHICH RATING AA-2X HAS BEEN APPLIED DURING MONTH:
Material underreamer; drive casing, casing couplings, shoes, head; sheets black metal; chainomatic balance, stainless steel weights;
Quantity 1; 31 joints, 10 joints, 41, 8, 1; 16; 1, 1 set.
W.P.B. Authorization No.
Supplier Oil Well Supply Co., Los Angeles; A. M. Jannsen Drilling Co., Portland; Brill Metal Works, Medford; Braun-Knecht-Heimann Co., San Francisco.

CERTIFICATION

The undersigned hereby certifies to the War Production Board, that

(1) he executed the foregoing statement on behalf of and by authority of the above-named Mine Operator;

(2) the above-named Mine Operator has, during the period covered by this report, complied with all the provisions of Preference Rating Order P-56, and has applied Ratings only in accordance therewith;

(3) during such period the Mine Operator's inventory of operating supplies and other material has not been greater than the minimum necessary for the efficient operation of his business, and the ratio of inventory (quantity) to current production has not exceeded the ratio of average year-end inventory (quantity) to average production for the years 1938, 1939, and 1940;

(4) the facts stated herein are, to the best of his knowledge and belief, true and correct.

Freeport Sulphur Company

January 10, 1943
(Date)

By:
(Signature of Authorized Official)

Mgr., Western Office
(Title)

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& MINERAL INDS.

MONTHLY REPORT OF PURCHASES

Machinery, Supplies, Maintenance Items and Repairs
under Preference Rating Order P-56

NAME OF MINE OPERATOR OR AUTHORIZED AGENT FOR SUCH OPERATOR Freeport Sulphur Co.

ADDRESS Box 160, Riddle, Oregon MINE SERIAL NO. 33-65

PURCHASES MADE IN MONTH OF November, 19 42.

I. PURCHASES TO WHICH RATING A-8 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

II. PURCHASES TO WHICH RATING A-3 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

III. PURCHASES TO WHICH RATING A-1-c HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

IV. PURCHASES TO WHICH RATING A-1-a HAS BEEN APPLIED DURING MONTH:
Material Brass clott sieve, sieve bottom pan, triangular files
Quantity 1, 1, 3 W.P.B. Authorization No.
Supplier Braun-Knecht-Heimann Co., 1400 16th St., San Francisco, Calif.

V. PURCHASES TO WHICH RATING AA-2X HAS BEEN APPLIED DURING MONTH:
Material 4 x 8 ft. 14-gauge black metal
Quantity 16 sheets W.P.B. Authorization No.
Supplier Lorenz Company, Medford, Oregon

CERTIFICATION

The undersigned hereby certifies to the War Production Board, that

(1) he executed the foregoing statement on behalf of and by authority of the above-named Mine Operator;

(2) the above-named Mine Operator has, during the period covered by this report, complied with all the provisions of Preference Rating Order P-56, and has applied ratings only in accordance therewith;

(3) during such period the Mine Operator's inventory of operating supplies and other material has not been greater than the minimum necessary for the efficient operation of his business, and the ratio of inventory (quantity) to current production has not exceeded the ratio of average year-end inventory (quantity) to average production for the years 1938, 1939, and 1940;

(4) the facts stated herein are, to the best of his knowledge and belief, true and correct.

Freeport Sulphur Company

December 10, 1942 By: Mgr., Western Office
(Date) (Signature of Authorized Official) (Title)

MONTHLY REPORT OF PURCHASES

Machinery, Supplies, Maintenance Items and Repairs
under Preference Rating Order P-56

NAME OF MINE OPERATOR OR AUTHORIZED AGENT FOR SUCH OPERATOR Freeport Sulphur Co.

ADDRESS Box 190, Grants Pass, Oregon MINE SERIAL NO. 33-65

PURCHASES MADE IN MONTH OF October, 19 42.

I. PURCHASES TO WHICH RATING A-8 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

II. PURCHASES TO WHICH RATING A-3 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

III. PURCHASES TO WHICH RATING A-1-c HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

IV. PURCHASES TO WHICH RATING A-1-a HAS BEEN APPLIED DURING MONTH:
Material
Quantity W.P.B. Authorization No.
Supplier none

CERTIFICATION

The undersigned hereby certifies to the War Production Board, that
(1) he executed the foregoing statement on behalf of and by authority of the above-named Mine Operator;
(2) the above-named Mine Operator has, during the period covered by this report, complied with all the provisions of Preference Rating Order P-56, and has applied Ratings only in accordance therewith;
(3) during such period the Mine Operator's inventory of operating supplies and other material has not been greater than the minimum necessary for the efficient operation of his business, and the ratio of inventory (quantity) to current production has not exceeded the ratio of average year-end inventory (quantity) to average production for the years 1938, 1939, and 1940;
(4) the facts stated herein are, to the best of his knowledge and belief, true and correct.

Freeport Sulphur Company

November 4, 1942 By: Mgr., Western Office
(Date) (Signature of Authorized Official) (Title)

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& MINERAL INDS.

MONTHLY REPORT OF PURCHASES

Machinery, Supplies, Maintenance Items and Repairs
under Preference Rating Order P-56

NAME OF MINE OPERATOR OR AUTHORIZED AGENT FOR SUCH OPERATOR Freeport Sulphur Co.

ADDRESS Box 190, Grants Pass, Oregon MINE SERIAL NO. 33-65

PURCHASES MADE IN MONTH OF September, 19 42.

I. PURCHASES TO WHICH RATING A-8 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

II. PURCHASES TO WHICH RATING A-3 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

III. PURCHASES TO WHICH RATING A-1-c HAS BEEN APPLIED DURING MONTH:
Material snatch block
Quantity one W.P.B. Authorization No.
Supplier James Trimble, 515 I Street, Grants Pass, Oregon

IV. PURCHASES TO WHICH RATING A-1-a HAS BEEN APPLIED DURING MONTH:
Material none
Quantity W.P.B. Authorization No.
Supplier

CERTIFICATION

The undersigned hereby certifies to the War Production Board, that

(1) he executed the foregoing statement on behalf of and by authority of the above-named Mine Operator;

(2) the above-named Mine Operator has, during the period covered by this report, complied with all the provisions of Preference Rating Order P-56, and has applied Ratings only in accordance therewith;

(3) during such period the Mine Operator's inventory of operating supplies and other material has not been greater than the minimum necessary for the efficient operation of his business, and the ratio of inventory (quantity) to current production has not exceeded the ratio of average year-end inventory (quantity) to average production for the years 1938, 1939, and 1940;

(4) the facts stated herein are, to the best of his knowledge and belief, true and correct.

Freeport Sulphur Company

October 10, 1942 (Date)
By: (Signature of Authorized Official)
Mgr., Western Office (Title)

✓

MONTHLY REPORT OF PURCHASES

Machinery, Supplies, Maintenance Items and Repairs
under Preference Rating Order P-56

NAME OF MINE OPERATOR OR AUTHORIZED AGENT FOR SUCH OPERATOR Freeport Sulphur Co.

ADDRESS Box 190, Grants Pass, Oregon MINE SERIAL NO. 33-65

PURCHASES MADE IN MONTH OF August, 19 42.

I. PURCHASES TO WHICH RATING A-8 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity ______ W.P.B. Authorization No. ______
Supplier ______

II. PURCHASES TO WHICH RATING A-3 HAS BEEN APPLIED DURING MONTH:
Material none
Quantity ______ W.P.B. Authorization No. ______
Supplier ______

III. PURCHASES TO WHICH RATING A-1-c HAS BEEN APPLIED DURING MONTH:
Material none
Quantity ______ W.P.B. Authorization No. ______
Supplier ______

IV. PURCHASES TO WHICH RATING A-1-a HAS BEEN APPLIED DURING MONTH:
Material none
Quantity ______ W.P.B. Authorization No. ______
Supplier ______

CERTIFICATION

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(1) he executed the foregoing statement on behalf of and by authority of the above-named Mine Operator;

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(4) the facts stated herein are, to the best of his knowledge and belief, true and correct.

Freeport Sulphur Company

September 10, 1942 (Date)

By: ______ (Signature of Authorized Official)

Mgr., Western Office (Title)

√

With my compliments
J. T. Cumberlidge.

GEOLOGY OF THE NICKEL MOUNTAIN MINE

RIDDLE, OREGON

John T. Cumberlidge

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ABSTRACT

Nickel-bearing saprolite developed during the early Tertiary over a northeast trending ultramafic body of Jurassic age near Riddle in southwestern Oregon. The principal nickel mineral is garnierite, but other complex nickel minerals may be present. There are two main orebodies, an upper (older) one associated with the Klamath peneplain, and a lower (younger) one on the Sherwood peneplain.

Saprolite constitutes the bulk of the ore, and was probably derived from peridotite and dunite through chemical decomposition by downward percolating meteoric groundwater. Decomposition took place by net loss of MgO, SiO_2, and Fe without a change in volume. Faults and joints provided permeable zones which localized saprolite development, and faulting may have helped preserve some ore from loss by erosion.

Garnierite-chalcedony boxwork ore was deposited by meteoric groundwater along faults, joints, and at the level of former water tables. Boxwork ore is entirely supergene, the chemical constituents having been derived from higher in the soil profile. The saprolites show evidence of both supergene and residual enrichment in nickel. Red and yellow soil occurs as a capping over saprolite and boxwork, and was derived from them by chemical and mechanical decomposition.

The present deposits are probably truncated remnants of a formerly thicker and much more extensive deposit which probably included laterite at the surface. The deposits started to form in the early Teriary due to deep chemical weathering under sub-tropical to warm temperate conditions. Early Tertiary erosion surfaces of low relief probably contributed to the predominance of chemical weathering over mechanical erosion. Alteration under present climatic conditions favors the formation of soil from saprolite rather than the formation of new saprolite from peridotite.

INTRODUCTION

The Nickel Mountain deposit occupies a unique position in the metal economy of the United States. Although the deposit is quite small, it produces seven per cent of domestic nickel requirements, and is the only producing nickel mine in the United States. Moreover, it is the only operation currently utilizing nickel silicate ore on the North American continent.

The deposit is located in southwestern Douglas County, about four miles west of the small town of Riddle (figure 1). (Figure 1 near here). The deposit covers much of the upper part of Nickel Mountain, including parts of Sections 8, 9, 16, 17, 18, 20, and 21, T30S, R6W, Willamette meridian.

The ore is mined by open pit methods by The Hanna Mining Company. After preliminary screening at the mine, ore is conveyed by an 8300 foot long aerial tramway to a smelter located at the foot of Nickel Mountain. The smelter, 2000 feet below mine level, is owned and operated by the Hanna Nickel Smelting Company.

Ore is smelted by an adaptation of the Ugine process (11) in which ferrosilicon is used to reduce iron and nickel oxides in molten ore to ferronickel containing about 48 per cent nickel. Production statistics over the life of the property are given in table 1. Expansion of the smelter facilities should increase the annual production in 1965. Present knowledge of ore reserves indicates a life of approximately 16 years, although technological innovation could change this somewhat.

Figure 1. Location of Nickel Mountain

Table 1. Production of Ore and Metal, 1954 - 1964

		Ore Shipped	
YEAR	Lbs. Ni. Produced	Dry Short Tons	% Ni
1954	318,489	98,583	1.58
1955	6,505,329	284,416	1.47
1956	11,382,984	408,961	1.53
1957	18,121,452	813,842	1.51
1958	21,233,634	846,489	1.51
1959	20,794,091	819,501	1.51
1960	22,228,720	874,318	1.50
1961	20,650,142	863,110	1.49
1962	21,138,893	874,646	1.50
1963	21,447,986	892,903	1.50
1964	22,472,891	1,070,866	1.44
Total	186,294,611	7,847,635	1.50

PREVIOUS WORK

An interesting description of early settlement in the area and exploration of the deposit can be found in an article written by the staff of the Oregon State Department of Geology and Mineral Industries (33). The nickel deposit was first discovered by shepherds in 1865, not long after the area was first settled, but it lay dormant until 1954 when production began.

The nickel deposit has been described by a number of writers. Geological aspects have been covered by Clarke (10), Von Foullon (15), Austin (3), Ledoux (26), Kay (23), Diller and Kay (13), Pecora and Hobbs (34 and 35), Schoenike (38), and most recently by Hotz (19). Mining and exploration methods were described by Foster (14), Van Voorhis (40), Walker (41), and Gustafson (16). The smelter and smelting operations were fully described by Coleman and Vedensky (11).

Many of these papers were written before or shortly after mining commenced in 1954. The additional information revealed by over ten years of mining and development drilling has given a better insight into the geology of the deposit than was formerly available from surface trenching and a limited amount of drilling.

This paper is intended to describe the geology of the Nickel Mountain deposits; to classify the types of ore which occur; to show the influence of climate, topography, and structure on ore development; and to investigate some of the effects of residual and supergene nickel enrichment. The factual data were obtained from study of the Riddle deposit. The conclusions may be applicable to other lateritic nickel deposits, but this is not necessarily assumed to be true.

GENERAL GEOLOGY

Nickel Mountain is situated at the northern end of the Klamath mountains (figure 2) (Figure 2 near here) which extend south into northern California. The Klamath mountains are composed of rocks older than the Tertiary volcanic rocks forming the Cascade Range to the east, and the Tertiary sedimentary rocks of the Coast Range to the west and north. The peridotite on which the orebody is located is one of several north to northeast trending ultramafic intrusions which traverse the area.

The Orebodies

The laterite-type ore on Nickel Mountain occurs as a discontinuous mantle of residual material covering approximately 500 acres with an average depth of only 50 feet. However, the apparent simplicity of the deposits is misleading. Jointing and faulting cause considerable variation in ore thickness (5 - 200 feet), and in ore type over relatively short distances.

There are two main orebodies, one coinciding roughly with the top of Nickel Mountain (3535 feet), and the other on a terrace on the south side of the mountain (figure 3). (Figure 3 near here). The lower terrace, known as the Lower orebody, slopes to the south at about 13 per cent. It ranges in elevation from 2000 to 2550 feet and is separated from ore above by a steep slope of barren peridotite. The south side of the terrace coincides essentially with the serpentinized and faulted contact of the ultramafic body with the Riddle formation (figure 4). (Figure 4 near here).

The Upper orebody includes the highest erosion level and a narrow discontinuous step in the topography at approximately 2900 feet. Ore associated with the two erosion levels merges, and is not distinguished in figure 3. The Upper orebody has a mean slope to the south of 31 per cent, but ore is preserved on slopes as steep as 47 per cent.

Figure 2. Geologic Map of Southwestern Oregon

Figure 3. Geologic Map of Nickel Mountain

Figure 4. North-South Profile Through the Lower and Upper Orebodies

Stratigraphy

The geology of the Riddle Quadrangle was first described by Diller and Kay (13). Since that time, the work of Imlay, Dole, Wells, and Peck (20) has further clarified the Jurassic-Cretaceous sequence in this part of Oregon. A recent compilation of Oregon geology west of the 121st meridian by Wells and Peck (42), and the succession given by Imlay et al. (20, p. 2777) have been used as a base for the stratigraphic sequence given in table 2.

Part of the Jurassic sequence is represented on Nickel Mountain. Rocks assigned to the Dothan formation outcrop mainly on the north side of the mountain (figure 3). In addition, faulted remnants of Dothan sediments have been preserved within the peridotite mass. The Dothan formation consists essentially of graywacke, but includes shale, conglomerate, and chert. As a rule, the fine grained members are thinly bedded, while the graywackes are thick and massive. In places, some of the sediments are schistose and are cut by thin quartz veinlets. No fossils were found in the Dothan formation.

The Dothan formation is intruded by rocks of basaltic, andesitic, and gabbroic composition, locally altered to greenstones. Thin chert lenses are associated spatially with the greenstones.

Riddle formation rocks are found on the south side of Nickel Mountain. Typically, the Riddle formation consists of thinly bedded fossiliferous siltstones with sandstone and shale, and includes conglomerate lenses. The siltstone and sandstones contain the pelecypod Buchia piochii (Gabb) considered diagnostic of the Riddle formation, while lenses of sandstone and grit within the conglomerate contain wood fragments and carbonaceous layers up to 5mm thick.

Table 2. Stratigraphic Column in the Riddle Area

SYSTEM	GROUP	FORMATION	INTRUSIVE ROCKS
Lower Cretaceous	Myrtle	Days Creek	
Upper Jurassic		Riddle	Ultramafic Intrusions?
		Dothan	

Ultramafic Rocks

The Nickel Mountain ultramafic rocks include peridotite (saxonite), dunite, and serpentinite. Peridotite is the predominant rock type and underlies most of the orebodies. Dunite accounts for perhaps ten percent of the ultramafic area and appears to grade into peridotite. Serpentinite occurs mainly close to contacts with Jurassic sediments.

The peridotite is a coarse grained rock containing approximately 80 percent olivine ($Fo_{90}Fa_{10}$) and 20 per cent enstatite ($En_{90}Fs_{10}$). Enstatite grains range up to 5mm in diameter, while the olivine grains are generally somewhat smaller. Minute grains of accessory chromite are found in both peridotite and dunite, and account for 0.3 - 1.0 per cent of the rock by weight. The magnesium content of olivine tends to be slightly higher in dunite than in peridotite.

Serpentinized peridotite and dunite are variable in composition, depending on the degree of serpentinization. Generally, peridotite and dunite contain from five to ten per cent of serpentinized olivine grains. Enstatite tends to remain unaltered until serpentinization has advanced towards completion. Secondary magnetite in microscopic layers and grains occurs with the serpentine minerals.

Contacts of the peridotite with the sedimentary formations on Nickel Mountain are faulted and the age relationships are uncertain. Faulted remnants of the Dothan formation are found within the peridotite suggesting that the intrusion may be of post Dothan age. Imlay et. al. (20, p. 2776) noted that the basal conglomerate of the Riddle formation contains some "limestone or serpentine" pebbles. In addition, Ramp (36, p. 5) reports cobbles of serpentine and partly serpentinized peridotite in conglomerates which also contain fossils of Portlandian (Riddle formation equivalent) age at Otter Point near Gold Beach in Curry County, Oregon. The two lines of reasoning, though not conclusive, indicate that the ultramafic intrusion and the serpentinization may be of post Dothan - pre Riddle formation age

Chemical Analyses

Chemical analyses of Nickel Mountain peridotite are given in table 3. Analyses by B. J. Grimm were made by standard wet chemical methods at the Hanna Nickel Smelting Company laboratory.

Loss on ignition, plus silica, magnesia, and the oxides of nickel, chrome, and iron account for approximately 97 - 98 per cent of the chemical constituents of peridotite and normal ore. Rapid routine analysis is accomplished by arcing a pulverized sample and reading the intensity of Mg, Fe, Cr, and Ni spectral emission on a quantometer. Loss on ignition varies with iron and nickel content, and can be estimated closely by reference to the analyses of these elements. Minor constituents such as Al, Ca, K, Na, Ti, P, and Mn average 2.5 per cent. The amount of SiO_2 can thus be found by subtraction from 100 per cent. Check chemical assays usually agree with calculated silica values to within ±2 per cent SiO_2.

A colorimetric method is also used to obtain accurate nickel analyses. Accuracy is ± .02 per cent Ni in normal ore. Unless otherwise stated, all analyses given in this paper are colorimetric or quantometric.

Table 3. Analyses of Fresh Peridotite and Serpentinite from Nickel Mountain. In Per Cent.

	1	2	3	4	5
SiO_2	42.7	43.2	43.7	42.8	42.4
Al_2O_3	1.0	1.10		1.1	1.05
Fe_2O_3	* 0.87	0.83	* 0.94	0.8	2.49
FeO	* 7.06	7.80	* 7.64	6.8	3.94
MgO	44.2	44.0	43.2	45.7	41.50
CaO	0.9	0.48		0.9	0.35
Na_2O	NR	NR		0.03	NR
K_2O	NR	NR		0.01	NR
H_2O^+	NR	1.47		1.6	7.18
L.O.I.**	1.42	NR		NR	NR
TiO_2	NR	0.01		0.02	0.01
P_2O_5	NR	0.01		0.02	0.005
MnO	0.15	0.12		0.12	0.09
CO_2	NR	0.05		0.12	0.15
Cr_2O_3	0.38	0.43	0.47	0.45	0.39
NiO	0.52	0.34	0.32	0.36	0.29
CoO	0.01	0.01	———	0.02	0.013
Total	99.98	99.85	96.27	100.85	99.85

NR = Not Run. *90% Total Fe converted to FeO, remainder to Fe_2O_3.

**L.O.I. = Loss on ignition, includes H_2O^+ and CO_2.

Sample Description

1. Single sample fresh peridotite. Analyst B. J. Grimm.
2. Composite sample fresh peridotite. Analyst B. J. Grimm.
3. Same sample as No. 2, but analyzed by quantometer and colorimeter.

4. Saxonite from Nickel Mountain. From Hotz (19, Table 2, p. 363).
5. Single sample of serpentinite. Analyst B. J. Grimm.

PHYSIOGRAPHIC HISTORY

Concordant summit levels at approximately 3500 feet are a conspicuous feature of the landscape around Nickel Mountain and throughout the Klamath mountains, although the precise elevation is variable. This surface was named the Klamath peneplain by Diller (12), who concluded that the long cycle of erosion and uplift was initiated at the close of the Eocene. Diller considered that marine sediments (Wimer formation) were forming on the western margin of the developing peneplain. These marine sediments are preserved in patches at an elevation of about 2000 feet along the western edge of the Klamath mountains in Del Norte County, California (21). Diller, and later Maxson (30, p. 135), assigned a late Miocene age to the Wimer formation, but Diller also considered the Wimer sediments to be erosional remnants of marine deposits found 10 to 15 miles westward at Point St. George, which Allen and Baldwin (2) have since concluded are of Pliocene age.

Cater and Wells (5), in considering the topography of the Gasquet quadrangle in northwestern California, emphasize that the surface on which the Wimer beds were deposited is separated from the Klamath peneplain by a distinct break in slope. They concluded that (p. 114) "the Klamath cycle of peneplanation ended with moderate regional uplift before the upper Miocene beds were deposited." Later subsidence allowed the Wimer sea to deposit upper Miocene sediments in the lower ends of the river valleys and along the coast bordering the land mass.

The Weaverville formation was considered by Diller (12, p. 12) to be associated with the development of a second major cycle of erosion which he named the Sherwood peneplain. Unfortunately, there is some doubt as to the age of the Weaverville formation. Diller thought the Weaverville was of Miocene age, but Hinds (18) and Jenkins (22) both thought it was chiefly Eocene. MacGinitie (29) did a considerable amount of work on fossil floras of the Weaverville formation and concluded that it was of Oligocene age. If the later is true, the Sherwood stage is Oligocene, and the Klamath peneplain is of pre-Oligocene age.

There appears to be no reason why the sequence of events discussed above cannot be applied to Nickel Mountain. If this is so, the Upper orebody (Diller's Klamath peneplain) is of pre upper Miocene age, and could be as old as the Eocene, while the Lower orebody, (possibly Diller's Sherwood stage) is of pre-Pliocene age. This dating, though not as close as one might wish, probably serves the present purpose of assigning an approximate age to the distinct ore levels on Nickel Mountain.

Other erosion levels in the Riddle area are considerably younger than the Klamath and Sherwood peneplains, and are found at lower elevations on the mountain side and in the present river valleys. Ore has not been developed where the younger terraces cut ultramafic rocks, and in fact, low level ore is conspicuously absent throughout the Klamath Mountain province.

Indirect evidence of the age of laterization is provided by the Cle Elum nickeliferous iron deposits in Kittitas County, Washington. These deposits are generally considered to be residual laterites, although portions of the ore appear to have been reworked (25). The deposits rest upon serpentinized peridotite and are overlain by continental sandstones of the Swauk formation. The age of the Swauk formation is uncertain, but Lupher (28, p. 8) concluded that "the Swauk Creek flora is suggestive of a time near the Mesozoic-Cenozoic boundary".

TERTIARY CLIMATE

Direct evidence of the early Tertiary climate is not preserved in sedimentary rocks on Nickel Mountain, but some indication of the prevailing climatic conditions at this time can be gained by study of continental Tertiary sediments and fossil bearing volcanic rocks in other parts of Oregon, Washington, and California. A fairly complete sequence of Tertiary terestrial deposits containing moderately abundant plant and tree flora has been preserved in the John Day Basin of eastern Oregon, and floral assemblages from other isolated areas in Oregon, Washington, and California can be given a stratigraphic position by reference to this sequence. The basin deposits have been described by a number of writers including Merriam (31), Knowlton (24), and Buwalda (4).

In a comprehensive survey of early Tertiary climate, Chaney (8) used two distinct floras to trace migration of climate. The two floras, one dominated by redwood, and the other by avocado, fig, and palmetto, indicate temperate and subtropical conditions respectively. Study of the distribution of the two floras has shown that during Eocene time, there was a lowland area extending from Washington to California which supported a subtropical vegetation. The similarity of floras west and east of the present Cascade axis indicates that this range was probably not in existence in the Eocene.

Subtropical conditions continued into the Oligocene, as shown by the Weaverville flora of California (29), but by the end of the Oligocene, the subtropical forests were migrating southwards and being replaced by redwoods. This is particularly well shown by the upper Oligocene flora from Bridge Creek near Mitchell in central Oregon (6). The flora indicates a redwood forest somewhat more diversified than modern Californian forests, but generally of the same type. By early Miocene, the redwood and other broadleaf deciduous genera were dominating the forests of middle latitudes in western North America. The Mascall flora of Miocene age is widely distributed through western Oregon, Washington, and California and, according to Chaney (7), indicates a climate comparable with that of modern oak - madrono forests which have about 39 inches of rainfall. The progressive change in climate culminated in the Pleistocene glaciation.

At the onset of the Pliocene, differences between the flora east and west of the Cascade axis can be seen. A redwood flora is known from western Oregon but is absent from Pliocene assemblages east of the Cascades. Thus it seems reasonable to conclude that the Cascade barrier came into existence in late Miocene or Pliocene time.

Coal swamps figure prominently in the Tertiary history of Oregon and Washington. Snavely (39), shows that they existed from early Eocene time to as late as the middle Miocene. Thick beds of partly carbonized wood are typical of the upper Miocene but are not recorded from Pliocene strata. The existence of coal swamps suggests a warm, humid climate at least until the middle of the Miocene in the coastal regions. By the start of the Pliocene these conditions had changed to a distinctly cooler climate.

Ferruginous bauxites are found in northwestern Oregon. According to Libbey et al. (27), laterization took place following extrusion of the Miocene basalts, from which the bauxites were derived, but prior to their folding in the Pliocene. Allen (1, p. 625) further states that the formation of bauxite was completed before the deposition of an overlying silt, probably of Pliocene age. The formation of bauxite strongly suggests at least a humid, warm temperate climate in the Miocene, although as Reiche (37, p. 81) points out, laterization is not always confined to tropical climates and may occur under temperate or even sub-polar climates.

The gradual change from a humid subtropical climate in the Eocene and Oligocene, to more temperate conditions in the Miocene and Pliocene appears to be well established. The coincidence of subtropical climate and low relief in the early Tertiary may have been responsible for the favorable conditions which allowed widespread development of nickeliferous deposits over ultramafic bodies in Oregon, California, and Washington.

ORE CLASSIFICATION

Ore grade is an important economic factor, and is significant in other ways, but classifying Nickel Mountain ore according to nickel grade tends to group together ores which otherwise are quite dissimilar. Instead of Ni, differences in texture and structure have been used to subdivide the ore into three main groups and six ore types, as shown in table 4.

The primary division between soil and saprolite is based on the presence or absence of joint planes, the appearance of residual rock boulders, and the granularity of interstitial decomposed material. The soil group is subdivided on color, while the saprolites are further subdivided according to the amount of fresh rock they contain. Boxwork ore is quite distinct, as it occurs in veins, and is composed of chalcedony and a number of hydrous Ni-Mg silicates, including garnierite. The term saprolite is used in its original sense to describe a decomposed but untransported rock, and to distinguish the high MgO - low Fe ore preserved on Nickel Mountain from typical low MgO - high Fe laterite which is not present.

Soil Group

The orebody is mantled by a cover of brick red soil which grades downward locally into a yellow soil. The soils account for approximately 20 per cent of the ore reserve, and their general distribution is shown in figure 3. The thickness averages ten feet, but soil may be virtually absent or up to 40 feet thick. The soil is a porous, incoherent material composed of pulverulent aggregates rich in hydrous iron oxides and clay minerals, and scattered fresh peridotite boulders, ranging in size from a few inches to over 20 feet in diameter. In some areas, irregular fragments of leached honeycomb chalcedony boxwork and chalcedony vein fragments are abundant. Soils developed over serpentinite are brown in color rather than brick red, and normally contain a smaller amount of nickel than red soil.

Table 4. Ore Classification

GROUP	ORE TYPE
Soil	Red Soil Yellow Soil
Saprolite	Soft Saprolite Hard Saprolite Saprolized Peridotite
Boxwork	Boxwork

The brick red color is caused by iron minerals and iron staining. The transitional change to yellow soil takes place over about one foot and reflects the change from predominantly ferric to predominantly ferrous compounds. Compared with saprolite ore, the soils are higher in Fe, and tend to be rather high in silica where the underlying ore is boxwork. The soils have a variable magnesia content, and are generally lower in nickel content than the ore which underlies them. Soils in the Lower orebody are higher in Fe and SiO_2, and lower in Ni and MgO than soils in the Upper orebody.

The top few inches of soil contains moderately abundant grains of magnetite approximately .3mm in size, and the whole soil thickness is slightly enriched in chromite and enstatite grains. The soils show no trace of original joint planes, and peridotite boulders are randomly distributed.

Where soil occurs over fresh peridotite, the soil contains abundant peridotite boulders, some of which may be quite large. Where soil occurs over a thick saprolite sequence, fresh peridotite boulders are either absent or few in number. No exotic rock float has been found in the soil, which probably means that the orebody was never capped by younger rocks.

One of the most distinctive features of the soils is the appearance of the peridotite boulders. These tend to be somewhat rounded and completely fresh except for a thin rusty skin which is never more than 5mm thick. This feature, combined with a total lack of relict joint planes in the soil portion, is in marked contrast with the physical appearance of saprolite.

The base of the soil cover may be thought of as an "unconformity" separating ores which differ both chemically and physically. Planar features in the underlying ore, such as boxwork veins and faults, do not penetrate the soil. The contrast between soil and saprolite is stressed because the differences probably imply somewhat different modes of origin. This will be discussed in a later section.

Boxwork Group

Some of the richest and most colorful ore on Nickel Mountain occurs as rather thick veins of garnierite, chalcedony, and serpentine, often showing typical boxwork texture. Boxwork ore from Nickel Mountain and other localities has been described in many publications, consequently only the major features of interest will be outlined here.

Pecora and Hobbs (34), in describing the ores on Nickel Mountain, used the term "boxwork layer" in a broader sense than it is presently being used. They distinguished between the peridotite basement and the red soil cover, and called the ore lying in between "the boxwork layer". Thus they included in the term material which is classified here as saprolite as well as boxwork *sensu stricto*.

There is some merit in the grouping used by Pecora and Hobbs. Thin garnierite-chalcedony-serpentine veinlets are very widely distributed in saprolite and coat most joint planes. However, these veinlets rarely exceed five per cent of the total weight of the material, the bulk of which is fresh and decomposed peridotite. On the other hand, zones of predominantly garnierite-chalcedony boxwork occur, some as much as 40 feet thick, and it is to these zones that the term "boxwork ore" is restricted here. Boxwork ore, so defined, accounts for approximately ten per cent of the total ore reserve. Saprolite ore with minor garnierite-chalcedony veinlets may grade into boxwork ore, but more often than not the transition is rather sharp, and the two should be considered separately. The separation may have genetic as well as economic significance.

The term boxwork ore, as presently used, covers a variety of textures, not all of which are true boxworks. Three main varieties can be distinguished:

(1) True boxwork veins. These vary in thickness from a few inches to more than fifteen feet, and are composed of thin-walled chalcedony boxes, 1-5cm square, commonly filled or partly filled with hydrous Ni-Mg silicates including garnierite, and minor amounts of limonitic earth.

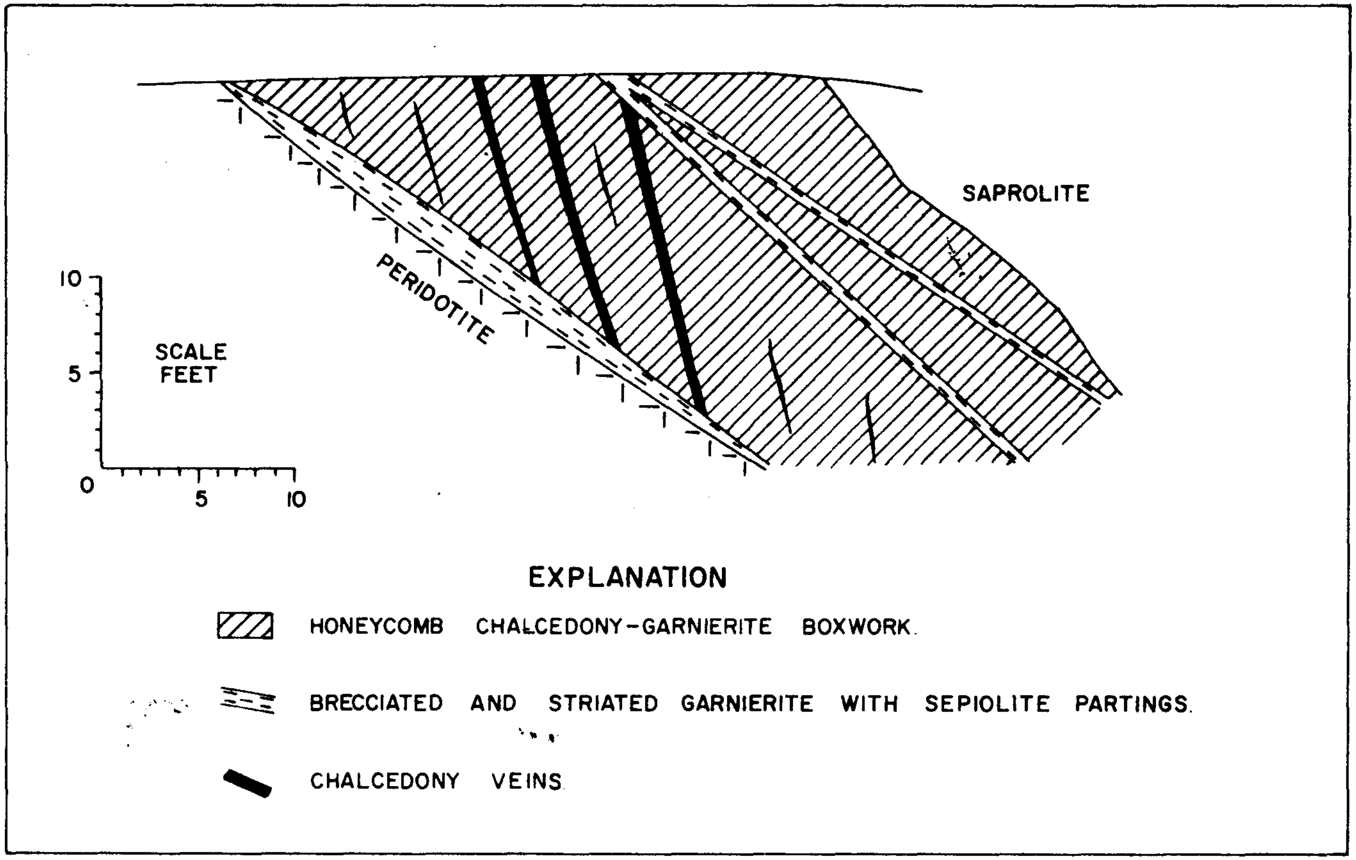
(2) Chalcedony veins, massive or banded. These are up to ten feet thick, are composed essentially of chalcedony in shades of white, gray, and brown and may contain up to 75% per cent SiO_2. Occasional bands or partings of garnierite are common, and some green chalcedony (chrysoprase) is also found. However, this ore is generally of lower grade than other types of boxwork.

(3) Breccia veins. These consist of fragments of peridotite, saprolite, serpentine, early chalcedony, or early garnierite, cemented by later chalcedony, serpentine and garnierite. Fault grooving and striae, often coated with later garnierite and chalcedony, are very common. Thin partings of soft, plastic, white or greenish sepiolite also occur with the breccia veins and may represent a fault gouge or mylonite.

True boxwork veins and breccia veins are nearly always vuggy or even cavernous. The openings typically are lined with garnierite and chalcedony, often showing bilateral symmetry. Thick boxwork zones are usually compound and often include representatives of all three varieties of boxwork. A normal sequence would be a brecciated and striated footwall, with an overlying true boxwork cut by thinner chalcedony veins as shown in figure 5. (Figure 5 near here).

Most boxwork ore in the Upper orebody is found along structural controls (faults, joints), but some boxwork along the south side of the orebody is in layers more or less parallel to the present surface and possibly represents fossil water tables. In contrast, most of the boxwork in the Lower orebody is flat lying and is believed to be related to fossil water tables.

Figure 5. Geologic Sketch Section Through Typical Compound Boxwork


SAPROLITE
PERIDOTITE
10
5
0
5
10
SCALE
FEET
EXPLANATION
HONEYCOMB CHALCEDONY-GARNIERITE BOXWORK.
BRECCIATED AND STRIATED GARNIERITE WITH SEPIOLITE PARTINGS.
CHALCEDONY VEINS.

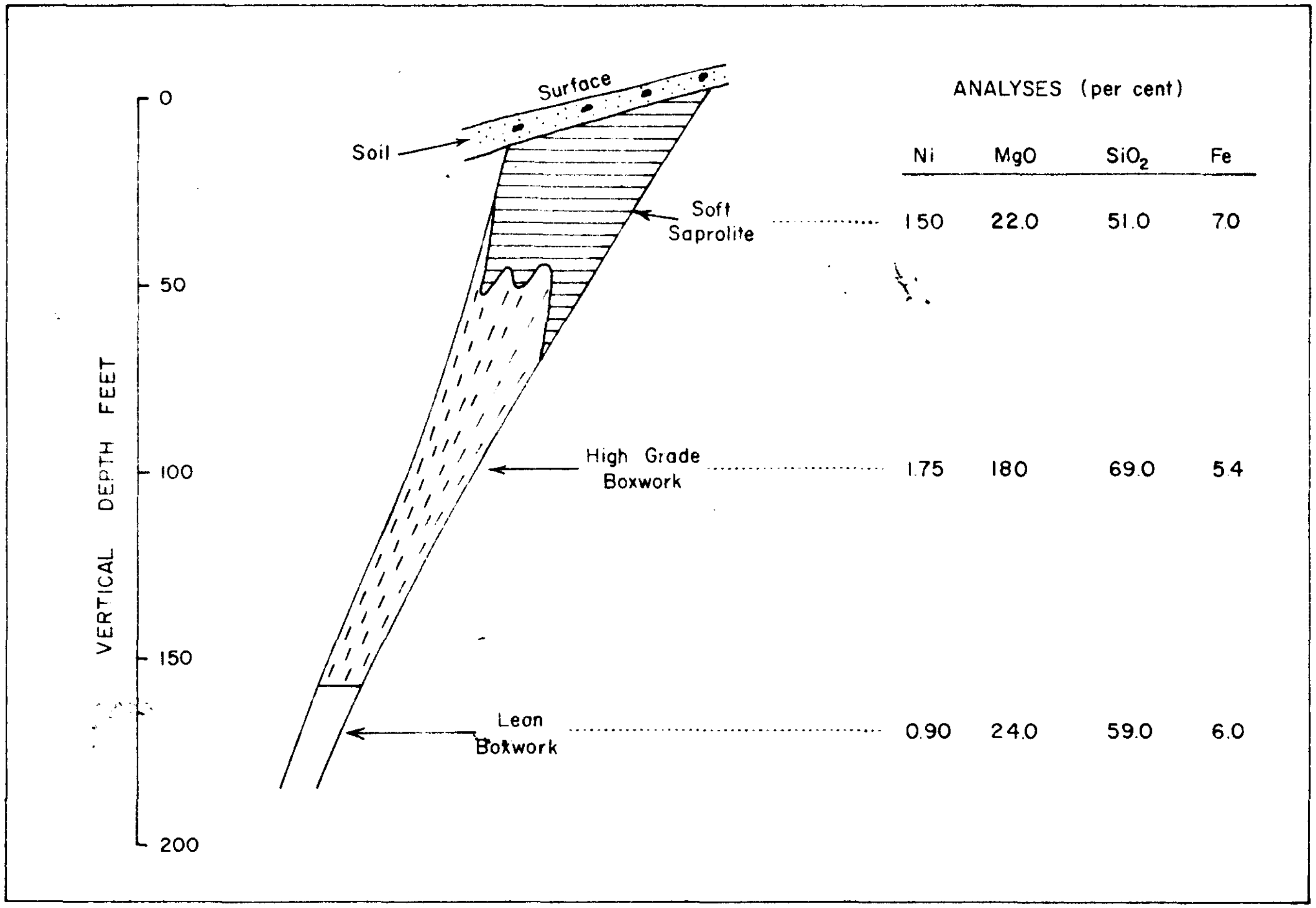
Average analyses given in table 5 show that boxwork is notably high in silica and nickel, but relatively low in magnesia and iron. Boxwork in the Upper orebody carries appreciably more nickel and slightly less iron than in the Lower orebody, thus contributing to the pattern of differences between the two orebodies.

Changes in the character of some boxwork veins with depth have been observed. Most boxworks extend to the top of the saprolite zone and leached fragments are found in the overlying soil cover. However, some boxworks are capped by high grade soft saprolite which grades downward into high grade boxwork, then into lean boxwork. Figure 6 shows a sequence which has been pieced together from a number of scattered drill hole intersections and bank samples. (Figure 6 near here). The analyses and depths given are intended only as a guide to the scale and type of changes, and to show the relative mobility of some of the major chemical constituents.

Iron is concentrated in the soft saprolite, and the nickel content is highest in the upper part of the vein. Silica increases to a maximum at about the middle of the high grade zone and decreases below this level. Magnesia is present in the soft saprolite as both hydrous and anhydrous silicates and tends to be moderate in amount. The richest portion of the boxwork vein is low in MgO, while the leanest part of the vein is high in MgO due to the abundance of hydrous silicates.

The sequence suggests that Ni and Fe are either relatively immobile or are easily re-deposited, silica is moderately mobile, and magnesia is highly mobile. Conceivably, veins of this kind could grade downward into material composed of only hydrous Mg-silicates, although this has never been proven by drilling.

Figure 6. Depth Zoning in a Hypothetical Boxwork Vein



ANALYSES (per cent)

	Ni	MgO	SiO_2	Fe
Soft Saprolite	1.50	22.0	51.0	7.0
High Grade Boxwork	1.75	180	69.0	5.4
Lean Boxwork	0.90	24.0	59.0	6.0

Table 5. Average Analyses of Boxwork Ore (per cent)

Orebody	Ni	MgO	SiO_2	Total Fe	L.O.I.
Upper	1.78	22.0	59.3	7.5	7.3
Lower	1.49	18.9	59.7	8.5	7.8

Boxwork ore marks the locations of major "plumbing" zones down which groundwater containing Ni, MgO, Fe, and SiO_2 migrated. Drill holes have penetrated boxwork ore as much as 260 feet vertically below the present surface. The thick compound boxworks in particular must have had a long history of use as channelways judging from the tonnage of deposited minerals.

Saprolite Group

Saprolite ore underlies most of the red soil areas and accounts for almost 70 per cent of the ore reserve. Because of their economic importance, they will be discussed in some detail. The saprolite group has been divided into three ore types based on the content of fresh, unaltered peridotite or dunite as follows:

Soft Saprolite	0 - 20% fresh rock by weight
Hard Saprolite	20 - 50%
Saprolized Peridotite	50 - 75%

Material containing more than 75 per cent fresh peridotite is classified as Peridotite or Bedrock and is generally not ore. The saprolite ore types represent a continuous sequence of rock decomposition in which peridotite, or dunite, was the starting point. Thus content of fresh rock is an index to the degree of alteration, and is used in this sense in the discussion which follows.

The classification based on fresh peridotite content is useful in that it can be applied to mine mapping, to bulk samples, and to heavy liquid and microscopic studies. However, it is not completely satisfactory when dealing with drill hole samples. This results from the fact that the ore can only be sucessfully drilled at present with a churn drill, and the sludge samples are difficult to classify visually. Some indication of the type of ore being drilled may be obtained by close inspection of the larger chips after washing out the mud, but most of the altered material and some of the peridotite is pulverized by the action of the drill bit.

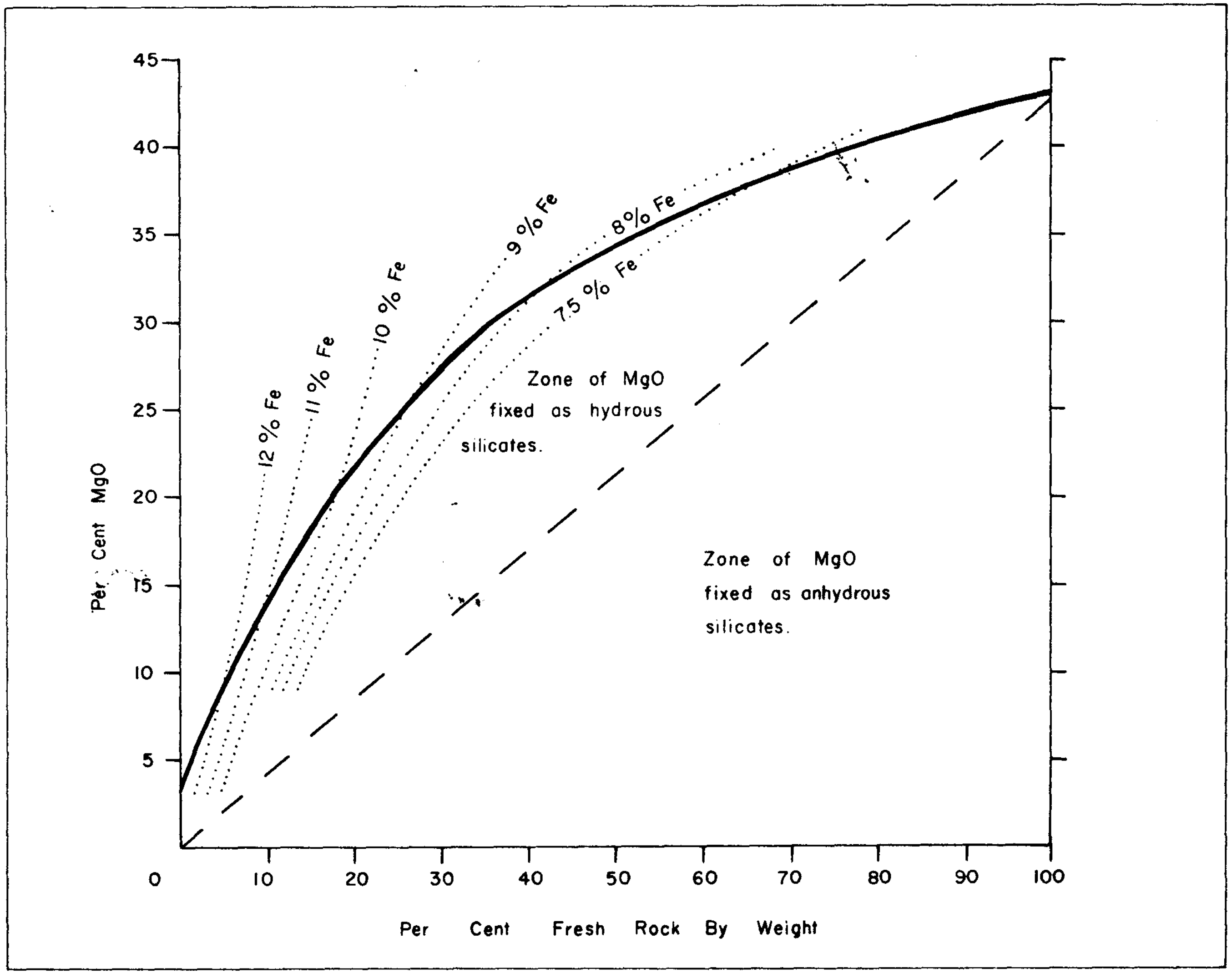
The most reliable indication of the fresh rock content of drill samples is obtained from chemical analyses. Pure peridotite contains approximately 44 per cent MgO, and using this as a basis, a relationship between MgO and rock content has been established. This correlation is not simple because several minerals in the ore contain MgO, the principal ones being primary anhydrous silicates such as olivine and enstatite, and secondary hydrous silicates such as garnierite, serpentine, and sepiolite. Study of mineral suites prepared by heavy liquid separation has shown that the ratio of hydrous to anhydrous Mg-silicates is fairly constant for a given content of fresh peridotite. Thus the MgO due to anhydrous silicates can be separated from MgO in hydrous silicates as shown by the dashed line in figure 7. (Figure 7 near here). The solid curved line in figure 7 represents the average rock content, and allows prediction of rock content from MgO analysis to within ± 10 per cent.

As a further refinement, an empirical relationship between iron and rock content has been developed. This relationship is used to correct the figure derived by the MgO method, thereby increasing the accuracy of prediction of rock content to ± 3 per cent. The correction due to iron content is also shown in figure 7.

Both MgO analysis and the amount of fresh rock may be used interchangeably; they vary together and both indicate the degree of saprolization. Where possible, rock content is estimated directly, but in the many places where only drill samples are available, the MgO - rock relationship is used.

The saprolites show the same kind of jointing as the peridotite from which they were derived, namely three or more sets of joint planes intersecting approximately at right angles and forming irregular blocks or rhombs. The joint planes are nearly always marked by thin films of garnierite, chalcedony, or serpentine, and the films are preserved with no sign of collapse or deformation even when all peridotite has been completely decomposed.

Figure 7. Relationship of MgO and Fe to the Amount of Fresh Rock in Crude Ore.


45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
Per Cent MgO
Per Cent Fresh Rock By Weight
12 % Fe
11 % Fe
10 % Fe
9 % Fe
8% Fe
7.5 % Fe
Zone of MgO fixed as hydrous silicates.
Zone of MgO fixed as anhydrous silicates.

Normally, each joint rhomb contains a core of fresh peridotite surrounded by concentric layers of saprolitic material. A progressive chemical change can be traced from the core to the joint planes. Compared with the rock core, the outermost layers are lower in MgO and higher in SiO_2, Fe, and Ni, indicating that decomposition took place from the joint surfaces inwards. Joint frequency must therefore have been an important factor controlling degree of saprolization.

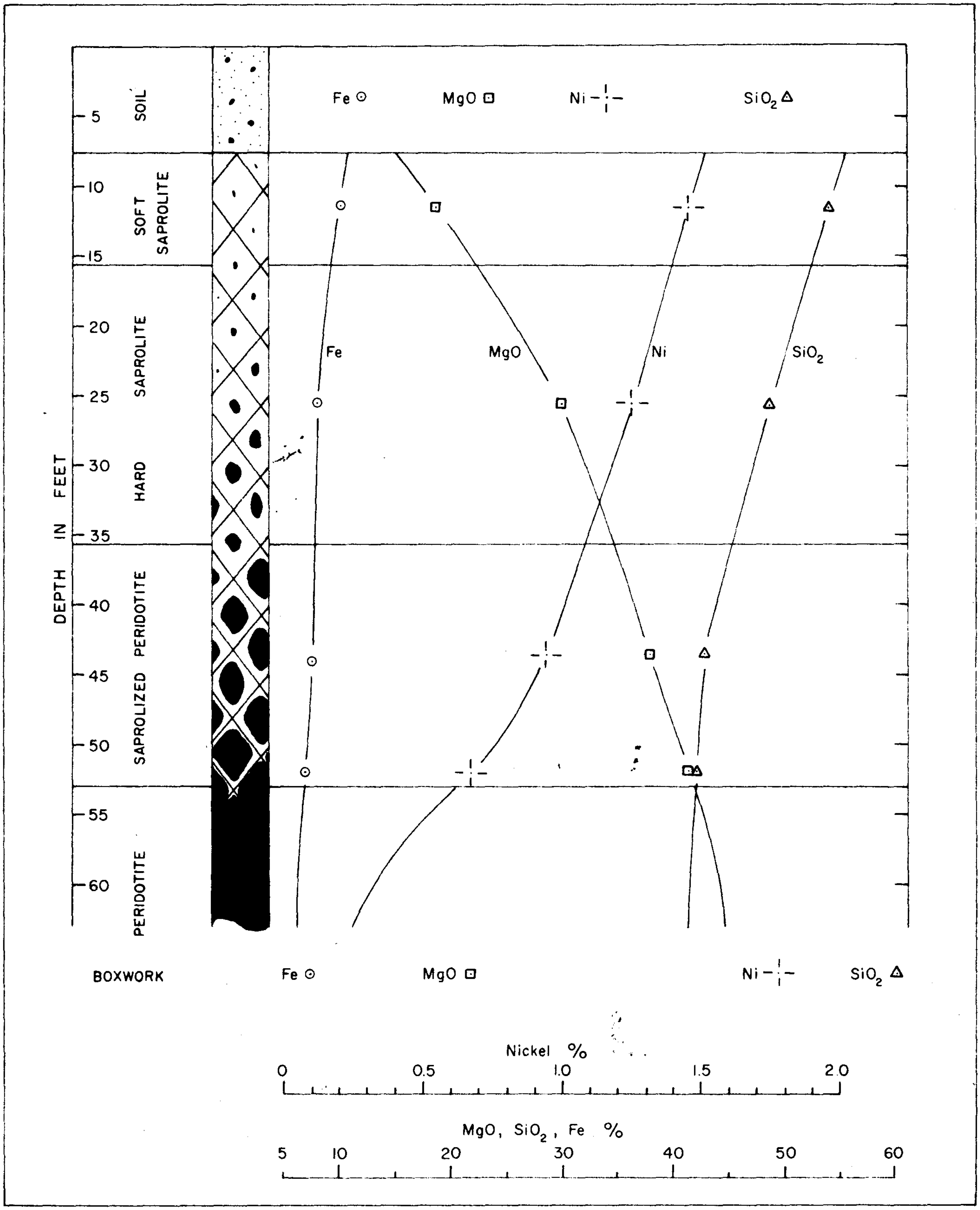
Decrease in the total amount of fresh rock is paralleled in general by a decrease in size of the fresh rock residuals. This would be expected if alteration was initiated along joint surfaces. However, the size of the residuals also depends on the closeness of joint spacing in the parent rock. A highly fractured or jointed parent rock produces small sized residual fragments regardless of the degree of saprolization.

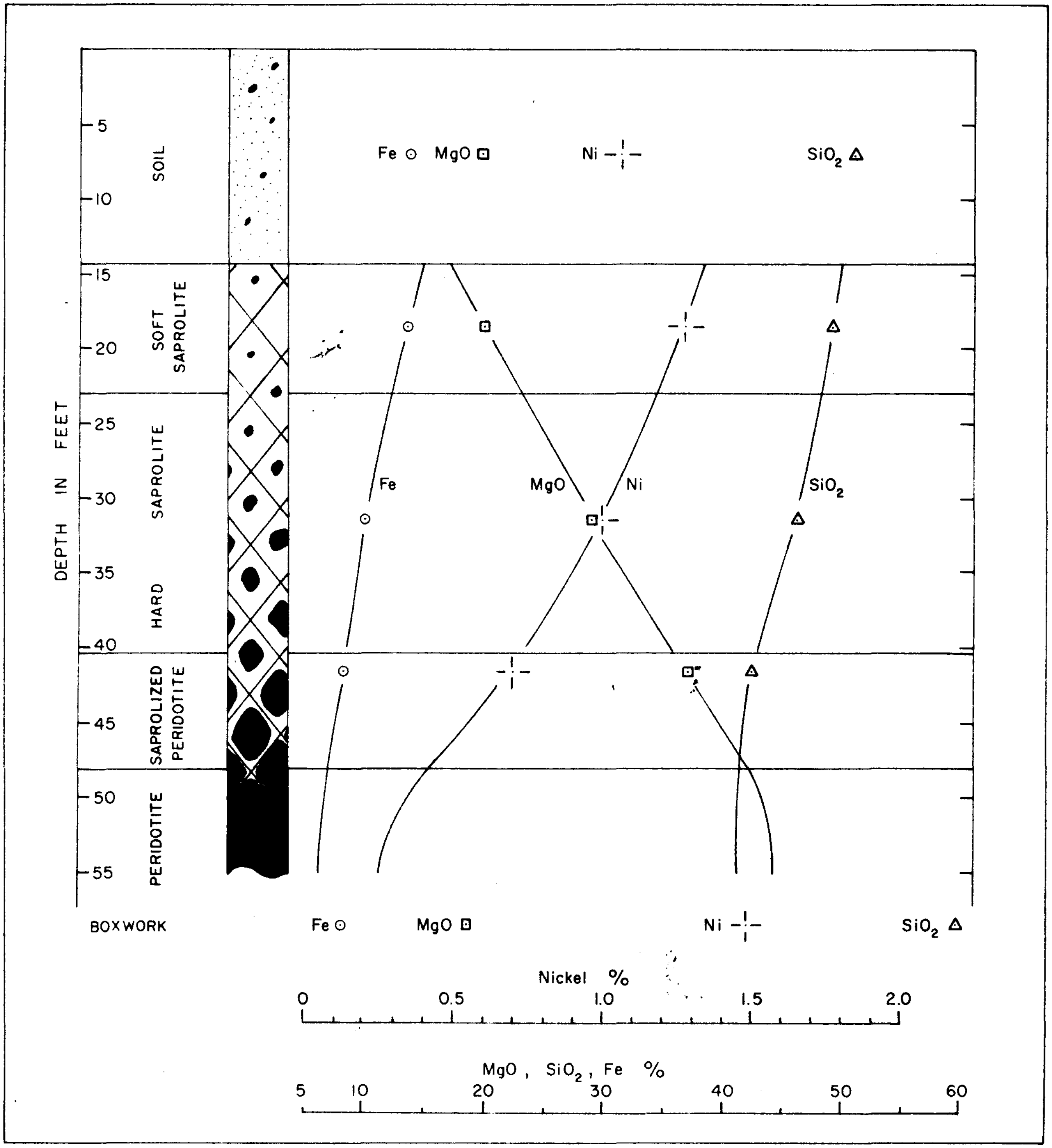
The chemistry of the saprolite sequence is shown graphically in figures 8 and 9 where grades of Ni, MgO, SiO_2, and Fe are plotted against thickness of each ore type. (Figures 8 and 9 near here). These profiles are not true vertical cross sections. Irregularities due to structure have been eliminated, and the resulting profile is an ideal section through a perfectly gradational sequence. Although this situation does not in fact obtain, the general sequence of chemical change attending saprolization is illustrated.

The two profiles are generally similar. Both show a systematic increase in MgO, and a decrease in Ni, SiO_2, and Fe as bedrock is approached. Differences between the two orebodies are also apparent. The total thickness of ore in the Upper orebody is about five feet greater than in the Lower orebody. Comparing ore type with ore type, the Upper orebody saprolites are uniformly higher in Ni, and lower in Fe than those in the Lower orebody. The SiO_2 and MgO contents tend to be variable but considering the saprolites as a whole, both orebodies have about the same SiO_2, while the Upper orebody is higher in MgO than the Lower orebody.

Figure 8. Chemistry and Thickness of Ore Types in the Upper Orebody

Figure 9. Chemistry and Thickness of Ore Types in the Lower Orebody


DEPTH IN FEET
5
10
15
20
25
30
35
40
45
50
55
60
SOIL
SOFT SAPROLITE
SAPROLITE
HARD
SAPROLIZED PERIDOTITE
PERIDOTITE
BOXWORK
Fe ⊙
MgO ⊡
Ni -¦-
SiO_2 △
Fe
MgO
Ni
SiO_2
Nickel %
0
0.5
1.0
1.5
2.0
MgO, SiO_2, Fe %
5
10
20
30
40
50
60


DEPTH IN FEET
5
10
15
20
25
30
35
40
45
50
55
SOIL
SOFT SAPROLITE
HARD SAPROLITE
SAPROLIZED PERIDOTITE
PERIDOTITE
BOXWORK
Fe ⊙ MgO ⊡ Ni -¦- SiO_2 △
Fe
MgO
Ni
SiO_2
Nickel %
0
0.5
1.0
1.5
2.0
MgO , SiO_2 , Fe %
5
10
20
30
40
50
60

The density of saprolite varies considerably, the most decomposed material being the least dense. As this is an important factor in making accurate ore reserve estimates, a series of bulk samples of about 200 tons each were collected to determine in-place tonnage factors. These samples were supplemented by a series of smaller samples obtained from hand dug test pits. The results of the sampling program are shown in figure 10 where tonnage factor (cu. ft/short ton) is plotted against MgO and ore type of the sample. (figure 10 near here). The dry in-place tonnage factor is controlled by mineral specific gravities and by porosity; the wet tonnage factor is further complicated by the degree of saturation.

The close relationship between in-place tonnage factor and degree of alteration reflects the large increase in porosity which is achieved without change in volume. Due to the incoherent nature of the material, direct measurements of porosity are difficult to make and usually inaccurate. However, porosity can be calculated from the dry in-place tonnage factor (Fd) if the true mineral specific gravity (Gm) is also known. Dry in-place tonnage factor is converted to dry in-place specific gravity (Gi) as follows:

$$Gi = \frac{2000}{Fd.\ 62.4}$$

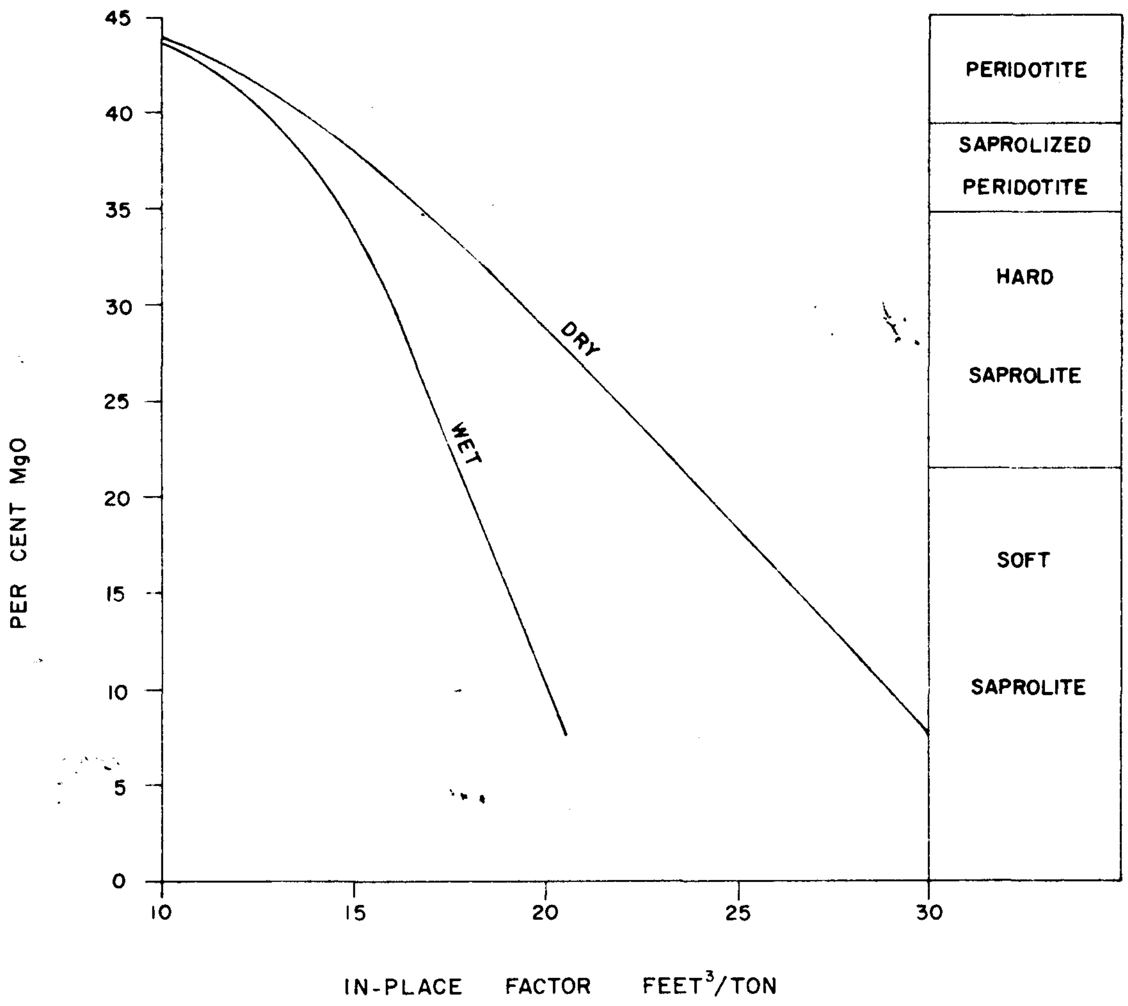
Porosity (P) is then obtained from

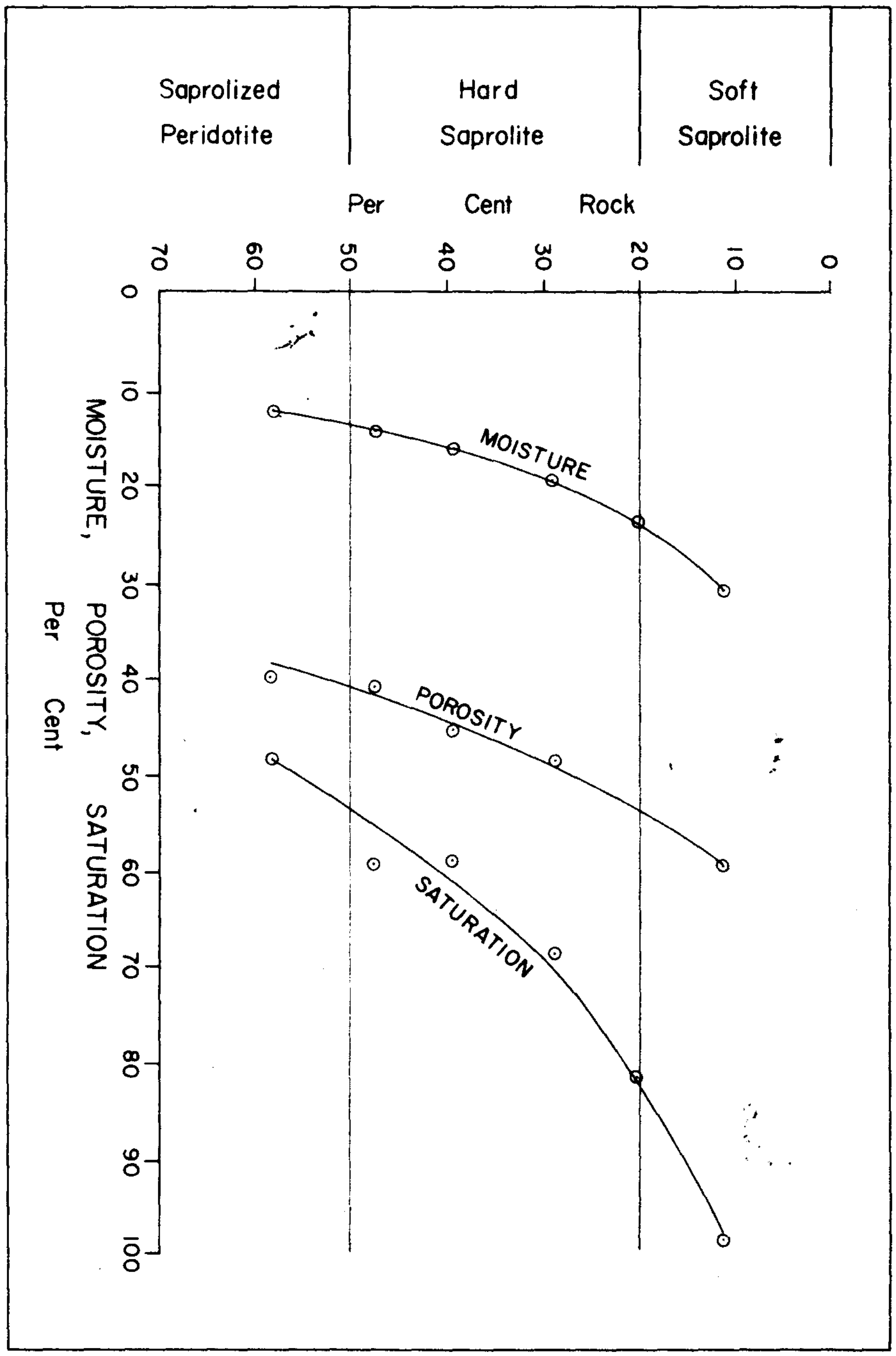
$$P = \frac{(Gm - Gi)}{Gm} \times 100$$

A clear relationship between porosity and degree of alteration is indicated by the six samples plotted in figure 11. (Figure 11 near here). The highest observed porosity is about 60 per cent, expressed as the ratio of void volume to total volume.

Figure 10. In-Place Tonnage Factors of Saprolite Ore Plotted Against MgO and Ore Type

Figure 11. Moisture Content, Porosity, and Degree of Saturation of the Ore Types


PER CENT MgO
45
40
35
30
25
20
15
10
5
0
10
15
20
25
30
IN-PLACE FACTOR FEET^3/TON
DRY
WET
PERIDOTITE
SAPROLIZED PERIDOTITE
HARD SAPROLITE
SOFT SAPROLITE


Saprolized Peridotite
Hard Saprolite
Soft Saprolite
Per Cent Rock
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
MOISTURE
POROSITY
SATURATION
MOISTURE, POROSITY, SATURATION
Per Cent

Given the moisture content and porosity of a sample, the degree of saturation (per cent volume of voids filled by water) can be calculated.

$$\%\ \text{vol. water} = \%\ \text{weight water} \times \text{wet in-place S. G.}$$

$$\%\ \text{saturation} = \frac{\text{vol. water}}{\text{porosity}} \times 100$$

Figure 11 also shows the results of this calculation plotted against fresh rock content of the samples used. Although the data points are few, the trend seems to be clear. As peridotite is decomposed, the in-place density decreases due to an increase in pore space. As pore space is made available, the resulting rock becomes increasingly saturated with water due to increased permeability. The increase in surface area available to chemical weathering, and the increase in permeability, may have had an important affect on the rate of saprolization.

The importance of the saprolite group is twofold. First, the saprolites account for a large part of the ore reserve and are valuable in their own right. Secondly, the saprolites have been preserved in place with a few, if any, physical changes so that their origin from peridotite can be demonstrated almost beyond doubt. This provides a stable foundation for theories regarding the origin not only of the saprolites, but also of boxwork and soil. The saprolites are secondary after peridotite. Boxworks were derived from the chemical breakdown of both peridotite and saprolite, and are also secondary. However, the soils were derived from saprolite and boxwork, and are therefore tertiary.

STRUCTURE

Depth and intensity of saprolization follows a pattern which is complex in detail but fairly simple in its broader aspects. The pattern is influenced by three structural elements, namely, former water tables, two sets of faults, and zones of intense jointing. These three elements make up the large scale structural framework which controlled ore distribution and the degree of saprolization.

Water Tables

A discontinuous zone of boxwork ore, more or less flat lying and sub-parallel to the present surface, is found at the eastern end of the Lower orebody and along the southern margin of the Upper orebody. The boxwork ore lies just below the base of the red soil and tends to drape over the underlying structures rather than conform to them. The location of this ore in the regolith is consistent with deposition of boxwork elements at a former water table or similar boundary surface. Apart from the two areas mentioned above, this type of boxwork ore is either absent or insignificant in amount.

Faults

Faulting and jointing controlled the localization of the saprolite ore. Two major faults show a relationship to existing ore. One of these, known as Rock Fault, strikes approximately east-west through the Upper orebody and dips to the south at 35-45° (figure 3). The fault has been exposed by mining operations for a strike length of 2800 feet and can be traced through surface mapping and drilling for an additional 3300 feet. At least two other sub-parallel faults have been mapped above Rock Fault. These faults branch from and converge with Rock Fault forming a fault zone which in places is 50 feet thick.

The low dip of Rock Fault suggests reverse movement, but ore thickness is greatest on the south or hanging wall side, implying that a greater thickness of ore was preserved as a result of normal movement. However, this is not necessarily true; thicker ore could have developed as a result of greater shattering in the hanging wall member regardless of the sense of movement. Striations on the several planes of movement pitch steeply (75°-90°) both west and east, indicating a strong component of dip slip. Striae are perfectly preserved in many places but, contrary to expectation, do not provide unequivocal proof of the direction of movement.

Rock Fault is overlain in many places by a remarkably thick boxwork which is invariably vuggy and in places cavernous. This implies that the boxwork was deposited in an open fracture, a condition not likely to be encountered under thrust fault conditions. In addition, the massive boxwork is cut by steeply dipping tension cracks filled with later barren chalcedony (figure 5). These too are consistent with normal movement, and the balance of evidence suggest that movement on Rock Fault was normal dip slip.

The footwall of Rock Fault is usually fresh peridotite, hence the name of the fault. Boxwork ore along the plane of Rock Fault is known to continue locally to a vertical depth of 260 feet below the present surface, indicating that the fault zone acted as a major artery for the escape of mineralized groundwater. Downward migrating groundwater would have impinged on the footwall, but clearly had little or no effect on the footwall peridotite, indicating that the footwall was sealed in some way.

The second major fault, known as Spring Fault, strikes approximately east-west through the Lower orebody. The fault dips 28°-60° to the north, and can be traced for approximately 10,000 feet. Reverse movement on Spring Fault is suggested by the fact that barren peridotite occurs at a higher level on the north (hanging wall) side of the fault. The plane of the fault is not marked by boxwork despite the fact that boxwork is prevalent in the Lower orebody. This contrasts markedly with Rock Fault, and suggests that the fault was not an "open" fracture. However, saprolite ore has been developed adjacent to Spring Fault to depths of 230 feet below the present surface.

Rock Fault and Spring Fault are both cut by north-south trending, steeply dipping, normal faults. Mining has exposed three cross faults cutting Rock Fault, and the existence of at least two other is suspected from drilling. Striations on the exposed cross faults pitch steeply, indicating essentially dip slip movement which resulted in horizontal offsets in Rock Fault of 10-220 feet. The structure of the Lower orebody is not as well known as that of the Upper orebody, and only one fault cutting Spring Fault has been recognized. The cross fault dips to the west, and the offset of Spring Fault is consistent with normal movement on the cross fault.

The relationship of faulting to the age of saprolization and boxwork formation is complex. Some of the factors having a bearing on age are as follows:

1. Rock adjacent to the known faults has been saprolized, and boxwork ore was deposited along many of the faults. Some saprolite and boxwork is therefore post-faulting.

2. The average thickness of saprolite south of Rock fault is much greater than on the north (footwall) side. This may mean that saprolization started before Rock fault came into existence, and that saprolite was preserved from erosion by downfaulting.

3. Striated and brecciated garnierite is common, thus some garnierite is pre-latest fault movement. Some garnierite cements brecciated garnierite fragments showing that there is more than one generation of garnierite, and that some garnierite is post-faulting.

These facts indicate that the processes of saprolization and boxwork formation started before the last period of fault movement, and continued for some time afterwards. Whether the period of saprolization synchronized exactly with the period of boxwork formation is not clear. The fact that many boxworks penetrate deeper into the peridotite basement than saprolite ore suggests that deposition of boxwork continued after saprolite had stopped forming, or that the rates of formation were different in different parts of the regolith. The two major faults were probably in existence long before ore started to form. Renewed movement in the early Tertiary cut some early-formed ore, but ore continued to develop after movement finally ceased.

Joints

Joint intensity exerted a considerable amount of control on both the depth and degree of saprolization by providing permeable avenues through an otherwise relatively impermeable rock. A relationship between joint spacing and degree of alteration can be recognized in the field. Massive blocky peridotite with a joint spacing of about 24 inches is little altered except along the joint planes, which are usually coated with films of garnierite and serpentine. On the other hand, relict joint planes in exposures of soft saprolite show a joint spacing of the order of two to six inches.

Although this is the general rule, a few exceptions are found, particularly close to major fault zones. In these zones, joint spacing may be less than two inches but the degree of alteration is often small. Where this is the case, the well jointed area has often been extensively mineralized by garnierite and chalcedony. This may have effectively sealed the rock against circulating groundwater, thereby preventing further decomposition to a typical saprolite.

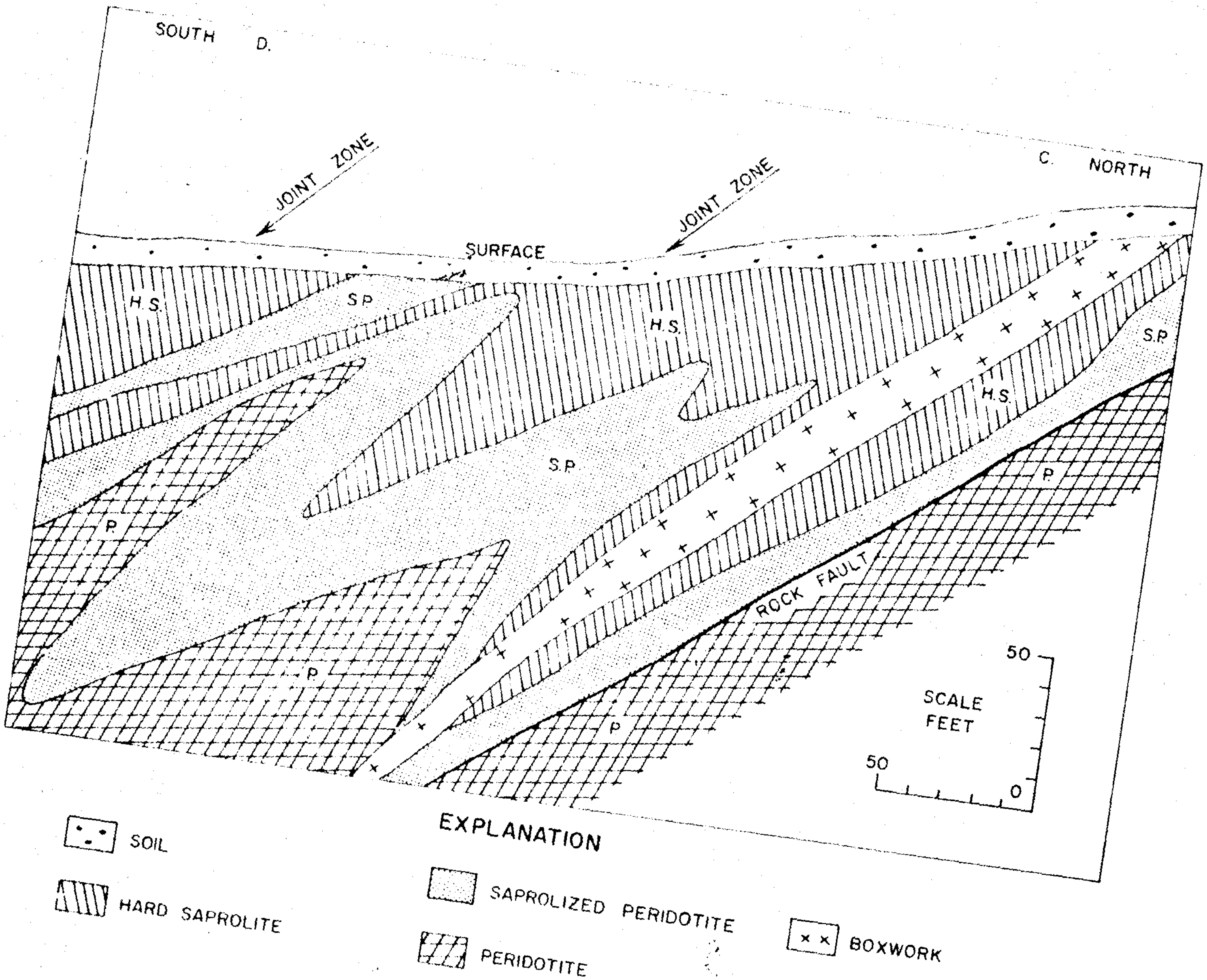
Irregularities in the bedrock togography can be related to permeable zones produced by faulting and jointing. This is shown in plan in figure 12, (Figure 12 near here) which reproduces a portion of the 3200 foot level of the Upper orebody. In this area, the major joint zones strike north-south and dip 50°-60° to the east. They are truncated by Rock Fault on the north, and cut by a "Y" shaped fault system in the southwestern part of the area. The pattern is similar in other parts of both orebodies, and results in a series of "ribs" of peridotite elongated in a north-south direction, and dipping steeply to the east. Saprolite ore types are not shown in the illustration because of scale limitations, but the centres of the large saprolite areas tend to be soft saprolite which grades outward into hard saprolite and saprolized peridotite. Boxwork ore is closely related to the faults.

A typical pattern of ore distribution in vertical cross section is shown in figure 13. (Figure 13 near here). In this example, two joint zones striking northeast and dipping to the southeast are cut by Rock Fault. Saprolite ore types are developed symmetrically around the joint zones. A layer of boxwork lies slightly above, but parallel to the plane of Rock Fault.

In detail, the distribution of ore types is more complex than shown in figures 12 and 13, and day to day mining operations have to be carefully controlled in order to provide an optimum product and to reduce stripping. The complex bedrock topography increases the problems of pit design, haulage road location, and equipment utilization.

Figure 12. Level Map Through a Portion of the Upper Orebody, 3200 Foot Elevation

Figure 13. Geologic Cross Section C-D, Showing the Intersection of Joint Zones and Rock Fault


SOUTH
D.
JOINT ZONE
JOINT ZONE
C.
NORTH
SURFACE
H.S.
S.P.
H.S.
S.P.
S.P.
H.S.
P.
P
P
P
ROCK FAULT
SCALE
FEET
50
50
0
EXPLANATION
SOIL
HARD SAPROLITE
SAPROLIZED PERIDOTITE
PERIDOTITE
BOXWORK

NET CHEMICAL GAINS AND LOSSES

Detailed mapping shows that saprolization involved no change in volume. As already noted, undeformed joint planes are preserved in the saprolites even when all vestiges of peridotite have disappeared. If saprolization truly involves no change in volume, net changes in chemistry can be followed by comparing the metal contents of equal volumes of peridotite and saprolite. The principles underlying the method are shown in table 6. The results of similar calculations on saprolites in the Lower and Upper orebodies are shown in figures 14 and 15. (Figures 14 and 15 near here).

The two graphs are generally similar in shape and to some extent in amount. Both show a net gain of Ni, and net losses of MgO, SiO_2, and Fe. Nickel enrichment is less in the Lower orebody, and the "nickel bulge," shown at the base of the hard saprolite in the Upper orebody, is probably in the soft saprolite horizon in the Lower orebody. The net gain in nickel can only be explained by the addition of nickel, presumably from higher in the profile. This is perhaps the best chemical proof of supergene enrichment as opposed to purely residual enrichment.

The net loss of iron, amounting in some cases to one third of the original iron in peridotite, appears to be at variance with residual iron enrichment which often accompanies laterization. In fact no conflict need exist. If magnesia and silica are lost at a greater rate than iron, the residual material will be enriched in iron.

Table 6. Calculation of Net Chemical Changes

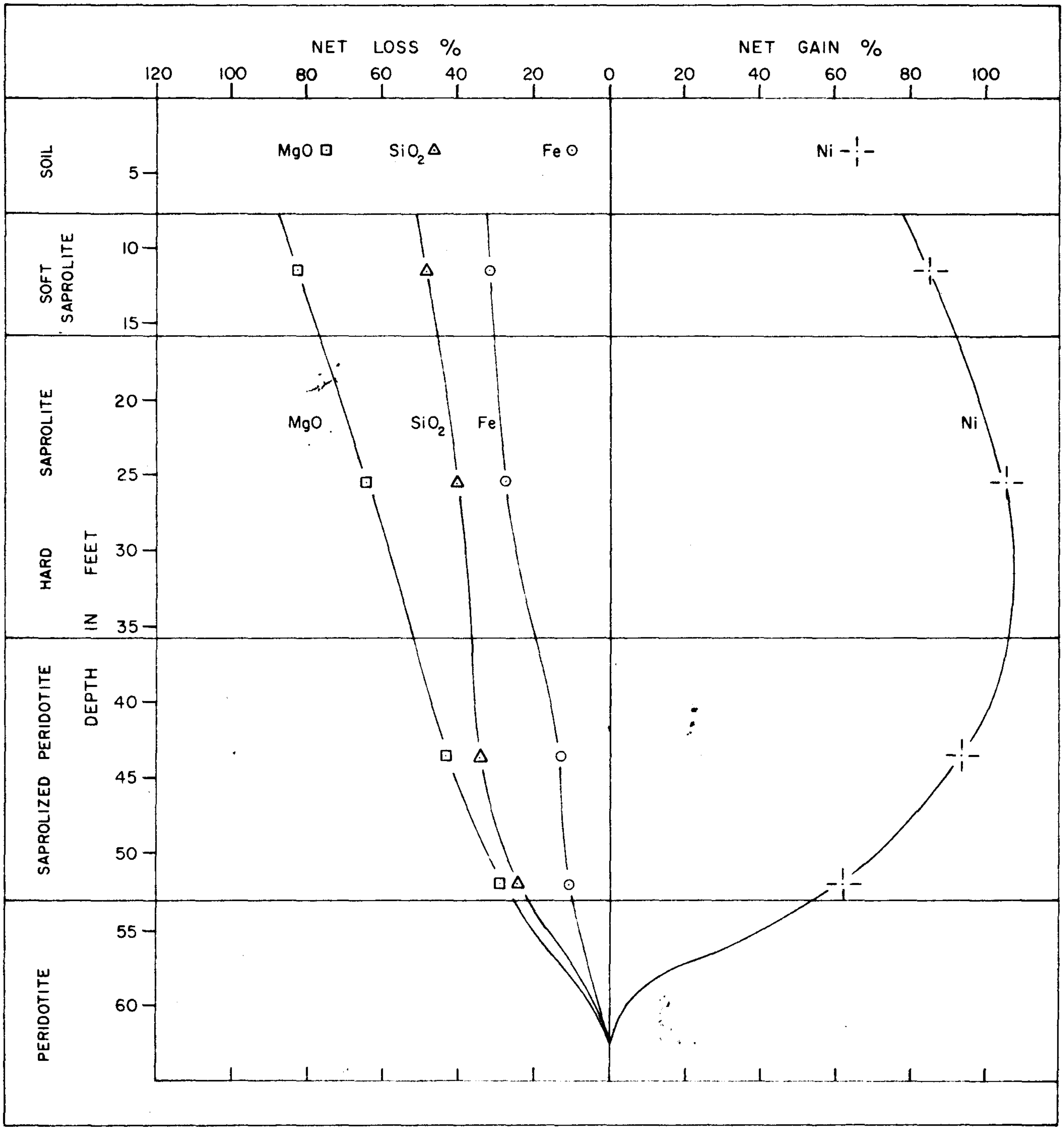
	Peridotite	Saprolite
Weight 1 Ft.^{3}	200 lbs.	104.2 lbs.
Ni Assay	0.32%	1.26%
Lbs. Ni/Ft.^{3}	0.64	1.32

Difference + 0.68 lbs. Ni

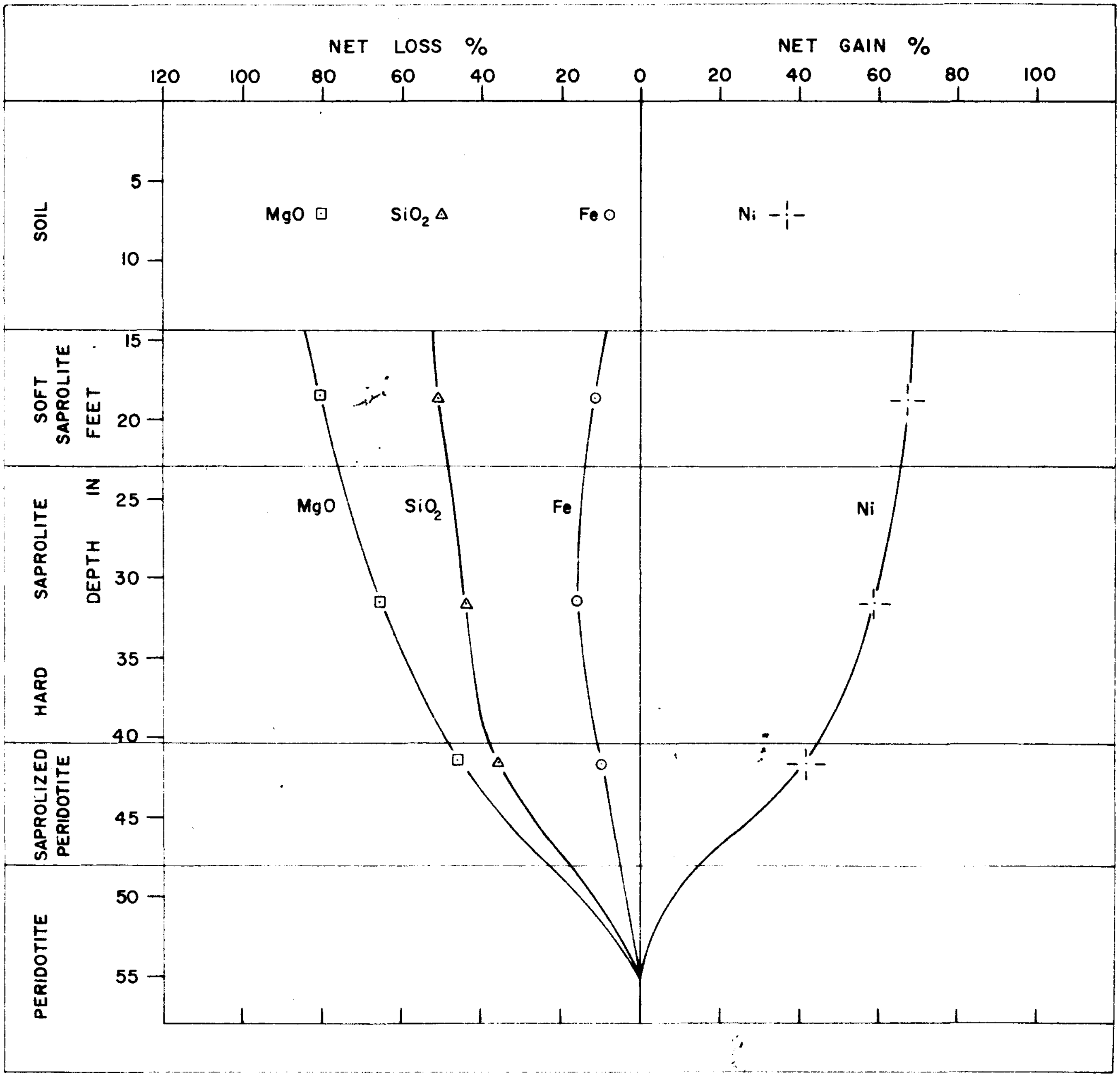
Net Change + 106%

Figure 14. Net Chemical Changes in the Upper Orebody Plotted Against Depth

Figure 15. Net Chemical Changes in the Lower Orebody Plotted Against Depth



NET LOSS %
NET GAIN %
120
100
80
60
40
20
0
20
40
60
80
100
MgO ⊡
SiO₂ △
Fe ⊙
Ni -¦-
SOIL
SOFT SAPROLITE
SAPROLITE
HARD
SAPROLIZED PERIDOTITE
PERIDOTITE
DEPTH IN FEET
5
10
15
20
25
30
35
40
45
50
55
60
MgO
SiO₂
Fe
Ni


NET LOSS %
NET GAIN %
120
100
80
60
40
20
0
20
40
60
80
100
DEPTH IN FEET
5
10
15
20
25
30
35
40
45
50
55
SOIL
SOFT SAPROLITE
HARD SAPROLITE
SAPROLIZED PERIDOTITE
PERIDOTITE
MgO ⊡
SiO₂ △
Fe ○
Ni -¦-
MgO
SiO₂
Fe
Ni

The results included in figures 14 and 15 for the soils are of doubtful value. The total lack of relict jointing, the presence of boxwork fragments, and the eroded appearance of peridotite boulders in the soil, all point to movement and therefore to some volume change. A change in volume invalidates the calculation. However, if there has been a change in soil volume, it probably tended towards decrease in volume, and increase in density. Hence the values given are maximum gains and minimum losses. Thus, the soils show a net loss of silica, magnesia, and total iron. The change in nickel content was small - probably a net gain.

Using alumina as a constant, Hotz (19, p. 380) calculated the net chemical changes shown by four near surface samples of Nickel Mountain ore. The chemical analyses of the samples show that they are not representative of typical soil, and the net changes are difficult to compare with the results presented here, which are based on the weighted averages of the two orebodies. It is perhaps sufficient to conclude that, so far as the soil is concerned, MgO always shows a net loss and that silica frequently does. The net changes in nickel and iron are probably small.

Hotz' samples are not at all representative of the saprolites proper, and for this reason the results cannot be compared with those given for saprolites in figures 14 and 15.

Because boxwork ore does not show relict jointing, the "equal volume" method cannot be used to follow net changes in chemistry. The vuggy texture of the boxwork shows that some or most boxwork was deposited in open fractures. The presence of angular fragments of fresh peridotite in some boxworks suggests further that the supergene solutions did not notably attack peridotite, and that replacement did not take place. Clearly, if boxwork was deposited in open fractures, the host saprolite would gain in all boxwork elements: it would be valid to correct the net chemical changes shown by the saprolites alone by adding the chemical contribution made by the boxwork veins.

Unfortunately, the amount of boxwork ore in each saprolite type has not been measured, so that ore types cannot be corrected individually. However, the saprolites as a group can be corrected as shown in table 7. The soils are not cut by boxwork veins and are therefore excluded from the tabulation. The figures given in table 7 agree in direction with the trends shown by saprolite ore alone indicating that the shapes of figures 14 and 15 are substantially correct.

The present amount of nickel in saprolite exceeds the total amount available from an equal volume of peridotite. The excess nickel is supergene, and if added to the supergene nickel represented by boxwork ore, the total excess amounts to approximately 52 per cent of the nickel in the Upper orebody, and 47 per cent of the nickel in the Lower orebody. If some nickel has been lost from the system, as is probable, supergene enrichment accounts for even more of the present nickel reserve.

It is extremely doubtful whether the present soil cover could have provided all the supergene nickel, and one is left with the presumption that the nickel was derived from a thicker sequence of ore, now lost by erosion, which existed on Nickel Mountain at some time during the evolution of the deposit.

Table 7. Net Chemical Changes in Saprolite and Boxwork Compared with a Volume of Peridotite Equal to the Volume of Saprolite Only

	Upper Orebody		Lower Orebody	
	Saprolite Only	Saprolite and Boxwork	Saprolite Only	Saprolite and Boxwork
Ni	+95.1	+110.9	+57.8	+90.0
MgO	-59.3	- 57.8	-68.5	-65.6
SiO_2	-39.8	- 35.8	-45.7	-36.2
Fe	-24.8	- 21.8	-15.6	- 5.9

+ Net Gain   - Net Loss   Values in Per Cent

ORE MINERALOGY

The large and small scale chemical variations in ore reflect the progressive mineralogical changes due to saprolization and supergene enrichment. These changes are difficult to follow microscopically because most of the minerals are fine grained and stained with iron oxides. Moreover, many of the secondary minerals belong to little understood and poorly classified mineral groups.

The ultramafic rocks on Nickel Mountain lack sulfides of any kind. This supports the generally accepted view that the presence of nickel in peridotite usually can be explained by the substitution of Ni^{2+} for Mg^{2+} in the olivine lattice. Most of the nickel in the orebody occurs in a number of secondary minerals or mineral groups, one of which is garnierite.

Garnierite

The existence of garnierite as a distinct mineral has been questioned by many workers. Pecora et al. (35, p. 22) concluded from a study of eight Nickel Mountain specimens that garnierite "is not a single mineral but a mixture of at least two and possibly three hydrosilicates analogous in structure to serpentine, deweylite, and saponite (pimelite)". They suggested retaining the name garnierite as a field term. Hotz (19, p. 385) concluded that his X-Ray diffraction data of the specimens of garnierite from Nickel Mountain could be interpreted as "mixtures of serpentine and a 10Å layered mineral".

Garnierite varies in color from a pale greenish yellow (1-Y 8/2)___/ through shades of moderate yellowish green (109Y 6/4) to a brilliant green (5G 6/6). The colors are more intense in wet specimens. Pecora et al. (35) showed a close relationship between color, refractive index, specific gravity, and tenor of nickel. Low grade samples are pale in color, have a low specific gravity (~2.55), and low refractive index (1.56 - 1.57).

Garnierite is megascopically homogeneous. It appears to be amorphous, and when dry it is brittle and soft (H=2-3). It has a white streak, and fracture surfaces are earthy and dull. Garnierite frequently shows a colloform texture. Dendritic manganese can be seen along fracture surfaces. Thin sections and grain mounts frequently show two or more generations of garnierite which can be distinguished by differences in grain size and color. Under crossed nicols, garnierite is crypto-crystalline and fibrous with low birefringence.

Occasional pieces of moderate yellow green (5GY 7/4), clay-like mineral having a sub conchoidal fracture are found, mainly along joint surfaces. The material adheres to the tongue and is megascopically homogeneous. It is brittle, has a white streak, a hardness of 3, and a greasy feel. One sample assayed 1.3 per cent nickel. Under the microscope it has a speckled mosaic texture. The mineral is feebly anisotropic and fibrous, has a mean refractive index of ~1.58, and a low birefringence (~.004). The mineral is probably a clay-like form of garnierite.

___/Color terms and designation from rock color chart, published by the Geological Society of America, 1963.

Chalcedony

Chalcedony occurs in a variety of pastel colors, including white, gray, yellow, brown, pink, and green. It is brittle and has a hackly fracture. Openings and vugs are commonly lined with chalcedony which has a sugary appearance due to light reflections from minute prism terminations. Some vugs, however, are lined with colloform chalcedony. Shrinkage cracks are typical of thinly layered chalcedony. Under crossed nicols, chalcedony appears as a distinctive mosaic of small particles, about .01 mm in diameter, each of which extinguishes separately. Thin sections of chalcedony cut normal to the walls of vugs sometimes show several curved, colored bands of mosaic chalcedony ending in a layer of slightly larger (.04mm) crystals of clear silica.

Garnierite and chalcedony are intimately associated both on a megascopic and microscopic scale, and exhibit a variety of textural relationships. The association and textures make it clear that they were deposited essentially at the same time. Colloform banding indicates that both garnierite and chalcedony were deposited partly as colloidal precipitates.

Sepiolite

Thin veins of a white to very pale green (10G 8/2) mineral are found occasionally in massive compound boxworks along Rock Fault. Hotz (19) identified this material as sepiolite. When wet, sepiolite is highly plastic but it dries to a semi-plastic or brittle material with a hardness of about 2 and a smooth or greasy feel. The vein material is foliated parallel to the vein walls. Microscopically, each mineral plate appears to be fibrous. The mean index of refraction is close to 1.53 and the birefringence is low ($\sim$.01). Sepiolite is not an important ore mineral, as it has been found only in places along the plane of Rock fault.

Chlorite

In the eastern part of the mine area, a micaceous, pale blue green (5 BG 7/2) mineral occurs in veins up to 2 inches thick along joints and fractures. The mineral has one strongly developed cleavage and two other partings at about 77° to each other, consequently the mineral crumbles to triangular or rhombic plates. The mineral is soft (H=2), has a white streak, and the specific gravity is about 2.43. One sample had the following partial chemical analysis.

NiO	SiO_2	R_2O_3	MgO	L.O.I.	Total
36.3	42.6	3.8	7.3	9.5	99.5

Analyst - E. J. Grimm

Under the microscope, this sample has a small (-) 2V, and low birefringence (∽ .04). Dr. M. A. Kays___/ notes that the X-ray diffraction pattern of this sample compares favorably with the A.S.T.M. index reference to penninite. The optical properties suggest that this may be a nickeloan chlorite in the schuchardite-nepouite series. The mineral has been found only at the east end of the present open pit in the Upper orebody on the 3160 foot level. It is not an important ore mineral.

Saprolite Minerals

Fresh olivine crystals decompose to a hard, brown, compact material known colloquially as "hard oxide". This in turn decomposes to a brownish yellow, soft, incoherent material termed "soft oxide". Alteration starts along fractures in the olivine crystals and continues until no trace of fresh olivine can be seen, and the material is completely opaque. Fine seams of serpentine and garnierite cut the altered material but do not appear to have controlled or influenced the formation of the "oxides".

___/ Personal communication April 5, 1963.

The brown color of "hard oxide" may be due to the development of poorly crystalline goethite and limonite, while the brownish yellow color of "soft oxide" may be due to an increase in the amount of limonite. Hotz (19, p. 369) reports that montmorillonite, chlorite, and talc constitute the clay fraction of the laterite at Eight Dollar Mountain in Josephine County, Oregon, about 50 miles southwest of Riddle. Because the geologic environments are similar, these minerals may also be present in the clay fraction on Nickel Mountain.

Clay sized fractions from crushed "hard oxide" were prepared by washing and decantation. Fine fragments of garnierite and serpentine were hand picked until the resulting clay fraction was microscopically free of green nickel-bearing minerals. Assays of this material show that it still contains between 1.0 and 2.0 per cent nickel. The form in which the nickel occurs is not known. It is likely that Ni^{2+} released from olivine would proxy for Mg^{2+} in montmorillonite, chlorite, serpentine, and talc. It is also likely that Ni^{2+} would be adsorbed on nearby limonite. If the conclusions drawn from the study of net chemical changes are accepted, nickel in this form could be a substantial portion of the total nickel reserve.

ORE GENESIS

Ore on Nickel Mountain is related to high level erosion surfaces which provided a gently sloping terrane suited to prolonged chemical weathering. The oldest peneplain, the Klamath, may date back to the Eocene, and all the erosion levels are pre-Pliocene in age. The climate in Oregon changed slowly from subtropical in the Eocene and Oligocene, through warm temperate conditions in the Miocene, and culminated in the Pleistocene glaciation. The present climate is temperate with a marked seasonal rainfall.

It has been shown that the present morphology of saprolite ore is consistent with weathering of peridotite by meteoric groundwater migrating down joints and other planes of weakness. The close relationship of ore to permeable zones indicates that drainage was an important factor in ore formation.

Although the preserved amount of saprolite derived from serpentinite is small, this may be due more to selective erosion than to serpentinite being an unfavorable parent rock. However, serpentinization is not a necessary stage in the formation of saprolite.

The thickness of saprolite in the Lower (younger) orebody is less than in the Upper (older) orebody. This may be a reflection of the amount of time each orebody was under the influence of a relatively favorable subtropical climate. Further confirmation of this may be found in the higher degree and greater depth of nickel enrichment in the Upper orebody profile.

Table 8 lists analyses of three selected samples representing 70,000 tons of soft saprolite containing little or no visible fresh peridotite. If the trend of chemical weathering were to continue towards a lower MgO, the resulting material might properly be classified as nickel laterite, and would be similar to some of the New Caledonian laterites described by Chételat (9). Nickel laterite may, therefore have overlain the saprolites at some time during the evolution of the deposit, and have been lost through subsequent erosion. Part of the present soil cover may be a reworked and leached residue from the laterite.

Table 8. Analyses of Selected Samples of Soft Saprolite (per cent).

Sample	Ni	MgO	SiO_2	Fe
1	1.11	15.5	56.0	11.7
2	1.46	13.2	50.5	9.9
3	1.36	14.0	50.5	15.3
Weighted Average	1.23	14.7	53.8	11.8

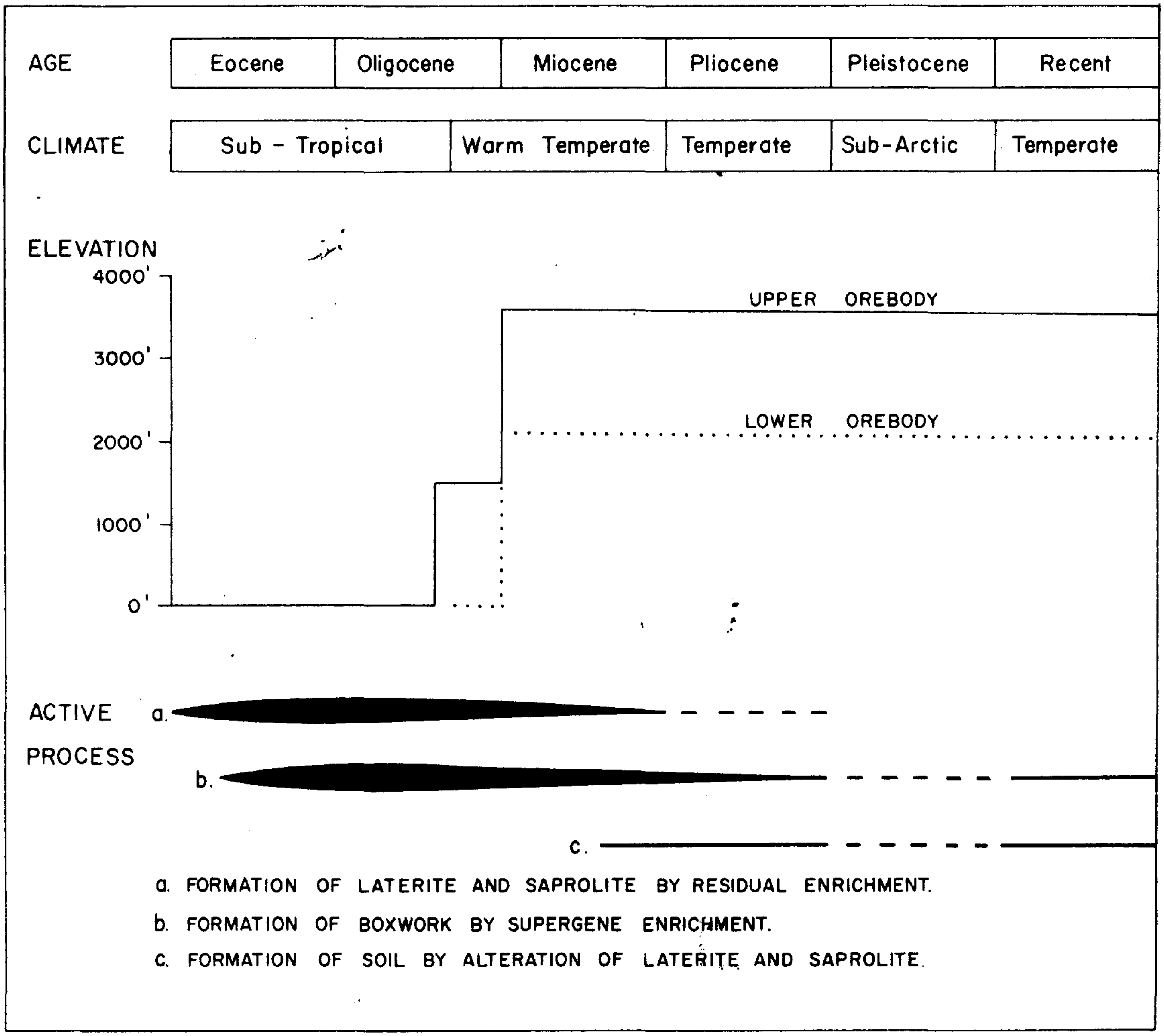
A distinction has been drawn between residual and supergene nickel enrichment. These processes overlapped, and it is likely that supergene enrichment took place partly as a result of residual enrichment, and perhaps continued long after residual enrichment of the saprolites had ceased. Successive stages in the genesis of the Nickel Mountain orebodies are summarized in figure 16, where changes in climate and elevation with time are related to the predominant ore forming process. (Figure 16 near here).

Residual enrichment of saprolite by selective leaching can be inferred from the data presented on net chemical changes, where large net losses of MgO and SiO_2, and smaller net losses of total Fe were shown. The large net gain of nickel does not preclude absolute loss of nickel; simply that more nickel was introduced than was lost.

The intimate association of garnierite and chalcedony indicates that they were deposited essentially at the same time. The physical and chemical conditions at various horizons within the saprolite profile at the time of formation are not known, hence it is difficult to postulate the mechanism of supergene enrichment. Precipitation from solution, and deposition as colloids are both possible mechanisms.

Experimental work by Mueller (32) and others has shown that nickel rich hydrous Mg-silicates can be synthesized at essentially atmospheric temperature and pressure. Mueller has also shown that ionic exchange of Ni^{+2} for Mg^{+2} can take place in a much more acidic environment than precipitation of nickel, suggesting that ionic exchange could occur at higher levels in the saprolite profile than precipitation. Whether this in fact took place is not known.

Figure 16. Stages in the Genesis of Ore on Nickel Mountain


AGE
Eocene
Oligocene
Miocene
Pliocene
Pleistocene
Recent
CLIMATE
Sub - Tropical
Warm Temperate
Temperate
Sub-Arctic
Temperate
ELEVATION
4000'
3000'
2000'
1000'
0'
UPPER OREBODY
LOWER OREBODY
ACTIVE PROCESS
a.
b.
c.
a. FORMATION OF LATERITE AND SAPROLITE BY RESIDUAL ENRICHMENT.
b. FORMATION OF BOXWORK BY SUPERGENE ENRICHMENT.
c. FORMATION OF SOIL BY ALTERATION OF LATERITE AND SAPROLITE.

The source of the supergene nickel and silica was probably the missing lateritic portion of the profile. Successive stages of uplift would tend to activate the drainage, thus enhancing the role played by supergene enrichment. Although the exact mechanism of boxwork deposition is not known, it was probably dependent on a gradual change in pH with depth. Erosion of the laterite cover would cause the pH zonation to shift downwards, thereby increasing the chance of early garnierite being redeposited lower in the profile.

Austin (3) was of the opinion that some of the quartz veins (garnierite-chalcedony boxwork veins) were deposited by hydrothermal solutions, but the field and chemical evidence does not support this point of view.

Some difference in the mode of origin accounts for the textural and chemical differences between soil and saprolite. If one assumes that soil was derived from saprolite (or a pre-existing laterite), then it is necessary to find a process whereby joint planes were obliterated, saprolitic skins were removed from residual rock fragments, boxwork veins were truncated and fragmented, the total Fe was increased, and Ni was decreased. Movement in the form of downhill creep, landslides, frost heave, and the like would tend to accomplish the textural changes involved. It is unlikely that the small amount of movement which did take place would completely destroy the former textures, but remnants of these textures are not found, suggesting that a chemical agency was also involved in the transformation.

If chemical transformation took place, the environment was not the same as the environment of saprolite formation. This is deduced from the fact that peridotite boulders in soil are not saprolized. It appears that the soil-forming environment was effective in altering previously formed saprolite, but not peridotite. Further confirmation of this can be seen in old test pits and older mining cuts in rocky ore which show evidence of decomposition under prevailing climatic conditions. In these cuts, the saprolite crusts are weathering to soil, but the peridotite at the cores of the joint rhombs is not being altered. If this were to continue, the end product would be similar in appearance to typical soil.

Neither soil nor saprolite are found on erosion levels below 1900 feet in the Riddle area. From this it may be concluded that saprolite is not forming under modern climatic conditions. The fact that soil appears to be forming over saprolite at higher levels, but does not form directly over peridotite at low levels, further confirms that soil does not originate directly from peridotite.Where soil is found directly overlying peridotite above 1900 feet, it is reasonable to assume that the saprolite once present has been changed to soil.

The soil/saprolite thickness ratio is appreciably greater in the Lower orebody suggesting that the thickness of soil in the Lower orebody may have been enhanced by erosion of the Upper orebody. Transported soil, probably overlying the Riddle formation, has been found in the NW¼ Sec. 21, and was derived from the Lower orebody.

For these reasons, it is likely that the soil cover originated from saprolite by a combination of mechanical movement accompanied by chemical weathering under more temperate conditions than were needed to produce saprolite.

Honeycomb boxwork fragments in the soil have been partly leached of their garnierite content and tend to be barren. When the larger fragments are broken, garnierite can often be seen enclosed by chalcedony septa. Some of this leaching is Recent as shown by thin coatings of a pale, whitish green nickeliferous material on modern tree roots. Other roots are partly replaced by the same whitish green material, and one of these assayed 1.83 per cent Ni. The wood fibers in this particular sample were still visible, showing that movement of nickel took place quite recently, certainly within the last 150 years.

Analyses of mine waters also shows modern movement of some of the major ore forming elements. Table 9 gives analyses of two water samples. Sample 1 was taken from a drillhole at a depth of 150 feet in the Upper orebody. The hole was stopped at Rock Fault and the sample is of water draining down the plane of the fault. Sample 2 was taken from a drillhole in the Lower orebody which was drilled into Spring Fault. The sample was collected at surface, approximately one year after the hole was completed.

Hawkes and Webb (17, p. 115) indicate that fresh water may contain from .02 - 10 ppb nickel. The nickel content of the two samples in table 9 is appreciably higher than the high end of the range (.01 p.p.m.). Modern groundwater is apparently continuing the process of supergene enrichment, but not the process of saprolization.

Table 9. Analyses of Natural Waters on Nickel Mountain (in p.p.m.)

Sample	Ni	MgO	SiO_2	Fe	Total Solids	pH
1	0.06	67.0	42.0	0.7	180.0	7.9
2	0.02	65.0	16.0	0.24	166.0	8.0

Analyst E. G. Wilson, Hanna Nickel Smelting Company

CONCLUSIONS

Sub-tropical to warm temperate conditions during the early Tertiary were responsible for the development of nickel laterite-saprolite profiles over peneplaned ultramafic bodies of Jurassic age. A series of mid-Tertiary tectonic events, which included at least one other major stage of terrace cutting and laterite-saprolite formation, lifted these deposits to approximately their present elevation. Active erosion due to uplift reduced the nickel deposits to their present thickness and areal extent.

Nickel Mountain ore was enriched in nickel by residual and supergene processes. Downward percolating meteoric groundwater selectively leached MgO, SiO_2, Fe, and Ni from the peridotite. The depth and degree of alteration was largely controlled by the intensity of jointing and faulting.

Saprolite is quantitatively the most important ore, and is recognizably residual after peridotite. Enrichment of nickel in the saprolites took place by selective loss of MgO, SiO_2, and to a lesser extent of Fe. In addition, nickel leached from overlying ore was redeposited in underlying saprolites by substitution for Mg or adsorbtion on limonite and clay minerals. Formation of saprolite was at a maximum in the early Tertiary due to favorable climate and topography.

Solutions or sols containing Ni, MgO, SiO_2, and some Fe migrated down major fracture zones, depositing some of the contained elements as chalcedony-garnierite boxwork ore. Colloform garnierite and chalcedony indicate that some of the material was carried and deposited in colloidal form. Supergene enrichment is probably still taking place today, although at a much reduced rate.

A thin layer of nickel bearing soil was derived from and blankets the saprolite and boxwork ores. The original ore textures have been lost, in part by movement, but also by chemical weathering under temperate conditions. Soil is probably still forming from saprolite ore, but is not forming directly from peridotite. The stability of anhydrous magnesium silicates under present climatic conditions is apparently much greater than the stability of hydrous silicates. Soil is generally of lower grade than the ore which underlies it due to leaching, which is still taking place.

Chemical and mineralogical trends in the preserved saprolites indicate that a laterite capping may once have covered the orebody, and that the full profile may have been very similar to some New Caledonian orebodies. If allowance is made for the physical and chemical differences between serpentinite and peridotite, many of the features of Cuban and Phillipine ores derived from serpentinite can also be matched. Nickel Mountain is the preserved remnant of a deposit which originated under conditions now prevailing in the tropics, modified by effects due to later temperate conditions, and presents an excellent opportunity of studying the root zone geology of a nickel laterite deposit.

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The Hanna Mining Company,
Riddle, Oregon.
November, 1965

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FWT 9/27

State Department of Geology and Mineral Industries

702 Woodlark Building
Portland, Oregon

Report by: Ray C. Treasher

Date: Aug. 10, 1943

Nickel Mountain (nickel)

Riddle area

Douglas Co.

Mr. O. D. Rohlfs, Principal Mining Engineer, Ferro-Alloys Branch, W.P.B., Washington, D. C. had requested that I take him to visit the Freeport Sulphur Co. property at Nickel Mtn. He arrived at 12:39 p.m. Sat., July 31st, with Mrs. Rohlfs, and they were taken to Nickel Mtn. and to Roseburg at 11:58 pm.

The access road is open about half way between the Discovery area and the West area. We went to the West area, looked at the shaft and entered the 500 foot adit. Rohlfs secured some excellent specimens. Note was made of garnierite in a narrow shear zone on the N. side near the floor, and as thin crusts along joint planes. We next visited the Discovery area, entered the adit and the shaft.

Rohlfs had Climax Moly. drilling data, but no Freeport data. In the West adit, about 2% for 100 ft. and then less than 1%, after fairly solid rock is encountered. At Discovery adit, 3% for 75 feet and then 1 to 1.5% in harder rock. Discovery shaft, up to 4% for 20 feet, and then the grade drops. Climax drill holes show erratic values but little below 30 ft.

Nickel seems confined to brown, soft zone and to depths of 30 feet. Even this will be erratic. The limonitic material of the "boxwork" may carry 1¼ %. The red soil may carry up to

3/4 % Mineralization is spotty. I'd be interested in Freeport's drilling results.

Some geologists prefer a hydrothermal origin for the garnierite, which theory I cannot see at all. Neither can I see laterization, with all the silica that is obviously present. Ralph Taylor (Freeport) collected silica gel, in the process of formation in the West area adit. I believe the silica, nickel, etc., came from the decomposition of the peridotite, in situ.

Rohlfs said that W.P.B. is interested in New Caledonian ores. Three furnaces are in operation. W.P.B. plans on a fourth furnace either at the mines, or in San Francisco. In event S. F. is chosen, domestic garnierite of plus 3% grade will be acceptable. Rohlfs idea is that if Freeport gives up their lease, W.P.B. might be interested in High-grading the deposit.

State Department of Geology and Mineral Industries

702 Woodlark Building
Portland, Oregon

RECEIVED
AUG 20 1942
STATE DEPT OF GEOLOGY
& MINERAL INDS.

NICKEL MOUNTAIN

Riddle Area
Douglas Co

Freeport Sulphur is exploring the nickel deposits here. Old workings have been cleaned out, particularly the adit and shaft at the "Discovery" and the 80 foot shaft and the lower adit at the "West area". In addition drilling has been started.

Climax Molybdenum drilled a north-south line of holes through the "Discovery" area on 400 foot centers, about 1938 or 1939. Hobbs and Pecora did not mention this work and it is doubtful if they knew of it. Freeport has started a line of holes 400 feet west, on 400' centers, and will continue to explore on that basis. The Climax work consisted of three holes, the deepest being 130 feet. The weighted average assay was 1.87 percent nickel.

Recent Freeport drilling proved nickel in this peridotite at a depth of 125 feet, - a zone 5 feet thick. Minor showings were found at 155 feet.

Certain observations were made at the time of the visit. They are recorded here for what they are worth, in an effort to evaluate Hobbs and Pecore's (H & P) observations and conclusions. A study of their paper is advisable.

Red soil seems to average remarkably uniform in nickel when nickel is present; both in the cover over the terraces and in "wash" at lower elevations according to H. & P. What does this indicate relative to supergene enrichment? Perhaps the present nickel showings represent a once continuous blanket that covered the Mountain, - later eroded into present terraces. (suggested by Dave Evans). H. & P., 42:214 state that the limonite enclosed in the boxwork assays about 1% nickel. This is very similar to the percent of nickel in the red soil. They also say that the abundance of quartz in garnierite decreases downward, yet we found silica being deposited, right now, in the lower rock.

CONFIDENTIAL

On p. 213 H. & P. mention a progression of paler varieties of garnierite to darker varieties toward the surfaces and that the darker colors represent richer material. In the lower adit, "West area", this is not true as dark garnierite is abundant in seams in the peridotite.

On p. 214, H. & P. state that brown cherty silica is more abundant nearer the surface, but I found abundant brown cherty silica in the lower adit, "West area", and have some beautiful specimens to prove it.

The above observations suggest difficulties with the H. & P. theory of origin and the apparent "upward" movement of silica and nickel in the second stage. Another suggestive feature is the similarity in nickel assays of the red soil and of the limonite between the boxwork. If the second stage is a re-concentration it is odd that that "matrix" should be so uniform in nickel content.

Some observations about silica were made. There is little silica in the red soil, except cellular masses that probably have worked up from the limonite zone like large rocks work upward in a gravelled road. Silica is abundant as box work in the limonite zone. Silica gel is being deposited at the present time in the peridotite, as evidenced by the gel on mine timbers and along joint cracks in the lower adit, "West area". Whether nickel is being deposited with the gel is not known.

The points of the above discussion is that silica apparently is moving downward. If the overlying limonite and red soil is true laterite, it should be deficient in silica Might there be a possibility that both silica and nickel are being leached from the peridotite at the present time.

A factor overlooked by H. & P. was the flat top of a portion of Nickel Mountain. This area is covered with a red soil of unknown depth. Outcropping peridotite frequently has cellular quartz on its surfaces. Some of this quartz shows garnierite.

Reference: H. & P. = Hobbs, S. Warren, and Pecora, William T., Nickel deposits near Riddle, Douglas County, Oregon: U.S.G.S. Bull. 931-I.

Informant: Ray C. Treasher, trip of July 30, 1942.

MAS DEPOSIT RECORD CODING & MATRIX ASSEMBLY COOKBOOK

This cookbook was assembled with the idea of being supplemental to the MAS MANUAL. It was designed to "ease the pain" in getting started in MAS in two areas:

1. Coding the MAS Record forms.
2. Assembling the Grade - Quantity matrix.

The deposit exemplified herein is the Nickel Mountain nickel orebody at Riddle, Oregon. Time did not permit the assembly of a complete backup file with substantiating data for all quantities and grades entered into the Resource Matrix; some of the numbers used are assumed to help complete the example.

All entries designated "E" are data items considered essential to the system, and must be entered. In instances where the available coding is not adequate to cover a particular situation, then the References and Comments Records are used in explanation.

Entries designated "O" are optional data items not absolutely essential to operation of the system, but represent good information that should be included.

Most mineral commodities entered into MAS require completion of a Beneficiation Record describing and costing out the beneficiation process, and a Transportation Record describing the path of the beneficiation product to the first market point. The residual nickel deposits are unique in that a direct ore reduction process is employed, and the ore itself is a marketable product, therefore these two Records are not used, and may be omitted.

Leading zeros required when so coded

U. S. BUREAU OF MINES
MINERALS AVAILABILITY SYSTEM

IDENTIFICATION

Record Reference - E

1 2 [4][1] State coded INDEX 001 — Oregon

3 5 [0][1][9] County coded INDEX 002 — Douglas

6 9 [0][0][0][1] Sequence Number — Enter in pencil, as sequence numbers may be changed

10 12 [0][1][0] Record Identification

13 ☐ Action Code - E coded INDEX 006 — Leave blank when entering initial data on a deposit

14 [C] Type of Deposit Description - E coded INDEX 007

Letter "C" signifies a complete, all record description. Letter "L" indicates a location description with no resource determinations and no mine or process costing. Can include up to the first 9 records.

15 16 [7][4] Year of Initial Information Entry - E — Last 2 digits of year of entry - does not change on updating

17 [4] Field Center Maintaining Backup File - E coded INDEX 008 — Code "4" = WFOC, to be used on all Oregon & California entries.

Commodity Description - E

	Commodity Name coded INDEX 009		Grade Units coded INDEX 010	
Commodity 1	18–20: [4][2][0]	Nickel	21: [1]	Weight percent
Commodity 2	22–24: [3][2][1]	Iron	25: [1]	Weight percent
Commodity 3	26–28: [1][5][0]		29: ☐	
Commodity 4	30–32: ☐☐☐		33: ☐	
Commodity 5	34–36: ☐☐☐		37: ☐	
Commodity 6	38–40: ☐☐☐		41: ☐	

42 [1] Current Operational Status - E coded INDEX 011 — Producer

43 [1] Type of Mining - E coded INDEX 012 — Surface

44 [2] 45 [9] 46 [9] Type of Minerals Holdings - E coded INDEX 013

Patented claims

No entry, space not used

Entered in order of importance, starting with Col. 44

47 [7] Resource Quantity Units - E coded INDEX 014 — Metric tons of crude ore, containing the commodities listed above

48 55 ☐☐☐☐☐☐☐☐ File Link - 0

Do not use - intended for possible BuMines statistical file linkage at some future time.

U. S. BUREAU OF MINES

MINERALS AVAILABILITY SYSTEM

DEPOSIT NAME

Record Reference - E

columns 1-9 and 13 comprise the Reference Number, and appear on all records

1 2 41 State coded INDEX 001

3 5 019 County coded INDEX 002

6 9 0001 Sequence Number

10 12 011 Record Identification

13 ☐ Action Code - E coded INDEX 006

Primary Name - E

commonly accepted current name

14 20 30 40 46

RIDDLE NICKEL MINE

Additional Names - 0 (Single space between words)

47 50 60 70 79

RIDDLE NICKEL LATERITE DEPOSIT

(A total of 10 property names may be entered)

Additional Names - 0

10 12 012 Record Identification

13 ☐ Action Code - E

14 20 30 40 46

HANNA NICKEL MINE

47 50 60 70 79

NICKEL MOUNTAIN MINE

Additional Names - 0

10 12 013 Record Identification

13 ☐ Action Code - E

14 20 30 40 46

47 50 60 70 79

Additional Names - 0

10 12 014 Record Identification

13 ☐ Action Code - E

14 20 30 40 46

47 50 60 70 79

Additional Names - 0

10 12 015 Record Identification

13 ☐ Action code - E

14 20 30 40 46

47 50 60 70 79

U. S. BUREAU OF MINES

MINERALS AVAILABILITY SYSTEM

OWNER/OPERATOR

First record. Up to 5 records may be used to describe complex ownership

Record Reference - E

1 2 | 4 1 | State coded INDEX 001

3 5 | 0 1 9 | County coded INDEX 002

6 9 | 0 0 0 1 | Sequence Number

10 12 | 0 2 0 | Record Identification

13 ☐ Action Code - E coded INDEX 006

No confidentiality

14 | 0 | Confidentiality - E coded INDEX 015

can be changed on updating

15 16 | 7 4 | Date of Information - E

17 | 3 | Status of Owner/Operator - E coded INDEX 016

Owner/Operator Name - 0

single space between words

18 20 30 40 51

| H A N N A   N I C K E L   M I N I N G   C O M P A N Y |

52 60 70 73

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

74 75 | 3 9 | State - 0 coded INDEX 001

Corporate headquarters, Ohio

United States

76 78 | 1 9 9 | Country - 0 coded INDEX 005

79 80 | 9 9 | Percent of Ownership - 0

Equivalent to 100 percent

Note: Detailed address of company, with both local operating and corporate addresses, should be incorporated in backup files.

10 12 | 0 2 ☐ | Record Identification

13 ☐ Action Code - E coded INDEX 006

14 ☐ Confidentiality - E coded INDEX 015

15 16 ☐☐ Date of Information - E

17 ☐ Status of Owner/Operator - E coded INDEX 016

Owner/Operator Name - 0

18 20 30 40 51

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

52 60 70 73

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

74 75 ☐☐ State - 0 coded INDEX 001

76 78 ☐☐☐ Country - 0 coded INDEX 005

79 80 ☐☐ Percent of Ownership - 0

Latitude - Longitude Calculation
From Seconds & Minutes to Fractional Degrees

Latitude

42° 57' 40"

$$\frac{40''}{60''\text{per}'} = 0.67'$$

$$\frac{57.67'}{60'\text{per}°} = 0.96117°$$

42.96117°

Longitude

123° 26' 32"

$$\frac{32''}{60''\text{per}'} = 0.53'$$

$$\frac{26.53'}{60'\text{per}°} = 0.44217°$$

123.44217°

Latitude

42°57'40"

```
            40• ÷
            60• =
•66666666666667 *

         57•67 ÷
            60• =
•96116666666667 *
```

= 42.96117°

Longitude

123° 26' 32"

```
            32• ÷
            60• =
•53333333333333 *

         26•53 ÷
            60• =
•44216666666667 *
```

= 123.44217°

U. S. BUREAU OF MINES
MINERALS AVAILABILITY SYSTEM

LOCATION

Record Reference - E

1 2 **41** State coded INDEX 001

3 5 **019** County coded INDEX 002

6 9 **0001** Sequence Number

10 12 **030** Record Identification

13 ☐ Action Code - E coded INDEX 006

Latitude - Longitude Location
(see attached calculation sheet)

Latitude - E
14 15 16 20 **42•96117**

21 **1** Direction - E coded INDEX 017 ← North latitude

Calculated to 5 place fractional degree

Longitude - E
22 24 25 29 **123•44217**

30 **4** Direction - E coded INDEX 017 ← West Longitude

Universal Transverse Mercator Location

31 32 ☐☐ Zone - E

33 ☐ Hemisphere - E coded INDEX 018

34 40 ☐☐☐☐☐☐☐ Northing - E

41 46 ☐☐☐☐☐☐ Easting - E

47 **2** Reference Point - E coded INDEX 019 ← Trench or pit

48 **2** Precision of Point Location Measurement - E coded INDEX 020 — To 100 meters – considering map scale and accuracy of measuring instrument

---

Public Land Survey Location

49 50 **33** Principal Meridian - E coded INDEX 021 ← Willamette

51 53 54 **030•0** Township - E fraction coded INDEX 022 — Township 30, right justified, w/ leading zeros; None

55 **2** Direction - E coded INDEX 017 ← South

56 58 59 **006•0** Range - E fraction coded INDEX 022 — Range 6, right justified, w/ leading zeros; None

60 **4** Direction - E coded INDEX 017 ← West

61 62 **17** Section - E

* 63 **9** 64 **7** 65 **3** Section Subdivision - E coded INDEX 023
SW¼ NW¼ S½

66 **2** Survey Status - E coded INDEX 024 ← Surveyed

* Method of entry is reverse of standard GLO procedure.

---

67 71 **00994** Elevation - E — Elevation of reference point, converted to meters
Right justified, leading zeros

72 **1** Datum for Elevation Measurement - E coded INDEX 025 ← Above mean sea level

73 **1** Precision of Elevation Measurement - E coded INDEX 020 ← To 10 meters

---

74 76 **168** U. S. G. S. 1:250,000 Quadrangle - E coded INDEX 003 ← Medford

RECORD 040, Columns 34-37

Publication used in coding: 1970 Edition, USGS Office of Water Data Coordination, Catalog of Information on Water Data:

MAPS SHOWING LOCATIONS OF WATER QUALITY STATIONS

Example: South Umpqua River Drainage Basin, containing the Riddle Nickel deposit.

Method of coding: Code is a four digit one. The first two digits are the map number wher the drainage is generally located, in this case 73 for Map 73; the last two digits represen the numerical position in the alphabet of the letter designating the specific location of the drainage, in this case the letter is M, and the numerical equivalent is 13 — — The total Drainage Basin code is therefore 7313.

U. S. BUREAU OF MINES
MINERALS AVAILABILITY SYSTEM

GEOGRAPHICAL AND ENVIRONMENTAL CHARACTERISTICS

Record Reference - E

1 2 41 State coded INDEX 001

3 5 019 County coded INDEX 002

6 9 0001 Sequence Number

10 12 040 Record Identification

13 ☐ Action Code - E coded INDEX 006

On site

14 1 Distance of Road Needed - E coded INDEX 026

15 1 Distance to Adequate Water Supply - E coded INDEX 027

16 1 Distance to Adequate Electrical Power Supply - E coded INDEX 026

Mining District - O

17 31 RIDDLE DISTRICT

space

Right Justified

O & C lands - BLM administered

32 33 49 Domain - E coded INDEX 028

34 37 7313 Drainage Basin - E coded - see manual

see attached sheet

Very rugged - over 450 meters local relief

38 6 Topography - E coded INDEX 029

Approximate, from USGS atlas

39 42 0170 Annual Precipitation - E (cm)

~2"

leading zero

Winter maximum

43 3 Distribution of Precipitation - E coded INDEX 030

Temperate

44 2 Temperature - E coded INDEX 031

Coniferous or deciduous forest

45 5 Vegetation - E coded INDEX 032

Clay

46 7 Soil Texture - O coded INDEX 033

commercial forestry

47 4 Primary Land Use - E coded INDEX 034

All year

48 4 Working Season - E coded INDEX 035

Available locally

49 2 Labor Supply - E coded INDEX 036

Environmental Sensitivity to Mineral Extraction - E
coded INDEX 037

	Land	Vegetation	Wildlife	Water	Air	Aesthetics	Sound	Overall
Short Term	50 4	52 2	54 2	56 2	58 4	60 4	62 3	63 3
Long Term	51 3	53 2	55 2	57 2	59 1	61 2		64 2

Average of all factors

640 ~~acres~~ (estimated) x 0.4047 hectares/~~acre~~ = 259.008, or 259 hectares

65 69 00259 Maximum Surface Area Potentially Disturbed - E (hectares)

leading zeros

70 2 Map Series - E coded INDEX 038

15 minute

71 80 CANYONVLLE Map Name - E

shortened to 10 characters by omitting vowells.

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MINERALS AVAILABILITY SYSTEM

EXPLORATION

First exploration record. Up t
10 exploration records, numbere
0 to 9, may be used.

Record Reference - E

1 2 [41] State coded INDEX 001

3 5 [019] County coded INDEX 002

6 9 [0001] Sequence Number

10 12 [050] Record Identification

13 [ ] Action Code - E coded INDEX 006

All material herein is published; no confidentiality considerations.

14 [0] Confidentiality - E coded INDEX 015

Date entered into the system. To be changed upon updating

15 16 [74] Date of Information - E

Ore mineral, exposed in place

17 [1] Mode of Discovery - 0 coded INDEX 039

18 21 [1864] Year of Discovery - 0

22 25 [1954] Year of First Significant Production - 0

signifies ongoing production

26 29 [9999] Year of Last Production - 0

Description of Exploration Methods Employed - 0

		Method Employed coded INDEX 040	Extent Employed coded INDEX 041	Extent Method Supports Resource Evaluation coded INDEX 041	Year of Work
Geologic mapping	Method 1	30 31 [11]	32 [3] Extensive	33 [1] Little	34 37 [1941]
core drilling	Method 2	38 39 [51]	40 [1] Little	41 [1]	42 45 [2942]
churn drilling	Method 3	46 47 [52]	48 [2] Moderate	49 [1]	50 53 [1942]
Bedrock sampling	Method 4	54 55 [90]	56 [2]	57 [1]	58 61 [1942]
Test shaft	Method 5	62 63 [61]	64 [1]	65 [1]	66 69 [1942]
Test adit	Method 6	70 71 [71]	72 [1]	73 [1]	74 77 [1942]

U. S. BUREAU OF MINES
MINERALS AVAILABILITY SYSTEM

EXPLORATION

second exploration record

Record Reference - E

1 2 [4 1] State coded INDEX 001

3 5 [0 1 9] County coded INDEX 002

6 9 [0 0 0 1] Sequence Number

10 12 [0 5 1] Record Identification

13 [ ] Action Code - E coded INDEX 006

14 [0] Confidentiality - E coded INDEX 015

15 16 [7 4] Date of Information - E

17 [1] Mode of Discovery - 0 coded INDEX 039

18 21 [1 8 6 4] Year of Discovery - 0

22 25 [1 9 5 4] Year of First Significant Production - 0

26 29 [9 9 9 9] Year of Last Production - 0

Description of Exploration Methods Employed - 0

		Method Employed coded INDEX 040	Extent Employed coded INDEX 041	Extent Method Supports Resource Evaluation coded INDEX 041	Year of Work
Trenching	Method 1	30 31 [8 1]	32 [3] Extensive	33 [1] Little	34 37 [1 9 5 2]
Bedrock sampling	Method 2	38 39 [9 0]	40 [3]	41 [1]	42 45 [1 9 5 2]
Geologic mapping	Method 3	46 47 [1 1]	48 [3]	49 [3] Ongoing exploration	50 53 [9 9 7 4]
Churn drilling	Method 4	54 55 [5 2]	56 [3]	57 [3]	58 61 [9 9 7 4]
	Method 5	62 63 [ ]	64 [ ]	65 [ ]	66 69 [ ]
	Method 6	70 71 [ ]	72 [ ]	73 [ ]	74 77 [ ]

U. S. BUREAU OF MINES

MINERALS AVAILABILITY SYSTEM

ROCK DESCRIPTION

First rock description record. Up
10 such records, numbered 0 to 9
may be used

Record Reference - E

1 2 41	State coded INDEX 001	3 5 019	County coded INDEX 002	6 9 0001	Sequence Number
10 12 060	Record Identification	13 ☐	Action Code - E coded INDEX 006		

14 36
ULTRAMAFIC INTRUSIVES Formation or Group Name - 0

37 39
221 ← Upper Jurassic
Geologic Age of the Formation or Group - 0
coded INDEX 042

Folding Faulting
40 41 42 43
1 2 ☐ ☐ Deformation of the Formation or Group - 0
coded INDEX 043
Left justified entries

44 46
219 ← Post Cretaceous
Geologic Age of Deformation - 0
coded INDEX 042

47
4 Relationship of Mineralization to Deformation - 0
coded INDEX 044
Mineralization following event.

* 48 50
199 In Situ Rock Density - E (gm/cm^3)
Leading zero not necessary
Refers to density of rock being mined, or to be mined

Rock Types - 0

	Rock Name coded INDEX 045		Relationship to Ore coded INDEX 046	
Rock Type 1	51 53 163	? Saxonite	54 5	55 9 ← Is ore
Rock Type 2	56 58 123	Dunite	59 5	60 9 ← Is ore
Rock Type 3	61 63 222	Serpentinite	64 6	65 ☐
Rock Type 4	66 68 ☐☐☐		69 ☐	70 ☐
Rock Type 5	71 73 ☐☐☐		74 ☐	75 ☐
Rock Type 6	76 78 ☐☐☐		79 ☐	80 ☐

Replaced by ore

Encloses ore

Note: If two codes are used, the most important is in the first column

* See attached sheet

In Situ Rock Density

(conversion from standard tonnage-volume factor to gm/cm³)

Hanna Mining Co. published conservative factor is 17 cubic feet per short ton in place.

$$\frac{2000\,(1\,\cancel{lb} \times 453.59\ gm/\cancel{lb})}{17\,\cancel{ft}^3 \times 28,317\ cm^3/\cancel{ft}^3} = 1.8845\ gm/cm^3$$

rounded off to 1.9 gm/cm³

```
          2,000•  ×
         453•59   =
        907,180•  *

             17•  ×
         28,317•  =
        481,389•  *

        907,180•  ÷
        481,389•  =
1•8845050468540   *
```

U. S. BUREAU OF MINES

MINERALS AVAILABILITY SYSTEM

ROCK DESCRIPTION

Record Reference - E

Second Rock Description record

1 2 [41] State coded INDEX 001

3 5 [019] County coded INDEX 002

6 9 [0001] Sequence Number

10 12 [061] Record Identification

13 ☐ Action Code - E coded INDEX 006

14 36 [DOTHAN FORMATION] Formation or Group Name - 0

37 39 [221] Geologic Age of the Formation or Group - 0 coded INDEX 042 — Upper Jurassic

Folding Faulting

40 [1] 41 [2] 42 ☐ 43 ☐ Deformation of the Formation or Group - 0 coded INDEX 043

44 46 [219] Geologic Age of Deformation - 0 coded INDEX 042 — Post Cretaceous

47 [4] Relationship of Mineralization to Deformation - 0 coded INDEX 044

Following event

48 50 [.] In Situ Rock Density - E (gm/cm3)

Not required, as rock will not be mined o processe

Rock Types - 0

	Rock Name coded INDEX 045		Relationship to Ore coded INDEX 046	
Rock Type 1	51 53 [312]	Sandstone	54 [2]	55 ☐
Rock Type 2	56 58 [315]	Shale	59 [2]	60 ☐
Rock Type 3	61 63 [311]	Conglomerate	64 [2]	65 ☐
Rock Type 4	66 68 [355]	Chert	69 [2]	70 ☐
Rock Type 5	71 73 [219]	Greenstone	74 [2]	75 ☐
Rock Type 6	76 78 [ ]		79 ☐	80 ☐

Lies along ore

U. S. BUREAU OF MINES
MINERALS AVAILABILITY SYSTEM

ROCK DESCRIPTION

Third Rock Description record

Record Reference - E

1 2 [4|1] State coded INDEX 001

3 5 [0|1|9] County coded INDEX 002

6 9 [0|0|0|1] Sequence Number

10 12 [0|6|2] Record Identification

13 ☐ Action Code - E coded INDEX 006

14 36 [RIDDLE FORMATION] Formation or Group Name - 0

37 39 [2|2|1] Geologic Age of the Formation or Group - 0 coded INDEX 042 ← Upper Jurassic

Folding Faulting

40 [1] 41 [2] 42 ☐ 43 ☐ Deformation of the Formation or Group - 0 coded INDEX 043

44 46 [2|1|9] Geologic Age of Deformation - 0 coded INDEX 042 ← Post Cretaceous

47 [4] Relationship of Mineralization to Deformation - 0 coded INDEX 044

Mineralization following event

Not required, as rock will not be mine or processe

48 50 ☐☐.☐ In Situ Rock Density - E (gm/cm3)

Rock Types - 0

	Rock Name coded INDEX 045		Relationship to Ore coded INDEX 046		
Rock Type 1	51 53 313	Siltstone	54 8	55 ☐	Near ore, but never in contact
Rock Type 2	56 58 312	Sandstone	59 8	60 ☐	
Rock Type 3	61 63 315	Shale	64 8	65 ☐	
Rock Type 4	66 68 311	Conglomerate	69 2	70 ☐	Lies along ore
Rock Type 5	71 73 ☐☐☐		74 ☐	75 ☐	
Rock Type 6	76 78 ☐☐☐		79 ☐	80 ☐	

U. S. BUREAU OF MINES

MINERALS AVAILABILITY SYSTEM

ECONOMIC AND GANGUE MINERALS

First Economic & Gangue Minerals record. Up to 10 such records, numbered 0 to 9, may be used.

Record Reference - E

1 2 [41] State coded INDEX 001

3 5 [019] County coded INDEX 002

6 9 [0001] Sequence Number

10 12 [070] Record Identification

13 [ ] Action Code - E coded INDEX 006

14 16 [122] Geologic Age of Mineralization - 0 coded INDEX 042 ← Miocene

17 [6] Overall Grain Size - 0 coded INDEX 047 ← variable

Mineral Description - 0 optional information - to be completed to the best of the evaluator's ability. If the data is not readily available, then omit.

Mineral Name coded INDEX 048	Mineral Class coded INDEX 049	Grain Size coded INDEX 047	Amount	Units coded INDEX 050
18 20 [210] garnierite	21 22 [16] silicate	23 [6]	24 27 [ ]	28 [1]
29 31 [299] limonite	32 33 [04] oxide ↑ leading zero	34 [6]	35 38 [ ]	39 [1]
40 42 [105] chalcedony	43 44 [15] silicate	45 [6]	46 49 [ ]	50 [1]
51 53 [442] sepiolite	54 55 [16] silicate	56 [6]	57 60 [ ]	61 [1]
62 64 [444] serpentine	65 66 [16] silicate	67 [6]	68 71 [ ]	72 [1]

Amount: no data

Units: weight percen

At Nickel Mountain, nickel-bearing soil and saprolite constitute a significant part of the ore reserve. This record has no way to adequately describe such "ore materials", so a description should be given in the REFERENCES and COMMENTS Records.

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DEPOSIT CHARACTERISTICS

Record Reference - E

1 2 4 1 State coded INDEX 001

3 5 0 1 9 County coded INDEX 002

6 9 0 0 0 1 Sequence Number

10 12 0 8 0 Record Identification

13 ☐ Action Code - E coded INDEX 006

No confidential information

14 0 Confidentiality - E coded INDEX 015

Fissure veins — shear zones — other – takes into account the soil and saprolite ores

15 16 0 1 17 18 0 2 19 20 1 0 Type of Ore Body - E coded INDEX 051

leading zeros

Residual concentration — Supergene enrichment

21 7 22 3 Mode of Origin - E coded INDEX 052

Irregular

23 3 24 ☐ 25 ☐ Shape of Ore Body - E coded INDEX 053

Left justified, in order of importance

Faulting — Fracturing (jointing)

26 3 27 2 Ore Controls - E coded INDEX 054

28 0 Undetermined (none) Degree of Wallrock Alteration - E coded INDEX 055

Undetermined (does not apply)

29 30 0 0 31 32 ☐☐ 33 34 ☐☐ Type of Wallrock Alteration - E coded INDEX 056

Left justified

Mineralized Zone Orientation and Dimensions

35 39 0 0 0 0 0 Average Depth to the Mineralized Zone - E (meters)

40 44 0 0 0 0 0 Minimum Depth to the Mineralized Zone - E (meters)

Leading zeros

45 48 0 0 0 0 Average Thickness of the Unconsolidated Material - E (meters)

49 52 0 0 0 0 Minimum Thickness of the Unconsolidated Material - E (meters)

53 58 0 0 1 8 3 0 Average Length of the Mineralized Zone - E (meters)

North — Degrees — East

59 1 60 61 4 5 62 3 Strike of the Mineralized Zone - E direction coded INDEX 017

Leading zeros

63 68 0 0 0 9 1 5 Average Width of the Mineralized Zone - E (meters)

Degrees — South *

69 70 3 5 71 2 Dip of the Mineralized Zone - E direction coded INDEX 017

72 75 0 0 1 5 Average Thickness of the Mineralized Zone - E (meters)

* In the case of a flat-lying deposit, code strike as 1 00 2 (North - South), and dip as 00 0

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MINERALS AVAILABILITY SYSTEM

SURFACE MINING

Mining Records are Keyed to Resource Matri Records. "1" signifies this Record is matched to the first Resource Matrix

Record Reference - E

1 2 [4 1] State coded INDEX 001

3 5 [0 1 9] County coded INDEX 002

6 9 [0 0 0 1] Sequence Number

10 12 [1 3 0] Record Identification

13 ☐ Action Code - E coded INDEX 006

could be coded confidential, if company cost data are used.

14 [0] Confidentiality - E coded INDEX 015

In this case, BuMines derived costs were used - no confidentiality.

15 16 [7 4] Year this Evaluation Enters the System - E

To be changed on update

17 [2] System Status - E coded INDEX 057

Operating system, estimated costs

18 19 [.5 5] Swell Factor - E

Estimated - need loose density for calculation (see manual for method)

20 22 [9 9.9] Percent Waste Rock - E

Undetermined

23 24 [1 3] Surface Mining Method - E coded INDEX 063

Bench mining

25 28 [0 0 0 0] Average Cover Thickness - E (m)

None - not applicable

Cover Description - E

Hardness coded INDEX 064

Percent of Specified Thickness

Horizon 1 29 ☐ 30 31 ☐☐

Horizon 2 32 ☐ 33 34 ☐☐

Horizon 3 35 ☐ 36 37 ☐☐

This section not applicable to Nickel Mountain and possibly to other "nickel laterites" where no cover is stripped and wasted prior to mining

38 [4] Ore Body Hardness - E coded INDEX 064

see manual

500 acres X 0.4047 hectares/acre = 202.35

39 43 [0 0 2 0 2] Surface Area - 0 (hectares) = 202 hectare

Leading zeros

44 46 [0 0 6] Bench Height - 0 (m)

20' benches

Leading zeros

47 48 ☐☐ Maximum Pit Slope - 0 (degrees)

Determined from field visit

49 54 [0 0 4 4 6 7] Estimated Mine Capacity - E (resource quantity units tons / day)

From 1972 production data, in metric tons of crude ore.

55 60 [0 0 0 0 0 0] Estimated Preproduction Stripping Volume - E (1000 m^3)

None

Derived from BuMines cost curves, escalated to 1974 costs

61 65 [0 1 . 2 5] Estimated Unit Production Cost - E (dollars / resource quantity unit)

Decimal occupies a full column

66 71 [0 0 1 0 0 0] Estimated Mine Capital Cost - E (1000 dollars)

$6000,100

72 73 [2 0] Estimated Production Period - E

years

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MINERALS AVAILABILITY SYSTEM

BENEFICIATION

Record Reference - E

1 2 ☐☐ State coded INDEX 001

3 5 ☐☐☐ County coded INDEX 002

6 9 ☐☐☐☐ Sequence Number

10 12 ☐ 5 ☐ Record Identification

13 ☐ Action Code - E coded INDEX 006

14 ☐ Confidentiality - E coded INDEX 015

15 16 ☐☐ Year this Evaluation Enters the System - E

17 ☐ System Status - E coded INDEX 065

Omit - not used for residual nickel deposits.

Product Description - E

	Process Feed Grade	Percent Recovery in this Beneficiation Product
Commodity 1	18 21 ☐☐☐☐	22 23 ☐☐
Commodity 2	24 27 ☐☐☐☐	28 29 ☐☐
Commodity 3	30 33 ☐☐☐☐	34 35 ☐☐
Commodity 4	36 39 ☐☐☐☐	40 41 ☐☐
Commodity 5	42 45 ☐☐☐☐	46 47 ☐☐
Commodity 6	48 51 ☐☐☐☐	52 53 ☐☐

54 ☐ Beneficiation Method Used - E coded INDEX 066

55 60 ☐☐☐☐☐☐ Amount of this Beneficiation Product Shipped - E

61 ☐ Units for Amount Shipped - E coded INDEX 067

62 ☐ Costing Option - E coded INDEX 068

63 ☐ Quantity Units for Capacity and Production Cost - E coded INDEX 014

64 69 ☐☐☐☐☐☐ Estimated Plant Capacity - E

70 74 ☐☐☐☐☐ Estimated Unit Production Cost - E

75 80 ☐☐☐☐☐☐ Estimated Capital Cost - E (1000 dollars)

First Comment Record. Up to 200 records can be used, numbered from 800 to 999

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REFERENCES AND COMMENTS

Record Reference - E

1 2 | 41 | State coded INDEX 001

3 5 | 019 | County coded INDEX 002

6 9 | 0001 | Sequence Number

10 12 | 800 | Record Identification

13 | ☐ | Action Code - E coded INDEX 006

Reference or Comment - 0

14–46: RECORD 070 NI BEARING SOIL AND

47–80: SAPROLITE ARE SIGNIFICANT PART OF

Second Comment Record

10 12 | 801 | Record Identification

13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14–46: ORE RESERVE BUT CANT BE CODED.

47–80: RECORD 130 COVER DESCRIPTION DOES

Third Comment Record

10 12 | 802 | Record Identification

13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14–46: NOT APPLY TO THIS TYPE OF DEPOSIT

47–80: .

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10 12 | ☐☐☐ | Record Identification

13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14–46:

47–80:

---

10 12 | ☐☐☐ | Record Identification

13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14–46:

47–80:

past projected "life of the ore body" figures an additional 6,000,000 mt was assigned totaling 30,000,000 mt at 75 percent probability (3 chances out of 4 that that tonnage is present) at the 1.38 percent grade. On the same reasoning, it was thought that an additional 4,000,000 mt would be present at 50 percent probability (2 chances out of 4) at the same grade, for a total of 34,000,000 metric tons.

The lower grade figures of 1.25 percent nickel and 1.0 percent nickel were obtained by including areas of lower-grade material that diluted the grade and increased tonnages. Probability levels were obtained by proportion from the basic mining grade tonnage numbers.

The higher grade figures of 2.0 percent nickel and 3.0 percent nickel were obtained from USGS data and represent small minable blocks of ground that would have to be selectively mined.

In an actual deposit the existence of the minable blocks of ground at certain tonnage and grade figures must be backed up by data of some kind, varying from company reserve figures to geological inference, with the validity of the data and the weight placed on it being reflected by the probability.

Length = 1830 meters, width 915 meters,
Thickness = 15 meters (all average figures)

1830 m x 915 m x 15 m = 25, 116,750 meters^3

Tonnage-volume factor is derived:
1.9 gm/cm^3 (in situ rock density) is equivalent to: 1.9 metric tons/meter^3

25,116,750 meters^3 x 1.9 metric tons/meter^3 = 47,721,825 metric tons, so the maximum matrix tonnage figure of 42,499,000 metric tons will "fit" within the dimensions established.

IV. A general approach completion of the Grade-Quantity matrix is given on page 5 of the yellow manual, and page 15 of the blue manual. For the Nickel Mountain deposit, the procedure was as follows:

1. Ore body was defined as an irregular block of ground 1830 meters long, 915 meters wide, and 15 meters thick (all average dimensions)

2. Minable grades were determined as

   a. 1.38 percent nickel (company data)

   b. 2.0 percent nickel (USGS data, for a much smaller tonnage)

   c. 3.0 percent nickel (USGS data, for a still smaller tonnage)

   d. 1.25 percent nickel (assumed grade for a larger tonnage than "a")

   e. 1.0 percent nickel (assumed lowest average minable grade)

3. Tonnage figures were determined thusly:

   The basic tonnage figure (at 90 percent probability) of 24,000,000 metric tons, at an average mining grade of 1.38 percent nickel was derived from company information giving a mine life of 20 years at a production of 1,200,000 mty. On the basis of past production that has exceeded

Matrix Assembly

I. Tonnages are cumulative: (1) From right to left within a specified probability level, and (2) Downward, within a specified Average Minable Grade. For example, the 1.0 percent Nickel tonnages represent a summation of all the higher grade range material plus enough material of a lower grade to make up a minable entity of 1.0 percent nickel ore. Material at a 50 percent probability level (for any average minable grade) contains all the ore at 75 percent and 90 percent probability, plus the additional tonnage of 50 percent certainty.

II. The Nickel Mountain deposit was taken down only to the 50 percent probability level, largely because sufficient data were available to set fairly definite spatial and confidence limits to the ore body, hence the lower probability levels do not apply. However, the system requires that the 25 percent and 10 percent probability entries be made (since all tonnages having a 50 percent probability of being there are obviously at least 25 percent or 10 percent "sure", then the 50 percent quantities are carried the rest of the way through the matrix).

III. For the Nickel Mountain deposit, the maximum tonnage established is 42,499,000 metric tons at an Average Minable Grade of 1.0 percent nickel, at the 50 percent probability level. In all cases, the maximum matrix tonnage recorded must be compatible with the maximum possible tonnage established by the dimensions of the mineralized zone, as entered on Record 080 (Deposit Characteristics) For Nickel Mountain, dimensions are:

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MINERALS AVAILABILITY SYSTEM

PROBABILISTIC GRADE - QUANTITY MATRIX

Reference Number - E

1 2 State: 41

3 5 County: 019

6 9 Sequence Number: 0001

10 Record Identification (1st digit): 1

Number of matrix being developed. More than one may be used, if alternative methods of developing the deposit are considered.

Commodity numbers from Identification Record (Record 010)

Average Minable Grades

Present average mining grade

Record Identification 11 12	Action Code 13	Commodity	14	15 19	20 24	25 29	30 34	35 39
01		Nickel	1	001.0	01.25	01.38	002.0	003.0
02		Iron	2	010.0	011.8	014.2	007.5	006.2
03								
04								
05								
06								

Tonnages are cumulative in two directions

Resource Quantity (thousands)

Company "proven ore" reserve at 1.38% Ni

Record Identification 11 12	Action Code 13	Probability	14 15	16 24	25 33	34 42	43 52	53 60
11		P 1	90	30000	27500	24000	1000	100
12		P 2	75	37500	34375	30000	1250	125
13		P 3	50	42499	38958	34000	1416	142
14		P 4	25	42499	38958	34000	1416	142
15		P 5	10	42499	38958	34000	1416	142

Maximum tonnage shown

61 62 Year of this Evaulation - E 74

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MINERALS AVAILABILITY SYSTEM

REFERENCES AND COMMENTS

First References Record. Up to 100 records can be used, numbered from 700 to 799

Record Reference - E

1 2 | 41 | State coded INDEX 001
3 5 | 019 | County coded INDEX 002
6 9 | 0001 | Sequence Number
10 12 | 700 | Record Identification
13 | ☐ | Action Code - E coded INDEX 006

Reference or Comment - 0

14 20 30 40 46
USGS BULL 931 I P 205 226

47 50 60 70 80

---

second reference record

10 12 | 701 | Record Identification
13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14 20 30 40 46
AIME ORE DEPOSITS OF US VOL 2

47 50 60 70 80
CHAP 79 P 1650 1672

Third reference record

10 12 | 702 | Record Identification
13 | ☐ | Action Code - E

Additional Reference or Comment - 0

14 20 30 40 46
MIN ENG V 9 NO 9 P 903 904

47 50 60 70 80

---

10 12 | ☐☐☐ | Record Identification
13 | ☐ | Action Code - E

dditional Reference or Comment - 0

20 30 40 46

50 60 70 80

---

10 12 | ☐☐☐ | Record Identification
13 | ☐ | Action Code - E

›nal Reference or Comment - 0

20 30 40 46

50 60 70 80

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MINERALS AVAILABILITY SYSTEM

TRANSPORTATION

Record Reference - E

1 2 ☐☐ State coded INDEX 001

3 5 ☐☐☐ County coded INDEX 002

6 9 ☐☐☐☐ Sequence Number

10 12 ☐☐☐ Record Identification

13 ☐ Action Code - E coded INDEX 006

14 15 ☐☐ Year this Evaluation Enters the System - E

16 21 ☐☐☐☐☐☐ Shipping Point - E Standard Point Location Code

22 ☐ Product Number of Material Shipped - E

23 24 ☐☐ Percent of Produced Material Shipped through this Alternative - E

Destination Description - E

25 30 ☐☐☐☐☐☐ Standard Point Location Code

31 35 ☐☐☐☐☐ Zip Code

36 ☐ Type of Facility coded INDEX 069

Transportation Description - E

	Mode coded INDEX 070	Distance (km)
Component 1	37 ☐	38 42 ☐☐☐☐☐
Component 2	43 ☐	44 48 ☐☐☐☐☐
Component 3	49 ☐	50 54 ☐☐☐☐☐
Component 4	55 ☐	56 60 ☐☐☐☐☐
Component 5	61 ☐	62 66 ☐☐☐☐☐
Component 6	67 ☐	68 72 ☐☐☐☐☐
Component 7	73 ☐	74 78 ☐☐☐☐☐

Omit - not used for residual nickel deposits ☺

Chromite Reserves

Alaska 132 subeconomic Podiform-type deposits and 1 placer deposit are estimated to contain 3.4 million to 4.3 million st chromic oxide (Cr_2O_3) in high-Cr and high-Fe chromite. Most of the deposits contain between 5 and 10% chromite and would require mine site beneficiation (See US Bu Mines IC 9087)

SW Oregon Low grade disseminated

Youngs Dailey Dozen - 30,000 long tons 15% Ch

3 or 4 other sites could possibly be developed to produce low grade disseminated chromite (Illinois River district) Together They may match the amount of Youngs mine.

N. California:

Del Norte Browns High Plateau massive high-grade metallurgical lump chromite. — 60,000 MT of 50% Cr_2O_3 and Cr:Fe ratio of 2.8 To 3.7

~~NICKEL~~ MOUNTAIN ~~MINE~~

Table 1

WEST SLOPE

JUNE 1 , 1968

DEPTH	Drill Hole No. 1	2	3	4	5	6	7	8	9	10
0 - 5	1.14	0.97	1.07	0.86	0.56	0.92	0.88	1.07	1.10	1.44
5 -10	1.14	1.13	1.33	1.19	0.60	0.89	0.85	1.67	1.01	1.62
10 -15	1.69	1.84	1.65	0.91	0.45	0.98	0.77	1.16		1.71
15 -20	1.41	1.82	1.61	0.96		1.01	0.94	1.06		
20 -25	1.46	1.78	1.09	1.00		1.00	1.04	1.00		
25 -30	1.31	2.05		0.83		1.07	1.19			
30 -35	1.33	1.94				1.01				
35 -40	1.58	1.88				0.88				
40 -45						0.70				
45 -50						0.60				

EAST SLOPE

DEPTH	Drill Hole No. 1	2	3	4	5	6	7	8	9	10	11	12
0 - 5	1.35	0.93	0.94	0.76	1.63	0.62	1.33	0.80	0.74	0.65	0.63	0.57
5 - 10	1.21	1.15	1.23	0.93	2.25	0.66	1.17	0.35	0.87	0.58	0.65	0.59
10 - 15	0.49	1.12	1.15	0.90	2.13	0.56	1.95		0.73	0.56	0.70	0.58
15 - 20		1.41	1.00	0.86		0.36	1.49		0.83		0.62	0.64
20 - 25			0.99			0.28	1.69		0.75		0.64	
25 - 30			0.88			0.26	1.86		0.59		0.62	
30 - 35						0.25	1.86					
35 - 40						0.41	1.57					
40 - 45							1.60					
45 - 50							1.52					

EN —

The Red colored portion of The map is the main nd lower Ore bodys, wHicH is public KNowledge - The reen represents our sattelite ore zones which are o some extent confidential as we aren't sure of he outlines or the geology. You can use your own ~~discretion~~ discretion as to the extent you wish to se this information.

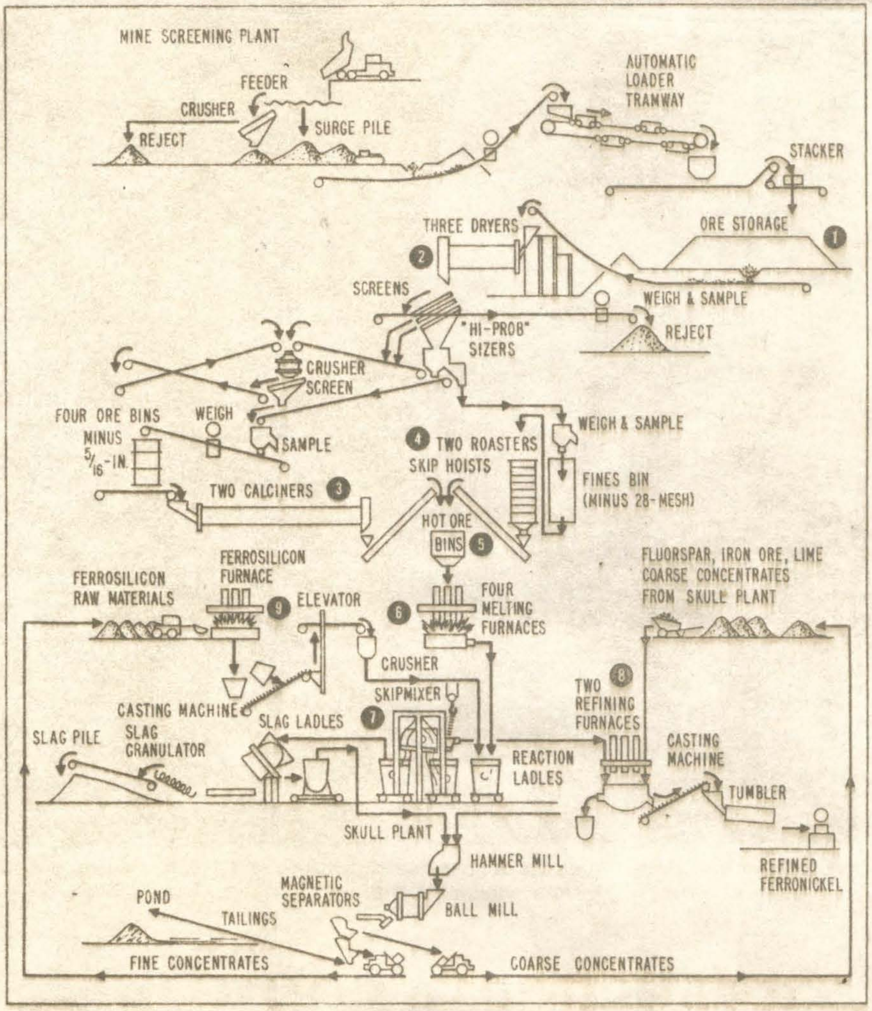
Hope this helps a little —

Regards
Ted

Continuous tramway delivers ore to smelter and produces a 500 hp credit.

Smelter Legend

1. Stockpile; to 100,000 tons.
2. Three dryers; two, 10 x 100 ft, one, 11 x 100 ft.
3. Two 9 x 250-ft rotary kilns, counter-current firing.
4. Two multiple hearth roasters.
5. Four 50-ton bins.
6. Four 20,000 kva tilting furnaces.
7. Skip mixer; handles 14.3-ton pours.
8. Two covered arc 2,500 kva furnaces.
9. One submerged arc 12,500 kva furnace.



Ferronickel builds-up at 800-900 lb per reaction at skip mixer in Hanna smelter.

2-in. track cables. At the discharge they are inverted and return to the mine in that position on a pair of 1½-in. cables. This system pumps a credit of some 500 hp through induction generators and the power is consumed at the mine. At the smelter the ore is bedded outside by an overhead conveyor and travelling wing trippers.

Making 50% nickel pigs

Unit smelter operations include: (1) Bedding, reclaiming and blending; (2) drying natural water of 21% to the 3 or 4% level; (3) screening to manipulate the basicity index at its best level, to also reject roughly 15% of low nickel-bearing oversize, and to split out by sizers minus 20-mesh fines; (4) calcining of minus 5/16-in. plus 20-mesh ore and roasting of fines to drive off water of crystallization and to adjust the tri-valent and di-valent iron ratios; (5) melting the ore in electric furnaces equipped with three self-baking Soderberg electrodes; (6) reducing the melt by means of ladling molten ore, the ferrosilicon reductant, and seed ferronickel back and forth seven times to promote the reduction reaction; (7) periodically thieving ferronickel from the reaction ladle after slag has been decanted; (8) refining thieved metal to dephosphorize it; and (9) casting pigs in 28-lb shapes.

Hanna makes its own ferrosilicon from local quartz, iron turnings, coke and wood chips in a 12,500 kva submerged arc furnace. It is crushed to minus ⅝-in. for addition to the process. Four tilting melting furnaces are arranged in two pairs of 20,000 kva each for each furnace. One roaster and one calciner feed each pair. They melt at 25 to 28 tph and are operated with open arcs.

The reactions proceed in three overlapping sequences as follows. (1) Fe_2O_3 to FeO; (2) nickel oxide to metal; and (3) FeO to the metallic state. To cut the consumption of ferrosilicon, carbon as sawdust (a product of local lumber industries) is added to the roasters and calciners to gain partial reduction of ferric iron to the ferrous state before melting. When the contents of a melting furnace is poured into a ladle in the skip mixer, a ladle of 9 to 14 tons of seed ferronickel is waiting on the other side. The latter is hoisted and poured into the ladle containing the freshly melted ore.

The nickel picture in 1967

Description	Dry tons (millions)	% Ni	lb nickel (millions)
Ore from stockpile	1.123	1.43	32.193
Hard rock rejected	0.175	0.77	2.686
Ore to process	0.948	1.56	29.478
Molten ore	0.859	1.69	29.053
Slag and tailing loss	—	—	2.474
Dust	—	—	0.424
Ferronickel produced	—	50.18	26.070

Recovery from ore to process (%)	88.44
Power consumption per pound of nickel produced (kwh)	29.49
Electrode paste (pounds per ton of ore poured)	7.3
Ferrosilicon (52% Si, per pound of Ni in molten ore)	1.45

TABLE II NICKEL PRODUCTION

Year	Pounds of contained nickel in ferro nickel produced	Average U.S. price per pound f.o.b. Port Colborne, Ontario	$ Approxima gross value
1954	318,489	$ .79 *	258,848
1955	6,505,329	.74 *	4,840,061
1956	11,382,984	.605 *	6,886,705
1957	18,121,452	.605 *	10,963,478
1958	21,233,634	.605 *	12,846,000
1959	20,794,091	.605 *	12,580,000
1960	22,228,720	.605 *	13,448,000
1961	20,650,142	.736	15,199,000
1962	21,138,893	.774	16,362,000
1963	21,447,986	.8275	17,748,000
1964	22,472,891	.8275	18,596,000
1965	25,333,000	.8275	20,963,000
1966	24,533,000	.8275	20,301,000
1967	26,070,000	.849	22,134,000
1968	26,252,000	.915	24,020,000
1969	26,172,000	1.028	26,905,000
1970	25,349,000	1.284	32,548,000
1971	25,934,000	1.305	33,843,000

* Contract agreement price with Government 79.39 cents for the first 5 million pounds and 60.5 cents a pound thereafter until contract completed in 1961.

ANALYSIS REPORT

HANNA NICKEL SMELTING CO.

Riddle, Oregon

To H. W. Hard

Chemical ✓

Quantometer

Lab. No.	Sample Description	~~Ni%~~					
107069	7/20 Quartz Mt.		3-38	—	W. A. Foster		
	SiO_2	97.99					
	Fe_2O_3	1.48					
	Al_2O_3	0.13					
	TiO_2	0.27					
	CaO	<0.03					
	Phos	<0.005					
	L.O.I	0.06					
107070	7/20 Quartz Mt.		3-39	—	W. A. Foster		
	SiO_2	97.34					
	Fe_2O_3	1.92					
	Al_2O_3	0.20					
	TiO_2	0.25					
	CaO	0.06					
	Phos.	<0.005					
	L.O.I.	0.20					

Date 7-24-59

Signed Eric Wilson

FM No. 602 RPCo.

```
                                        RECORD IDENTIFICATION
                                          RECORD NO............  W000690
                                          RECORD TYPE..........  X1M
                                          COUNTRY/ORGANIZATION.  USGS
                                          DEPOSIT NO...........  4102
                                          MAP CODE NO. OF REC..

                                        REPORTER
                                          NAME..........................  COURY, ANNY B.
                                          DATE..........................  72 08
                                          UPDATED.......................  79 02
                                          BY............................  BRADLEY, ROBIN; WALKER, G. W.

 NAME AND LOCATION
   DEPOSIT NAME.................  HANNA NICKEL MINE
   SYNONYM NAME.................  NICKEL MOUNTAIN

   MINING DISTRICT/AREA/SUBDIST.  RIDDLE

   COUNTRY CODE.................  US
   COUNTRY NAME:  UNITED STATES

   STATE CODE...............  OR
   STATE NAME:  OREGON

   COUNTY...................  DOUGLAS
   DRAINAGE AREA............  17100302 PACIFIC NORTHWEST
   PHYSIOGRAPHIC PROV.......  13 KLAMATH MOUNTAINS

   QUAD SCALE         QUAD NO OR NAME
    1: 62500            CANYONVILLE

   LATITUDE           LONGITUDE
    42-57-40N           123-26-20W

   UTM NORTHING       UTM EASTING        UTM ZONE NO
    4756374.7           464203.3           +10

   POSITION FROM NEAREST PROMINENT LOCALITY:  8 MILES WEST OF CANYONVILLE

   LOCATION COMMENTS: DEPOSIT COVERS UPPER PART OF NICKEL MTN.  INCLUDES PARTS OF SECTIONS, 8 , 9 , 16 , 17 , 18 , 2
     AND 21 OF T 30 S, R 6 W.


 COMMODITY INFORMATION
   COMMODITIES PRESENT..........  NI   CO   PGM

     PRODUCER(PAST OR PRESENT):
                MAJOR PRODUCTS.. NI
```

```
  COMMODITY SPECIALIST INFORMATION:
    PGM POT

  ORE MATERIALS (MINERALS,ROCKS,ETC.):
    GARNIERITE, PERIDOTITE

      MAIN ORE MINERALS:
        GARNIERITE

      MINOR ORE MINERALS:
        SEPIOLITE, CHLORITE

  COMMODITY COMMENTS:
    ORES ARE CLASSIFIED INTO GROUPS:  SOIL (RED AND YELLOW), SAPROLITE (SOFT, HARD SAPROLIZED PERIDOTITE), AND
    BOXWORK.  SOILS ACCOUNT FOR 20 % OF ORE RESERVE AVERAGING 10 FT. THICK, VARYING FROM ZERO TO 40 FT.  SAPROLITE
    ACCOUNTS FOR 70 % OF RESERVES.  BOXWORK GROUP ACCOUNTS FOR REST OF RESERVE WITH AVERAGE GRADE OF 1.78 % NICKEL I
    UPPER DEPOSIT AND 1.49 % IN UPPER DEPOSIT.  PGM BASED ON ANALYSIS, HOTZ AND EDUCATED GUESS, NEEDS TO BE CHECKED.

  ANALYTICAL DATA(GENERAL)
    PARENT ROCKS RANGE FROM 0.52 TO 0.29 % NICKEL


EXPLORATION AND DEVELOPMENT
  STATUS OF EXPLOR. OR DEV.  7
                             PROPERTY IS ACTIVE  ACTIVE
  YEAR OF DISCOVERY........  1864
  BY WHOM..................  SHEEPHERDERS
  NATURE OF DISCOVERY......  B
  YEAR OF FIRST PRODUCTION.  1882
  PRESENT/LAST OPERATOR....  HANNA MINING CO


DESCRIPTION OF DEPOSIT

  DEPOSIT TYPES:
    LATERITE
  FORM/SHAPE OF DEPOSIT: STRATIFIED BLANKET

  SIZE/DIRECTIONAL DATA
    SIZE OF DEPOSIT......  LARGE
    DEPTH TO TOP ........  3          FEET
    MAX LENGTH...........  6000       FT
    MAX WIDTH............  3000       FT
    MAX THICKNESS........  220        FEET
  COMMENTS(DESCRIPTION OF DEPOSIT):
    500 ACRES OF DISCONTINUOUS MANTLE, AVERAGING 50 FT. THICK BUT VARYING FROM 5 TO 200 FT.  TWO MAIN ORE BODIES ONE
    ON TOP OF NICKEL MTN. CALLED UPPER DEPOSIT, AND ONE ON TERRACE ON SOUTH SIDE OF MTN.  CALLED LOWER DEPOSIT.

DESCRIPTION OF WORKINGS
     SURFACE

  COMMENTS(DESCRIP. OF WORKINGS):
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PRODUCTION
     YES
     LARGE PRODUCTION


 ANNUAL PRODUCTION (ORE,COMMOD.,CONC.,OVERBURD.)

   ITEM          ACC  AMOUNT  THOUS.UNITS YEAR  GRADE,REMARKS
  1  NI   ACC        000011.8 MET TONS    1971  NI IN ORE
  2  NI          ACC 000018.3 TONS        1979
  3  ORE  EST        00000860 MET TONS    1974;1.38% NI


 CUMULATIVE PRODUCTION (ORE,COMMOD.,CONC.,OVERBUR.)

   ITEM          ACC  AMOUNT  THOUS.UNITS YEAR  GRADE,REMARKS
  15 NI          ACC 000247.7 TONS        1953-1979

PRODUCTION YEARS.......  1971

SOURCE OF INFORMATION (PRODUCTION).. CORNWALL, H.R., 1966, NICKEL DEPOSITS OF NORTH AMERICA: U.S.GEOL. SURVEY BUL
  1223

PRODUCTION COMMENTS....  AVERAGE GRADE OF ORE: 1.4% ONLY DOMESTIC NICKEL PRODUCTION.  SINCE 1957, ANNUAL PRODUCTI
  HAS BEEN 10 TO 13 THOUSAND TONS; 1972 PRODUCTION FIGURES NOT AVAILABLE CORNWALL, H.R., 1966, REPORTS, 'PRODUCTI
  RECORDS FOR THE FIRST 10 YEARS OF OPERATION, PLUS CONSIDERATION OF PRESENT CAPACITY AND MINIMAL REQUIREMENTS FR
  PROFITABLE EXPLORATION OF A METAL DEPOSIT, INDICATE THAT THE DEPOSIT IS LARGE ENOUGH TO SUPPORT A PRODUCTION RA
  OF 12,000 MET TONS PER YEAR FOR A MINIMUM OF 30 YEARS.' 1964 PRODUCTION WAS 12,700 M.T. OF NICKEL...1973 MINE A
  SMELTER OUTPUT WAS 11,735 M.T. NICKEL, 1972 OUTPUT WAS 11,900 M.T. NICKEL.



RESERVES AND POTENTIAL RESOURCES

   ITEM          ACC  AMOUNT  THOUS.UNITS  YEAR GRADE OR USE
  1  NI          EST 00000240 MET TONS    1973  NI IN ORE RESERVES
  2  CO          EST 00000008 MET TONS    1973; CALCULATED
  4  ORE NI CO   EST 00016000 MET TONS    1973; 1.50% NI, 0.05% CO
  5                                       1973  1.50% NI, (AVERAGE)
  6

  SOURCE OF INFORMATION (RESERVES/POT RESOURCES).. VHAY, JOHN S., ET AL, 1973, COBALT: (IN US MINERAL RESOURCES,
    GEOL. SURVEY PROF. PAPER 820, P. 148).


RESERVES ONLY

   ITEM          ACC  AMOUNT  THOUS.UNITS  YEAR GRADE OR USE
  1  NI          EST 00000136 MET TONS    1973  NI IN ORE
  5  NI-ORE       EST00009070 MET TONS    1973  1.50% NI

  COMMENTS (RESERVES)..  CORNWALL, H.R., 1966, REPORTS SEVERAL OTHER DEPOSITS IN SOUTHWESTERN OREGON AND NORTHWES
    CALIFORNIA, INCLUDING EIGHT DOLLAR MOUNTAIN, WOODCOCK MT., RED FLATS, PINE FLAT MT., AND LITTLE RED MOUNTAIN
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SOURCE OF INFORMATION (RESERVES).. CORNWALL, H.R., SEE REF. 1.

GEOLOGY AND MINERALOGY

AGE OF HOST ROCKS............ MID PLIO
HOST ROCK TYPES.............. LATERITE
IGNEOUS ROCK TYPES........... PERIDOTITE, DUNITE, SERPENTINITE

AGE OF MINERALIZATION........ TERT

PERTINENT MINERALOGY......... CHALCEDONY

IMPORTANT ORE CONTROL/LOCUS.. THE LATERITE OCCURS IN TWO AREAS, THE FIRST AND LARGEST AREA COVERS THE TOP OF TH MOUNTAIN AND IS THE ONE THAT HAS BEEN MINED; A SECOND DEPOSIT, CONSIDERABLY SMALLER, OCCURS IN A BENCH ON THE SOUTHEASTERN SLOPE OF THE MOUNTAIN. BOTH DEPOSITS OVERLIE FRESH PERIDOTITE AND HAVE A WELL-DEVELOPED QUARTZ-GARNIERITE BOXWORK ZONE.

GEOLOGICAL DESCRIPTIVE NOTES. SURFACE BLANKET DEPOSIT, FORMED BY TWO-STAGE LATERITIC WEATHERING OF PERIDOTITE O FLATTER UPPER SURFACES OF MOUNTAIN. THE NICKEL(AND COBALT?)ORIGINALLY IN THE OLIVINE. AMOUNT OF CO IN OLIVIN AND ORE NOT REPORTED

GEOLOGY (SUPPLEMENTARY INFORMATION)

REGIONAL GEOLOGY

MAJOR REGIONAL STRUCTURES.. THE LATERITES OCCUR ON FLAT-LYING TO GENTLY SLOPING EROSIONAL SURFACES, INCLUDING BROAD PLATEAU-LIKE SUMMITS, SADDLES, AND TERRACES. THE HIGHEST CONCORDANT EROSIONAL SURFACES FORM THE MOUNTA TOPS AND REPRESENT THE OLDEST PENEPLAINS, PROBABLY MIDDLE TERTIARY IN AGE. THE SURFACES ON THE FLANKS OF THE MOUNTAINS AND ON LOWER TERRACES OF THE MOUNTAINS ARE, FOR THE MOST PART, YOUNGER EROSION SURFACES, BUT AT A PLACES THE TERRACES REPRESENT OLDER, HIGHER EROSION SURFACES THAT HAVE BEEN DOWNFAULTED BY GRAVITATIONAL SLUMPING. CONTACTS OF PERIDOTITE AND RIDDLE AND DOTHAN FAULT CONTACTS REGIONAL; ROCK FAULT AND SPRING FAULT RELATED TO SAPROLITE FORMATION; JOINTS RELATED TO DEPTH OF SAPROLITE; FORMER WATER TABLE RELATED TO BOXWOR ORE

LOCAL GEOLOGY

NAMES/AGE OF FORMATIONS,UNITS,OR ROCK TYPES
1) NAME: RIDDLE FORMATION, SILTSTONE, SANDSTONE, SHALE
   AGE: JUR
2) NAME: DOTHAN FORMATION, GRAYWACKE, SHALE, CONGLOMERATE, CHERT
   AGE: JUR

GENERAL COMMENTS

THREE LAYERS IN SOIL ZONE:(1) BRICK RED SOIL(MOST CO HERE?); (2)YELLOW LIMONITIC LAYER WITH SOME QUARTZ GARNIERI BOXWORK; (3)BOXWORK OF QUARTZ AND GARNIERITE IN NEARLY FRESH PERIDOTITE. ALL ZONES HAVE SOME NICKEL AND ARE MIN LAYER(3) HAS HIGHEST GRADE: UPDATE BY GLENN L. SHAFFER-1/75, GEOLOGIC DESCRIPTION, PRODUCTION DATA, RESERVES AN POTENTIAL RESOURCES. SMELTER ANNUAL CAPACITY 11,800 M.T. SEE CUMBERLIDGE AND CHACE FOR GEOLOGIC MAPS AND ASSAY DATA. USGS RECORD (M046850) MERGED WITH THIS RECORD AND DELETED FROM THE OREGON FILE

GENERAL REFERENCES

1) PECORA, W.T., AND HOBBS, S.W., 1941, USGS BULL. 931-I, P. 205-226
2) BOGERT, J.R., 1960, MINING WORLD, VOL. 22, NO. 11, P. 33-37
3) HOTZ, P.E., 1964, ECONOMIC GEOLOGY, VOL. 59, NO. 3, P. 356-396

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CRIB MINERAL RESOURCES FILE 12

                                     RECORD IDENTIFICATION
                                       RECORD NO............  M061616
                                       RECORD TYPE..........  XIM
                                       COUNTRY/ORGANIZATION.  USGS
                                       DEPOSIT NO...........  030
                                       MAP CODE NO. OF REC..

                                     REPORTER
                                       NAME.........................  JOHNSON, MAUREEN G.
                                       DATE.........................  76 05
                                       UPDATED......................  81 03
                                       BY...........................  FERNS, MARK L. (BROOKS, HOWARD C.)

 NAME AND LOCATION
   DEPOSIT NAME..................  NICKEL MOUNTAIN GROUP
   SYNONYM NAME..................  UPPER OCCURRENCE

   MINING DISTRICT/AREA/SUBDIST.  RIDDLE

   COUNTRY CODE..................  US
   COUNTRY NAME:  UNITED STATES

   STATE CODE...............  OR
   STATE NAME:  OREGON

   COUNTY...................  DOUGLAS
   DRAINAGE AREA............  17100302 PACIFIC NORTHWEST
   PHYSIOGRAPHIC PROV.......  13 KLAMATH MOUNTAINS

   QUAD SCALE           QUAD NO OR NAME
    1:   62500            CANYONVILLE

   LATITUDE             LONGITUDE
    42-57-37N             123-26-37W

   UTM NORTHING         UTM EASTING          UTM ZONE NO
    4756275.              463820.               +10

   TWP......  30S
   RANGE....  06W
   SECTION..  17
   MERIDIAN.  W.M.

   ALTITUDE..  3240  FT

   POSITION FROM NEAREST PROMINENT LOCALITY:  ON HANNA NICKEL PROPERTY
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                POTENTIAL.......
                OCCURRENCE....... CR    RH

    COMMODITY SPECIALIST INFORMATION:
      PGM OCCUR

    ORE MATERIALS (MINERALS,ROCKS,ETC.):
      CHROMITE

    ANALYTICAL DATA(GENERAL)
      FRESH DUNITE WITH ABOUT 15% DISSEMINATED CHROMITE ASSAYED 50.60% CR2O3, 19.52% FE, 6.63% SIO2 ; RH 0.025 PPM


  EXPLORATION AND DEVELOPMENT
    STATUS OF EXPLOR. OR DEV.  1


  DESCRIPTION OF DEPOSIT

    DEPOSIT TYPES:
      DISSEMINATED
    FORM/SHAPE OF DEPOSIT: LENS

    SIZE/DIRECTIONAL DATA
      SIZE OF DEPOSIT......  SMALL
      MAX LENGTH...........  12 FT
      MAX WIDTH............  4 FT
      STRIKE OF OREBODY....  N20E
      DIP OF OREBODY.......  55SE


  PRODUCTION
        NO PRODUCTION

  GEOLOGY AND MINERALOGY

    AGE OF HOST ROCKS............  JUR


  GENERAL REFERENCES
    1) RAMP, LEN, 1972, GEOLOGY AND MINERAL RESOURCES OF DOUGLAS COUNTY, OREGON: OREGON DEPT. GEOLOGY AND MINERAL IN
      BULL. 75, 106 P.
    2) RAMP, LEN, 1961, CHROMITE IN SOUTHWESTERN OREGON:  OREGON DEPT. GEOLOGY AND MINERAL IND. BULL. 52, 169 P.
    3) PAGE, N.J, JOHNSON, M.G., HAFFTY, JOSEPH, AND RAMP,  LEN, 1975, OCCURRENCE OF PLATINUM GROUP METALS IN
      ULTRAMAFIC ROCKS OF THE MEDFORD-COOS BAY 2 DEGREE QUADRANGLE, SOUTHWESTERN OREGON: U.S. GEOL. SURVEY MISC. FIEL
      STUDIES MAP MF-694
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CRIB MINERAL RESOURCES FILE 12

                                        RECORD IDENTIFICATION
                                          RECORD NO............  M061218
                                          RECORD TYPE..........  X1M
                                          COUNTRY/ORGANIZATION.  USGS
                                          MAP CODE NO. OF REC..

                                        REPORTER
                                          UPDATED.........................  81 03
                                          BY..............................  FERNS, MARK L. (BROOKS, HOWARD C.)

 NAME AND LOCATION
   DEPOSIT NAME..................  NICKEL MOUNTAIN GROUP
   SYNONYM NAME..................  LOWER OCCURRENCE

   MINING DISTRICT/AREA/SUBDIST.  RIDDLE

   COUNTRY CODE..................  US
   COUNTRY NAME:  UNITED STATES

   STATE CODE..............  OR
   STATE NAME:  OREGON

   COUNTY..................  DOUGLAS
   DRAINAGE AREA...........  17100302 PACIFIC NORTHWEST
   PHYSIOGRAPHIC PROV......  13 KLAMATH MOUNTAINS
   LAND CLASSIFICATION.....  20

   QUAD SCALE          QUAD NO OR NAME
    1: 62500             CANYONVILLE

   LATITUDE            LONGITUDE
    42-57-11N            123-26-07W

   UTM NORTHING        UTM EASTING          UTM ZONE NO
    4755492.2            464495.2             +10

   TWP......  030S
   RANGE....  006W
   SECTION..  20
   MERIDIAN.  W.M.

   ALTITUDE.. 2550


 COMMODITY INFORMATION
   COMMODITIES PRESENT..........  CR

     PRODUCER(PAST OR PRESENT):
                MAJOR PRODUCTS.. CR
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  MASSIVE FLOAT:  54.60% CR2O3, 10.08% FE; SIMILIAR ORE 51.60% CR2O3, 10.75% FE.


EXPLORATION AND DEVELOPMENT
  STATUS OF EXPLOR. OR DEV.  8


DESCRIPTION OF DEPOSIT

  DEPOSIT TYPES:
    MASSIVE CHROMITE
  FORM/SHAPE OF DEPOSIT: LENS, PODS

  SIZE/DIRECTIONAL DATA
    SIZE OF DEPOSIT......  SMALL

DESCRIPTION OF WORKINGS
     SURFACE


PRODUCTION
      YES
      SMALL PRODUCTION


 CUMULATIVE PRODUCTION (ORE,COMMOD.,CONC.,OVERBUR.)

   ITEM        ACC  AMOUNT  THOUS.UNITS YEAR  GRADE,REMARKS
  15 ORE  EST      0000.241 TONS        1916-1918     HIGH GRADE (1917= 55% CR2O3)
  16 ORE  EST      0000.199 TONS        1952-1958     42% CR2O3 TO 48% CR2O3
  21 TOTAL          .440    TONS        50.23 % CR2O3 (WEIGHTED AVERAGE GRADE)

GEOLOGY AND MINERALOGY

  AGE OF HOST ROCKS............  JUR


GENERAL REFERENCES
  1) RAMP, LEN, 1972, GEOLOGY AND MINERAL RESOURCES OF DOUGLAS COUNTY, OREGON: OREGON DEPT. GEOLOGY AND MINERAL IND
    BULL. 75, 106 P.
  2) RAMP, LEN, 1961, CHROMITE IN SOUTHWESTERN OREGON:  OREGON DEPT. GEOLOGY AND MINERAL IND. BULL. 52, 169 P.
  3) THAYER, T. P., 1974, UNPUBL. DATA
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State Department of Geology and Mineral Industries

702 Woodlark Building
Portland 5, Oregon

Reconnaissance geology of secs. 18, 19, 30, and 31, T. 30 S., R. 6 W., and secs. 13, 23, 24, 25, 26, 35, and 36, T. 30 S., R. 7 W., Douglas County, Oregon

By

Hollis M. Dole and David J. White

ABSTRACT

A geologic reconnaissance of a twelve square mile area in the southwestern part of T. 30 S., R. 6 W., and the southeastern part of T. 30 S., R. 7 W., does not show anything that would indicate this to be a better prospecting area than areas of similar rocks found elsewhere in southwestern Oregon. The metavolcanic and serpentine rocks are recommended as the most likely sites of ore deposits but it is emphasized that intensive prospecting will be necessary to determine the economic possibilities of these areas. The present price of chromite and its insecure future suggests that immediate encouragement should be given for prospecting in the rocks in which this ore might occur.

The geologic map shows the distribution of the various formations found. The formations include both sedimentary and igneous rocks and range in age from late Mesozoic to early Tertiary.

GEOLOGY

Introduction

The area covered by this geologic reconnaissance consists of sedimentary and igneous rocks of the late Mesozoic and early Cenozoic periods. The surficial deposits of Quaternary age were not mapped and will not be discussed.

Igneous Rocks

Jurassic metavolcanics. All rocks in this category show some metamorphism and in most instances their original character is deciphered with difficulty. Probably most were originally flow rocks, as determined by their fine-grained character, and most are of an intermediate composition.

The more resistant rocks of this series form sharp cliffs and the less resistant have slopes covered with considerable rubble. Outcrops are numerous but due to jointing and metamorphism their structure is masked. Generally, these rocks trend NE with high dips to the SE. Their contact with the sediments of the Dothan formation appears to be conformable and for this reason they are thought to be of similar geologic age, that is, late Jurassic. The serpentine is intrusive into the metavolcanics and the contact of the metavolcanics with the Cretaceous sediments in the northwestern part of the area is marked by a series of faults.

Serpentine. Included in the areas mapped as serpentine is considerable peridotite but as it has been serpentinized to varying degrees no attempt was made to distinguish the serpentine from the serpentinized peridotite. Blocky outcrops in the area generally indicate peridotite. Zones of shearing within the serpentine are shown by a "backbone" or a "fish scale" type serpentine. These zones show lineation which undoubtedly is a result of the forces that produced the shearing. The lineation varies in strike from N 35° E to N 65° E and has steep dips to the NW or SE.

All contacts of the serpentine with the other formations show cross cutting relations. The serpentine has invaded the Dothan formation and the metavolcanics and is in fault contact with the younger sedimentary formations. From evidence found elsewhere the age of the serpentine is established as very latest Jurassic or early Cretaceous.

Dikes. Several dikes are noted on the map and float found in the field suggests that they are probably more common than indicated. The dikes are variable in composition, even over a short distance, but all have high percentages of feldspar; quartz was noted in some hand specimens but generally the rocks tend to be fairly basic. The dikes are intrusive into the serpentine or are found in the volcanics a short distance from the serpentine. Their association in zones of shearing near the volcanics or near the sediments may indicate that they are the products of reaction between the sediments or volcanics and the serpentine or that they are the more mobile constituents of the invaded rocks which formed upon intrusion of the serpentine or upon faulting. However, a magmatic origin should not be disregarded.

Sedimentary Rocks

Dothan formation. The Dothan formation in this area is very similar to its type locality in Cow Creek Canyon, a short distance to the southwest. Graywackes and shales predominate; chert and conglomerate occur in minor quantities.

The general NE strike and high dip to the SE which is so common in the Dothan formation of the Dutchman Butte and Riddle quadrangles is still the dominant attitude in this area.

The age of the Dothan formation is late Jurassic.

Knoxville formation. A fairly large area of Knoxville age rocks is found at the eastern edge of the map area. This series continues eastward below Nickel Mountain and forms a fairly regular band that crosses the Umpqua River at the U. S. Highway 99 bridge just northwest of the town of Myrtle Creek. Small inliers of Knoxville conglomerate are found in the serpentine in the Beatty Creek area. From this evidence it appears that in this area the Knoxville formation has been engulfed by the serpentine. The contacts of the Knoxville formation with the Umpqua formation are faults.

The Knoxville formation is dominantly a pebble conglomerate. The pebbles are almost entirely of chert and are well rounded. Sphericity of the pebbles is fair. Cementation is mainly silica. Jointing has sheared the pebbles so that a joint surface presents a very smooth face - cutting through pebbles and matrix with very little difference. The composition of the pebbles and the shearing are the main criteria for distinguishing this formation from the other sediments.

Little structure is evident in the Knoxville conglomerates and so their attitude is poorly known. Fossils found in similar-appearing rocks in the Dutchman Butte area indicate a very late Jurassic age for this formation.

A small patch of shale striking N 20° E and dipping 85° SE surrounded by serpentine was found in sec. 35, T. 30 S., R. 7 W. It is thought this shale belongs to the Knoxville formation.

Cretaceous undifferentiated. The rocks mapped as "Cretaceous undifferentiated" include the sedimentary rocks deposited during the Cretaceous period. No effort was made to distinguish the subdivisions of the period. These rocks are largely medium-grained sandstones but minor amounts of shale and conglomerate are found. Leaf impressions and invertebrate fossils are occasionally found but they are not common.

The structure of the sediments indicates two basins of deposition: one in Cow Creek Valley and the other in the upper Buck Creek and Thompson Creek area in the Dutchman Butte quadrangle. The contact between these rocks and the younger Umpqua formation is a sedimentary one but the contact with the older formations is faulted. Faults are common in the Cretaceous rocks but the strong jointing and slight metamorphism which marks the Knoxville and Dothan formations is lacking. In this respect, these rocks are more similar to the younger Eocene rocks than the older Jurassic rocks. This indicates that most of the severe orogenic movements and serpentine intrusion took place before these rocks were deposited.

Umpqua formation. The sedimentary rocks of Eocene age in this and the surrounding locality are termed the Umpqua formation. In the map area the Umpqua formation is largely massive boulder conglomerate but on the valley floor near Riddle, shale and sandstone predominate. The conglomerate forms bold cliffs and in Cow Creek it produces rapids.

In the cliffs above the Riddle "swimming hole" the rocks of the conglomerate have an average size of approximately 4 inches and a maximum size of 8-10 inches. The matrix, which makes up around 60 percent of the mass, is dominantly clay size material. The pebbles and boulders are mainly graywacke and metavolcanics. The strata of the cliffs in this area have a strike of N 45° E and a dip of 22° to the SE.

ECONOMICS

The serpentine, dikes, and metavolcanics are thought to be the only rocks which offer likely areas for prospecting. Many minor prospects have been found in all of these rocks but no known production to amount to anything has been recorded. Veins which contain minor amounts of gold and copper have been prospected in the metavolcanics and dikes. Disseminated chromite and small pods of chromite have been found in the serpentine. Minor amounts of asbestos were observed in the same rocks. Practically all drainages have been worked for placer gold but from the extent of the workings they do not appear to have been very productive.

For almost 100 years prospectors have been in southwestern Oregon and it is unlikely that any large metallic mineral deposit outcropping at the surface would have escaped their attention. Inasmuch as no large deposits have been discovered in the area of this map it is assumed that if deposits of value are to be found it will be the result of extensive prospecting or that minerals which have recently become of importance will be recognized.

Because of the present favorable price of chromite it is suggested that the areas of serpentine receive the greatest attention in prospecting, for it is only in ultrabasic rocks that lode chromite occurs. As there is no assurance that the Federal Government will continue to buy chromite at the present price after June 30, 195~~5~~7, it would appear prudent to encourage prospecting.

During the course of this investigation nothing was found that indicated this area to be a better prospecting area than any other place in southwestern Oregon in which rocks of a similar character are found.

Table II

~~RIDDLE PROPER~~TY - MINE & SMELTER PRODUCTION SUMMARY

Year	Crude Tons Mined	Nickel Production (pounds)
1954	129,000	319,000
1955	423,000	~~8,464,000~~ 6,505,000
1956	614,000	11,383,000
1957	1,087,000	18,122,000
1958	1,243,000	21,234,000
1959	1,287,000	20,794,000
1960	1,426,000	22,229,000
1961	1,422,000	20,650,000
1962	1,395,000	21,139,000
1963	1,480,000	21,448,000
1964	1,813,000	22,473,000
1965	1,898,000	25,333,000
1966	1,691,000	24,533,000
1967	1,672,000	26,070,000
1968	1,898,000	26,252,000
1969	1,781,000	26,172,000
1970	2,137,000	25,349,000
1971	2,215,000	25,934,000
TOTAL	25,611,000	~~367,898,000~~ 365,939,00

EJM:7/11/72

TABLE II NICKEL PRODUCTION

Year	Pounds of contained nickel in ferro nickel produced	Average U.S. price per pound f.o.b. Port Colborne, Ontario	$ Approximat gross value
1954	318,489	$ .79 *	258,848
1955	6,505,329	.74 *	4,840,061
1956	11,382,984	.605 *	6,886,705
1957	18,121,452	.605 *	10,963,478
1958	21,233,634	.605 *	12,846,000
1959	20,794,091	.605 *	12,580,000
1960	22,228,720	.605 *	13,448,000
1961	20,650,142	.736	15,199,000
1962	21,138,893	.774	16,362,000
1963	21,447,986	.8275	17,748,000
1964	22,472,891	.8275	18,596,000
1965	25,333,000	.8275	20,963,000
1966	24,533,000	.8275	20,301,000
1967	26,070,000	.849	22,134,000
1968	26,252,000	.915	24,020,000
1969	26,172,000	1.028	26,905,000
1970	25,349,000	1.284	32,548,000
1971	25,934,000	1.305	33,843,000

* Contract agreement price with Government 79.39 cents for the first 5 million pounds and 60.5 cents a pound thereafter until contract completed in 1961.

OREGON NICKEL PROJECT

One of the most important events in Oregon mining history took place January 16 in Washington, D.C., when the Defense Materials Procurement Agency signed a contract with Hanna Coal and Ore Corporation and the Hanna Nickel Smelting Company, both subsidiaries of the M. A. Hanna Company, Cleveland, Ohio, for the production of nickel from Nickel Mountain near Riddle, Douglas County, southwestern Oregon. The contract calls for the production of from 95,000,000 to 124,000,000 pounds of nickel in ferronickel which will contain at least 25 percent nickel and not more than 75 percent iron. The Hanna Coal and Ore Corporation agrees to develop the mine on Nickel Mountain at its own expense to cost approximately $4,300,000. Ore from the deposit will be sold to the Government at $6 a ton. In turn, the Government will sell the ore to the Hanna Nickel Smelting Company at the same price and the smelting company will treat the ore in an electric furnace plant to produce the ferronickel. This plant will be located about 2 miles down the mountain from the mine and will consist reportedly of four primary furnaces, one refining furnace, and two auxiliary furnaces.

It was announced in the press on February 3 that according to H. L. Pierce, Vice President of Hanna Coal and Ore Corporation and of Hanna Nickel Smelting Company, a contract has been awarded to the Bechtel Corporation, San Francisco, to handle the design, engineering, and construction of the nickel smelting plant at Riddle.

The Hanna Smelting Company will use a patented process developed in France by the Societe D'Electro-Chimi, D'Electro Metallurgie et des Acieries Electrique D'Ugine. This process has been used in treating New Caledonia ores having characteristics similar to the nickel silicate ore on Nickel Mountain. The contract price is 79.39 cents per pound for the first 5,000,000 pounds of nickel produced in the ferroalloy and 60.5 cents per pound thereafter.

The Government agrees to advance $24,800,000 for construction of the smelter and related expenses. The contract includes rapid amortization of the facilities installed.

The importance of this development to Oregon cannot be overemphasized. Nickel is one of the most strategic of metals needed in national defense and Nickel Mountain contains by far the largest deposit of nickel ore known in the United States. Moreover, the economy of the State will be greatly benefited by this large production of new wealth.

F.W.L.

****

OREGON

● A prediction that ferronickel will be produced by next June at the M. A. Hanna Co. development at Riddle was heard on the mining and smelting project site by a Portland Chamber of Commerce group which spent a day as company guests inspecting facilities under construction.

Earl S. Mollard, general manager for Hanna Nickel Smelting Co. told the 35 industrialists the installation of four electric furnaces should begin in January and initial ingots should be poured five months later.

Steel for the smelter structure, which along with other units of the multi-million dollar project is under contract to Bechtel Corp., San Francisco, was beyond 100 ft. in height, the shop building completed, and four ore bins of 900 tons capacity erected.

Clearing of the slopes of Nickel Mountain, source of the ore, is well advanced on the area where initial bench mining is planned. In the smeltering structure area, concrete nests for furnaces have been poured. This building is 400 ft. long and 120 ft. wide.

Company engineers explained the two-ton bucket cable tramway, to drop 2,400 ft. from ridge to operation site, is expected to have a capacity of 3,000 tons a day of wet ore. Wing belts will convey the ore from dumps, feed underground from the storage areas to driers which will burn oil or wood sawmill wastes, the latter plentiful in the lumber area industries. Dried and crushed ore will move from the four bins into a pair of rotating calciners, each 250 ft. long, from which it will feed at 700 deg. C into bins above the furnaces. Officials reported they are trying to determine what uses they might find for the slag. Tests indicate it is not usable for highway surfacing or aggregate.

The government contract for mining and smelting of the defense stockpiling program metal calls for quantities indicating an 8 yr. operating cycle. But on the basis of planned capacity and ore reserves a 30- to 40-yr. operation is indicated, assuming an economic operation after the government contract is completed. In this respect, *The Portland Oregonian* reported amortization is so arranged that Hanna can acquire the smelting facility, financed by government advance, for $2.8-million at the end of the stockpiling contract.

Mollard is a veteran of 35 years with Hanna and predecessor companies. Plant superintendent will be Emmons Coleman, who joined Hanna in May after 10 years with Bradley Mining Co., Stibnite, Idaho, and 15 years with Idaho Power Co.

December, 1953—Engineering and Mining Journal

FEDERALLY BACKED OREGON OPERATION TO GIVE NATION NEEDED NICKEL

Green rock first noted in southern Oregon by sheepherders nearly 90 years ago appears destined to provide the state with its biggest mining enterprise to date--and the United States its first real source of nickel.

Thickly forested Nickel mountain, five miles west of Riddle in Douglas county, is marked for decapitation in yielding thousands of tons of a critical metal needed in the nation's defense.

Nickel is vital in toughening armor plate and making stainless steel, yet only a small fraction is mined domestically.

Action in Washington, D. C., has cleared most of the way for a start this summer on mining and smelting facilities to cost between $25,000,000 and $30,000,000. The mine is scheduled to be in operation by summer of 1954 and the smelter by the following October.

Subsidiaries of the M.A. Hanna company, Cleveland, O., a top-flight outfit handling millions of tons of coal and iron ore in this country and developing huge iron deposits in eastern Canada, will take on the Oregon nickel task.

Project State's Biggest

The Hanna Coal and Ore corporation will develop the mining operation at its own expense at a cost estimated close to $4,300,000. The defense procurement administration will advance up to $24,800,000 to the Hanna Nickel Smelting company to construct crusher and smelter.

That's the biggest thing that's ever come to Oregon mining. Riddle's development won't loom large against the huge nickel operations near Sudbury in Canada, but it will be of respectable size.

Hanna has agreed to produce for Uncle Sam at least 95,000,000 pounds of nickel contained in ferronickel. That's regarded as a minimum. Drillings have pretty well proved that two deposits on the prominence which also has long been known as Piney mountain, contain 20,000,000 tons of nickel ore, perhaps considerably more.

It's the largest known nickel deposit in this country, and the richest despite its low content of 1 to 3 per cent of the pale, hard metal. The nickel is locked in the silicate mineral, garnierite, with an approximate 6 per cent of iron.

Alloy to Rate High

That combination is why smelting will yield ferronickel, instead of nearly pure nickel as in Canada. Most nickel goes into nickel steel, anyhow, so the mixture is quite acceptable to industry.

Most nickel steels contain only 1 or 2 per cent of the toughening metal, though they range up to more than 25 per cent. The alloy produced at Riddle is expected to run around 25 per cent nickel. Enough chromite exists in the ore to bring the product closer to actual stainless steel, though its use in stainless is rated unlikely.

Cost Factor Reduced

Oregon mining men have dreamed for decades of a going nickel operation, but economics long had them beat. Ore removal appeared feasible. The best deposits on Nickel mountain lie on terraces and slopes from 2000 feet elevation upward toward the summit of 3533 feet. Power shovels can scrape off the red earth overburden, permitting open pit mining.

But a new, cheap process for treating nickel silicate ores was needed--or a big boost in the price of nickel--to make an operation at Riddle feasible. The key has been found for the lock, with government aid to make an admittedly marginal venture attractive to a private company.

Cheaper methods for producing the ferro-nickel have come out of years of intensive research. The Albany laboratory of the U.S. Bureau of mines has come up with a smelting process peculiarly adaptable to Oregon's timber economy--it uses two tons of hog fuel to one ton of ore as a substitute for coke in the furnaces.

But the Hanna interests have adopted a closely-guarded French process, it is reported in mining circles. Developed by the French Societe d'Ugine, the process is being used on nickel ore from New Caledonia. Hanna reportedly will pay a royalty for its use.

What the advantage of the Ugine process may be is unclear to mineralogy men locally. It may utilize ferrosilicon as a reducing agent, one surmised.

Financing of the Riddle development is something of a riddle in itself, but apparently John Q. Taxpayer will be nipped to help boost strategic nickel supplies.

The mining subsidiary has contracted to sell the government enough ore to produce 95,000,000 pounds of nickel at $6 per dry ton of ore with 1.5 per cent of nickel, the average grade shown in test drillings. This is for the books, as the government then will turn around and sell the ore to the smelting company at the same figure.

Price Schedule Set

Hanna Nickel Smelting will produce ferronickel ingots at a price not to exceed 79.39 cents a pound for the first 5,000,000 pounds of nickel--a price not far from the current market figure of about 60 cents.

However, amortization provisions constitute a heavy subsidy. All but $2,800,000 of the federal advance to the smelting firm can be written off during the term of the contract, which runs to June 30, 1962, if the company fulfills its production commitment.

If Hanna wishes to retain the smelting facility at that time, it will owe the government only the $2,800,000. Continuation after 1962 is considered dubious unless new technical improvements arise or the nickel market climbs.

The Riddle smelter, it is reported, will have four primary furnaces, one refining furnace and two auxiliary furnaces. These will be electrically heated. Bonneville power administration has given the operation a commitment for 65,000 kilowatts of firm power, part of it for 1954 and the full amount by 1955.

The ore will go through a primary crusher at the mine site, then move between two and three miles down the slope of Nickel mountain, probably by conveyor either of the bucket or rubber belt type. The ore then will be recrushed and dried before smelting.

Other Deposits Known

Other deposits of nickel are known in the Northwest, but the Riddle body is the only one giving promise of production. All are at a disadvantage against Canadian ores, because the latter's sulphide combination yields nearly pure nickel through a relatively inexpensive process.

In southern Oregon two other deposits have been sampled and partially explored. A 4000-acre area at Red Flats in Curry county is being studied by the U.S. Bureau of Mines. Surface ore there contains 1.5 per cent nickel, said Regional Director Stephen Shelton; about in line with 1948 findings of a less intensive check by the state department of geology and mineral industries.

Size of this deposit has not been determined, but its location 20 miles in from the ocean and far from a railroad is discouraging. The third deposit in the region is at Woodcock mountain between Kerby and O'Brien in Josephine county, also far from a railroad.

A few sulphide deposits containing nickel, a little copper and a tiny amount of cobalt also are known in southern Oregon. But generally the hauling of the ore from other sites to Riddle is regarded as not feasible.

Second largest known nickel deposit in the Northwest, however, is in central Washington, 26 miles north of Cle Elum, and contains an estimated 5,500,000 tons smelting about 1 per cent nickel, 45 per cent iron and 1.7 per cent chromium. The deposit is regarded as not sufficient to justify a smelting operation under present conditions.

Oregon's story goes clear back to 1864 with the discovery on Nickel mountain. First to do much exploring and treating of

---

TREASURY SECRETARY HEADS HANNA CONCERN

The M. A. Hanna company name has become familiar to the nation's readers largely in recent months, not because of the nickel project, but because its shrewd boss, George M. Humphrey, has just become secretary of the treasury.

The $250,000,000 corporation dominates coal and iron mines, a steel corporation, ships, chemical plants, banks and a rayon factory. Its biggest new undertaking is a $200,000,000 iron ore development in remote Labrador, with private funds.

---

ore was W. Q. Brown of Riddle, between 1880 and 1900. He owned a large part of the mountain, which rises slightly higher than others around it.

But recurrent testing made little progress until World War II and its impetus for stockpiling of strategic metals. A geological survey report of 1942 estimated the deposit at something more than 6,000,000 tons on about 162 acres. Then the Freeport Sulphur company made 50 to 60 diamond drillings and boosted estimates to 20,000,000 tons in two ore bodies.

Freeport Sulphur abandoned Oregon to build the Nicaro plant in Cuba, another of the three foreign sources available to the United States. This nickel operation fell idle at war's end but was revived in late 1951.

Work at Nickel mountain was resumed in 1949 when the Hanna company leased mineral rights, with option to buy. For many years the site belonged to the Edson F. Adams estate, Oakland, Cal.

Hanna has sent ore samples to many laboratories for help in working out a refining process, including those of the federal bureau of mines, its own in the east and some in Europe.

Compared to the normal U.S. nickel consumption of more than 130,000 tons a year, the potential at Riddle is small, but defense production leaders consider the Oregon deposit well worth developing.

By: Merlin Blais, Staff Writer
The Oregonian--1-25-53

UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary
GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Bulletin 931-I

NICKEL DEPOSIT NEAR RIDDLE DOUGLAS COUNTY, OREGON

BY

WILLIAM T. PECORA

AND

S. WARREN HOBBS

Strategic Minerals Investigations, 1941
(Pages 205-226)

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NICKEL DEPOSIT NEAR RIDDLE,
DOUGLAS COUNTY, OREGON

By William T. Pecora and S. Warren Hobbs

ABSTRACT

The Riddle nickel deposit, on the slopes of Nickel Mountain about 5 miles northwest of Riddle, Douglas County, Oreg., was discovered in 1864. Since then much prospecting and preliminary development work has been done, but no ore has been shipped except small lots used for metallurgical tests.

The deposit is a layered blanket, containing the nickel silicate garnierite, which rests upon unserpentinized peridotite. This blanket ranges in thickness from a few feet to a maximum of 60 or 70, but with an average of about 20 feet. It is best developed on terraces, flats, and gentle mountain slopes above an elevation of 2,000 feet. It consists of three layers, a top brick-red soil layer, an intermediate thick yellow limonitic layer with some quartz-garnierite boxwork, and a root layer composed of quartz-garnierite boxwork in nearly fresh bedrock that is a transitional phase between weathered material and fresh peridotite. The disposition of the boxwork veins was controlled by original blocky jointing in the peridotite. Nickel occurs in all three layers of the blanket but is most abundant in the boxwork veins carrying garnierite. The darker green varieties of the garnierite contain the highest percentage of nickel.

The nickel is believed to have been derived from olivine in the peridotite by decomposition during lateritic weathering, which probably took place during late Tertiary time, before the present regional surface at an elevation of 2,000 feet was dissected. This process formed limonite and nickel-poor garnierite. Under present climatic conditions the original laterite has undergone a change resulting chiefly in a boxwork of quartz and nickel-rich garnierite.

About 162 acres of ground are underlain by a blanket containing over 6,000,000 tons of material, 1 to 2 percent of which is probably nickel. Eighty thousand tons have been proved to contain 2 to 3 percent of nickel, and 75,000 tons have been proved to contain 1 to 2 percent of nickel. A new method of treating low-grade silicate material would have to be devised before this large deposit could be utilized.

INTRODUCTION

The Riddle nickel deposit is on Nickel Mountain, also called Piney Mountain, about 5 miles northwest of Riddle, Douglas

County, Oreg. (fig. 20). The deposit is an unevenly distributed surficial blanket, containing the nickel silicate garnierite, which rests upon peridotitic rocks on the western, southern, and southeastern slopes of the mountain above an elevation of 2,000 feet.

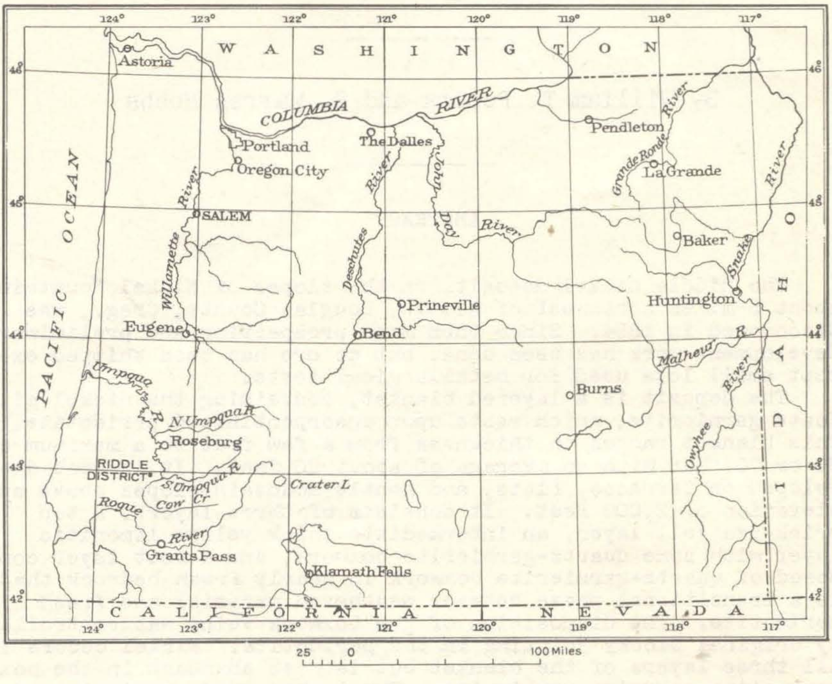

Figure 20.--Index map showing location of the Riddle nickel deposit.

Riddle, which has a population of about 200, is at an elevation of about 700 feet on the north side of Cow Creek a mile west of its junction with the South Umpqua River. It is on the Southern Pacific Railroad, and it is about 230 miles by highway south of Portland. A poorly conditioned dirt road about 5 miles long connects the town with the nickel deposit.

History and development

Since the discovery of the deposit by sheepherders in 1864, much prospecting and exploration has been done on Nickel Mountain, but up to the present no nickel ore has been shipped except small lots used for experimental metallurgical tests. From 1880 to 1900, Mr. W. Q. Brown of Riddle owned a large portion of the deposit, and under his direction it was actively explored. Mr. Brown also experimented with concentration and treatment of the ore. The property that contains most of the deposit is now owned by Mr. Edson F. Adams of Oakland, Calif.

The accessible workings include 75 small pits and trenches, 6 adits, 3 shafts, and about 5 large open cuts. The longest adit is 300 feet long and the deepest shaft is 83 feet deep. The dump piles contain about 4,000 tons of material--practically all that has been excavated from the workings--in which the nickel content ranges from 1/2 to 3 percent. If garnierite ore of this low grade could be successfully concentrated or treated, there would be a huge potential reserve of nickel in the deposit. Mining of the deposit would involve no unusual problems; the principal obstacle to operation is the difficulty of profitably treating such low-grade ore.

Field work and previous investigations

During September and October 1940, the writers made a detailed study of the mode of occurrence of the nickel and prepared a map of the deposit. The geology of the Riddle quadrangle, in which the deposit is situated, has been described by Diller and Kay,1/ and the nickel deposit has been described by Clarke,2/ Von Foullon,3/ Austin,4/ Ledoux,5/ and Kay.6/

1/ Diller, J. S., and Kay, G. F., U. S. Geol. Survey Geol. Atlas, Riddle folio (No. 218), 1924.

2/ Clarke, F. W., Some nickel ores from Oregon: Am. Jour. Sci., 3d ser., vol. 35, pp. 483-488, 1888; U. S. Geol. Survey Bull. 60, pp. 21-26, 1890.

3/ Von Foullon, H. B., On Riddle, Oregon: K. K. Geologische Reichsanstalt, Jahrb., vol. 42, pp. 224-234, Vienna, 1892.

4/ Austin, W. L., The nickel deposits near Riddle's, Oregon: Colorado Sci. Soc. Proc., vol. 5, pp. 173-196, 1896.

5/ Ledoux, A. R., Notes on Oregon nickel prospects: Canadian Min. Inst. Jour., vol. 4, pp. 184-189, 1901.

6/ Kay, G. F., Nickel deposits of Nickel Mountain, Oregon: U. S. Geol. Survey Bull. 315, pp. 120-128, 1906.

The authors are indebted to F. C. Calkins and H. G. Ferguson, of the Geological Survey, for many helpful suggestions during the preparation of this report. The chemical analyses were made by Victor North, also of the Geological Survey.

Topography

The topography of the Riddle quadrangle is typical of a large part of the Pacific Coast Ranges. The relief is about 3,000 feet. The summit of Nickel Mountain has an altitude of 3,533 feet and rises a few hundred feet above the neighboring ridges. The ridge crests are fairly uniform in altitude and were believed by Diller [7] to represent the widespread Klamath peneplain of late Tertiary age. Dissected erosion surfaces, the chief of which has an elevation of about 2,000 feet, are also recognizable at lower altitudes. In a detailed analysis of the topography of Nickel Mountain, given in a later section, the distribution of the ore is correlated with the topography. The physiographic history of the region has been an important factor in the formation and localization of the nickel deposit.

GEOLOGY

The areal distribution of the rocks in the vicinity of Nickel Mountain is shown on plate 37.[8] A large irregular body of peridotite and serpentine, which extends northeast and southwest from Nickel Mountain, is of principal interest, because the nickel deposits are related to the peridotite. The peridotite and serpentine body is intrusive into Jurassic sandstone and late Jurassic greenstone and related rocks, and is probably late Jurassic. The structure of these older rocks has a predominant northeasterly trend. They are unconformably overlain by the Knoxville formation and younger sedimentary rocks.

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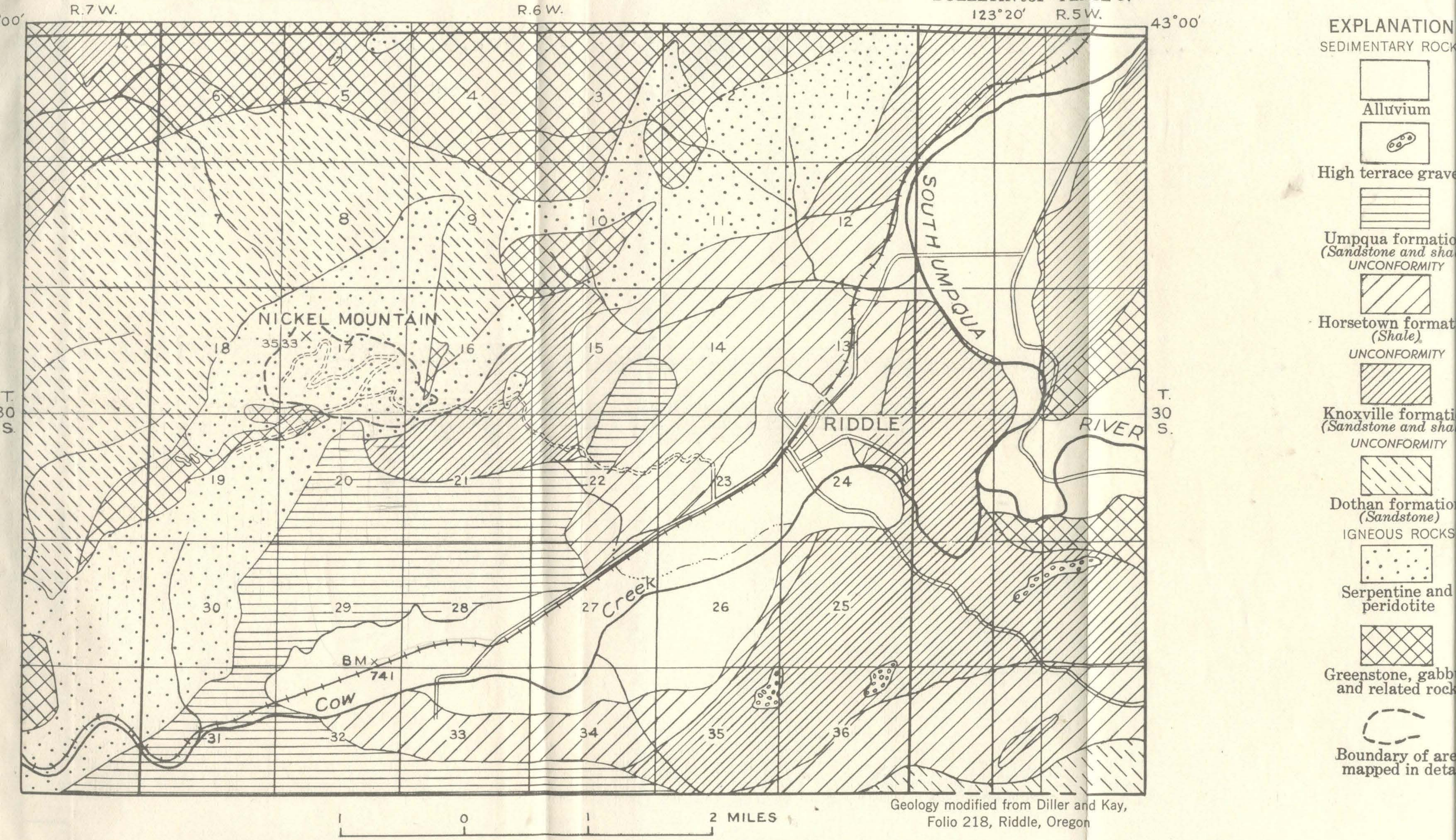
[7] Diller, J. S., Mineral resources of southwestern Oregon: U. S. Geol. Survey Bull. 546, pp. 12-14, 1914.

[8] The geology shown on plate 37 is modified from Diller and Kay, op. cit.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BULLETIN 931 PLATE 37



Geology modified from Diller and Kay, Folio 218, Riddle, Oregon

GEOLOGIC MAP OF THE VICINITY OF NICKEL MOUNTAIN, DOUGLAS COUNTY, OREGON

U. S. GOVERNMENT PRINTING OFFICE: 1942 O - 430320

(Faces p. 208)

Peridotite

In the ultrabasic intrusive mass of Nickel Mountain, peridotite is far more abundant than its derivative, serpentine. This is true of the entire intrusive body as well as the small part shown on plate 38, with which the nickel deposits are associated. In previous geologic reports on this region, "serpentine" is commonly used as a collective term for all the ultrabasic intrusive rocks, but as the nickel ore is associated only with the unserpentinized peridotite, it is essential to discriminate in this report between true serpentine and the peridotite from which the serpentine is derived. The name serpentine is therefore applied only to the serpentinized ultrabasic rocks, and the unaltered rock is called peridotite.

The peridotite is partly dunite and partly saxonite. Dunite contains more than 90 percent of olivine, ($(Mg,Fe)_2SiO_4$), and saxonite contains, with its dominant olivine, as much as 40 percent of the orthorhombic pyroxene enstatite, ($(Mg,Fe)SiO_3$). Dunite and saxonite are not shown separately on the geologic map (pl. 38). Field study revealed no system in the distribution or structural orientation of masses of the two rocks. Although no fine-grained or chilled varieties were seen, large irregular masses of saxonite appear in places to be intrusive into dunite. Probably both rocks were formed in the same intrusive episode, but the saxonite crystallized later than the dunite.

The saxonite and dunite are coarse-grained and hard, and both contain a little scattered chromite, ($FeCr_2O_4$), but the few segregations of chromite are always associated with the dunite. Both rocks are dark yellow green on unweathered surfaces. In weathered outcrops the dunite is brownish green and exhibits a fine-textured lattice-work of joints. The weathered saxonite is dark reddish brown and has a coarse blocky jointing that makes it more resistant to weathering than the dunite, and it is further distinguished by a pitted surface, because the pyroxene in it is more resistant to weathering than the olivine. This feature is especially noticeable where decay of the rock is far advanced, the olivine being completely changed to yellow limonite whereas the pyroxene remains in recognizable crystals.

As the nickel content of olivine is greater than that of enstatite (see table on p. 211), unweathered dunite has a higher nickel content than unweathered saxonite. Under certain conditions of weathering the nickel originally contained in the olivine became concentrated in the nickel-magnesium silicate garnierite, which, together with quartz, forms veinlets in both rocks. These veinlets are more abundant in the dunite than in the saxonite, as the dunite is the more closely jointed. The ratio of garnierite to quartz is also higher in the veins cutting dunite, as the larger olivine content affords a larger supply of nickel.

A brick-red soil which is developed on the surface of the nickel deposits is described in the section that deals with the deposits.

Serpentine

A band of partly or completely serpentinized peridotite, from 10 to several hundred feet in width, separates the unaltered parts of the intrusive body from the older rocks wherever the contact was observed. This border facies of the ultrabasic intrusive rock consists mainly of a black, fine-grained serpentine. In many specimens the pyroxene is unaltered although the olivine is completely serpentinized, but commonly the pyroxene also is serpentinized, being altered to lustrous bronze-colored pseudomorphs of bastite. Some of the partly altered peridotite contains veins of serpentine.

In places within the border zone of the intrusive there are masses of green slickensided serpentine. This material encloses rounded blocks of the black, fine-grained serpentine, from which it evidently was derived. A similar association was observed by Palache [9] in the serpentine of the California Coast Ranges.

Analyses of two samples of serpentine show that it contains more nickel than the olivine samples that have been analyzed (see table below). However, no nickel deposit has been found in serpentine. Both varieties of serpentine weather to a gray-brown soil that is conspicuously different from the soil over peridotite.

Analyses of rocks and minerals from Nickel Mountain

	1	2	3	4	5	6
SiO_2........................	41.43	42.81	....	....	....	....
Al_2O_3........................	.04	Not det.	....	....	....	....
Fe_2O_3........................	2.52	2.61	....	....	....	....
FeO........................	6.25	7.20	....	....	....	....
CaO........................	.55	None	....	....	....	....
MgO........................	43.74	45.12	....	....	....	....
NiO........................	.10	.26	0.32	0.05	0.45	0.33
Cr_2O_3........................	.76	.79	....	....	....	....
Loss on ignition...........	4.41	.57	....	....	....	....
	99.80	99.36	....	....	....	....
Ni........................	.08	.20	.25	.04	.35	.26

1. Peridotite (saxonite) with more than two-thirds olivine. Clarke, F. W., op. cit. (1888), p. 485.

2. Olivine, not entirely free from enstatite and chromite. Clarke, F. W., op. cit. (1888), p. 485.

3. Olivine. Von Foullon, H. B., op. cit., p. 226.

4. Orthorhombic pyroxene ("bronzite"). Von Foullon, H. B., op. cit., p. 226.

5. Serpentine from locality near border east of stock. Von Foullon, H. G., op. cit., p. 233.

6. Serpentine from locality northeast of Nickel Mountain. Kay, G. F., op. cit., p. 126. George Steiger, analyst.

THE NICKEL DEPOSIT

The typical ore [10] of the nickel deposit is a blanket of deeply weathered peridotite, now almost entirely altered to limonite, which is host to an intricate lattice boxwork of quartz-garnierite veins. The deposit was formed during the weathering

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[9] Palache, Charles, Lherzolite and associated rocks of the Potrero, San Francisco: California Univ., Dept. Geology, Bull. 1, pp. 161-180, 1894.

[10] The term "ore" is not used here in the strict sense, being applied for convenience to material not rich enough to be worked profitably, in place of such cumbersome phrases as "potential ore", "nickel-bearing material".

of the unserpentinized peridotite upon which it rests, by a twofold supergene process which involved the release of nickel from the primary minerals and its combination in nickel-poor secondary minerals under a humid tropical climate, and its subsequent concentration in nickel-rich garnierite under a humid temperate climate. The deposits are the remains of a once more extensive blanket, which probably at one time covered most or all of the peridotite in the area. Landsliding, rill wash, and slope wash have stripped parts of the deposit from the unweathered peridotite. The weathered blanket is constantly undergoing further chemical change, so that in small areas further enrichment in nickel is being effected, apparently by the breaking down of early formed garnierite that contains relatively little nickel and the formation of nickel-rich garnierite and quartz. Garnierite does not seem to be forming directly from the peridotite under present climatic conditions.

Mineralogy

The principal minerals of the nickel deposit are garnierite (hydrous nickel-magnesium silicate), quartz, chalcedony, and chert (three varieties of silica), and limonite (hydrated iron oxide). A small quantity of chromite ($FeCr_2O_4$) and manganese oxide are also present.

Garnierite.--The garnierite ranges in color, even in the same vein or hand specimen, from yellowish green through apple green to blue green. The darkest variety, which presumably has the highest nickel content, occurs in some places as veinlets in the yellowish-green variety. When the mineral is wet it is darker-colored than when it is dry. Some of it then crumbles under slight pressure, and some spreads like paste. The dry garnierite is soft but brittle, and will adhere to the tongue. Analyses of garnierite from Nickel Mountain are shown in the table on page 213.

Analyses of garnierite from Nickel Mountain

	1	2	3	4
SiO_2	44.73	48.21	40.55	48.82
$Al_2O_3 + Fe_2O_3$	1.18	1.38	1.33	.06
MgO	10.56	19.90	21.70	18.49
NiO	27.57	23.88	29.66	19.04
H_2O+	6.99	6.63	7.00	12.29
H_2O-	8.87			
	99.90	100.00	100.24	98.70
Ni	21.67	18.77	23.31	14.97

1. Clarke, F. W., op. cit. (1888), p. 484.
2 and 3. Blake, W. P., Nickel: Mineral Resources U. S., 1882, p. 404.
4. Von Foullon, H. B., op. cit., p. 272. (Apple-green garnierite.)

Enriched garnierite.--Much of the garnierite of the main ore zone shows evidence of recent enrichment in nickel through the breakdown of an earlier-formed, nickel-poor variety. Near the base of the decomposed mantle rock a greenish-yellow to colorless variety of garnierite has been found in partly weathered dunite. This material is always below the ore and is well-exposed along the road bed and road cuts in the southeastern part of the deposit, in some places on the steep slopes in fresh peridotite, and on the bed-rock areas of the summit of Nickel Mountain. Quartz and green garnierite are both absent or rare at these localities, but if one is present, the other is also. Both enriched garnierite and quartz may occur as veins in the pale garnierite, but the quantity of the enriched material increases toward the surface and develops a network of cross-cutting quartz-garnierite veins. This is well shown at the Discovery and West Workings. The order of formation in all places is from pale garnierite to deeper-colored garnierite, and a rude zoning indicates a progression from pale varieties at depth to deeper-colored varieties toward the surface. This indicates a process of supergene nickel enrichment in garnierite, and the pale, unenriched garnierite, which is accompanied by limonite, is believed to be the source of both the nickel and the silica concentrated by the recent enrichment process.

Quartz.--The quartz which is persistently associated with the garnierite in the boxwork veins is commonly white and fine-grained. The quartz of the thin, flaky veinlets in the garnierite is porcellaneous, while that of the thicker veins is coarser and partly brownish. Brown chalcedony or cherty silica is common near the surface of the deposit. Quartz is generally more abundant than garnierite in the boxwork, but its relative abundance decreases downward from the surface.

Limonite.--Most of the limonite is soft and easily removed from the boxwork, but at a few places near the surface part of the limonite is silicified to a brown, chert-like mass. One sample of limonite from between the quartz-garnierite veins of the boxwork contained about 1 percent of nickel.

Layers of the deposit

The nickel deposit is layered, as is well shown in the vertical section exposed at the Discovery workings and represented in figure 21. A top layer of brick-red soil, 2 to 3 feet thick, covers the main layer, 40 feet thick, of quartz-garnierite boxwork in limonite. Locally the boxwork layer contains "boulders" of peridotite, which are incompletely altered residuals. The base of the boxwork layer is very irregular, but is approximately parallel to the hill slope. Below the boxwork layer is the basal or root layer. In it prongs of the peridotite project upward, and, conversely, roots of the boxwork project downward into fresh peridotite. The maximum depth of boxwork roots in peridotite is not known but is estimated to be about 150 feet.

Brick-red soil layer

The top layer of the deposit averages 2 to 3 feet in thickness and ranges from a thin veneer up to 9 feet. It consists of brick-red soil, soft and incoherent, containing small round pellets of red iron oxide and, at the surface in a few places,

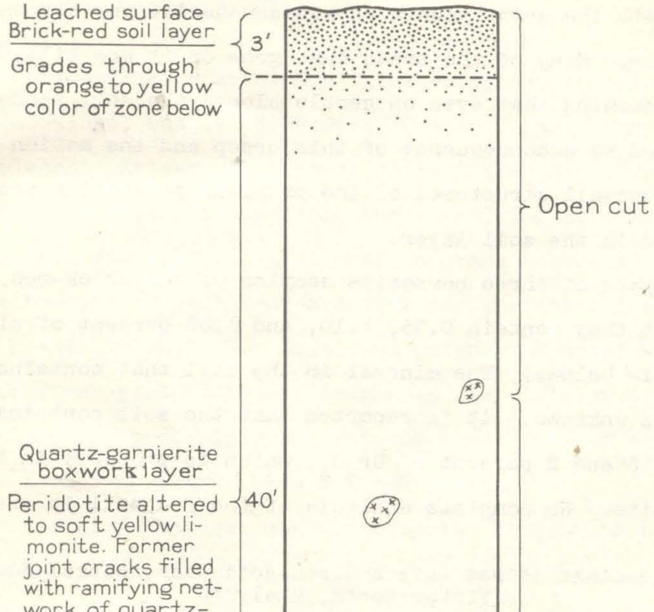

Figure 21.--Diagrammatic sketch of a vertical section of the mineral deposit at the Discovery workings.

small pieces of dull quartz or larger fragments of spongy quartz. The quartz, which is commonly stained with much manganese oxide, is a residue of weathered boxwork, and hence may be an excellent guide to unexposed boxwork ore.

The brick-red soil layer, originally derived from peridotite, supports a moderately heavy growth of vegetation, which contrasts with the scant growth on areas underlain by serpentinized peridotite. Many of the trees that grow on it are tilted and curved, showing that even on gentle slopes the soil tends to creep, and as a consequence of this creep and the action of plant roots all structures of the original peridotite are obliterated in the soil layer.

Analyses of three composite samples of the brick-red soil show that they contain 0.95, 1.10, and 1.02 percent of nickel. (See table below.) The mineral in the soil that contains the nickel is unknown. It is reported that the soil contains between 0.75 and 2 percent of Cr_2O_3, which is probably in the form of chromite. No complete analysis of the red soil is available.

Nickel content of red soil and red-soil wash, Nickel Mountain
[Victor North, analyst]

Sample No.	Description	Location	Ni (percent)
1	Red-soil wash.......	Composite samples from surface southeast of the Discovery area.	0.61
2			.71
3	Brick-red soil......	Composite sample from surface near summit of Nickel Mountain.	.95
4	....do..............	Composite sample from surface of 2 acres around Discovery shaft.	1.10
5	....do..............	Channel sample at Discovery open cut, 4 ft. below surface, 3 ft. above boxwork ore.	1.02

Wash derived from the brick-red soil layer of the upper slopes partly covers terraces and the bottoms of small valleys on the lower slopes of Nickel Mountain. Analyses of two composite samples of this wash material collected southeast of the Discovery area (see pl. 38 and fig. 22) show that they contain 0.61 and 0.71 percent of nickel. The wash also contains very small grains of chromite.

Quartz-garnierite boxwork layer

The boxwork layer attains a thickness of 40 feet at the Discovery workings, but it is between 10 and 20 feet thick in most other places. At several places, boxwork ore can be seen to project downward like roots into the underlying peridotite. This is well shown at the West shaft where a narrow irregular root of boxwork extends downward from the surface for at least 85 and possibly 100 feet. Scattered patches of boxwork ore in areas of fresh peridotite are common in the vicinity of the main ore bodies, and probably represent the lower ends of the root zone of a once more extensive boxwork layer.

Two striking features characterize the boxwork in both the boxwork layer and the roots: (1) The intimate quartz-garnierite veins form a honeycomb in yellowish, hard or soft limonitic material weathered from peridotite, and (2) local fractures and fracture veins with slickensided walls are common.

Boxwork veins.--Individual veins in the boxwork layer consist mainly of intergrown quartz and garnierite, and they range from paper-thin sheets to veins 2 inches or more in thickness. Quartz commonly forms the walls of the veins and encloses the garnierite, but it also forms intricate networks of very thin, white, porcellaneous veins in the nickel mineral. The relative proportions of the two minerals in the veins vary greatly from place to place. The boxwork layer on the north face of the Discovery open pit, which is exceptionally rich in garnierite, is estimated to contain 5 percent of garnierite, 15 percent of quartz, and 80 percent of limonite. Here, the boxwork layer averages between 3 and 4 percent of nickel. Elsewhere, garnierite commonly makes up 5 to 10 percent of the individual boxwork veins, but less in the veins near the surface in which leaching or rain wash have been active. Below the surface the veins are compact, but near and at the surface they contain open spaces whose walls are coated with brown-stained quartz. Brown quartz locally replaces the white quartz.

The garnierite varies in color and composition in the same vein. Green is the predominant color, and the shade of green is darker when the boxwork is wet. Both the percentage of garnierite in the veins and the nickel content of the mineral itself must be estimated before any evaluation of a boxwork exposure can be made by inspection in the field.

In some places the boxwork, naturally exposed on the surface, is almost entirely leached of its garnierite, and there remains a heavy, spongy mass of brown and white quartz. When this leached outcrop material is broken, small angular or rounded fragments of garnierite are frequently found within the protective quartz. Much of the boxwork ore of the dump piles also shows this feature. The exposed garnierite is more easily washed from the boxwork by rain than leached by the chemical activity of the water. Large masses of the sponge-quartz outcrops are exposed on the surface of the gentle slope immediately below the summit. Prospect pits prove conclusively that such leached outcrops can be used as guides for location of unexposed boxwork ore, but it is reported that the boxwork ore exposed beneath such leached outcrops contains less than 2 percent of nickel.

Joints and fractures in the fresh peridotite have been the main factor in controlling the pattern as well as the thickness of the veins. The coarse rectangular joint plan of the saxonite supports a very coarse boxwork. The largest observed joint block of saxonite is about 4 feet in diameter, many are 1 to 2 feet, but most of the blocks are only a few inches across. The thickness of the individual veins of the boxwork varies in proportion to the size of the joint blocks that the veins enclose. The thickest of the veins of the boxwork are about 2 inches; the thinnest are mere films a fraction of an inch across. The individual cells of the boxwork frequently contain a core of unweathered peridotite in a soft limonitic matrix, and this relationship is evidence of the process by which the peridotite was altered to form the ore. The closely spaced joints of the dunite, on the other hand, support a finer-textured boxwork of thinner septa; the joint blocks are rarely more than an inch across, are completely weathered, and are enclosed in a lacework of quartz and garnierite.

The limonite interstitial to the boxwork veins is soft and crumbly in the boxwork layer but is hard and compact at some places in the boxwork roots. A carefully collected sample, weighing about an ounce, of soft limonite from the boxwork deposit at the portal of the Discovery adit contained 1.3 percent of nickel (see table on p. 220).

Fracture veins.--Open fractures are numerous in the boxwork ore and also in the peridotite that contains the boxwork root. Brown and white quartz and light- to dark-green garnierite form veins along these fractures, and both minerals show slickensides. The thickest vein, observed at the West shaft, ranges in thickness from 6 inches to a foot in a distance of 30 feet. Some fragments of the vein on the dump are 14 inches wide and consist predominantly of white and brown quartz, which encloses scattered small pellets of garnierite. The brown quartz is banded and flinty and clearly replaces the white quartz. Some cavities in quartz are lined with mamillary crusts of dark-green garnierite and brown quartz.

Along some parts of the veins apple-green to blue-green garnierite has been deposited. The thickest vein of garnierite was observed on the south wall of the West open cut, where it ranged in thickness from 1 to 3 inches in a distance of 15 feet. The veins are not persistant in depth and commonly extend less than 20 feet along the strike. Boxwork is characteristically present in the wall rock and at the edges of the fracture veins.

The attitude of the veins in the deposit is not systematic. Low dips are commoner than high ones for veins near the surface, but high dips are most characteristic for fracture veins in the roots. Where slickensides are present, movement is indicated in a direction down the present slopes of Nickel Mountain. The fractures that contain the fracture veins are possibly results of slumping, landsliding, or local collapse of the mineral deposit.

Nickel content of samples from boxwork and root zone, Nickel Mountain
[Victor North, analyst]

Sample No.	Description and Location	Ni (percent)
1	Limonite between boxwork, portal of Discovery adit.	1.31
2	Rich pocket of garnierite ore from fracture vein in west wall of Discovery shaft.	8.09
3	Composite of five channel samples of boxwork ore from walls of Discovery open pit, representative of upper 15 ft. of boxwork.	2.07
4	Composite sample from 30 ft. of boxwork ore in Discovery shaft.	2.81
5	From bottom 5 ft. of Discovery shaft; part boxwork ore and part peridotite.	1.84
6	Composite sample from outer 150 ft. of Discovery adit; part boxwork ore and part peridotite.	2.06
7	From breast of Discovery adit, 175 ft. from portal; part boxwork ore and part peridotite.	1.35
8	Composite sample from upper 35 ft. of West shaft; mostly boxwork ore.	1.94
9	From bottom 4 ft. of West shaft (84-88 ft. below surface); mostly peridotite with films of garnierite and glassy quartz along fractures in rock.	.83
10	Composite sample from outer 155 ft. of West adit; mostly boxwork.	1.04
11	Composite sample from inner 145 ft. of West adit (to face at 300 ft. from portal); mostly peridotite.	.34

Root layer

The lowermost part of the blanket of ore is a zone in which root-like extensions of the boxwork material above penetrate the underlying fresh peridotite. The zone is very irregular and marks the transition from ore to bedrock. The boxwork roots project downward into the fresh peridotite to an unknown depth.

In the boxwork deposits of the West area and of the steep slope northwest of the Discovery deposit, which are interpreted as parts of the root zone, the greatest known depth of the roots is about 85 feet. This figure depends on the fact that the breast of the West adit, which lies about 40 feet directly below the bottom of the West shaft, is in partly weathered peridotite with thin flakes of quartz and garnierite.

Only the boxwork roots need be explored in the root zone. Except where enrichment has taken place, the boxwork roots reportedly contain less than 1 percent of nickel.

Origin

Relation to slopes

It is generally recognized that the best deposits of garnierite lie on terraces and gentle slopes at altitudes above 2,000 feet, and such ground therefore has been the most thoroughly prospected. (See fig. 22.) Some terraces cut on fresh peridotite below 2,000 feet, are mantled with wash, consisting partly of boxwork and partly of red soil derived from upper slopes. The West area and the steep slope northwest of the Discovery area contain root deposits of a former gentle surface of higher elevation which, before erosion to the present slope, was probably rich in boxwork ore. Debris from the West area boxwork is abundant on a 2,500-foot terrace west of the mapped area of plate 38.

The dissected terrace at 2,000 feet is part of a widespread erosion surface, and it is evidently much older than the stream terraces, at least 500 feet lower, from which Pleistocene vertebrate remains have reportedly been collected. The deposits are probably not much younger than the 2,000-foot terrace, for no garnierite and limonite layer is known to have formed on any terrace cut on peridotite below the 2,000-foot terrace level. All local terraces in peridotite between 2,000 feet and the

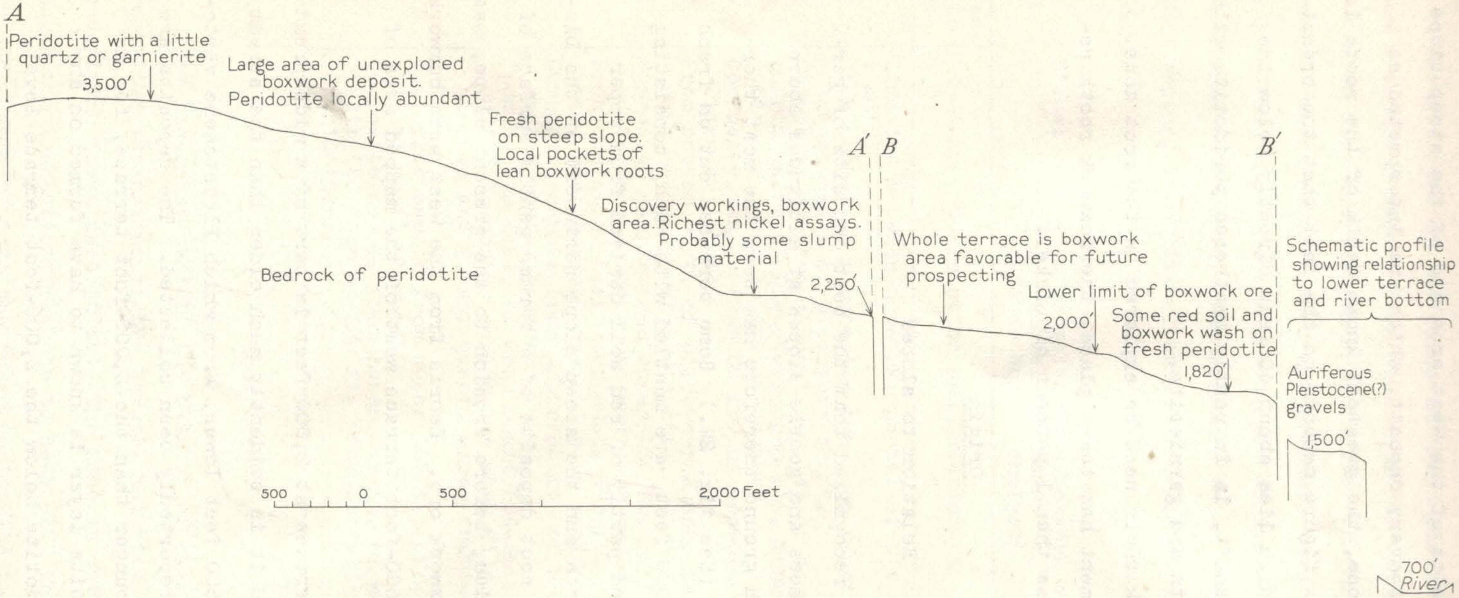

Figure 22.--Composite and schematic profile of the southeast side of Nickel Mountain and the adjacent area, showing relationship of ore to topography.

summit of Nickel Mountain, on the other hand, have deep roots of boxwork ore. The writers therefore believe that the weathering of peridotite to a lateritic soil made up chiefly of limonite and nickel-poor garnierite took place during the time interval, probably late Tertiary, in which the Klamath Upland Surface was uplifted and dissected, to form ultimately a widespread mature erosion surface whose base level in the area near Nickel Mountain is now represented by the 2,000-foot terrace. According to this interpretation, the present nickel deposit is largely a partially reworked remnant of a lateritic soil blanket, which originated in late Tertiary time, and no further weathering of this kind occurred in the peridotite that was later exposed by dissection of the 2,000-foot terrace.

Formation of boxwork

Either of two conditions may have produced a deeply weathered limonitic blanket on the peridotite during the formation of the late Tertiary 2,000-foot erosion level: (1) climatic conditions differing from that of later, presumably Quaternary time, or (2) longer weathering under the same climatic conditions. The writers favor the first alternative, and believe that the late Tertiary weathering was lateritic. A humid and tropical to subtropical climate would produce laterite on a peridotite surface of low relief. While the olivine was decomposing under these conditions, magnesium, nickel, and silica combined with water to form nickel-poor garnierite, and iron oxidized to form limonite. In true laterites, quartz is not precipitated within the deposit.

Under Recent humid-temperate climatic conditions new laterite did not form, but the laterite already formed became further altered. Decomposition of garnierite at the surface released silica, magnesium, and nickel. Much of the silica was precipitated as quartz, some magnesium was leached and lost, and much nickel was redeposited lower down to form green nickel-rich garnierite associated with quartz. In the root zone the nickel-poor garnierite has been partly decomposed and enriched in place.

The quartz-garnierite boxwork is therefore attributed to Recent weathering of the lateritic product of Tertiary weathering. Garnierite and quartz are being deposited at the present time along fractures in peridotite below the boxwork.

Both Von Foullon [11] and Kay [12] have argued that garnierite was formed by the weathering of serpentine derived from peridotite; and Austin [13] believed that the quartz-garnierite veins were of hydrothermal origin. In the writers' opinion, on the contrary, field evidence strongly indicates that the garnierite was derived from peridotite rather than serpentine and deposited, together with quartz, by a secondary supergene rather than hydrothermal action.

Reserves

Grade

Under present conditions, garnierite ore containing less than 5 percent of nickel cannot be worked profitably. Most of the deposit at Nickel Mountain contains only 1 or 2 percent of nickel, and only a relatively small part, reckoned in minable tonnages, contains as much as 2 to 3 percent.

Calculations from samples totaling a few hundred pounds indicate that the boxwork ore at the Discovery workings contains between 2 and 3 percent of nickel, but representative samples of boxwork ore from other parts of the deposit contain less than 2 percent of nickel. Samples weighing a few pounds and containing 3 to 5 percent or more of nickel can indeed be collected--one taken by the writers from the richest pocket of garnierite ob-

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[11] Von Foullon, H. B., op. cit.
[12] Kay, G. F., op. cit.
[13] Austin, W. L., op. cit.

served contains 8.09 percent of nickel--but these samples are not representative. The results of the writers' sampling indicate that the nickel content of the deposit is lower than has been reported. Kay,[14] for example, states that two specimens, collected as representing average boxwork ore, contained 5.35 and 4.94 percent of nickel, and that about 20 tons of ore, shipped by the Oregon Nickel Mines Co. for experimental purposes, was reported by the company to contain between 5 and 8 percent of nickel.

Estimates of tonnage

At the Discovery shaft, adit, open cut, and adjacent trenches there is a proved minimum of 80,000 tons[15] of boxwork ore in which the nickel content is estimated to be at least 2 but not more than 3 percent. In the area surrounding the Discovery open cut there is probably at least 200,000 tons of the same grade. The exposures over a wider area about the Discovery workings indicate that there is probably about 2,000,000 tons

Estimated tonnage of nickel ore at Nickel Mountain

Location	Proved ore (tons)	Probable ore (tons)	Estimated Ni content (percent)
Boxwork:[1]			
Discovery workings........	80,000	200,000	2 to 3
West workings.............	50,000	....	1 to 2
Miscellaneous trenches, pits, short adits, dumps	25,000	....	1 to 2
Discovery area............	......	2,000,000	1 to 2
West area.................	......	500,000	1 to 2
Upper area................	......	3,000,000	1 to 2
Brick-red soil:[2]			
Discovery area............	......	240,000	½ to 1½
West area.................	......	48,000	½ to 1½
Upper area................	......	300,000	½ to 1½

[1] Boxwork calculations based on 20 cu. ft. per ton.
[2] Red soil calculations based on 25 cu. ft. per ton.

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[14] Kay, G. F., op. cit., p. 124.

[15] Calculations of boxwork ore are based on an estimate of 20 cubic feet per ton.

more material with a nickel content of 1 to 2 percent. Further prospecting within this promising area might justify a higher estimate.

At the West workings, the shaft, open cuts, and adit develop a proved minimum of 40,000 tons of boxwork ore, and at the open cuts north of the West adit there is at least 10,000 tons of proved ore, having a nickel content between 1 and 2 percent. The probable ore in the area about the West workings amounts to about 500,000 tons, of the same grade.

Scattered pits, trenches, short adits and dump piles partly block out about 25,000 tons of boxwork ore containing between 1 and 2 percent; this also may be regarded as proved ore.

For the large area east of the West workings, the estimate of probable ore is 3,000,000 tons with a grade of 1 to 2 percent. Much of this area is as yet unexplored, so that a larger tonnage is possible. In some places, however, the boxwork ore may contain less than 1 percent and in others more than 2 percent.

In all, the Nickel Mountain deposit contains more than 6,000,000 tons of boxwork ore, composed of limonite, quartz, garnierite, and chromite, with a nickel content of 1 percent or more. There is, in addition, over 600,000 tons of brick-red soil containing 1/2 to $1\frac{1}{2}$ percent of nickel.

The deposit can be mined by power shovels at low cost, but a new method of treating nickel silicate ores or a great increase in the price of nickel would be required to make mining of the deposit profitable.

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State Department of Geology and Mineral Industries

702 Woodlark Building
Portland, Oregon

NICKEL MOUNTAIN

Riddle Area

Freeport Sulphur is exploring the nickel deposits here. Old workings have been cleaned out, particularly the adit and shaft at the "Discovery" and the 80 foot shaft and the lower adit at the "West area". In addition drilling has been started.

Climax Molybdenum drilled a north-south line of holes through the "Discovery" area on 400 foot centers, about 1938 or 1939. Hobbs and Pecora did not mention this work and it is doubtful if they knew of it. Freeport has started a line of holes 400 feet west, on 400' centers, and will continue to explore on that basis. The Climax work consisted of three holes, the deepest being 130 feet. The weighted average assay was 1.87 percent nickel.

Recent Freeport drilling proved nickel in this peridotite at a depth of 125 feet, - a zone 5 feet thick. Minor showings were found at 155 feet.

Certain observations were made at the time of the visit. They are recorded here for what they are worth, in an effort to evaluate Hobbs and Pecore's (H & P) observations and conclusions. A study of their paper is advisable.

Red soil seems to average remarkably uniform in nickel when nickel is present; both in the cover over the terraces and in "wash" at lower elevations according to H. & P. What does this indicate relative to supergene enrichment? Perhaps the present nickel showings represent a once continuous blanket that covered the Mountain, - later eroded into present terraces. (suggested by Dave Evans). H. & P., 42:214 state that the limonite enclosed in the boxwork assays about 1% nickel. This is very similar to the percent of nickel in the red soil. They also say that the abundance of quartz in garnierite decreases downward, yet we found silica being deposited, right now, in the lower rock.

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On p. 213 H. & P. mention a progression of paler varieties of garnierite to darker varieties toward the surfaces and that the darker colors represent richer material. In the lower adit, "West area", this is not true as dark garnierite is abundant in seams in the peridotite.

On p. 214, H. & P. state that brown cherty silica is more abundant nearer the surface, but I found abundant brown cherty silica in the lower adit, "West area", and have some beautiful specimens to prove it.

The above observations suggest difficulties with the H. & P. theory of origin and the apparent "upward" movement of silica and nickel in the second stage. Another suggestive feature is the similarity in nickel assays of the red soil and of the limonite between the boxwork. If the second stage is a re-concentration it is odd that that "matrix" should be so uniform in nickel content.

Some observations about silica were made. There is little silica in the red soil, except cellular masses that probably have worked up from the limonite zone like large rocks work upward in a gravelled road. Silica is abundant as box work in the limonite zone. Silica gel is being deposited at the present time in the peridotite, as evidenced by the gel on mine timbers and along joint cracks in the lower adit, "West area". Whether nickel is being deposited with the gel is not known.

The points of the above discussion is that silica apparently is moving downward. If the overlying limonite and red soil is true laterite it should be deficient in silica Might there be a possibility that both silica and nickel are being leached from the peridotite at the present time.

A factor overlooked by H. & P. was the flat top of a portion of Nickel Mountain. This area is covered with a red soil of unknown depth. Outcropping peridotite frequently has cellular quartz on its surfaces. Some of this quartz shows garnierite.

Reference: H. & P. = Hobbs, S. Wgrren, and Pecora, William T., Nickel deposits near Riddle, Douglas County, Oregon: U.S.G.S. Bull. 931-I.

Informant: Ray C. Treasher, trip of July 30, 1942.

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Portland, Oregon

OREGON NICKEL MINES Riddle Area.

Owner: CONFIDENTIAL.

Location: sec. 17, T. 30 S., R. 6 W., with the main nickel deposits in the south half of sec. 17, covering the summit and south side of Nickel Mountain, plus two mining claims that lie partly in SW¼, sec. 17 and SE¼ sec.18.

Area: 640 acres, plus fractions of two mining claims.

History: see Bulletin No. 14-C, Vol. 1, under Nickel Mountain.

Development: A great number of test pits, trenches, etc. There are two main sets of workings; a lower pit at elev. about 2600' and an upper pit at an elev. of about 3200' on the north side.

Lower Pit: consists of a 100' adit and a 35' shaft as well as a quantity of surface pit around the group. (see photographs)

Upper Pits: a series of test trenches, an 80' shaft, a 300' adit now caved about 100' from the portal. There is another group of pits and trenches about 600' E-NE of the upper pit.

Smelter: Foundations were laid for a smelter well below the workings. Remains of the foundations may still be seen. It is reported that the brick were burned from the red soil "and that nickel sweated out of the bricks during burning". The smelter was never completed. Most of the workings were done by the former company. The present holders are sampling all workings and adding data from drill holes and new locations.

Geology: The area is underlain by ultra basics, probably peridotite, with a small amount of serpentine. A mahogany-red soil develops above the peridotite. In many cases the red soil is underlain by an ocherous mass, similar to gossan, that is cut by the light green genthite. Time spent did not permit any conclusions as to structure.

At the "lower pit", genthite is found in the ocherous gossanoid material, wh ere it occurs as narrow, discontinuous veinlets and small to larger masses. Apparently, nickel silicates penetrated the ocheroid masses along fracture planes and, in part, replaced the iron oxide. In the 35' shaft, and at the portal of the adit, the concentration of genthite is greater and is classed as "high-grade".

In the "upper pit", the siliceous nature of the genthite is more pronounced. Large masses of "opal", or chalcedony stained by genthite, are common. These masses are quite resistant and weather out of the ocher; their surfaces are quite rough and reflect all the fine irregularities of the ocher in which it occurs. There are masses of "high-grade" genthite, grading into chalcedony which may have a greenish to pinkish cast. In addition, there are the narrow veinlets and smaller masses seen at the "lower pit".

Brevity of the inspection does not justify definite conclusions. However, my impressions are given, subject to change with additional work:

It is reported that the peridotite carries 0.05% Ni. The peridotite weathered and produced a gossan (this doesn't sound right, I know) which in turn weathered to

Geology (continued)

a mahogany-red soil. The weathering process released silica, which picked up nickel and deposited it through the ocher, or gossan, as genthite. When sufficient nickel was absent, the silica was deposited as chalcedony. The mahogany-red soil did not permit penetration of silicates, and the residual nickel is left in it. Just why and how all these things happened is not at all clear, if they did happen this way.

Reported analyses by new company: The peridotite contains 0.05% Ni on the average. The mahogany-red soil contains an average of 0.75-1.25% Ni. The light greenish genthite averages 1.25-3.25% Ni. On the assay map I saw only one assay less than 0.7% Ni. In the "lower pit", the 35' shaft averages 3+% and the rest of the area in the pit from 1.25-3%. Three drill holes show a depth of around 100 ft. (?) to peridotite bedrock, and the average is 2+%. In the "upper pit" the 80' shaft is in ore and, as I remember it, averages 2+% with the best ore at 35'. Other assays in the area are also good. The two "pits" have 700' difference in elevation and are ½ mile apart (2.4 miles by road.)

An area E-NE of the upper pit was tested at the surface and all went above 1%.

According to A. E. Hepburn, their company figures an ore reserve of a quarter million tons. I can't quite see that they've proven this much ore, but it may well be that it is indicated. Hepburn states that 2% ore can go directly to the furnace without concentration. However, his story didn't always check on this point. He claims that their big problem is to concentrate the red soil low grade and the genthite low grade so it can all be mined open pit and shovel. He says that electrostatics and leaching are being tried. If a concentrating process can be devised, their company is ready to shoot.

Apparently, sulfur is needed in the process. He proposes to work the Silver Peak Mines, roasting the sulfide ores to produce sulfur, and later recovering the Cu and Zn.

I can't quite type Hepburn. He claims to represent Requa of Idaho Almaden, and other reports indicate that Requa has been at Nickel Mountain and Silver Peak. Yet so much of his stuff sounds "crackpot". I'd like to know what Hepburn's status is!

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Samples: The "low-grade" is the mahogany-red soil from the "lower pit". Hepburn says this is their real problem. The other sample is the gossanoid materail that also needs concentrating--yet, according to another Hepburn-story, 2% ore is smelter feed. The large chunks are "high grade" from the "lower pit" and may assay over 5%, in part.

Informant: Ray C. Treasher with A. E. Hepburn, Sept. 16, 1941.

Report by: R.C.T.

State Department of Geology and Mineral Industries

702 Woodlark Building
Portland, Oregon

Report by: Ray C. Treasher

Date: Aug. 10, 1943

Nickel Mountain (nickel)

Riddle area
Douglas Co.

Mr. O. D. Rohlfs, Principal Mining Engineer, Ferro-Alloys Branch, W.P.B., Washington, D. C. had requested that I take him to visit the Freeport Sulphur Co. property at Nickel Mtn. He arrived at 12:39 p.m. Sat., July 31st, with Mrs. Rohlfs, and they were taken to Nickel Mtn. and to Roseburg at 11:58 pm.

The access road is open about half way between the Discovery area and the West area. We went to the West area, looked at the shaft and entered the 300 foot adit. Rohlfs secured some excellent specimens. Note was made of garnierite in a narrow shear zone on the N. side near the floor, and as thin crusts along joint planes. We next visited the Discovery area, entered the adit and the shaft.

Rohlfs had Climax Moly. drilling data, but no Freeport data. In the West adit, about 2% for 100 ft. and then less than 1%, after fairly solid rock is encountered. At Discovery adit, 3% for 75 feet and then 1 to 1.5% in harder rock. Discovery shaft, up to 4% for 20 feet, and then the grade drops. Climax drill holes show erratic values but little below 30 ft.

Nickel seems confined to brown, soft zone and to depths of 30 feet. Even this will be erratic. The limonitic material of the "boxwork" may carry 1½ %. The red soil may carry up to

(2)

3/4 % Mineralization is spotty. I'd be interested in Freeport's drilling results.

Some geologists prefer a hydrothermal origin for the garnierite, which theory I cannot see at all. Neither can I see laterization, with all the silica that is obviously present. Ralph Taylor (Freeport) collected silica gel, in the process of formation in the West area adit. I believe the silica, nickel, etc., came from the decomposition of the peridotite, in situ.

Rohlfs said that W.P.B. is interested in New Caledonian ores. Three furnaces are in operation. W.P.B. plans on a fourth furnace either at the mines, or in San Francisco. In event S. F. is chosen, domestic garnierite of plus 3% grade will be acceptable. Rohlfs idea is that if Freeport gives up their lease, W.P.B. might be interested in High-grading the deposit.

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Owner: CONFIDENTIAL.

Location: sec. 17, T. 30 S., R. 6 W., with the main nickel deposits in the south half of sec. 17, covering the summit and south side of Nickel Mountain, plus two mining claims that lie partly in SW¼, sec. 17 and SE¼ sec.18.

Area: 640 acres, plus fractions of two mining claims.

History: see Bulletin No. 14-C, Vol. 1, under Nickel Mountain.

Development: A great number of test pits, trenches, etc. There are two main sets of workings; a lower pit at elev. about 2600' and an upper pit at an elev. of about 3200' on the north side.

Lower Pit: consists of a 100' adit and a 35' shaft as well as a quantity of surface pit around the group. (see photographs)

Upper Pits: a series of test trenches, an 80' shaft, a 300' adit now caved about 100' from the portal. There is another group of pits and trenches about 600' E-NE of the upper pit.

Smelter: Foundations were laid for a smelter well below the workings. Remains of the foundations may still be seen. It is reported that the brick were burned from the red soil "and that nickel sweated out of the bricks during burning". The smelter was never completed. Most of the workings were done by the former company. The present holders are sampling all workings and adding data from drill holes and new locations.

Geology: The area is underlain by ultra basics, probably peridotite, with a small amount of serpentine. A mahogany-red soil develops above the peridotite. In many cases the red soil is underlain by an ocherous mass, similar to gossan, that is cut by the light green genthite. Time spent did not permit any conclusions as to structure.

At the "lower pit", genthite is found in the ocherous gossanoid material, where it occurs as narrow, discontinuous veinlets and small to larger masses. Apparently, nickel silicates penetrated the ocheroid masses along fracture planes and, in part, replaced the iron oxide. In the 35' shaft, and at the portal of the adit, the concentration of genthite is greater and is classed as "high-grade".

In the "upper pit", the siliceous nature of the genthite is more pronounced. Large masses of "opal", or chalcedony stained by genthite, are common. These masses are quite resistant and weather out of the ocher; their surfaces are quite rough and reflect all the fine irregularities of the ocher in which it occurs. There are masses of "high-grade" genthite, grading into chalcedony which may have a greenish to pinkish cast. In addition, there are the narrow veinlets and smaller masses seen at the "lower pit".

Brevity of the inspection does not justify definite conclusions. However, my impressions are given, subject to change with additional work:

It is reported that the peridotite carries 0.05% Ni. The peridotite weathered and produced a gossan (this doesn't sound right, I know) which in turn weathered to

Geology (continued)

a mahogany-red soil. The weathering process released silica, which picked up nickel and deposited it through the ocher, or gossan, as genthite. When sufficient nickel was absent, the silica was deposited as chalcedony. The mahogany-red soil did not permit penetration of silicates, and the residual nickel is left in it. Just why and how all these things happened is not at all clear, if they did happen this way.

Reported analyses by new company: The peridotite contains 0.05% Ni on the average. The mahogany-red soil contains an average of 0.75-1.25% Ni. The light greenish genthite averages 1.25-3.25% Ni. On the assay map I saw only one assay less than 0.7% Ni. In the "lower pit", the 35' shaft averages 3+% and the rest of the area in the pit from 1.25-3%. Three drill holes show a depth of around 100 ft. (?) to peridotite bedrock, and the average is 2+%. In the "upper pit" the 80' shaft is in ore and, as I remember it, averages 2+% with the best ore at 35'. Other assays in the area are also good. The two "pits" have 700' difference in elevation and are ¼ mile apart (2.4 miles by road.)

An area E-NE of the upper pit was tested at the surface and all went above 1%.

According to A. E. Hepburn, their company figures an ore reserve of a quarter million tons. I can't quite see that they've proven this much ore, but it may well be that it is indicated. Hepburn states that 2% ore can go directly to the furnace without concentration. However, his story didn't always check on this point. He claims that their big problem is to concentrate the red soil low grade and the genthite low grade so it can all be mined open pit and shovel. He says that electrostatics and leaching are being tried. If a concentrating process can be devised, their company is ready to shoot.

Apparently, sulfur is needed in the process. He proposes to work the Silver Peak Mines, roasting the sulfide ores to produce sulfur, and later recovering the Cu and Zn.

I can't quite type Hepburn. He claims to represent Requa of Idaho Almaden, and other reports indicate that Requa has been at Nickel Mountain and Silver Peak. Yet so much of his stuff sounds "crackpot". I'd like to know what Hepburn's status is!

Samples: The "low-grade" is the mahogany-red soil from the "lower pit". Hepburn says this is their real problem. The other sample is the gossanoid materail that also needs concentrating--yet, according to another Hepburn-story, 2% ore is smelter feed. The large chunks are "high grade" from the "lower pit" and may assay over 5%, in part.

Informant: Ray C. Treasher with A. E. Hepburn, Sept. 16, 1941.

Report by: R.C.T.

Mining Journal Aug 15, 1941

NICKEL NEAR RIDDLE, OREGON, INVESTIGATED BY SURVEY

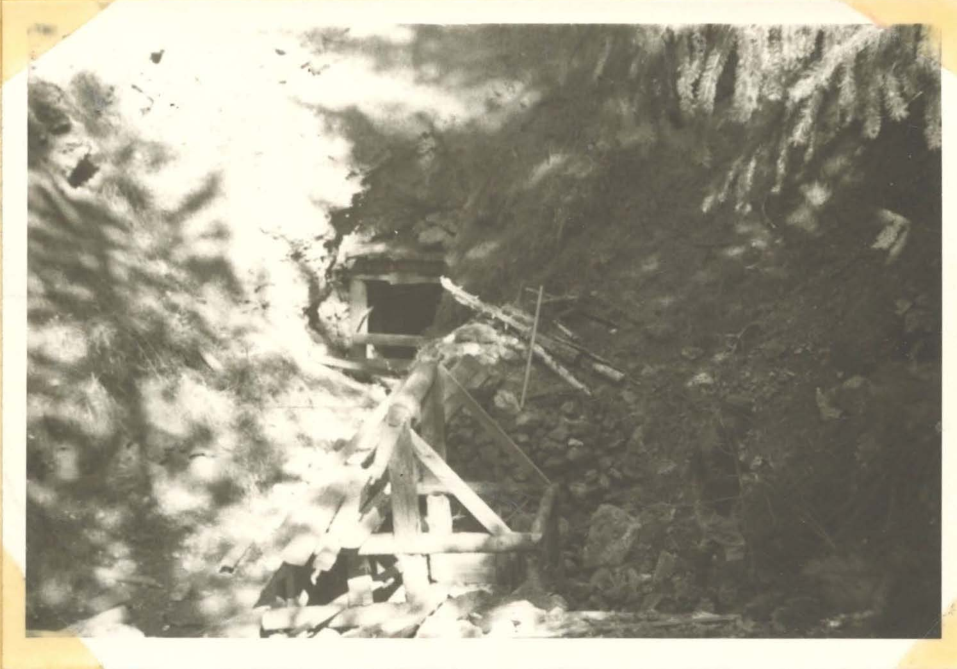
AS A PART of the investigation of domestic deposits of strategic minerals by the Geological Survey, two of the survey's geologists, W. T. Pecora and S. W. Hobbs, have examined a nickel deposit about five miles northwest of Riddle, Douglas County, Oregon. The town is 230 miles south of Portland by highway and is on the Southern Pacific railroad.

The nickel deposit is a rather irregular blanket on the western, southern, and southeastern slopes of Nickel Mountain. It was formed as a result of the concentration by weathering agencies of the small quantities of nickel originally present in the silicate minerals that compose the peridotite underlying the mountain. The peridotite is a dark igneous rock made up largely of the minerals olivine and pyroxene; it is commonly altered to serpentine along its contact with the sandstones and greenstones into which it was intruded. The concentrations of nickel, however, appear to be limited to the ores underlain by the peridotite and not to overlie the serpentinized masses.

The nickel-bearing blanket is best developed on terraces and gentle slopes above an altitude of 2,000 feet, where its thickness reaches a maximum of 60 to 70 feet. Within the blanket, nickel is present chiefly in the mineral garnierite, a hydrous silicate of nickel and magnesium. The garnierite varies in nickel content, the darker varieties having the larger amounts. Three layers or zones may be distinguished in the blanket; a thin upper brick-red soil layer at the surface, which is relatively low in nickel; a thick intermediate layer, richer in nickel and composed of limonite cut by a network of quartz and garnierite veinlets; and a bottom layer in which thin veinlets of quartz and garnierite occur in unaltered peridotite. The network of veinlets in the second and third layers is thought to have formed along the blocky jointing in the unaltered peridotite.

Pecora and Hobbs believe that the concentration of the nickel originally present in the peridotite, which is in the order of 0.2 per cent, into the higher grade garnierite-bearing material of the blanket deposit was the result of two successive long-continued climatic cycles. During the earlier cycle the minerals of the peridotite were decomposed, forming an aggregate of hydrous iron oxides and nickel-poor garnierite. The more recent temperate and humid cycle resulted in the solution of the nickel-poor garnierite and its redisposition in veinlets as quartz and nickel-rich garnierite.

No comprehensive sampling program of the entire deposit has been undertaken; such sampling as has been done indicates that the great bulk of the deposit contains from 1 to 2 per cent of nickel and a much smaller part contains from 2 to 3 per cent of nickel. Should emergency conditions result in a substantially higher price for nickel or stimulate the development of a practicable method of treatment for low-grade nickel silicate ores, the deposits on Nickel Mountain would provide a reserve of some 6,000,000 tons of material with an average nickel content of 1 to 2 per cent and in addition possibly 250,000 to 300,000 tons that contain 2 to 3 per cent nickel, of which 80,000 tons in the vicinity of the discovery workings can be regarded as proved ore.



ECONOMIC GEOLOGY

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Applied Geology at the Nickel Mountain Mine, Riddle, Oregon

F. M. CHACE, J. T. CUMBERLIDGE, W. L. CAMERON, AND S. D. VAN NORT

Abstract

Applied geology at the Nickel Mountain nickel-silicate mine, the only producing nickel mine in the United States, in its broader aspects is little different from that where mining geology is used extensively in mining metallic mineral deposits. Important differences arise, however, because of the nature of the ore deposit, its general geology, mineralogy, structure, rock alteration, chemistry, and origin, all of which are unique in North America.

The Riddle ore bodies are nickel-silicate or nickel-bearing saprolite deposits that probably represent the erosional remnants of original nickel-laterites that formed on old erosion surfaces by weathering and supergene enrichment. Much of the initial, deep, residual products of weathering now have been removed by erosion, leaving a complex blanket of decomposed, leached, and enriched saprolite that grades laterally and downward into fresh peridotite and dunite. The ore mineralization extends downward along a rather definite fracture and fault system forming nickel silicate-chalcedony (or boxwork) veins in depth.

Applied geology consists of (1) the collection of geologic facts by open pit mine mapping, drilling and laboratory work, and (2) the use of geologic data in ore reserve computations, mine planning, grade control and study of special problems relating to mining, beneficiation, and smelter operation. Each of these pursuits has important and interesting ramifications owing to the characteristics of the ore deposits and the reliance that must be placed on the geological work for successful mine operation. Grade control, which includes not only the control of nickel grade but also the selection of ores to be blended for optimum smelter performance, is perhaps the single most important aspect of applied geology and essential to the successful operation of the mine.

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Introduction

FROM a casual point of view, applied geology at the Nickel Mountain ore deposit at Riddle, Oregon, is little different from that in other mines where geology is used extensively. The geologist's duties include: (1) geological mine mapping, (2) supervision of drilling and mine development, and the interpretation of sampling results, (3) preparation and maintenance of geological maps, sections, and other records, (4) estimation of ore reserves, (5) assistance in mine planning, (6) supervision and scheduling of grade control during mining operations, and (7) study of special problems relating to the mining and smelting operations.

Only when the geology of the Riddle ore deposit is examined in detail does it become apparent that these rather routine and prosaic assignments have considerably more significance and importance at Riddle than at the usual underground or open pit sulfide ore deposit. The differences arise from the unique nature of the ore deposit itself, its unusual geology, mineralogy, structure, rock alteration, and chemistry; and the reliance that is placed on the mine geologist to guide successful mining and smelting operations. The geological features that must be observed, mapped, interpreted, and translated into usable advice and instructions to the operating departments present new challenges and problems in the use of applied geology and are unusual on the North American continent.

The Riddle ore bodies are nickel-bearing saprolite or nickel-silicate deposits that probably represent the erosional remnants of original nickel-laterites that formed on old erosion surfaces by weathering and supergene enrichment processes. Much of the initial, deep, residual products of weathering now have been removed by erosion, leaving a complex blanket of decomposed, leached, and enriched saprolite that grades laterally and downward into fresh peridotite and dunite. The ore mineralization extends downward along a rather definite fracture and fault system forming nickel silicate-chalcedony (or boxwork) veins in depth.

The purpose of this paper is to describe briefly the geologic techniques applied at Riddle and to discuss the various aspects of the work done by the mine geologist. Although an understanding of the paper requires a rather thorough knowledge of the geology of the nickel deposit itself, a distinction must be made between the geological mapping and detailed research that was done to achieve an understanding of the geology and origin of the deposit, and the techniques that are now used in applying that knowledge to mining. It is only the applied geology that we are concerned with here.

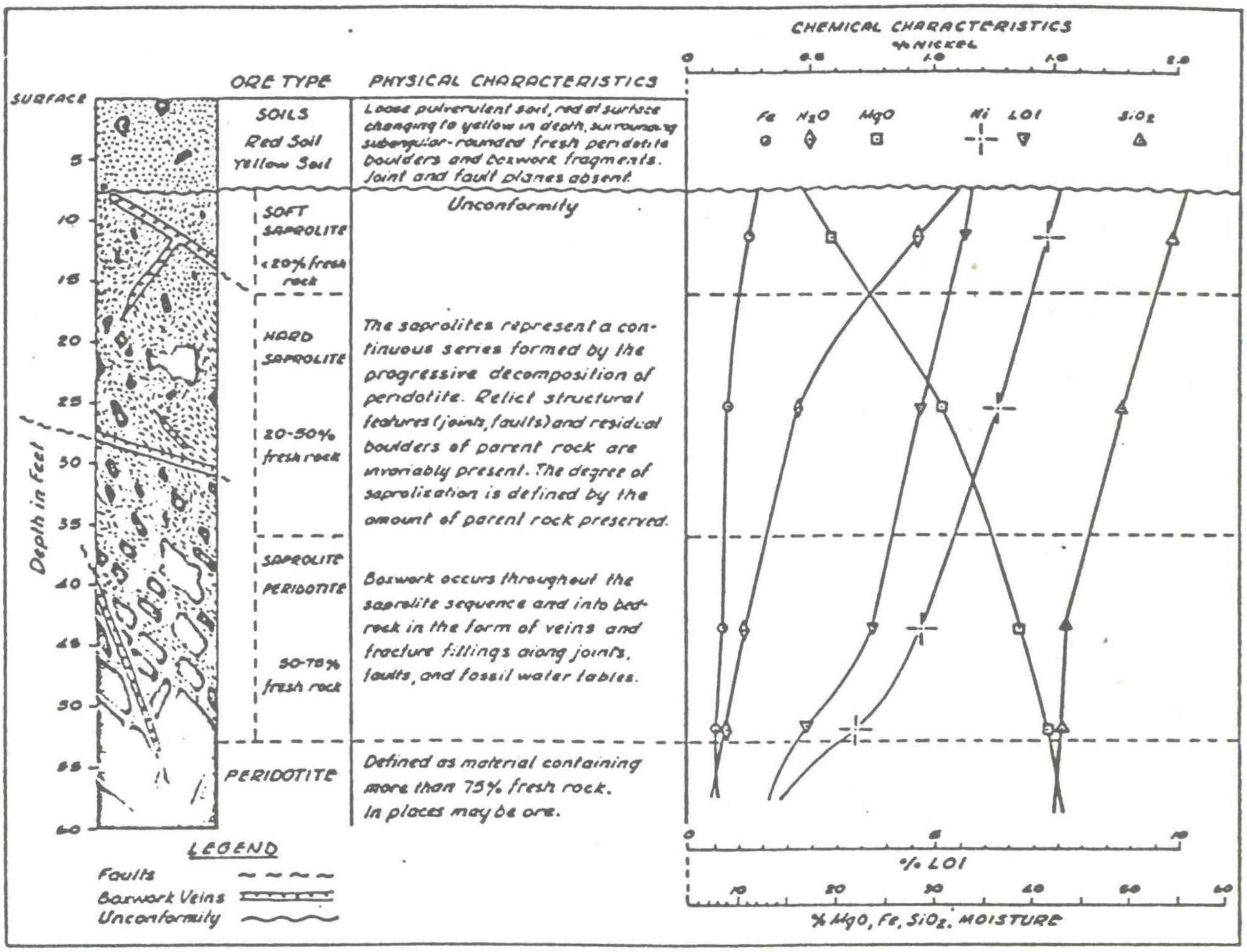
Effective application of mining geology to this type of deposit is possible only when the geology is rather thoroughly known in three dimensions well in advance of mining. In addition to the surface geology and the geology exposed in the upper benches of the mine, the characteristics of the deposit in depth must also be known and understood in considerable detail. To attain this knowledge in deposits of this type, substantial deep drilling must be done before mining starts, and it must be done to the extreme bottom of the ore deposit and into solid bedrock. This is necessary to determine geological and chemical conditions at depth that are not observable in the upper parts of the ore body, but which, when projected upward, reveal important bedrock and structural features, such as rock ribs and fault zones, that otherwise would not be suspected. Knowledge of these features is essential for an accurate interpretation of the upper part of the ore bodies.

The importance of drilling cannot be emphasized too strongly. Where necessary, drilling is continued into uneconomic material solely to obtain structural and petrological information. Mine operating staffs are rarely sympathetic toward this point of view, and usually are unwilling to approve the cost unless convinced of its necessity. The mine geologist must have the wit and courage to insist on having, in advance, as complete information on the ore deposit as possible. At the Nickel Mountain mine considerable success has been achieved along this line as a result of the utmost cooperation of mining, smelting, and geological departments.

Geology of the Ore Deposit

The geology of the Nickel Mountain ore deposit has been described by a number of authors, including Cumberlidge and Chace (1967), Hotz (1964), and Pecora and Hobbs (1942). A more complete bibliography is given in the paper by Cumberlidge and Chace (1967). Only a brief summary of the geology is given here to provide sufficient geological setting for an understanding of the application of geology to the mining of the deposits.

The nickel-silicate deposits are located on Nickel Mountain, 4 miles west of Riddle in southwestern Oregon, and are residually enriched cappings over a peridotite intrusive body, which is one of several similar Jurassic ultrabasic rock masses that underlie the Klamath Mountains in northwestern California and southwestern Oregon. Two nickel-silicate (or nickel saprolite) ore bodies are present. The larger, Upper Ore Body, occurs at the crest of Nickel Mountain at an elevation of 3,535 feet and conforms to the Klamath Peneplain; the smaller, Lower Ore Body, formed on a topographic terrace, the Sherwood Level, at a lower elevation (2,000 to 2,550 feet) on the south side of the mountain. The ore bodies originated at different times during periods of prolonged stability in the erosion cycle and now undoubtedly represent the eroded remnants of previously more extensive nickel-bearing laterite-saprolite deposits that formed over the ultrabasic rocks. The laterite cappings that were undoubtedly present over the original deposits have now been eroded, leaving exposed the underlying saprolitic material, enriched in nickel, that forms the present ore bodies. A thin mantle of red and yellow soil overlies the saprolitic ore and probably originated by later weathering of the saprolite. The saprolite itself formed by progressive chemical decomposition of peridotite and dunite through the selective removal of iron, magnesia, and silica and the residual concentration and enrichment



Loose pulverulent soil, red at surface changing to yellow in depth, surrounding subangular-rounded fresh peridotite boulders and boxwork fragments. Joint and fault planes absent.

The saprolites represent a continuous series formed by the progressive decomposition of peridotite. Relict structural features (joints, faults) and residual boulders of parent rock are invariably present. The degree of saprolization is defined by the amount of parent rock preserved.

Boxwork occurs throughout the saprolite sequence and into bedrock in the form of veins and fracture fillings along joints, faults, and fossil water tables.

Defined as material containing more than 75% fresh rock. In places may be ore.

FIG. 1. Columnar Section, showing physical and chemical characteristics of ore types.

of nickel. The relative losses and gains of these constituents took place without reduction in volume, and with the preservation of the original rock textures, joints, and fractures of the peridotite bedrock. Figure 1 is a generalized columnar section of the Upper Ore Body showing (1) the relative positions of soil, soft saprolite, hard saprolite, saprolitized peridotite, and bedrock peridotite and (2) the chemical and physical changes with depth of silica, iron, nickel, and magnesia. This profile has considerable genetic significance and an understanding of it is essential for the successful application of mining geology at Riddle.

As mining progressed in depth it became apparent that the Upper Ore Body had a definite structural control by faults, fractures, and joints. The major controlling structures were pre-ore (with some post-ore movement) and consist of Rock Fault, which forms the footwall of the Upper Ore Body, and a series of subparallel diagonal cross faults roughly at right angles to Rock Fault (Figs. 2, 3). These faults controlled the downward weathering and leaching of the bedrock and provided the loci for deposition of nickel and silica in the form of garnierite-bearing chalcedony veins that locally are called "boxworks." The deep ore channels follow the downward extensions of the stronger cross-faults.

Figure 2, reproduced from Cumberlidge and Chace (1967), is a part of the 3,200-foot level, Upper Ore Body, and illustrates the principal geologic features of the mine, including distribution and structural relations of bedrock, ore types, soil, silica boxwork veins, and faults. A typical cross section of the Upper Ore Body is given in Figure 3.

Ore Types

In the application of geology at Riddle, considerable importance is given to the recognition and classification of ore into definite types that have a direct influence on mining and smelting operations and, therefore, are important in ore grading and ore blending during mining. Nickel content of the ore, of course, is the most important economic factor, but a classification of the Nickel Mountain ore solely ac-

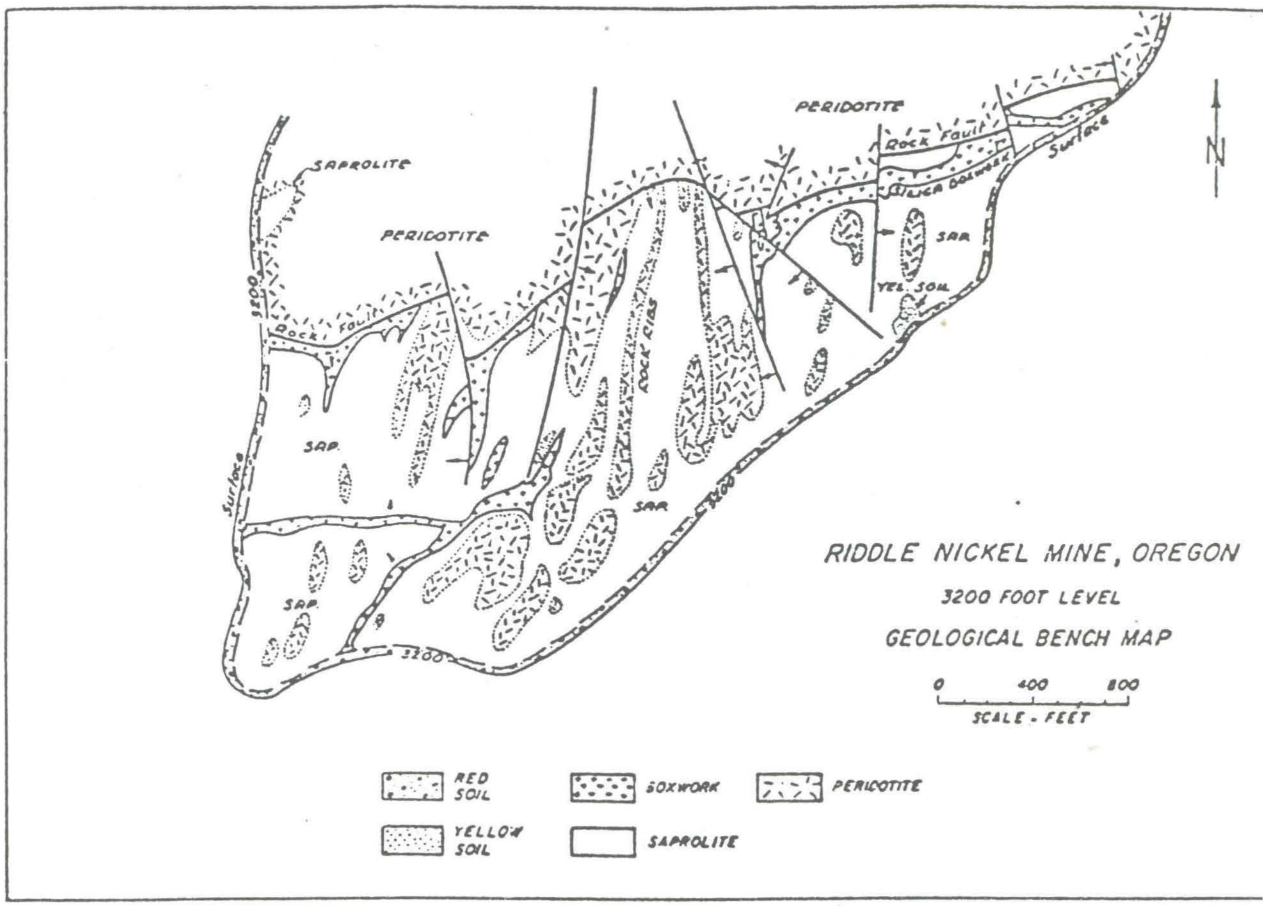


FIG. 2. Geological map, 3,200-foot level.

cording to nickel grade would group together ores that otherwise are quite dissimilar. Instead of nickel content, differences in texture and structure are used to subdivide the ore into three main groups. soil, saprolite, and boxwork with six subordinate ore types. These are illustrated on the columnar section, Figure 1.

The distinction between soil and saprolite is based on the presence or absence of joint planes, the characteristics of residual rock boulders, and the granularity of interstitial decomposed material. The soil group is subdivided on the basis of color, while the saprolites are further subdivided according to the quality and quantity of parent rock present, particularly its hardness and freshness. The term "saprolite" is used in its original sense, as defined by Becker (1895) to describe a rock that has been decomposed chemically but has not been transported and which preserves the original textures and structures of the parent rock. The term also serves to distinguish the high magnesia-low iron material preserved on Nickel Mountain from typical low magnesia-high iron laterite which is not present but is commonly associated with nickel-silicate deposits elsewhere. Boxwork c is quite distinctive, as it occurs in veins and is co posed of chalcedony with several hydrous nickel-ma nesia silicates, predominantly of the garnierite grou

Soils.—Red and yellow soils form an unconfor able surface mantle overlying the saprolitic ore. T soils are composed of loose pulverulent aggregates hydrous iron oxides and clay containing scatter boulders of fresh peridotite. The high proportion hydrous iron oxides in the soil is indicated by hig iron analyses. The boulders in the soil are mos rounded or subangular and are surprisingly fresh cept for a thin, rusty skin of decomposed rock. T red and yellow soils simply indicate the oxidat state of the iron oxides and are readily distinguish by color. Nickel content of the soils averages percent, but locally may range up to 1.7 percent.

The soils account for about 20 percent of the reserve. The thickness averages 10 feet, but may be virtually absent or up to 40 feet thick. So over serpentinite are brown in color, rather than br red or yellow, and normally have a lower nickel c tent than red soil. Scattered fragments of boxw ore are found in the soil.

Planar structures in the underlying ore, such as boxwork veins, joints, and faults, do not extend into the soil. Clearly much of the soil had a different origin than the saprolite.

Saprolites.—Nickel-bearing saprolite underlies most of the red soil areas on Nickel Mountain and accounts for 70 percent of the ore reserves. The saprolites formed in place with a minimum of textural and structural change; hardness and density do change. Chemical decomposition is rather complete. The saprolites form a continuous transitional zone from soft saprolite immediately below the soils, through hard saprolite and saprolitized peridotite into fresh peridotite or dunite in depth. Their derivation from the fresh ultrabasic rocks can be demonstrated beyond a reasonable doubt. The profile of ore types (Fig. 1) illustrates the chemical and physical changes in the ore body from the surface downward into fresh rock.

The content of fresh, undecomposed peridotite in the saprolite is an indication of the degree of chemical decay of the original fresh rock and to some extent the grade of the ore. The varieties of saprolite ore distinguished on the basis of rock content are:

Soft saprolite	0– 20% Rock
Hard saprolite	20– 50% Rock
Saprolitized peridotite	50– 75% Rock
Peridotite	75–100% Rock

Material containing 75 to 100 percent peridotite boulders, classed as bedrock, generally is not ore. This classification, based on fresh peridotite rock content, is useful in mine mapping, in bulk sampling, and in heavy liquid and microscopic studies. Moreover, it is an important factor in mining.

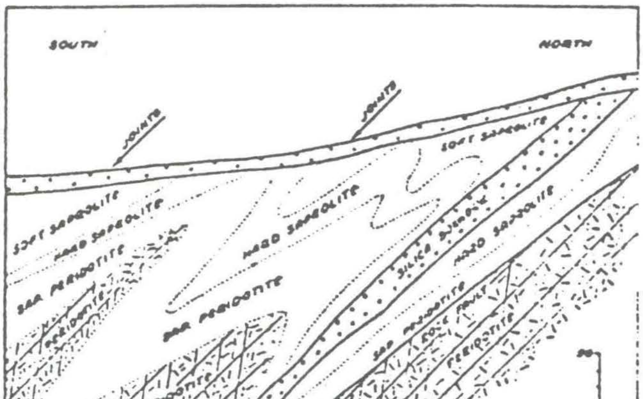


FIG. 3. Geological cross-section North-South, across Nickel Mountain Mine.

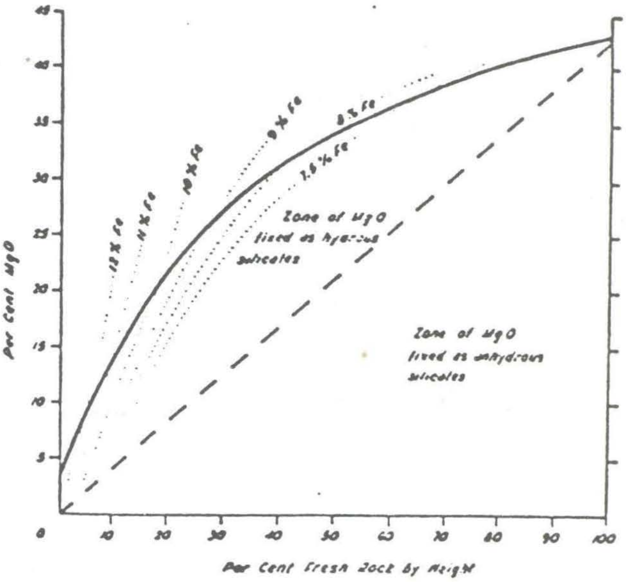


FIG. 4. Relationship of MgO and Fe to amount of fresh rock (peridotite) in crude ore.

The following pertinent details concerning the saprolite ore are largely quoted from the paper by Cumberlidge and Chace (1967).

The most reliable indication of the fresh rock content of drill samples is obtained from chemical analyses. Pure peridotite contains approximately 40% MgO and, using this as a basis, a relationship between MgO and rock content has been established. This correlation is not simple because several minerals in the ore contain MgO; the principal ones are primary anhydrous silicates such as olivine and enstatite, and secondary hydrous silicates such as garnierite, serpentine, and sepiolite. Study of mineral suites prepared by heavy liquid separation has shown that the ratio of hydrous to anhydrous Mg-silicates is fairly constant for a given content of fresh peridotite. Thus, the MgO due to anhydrous silicates can be separated from MgO in hydrous silicates as shown by the dashed line in Figure 4. The solid curved line in this figure represents the average rock content, and allows prediction of rock content from MgO analysis to within ±10 percent.

As a further refinement, an empirical relationship between iron and rock content has been developed. This relationship is used to correct the figure derived by the MgO method, thereby increasing the accuracy of prediction of rock content to ±3 percent. The correction owing to iron content is also shown in Figure 4.

Both MgO analysis and the amount of fresh rock may be used interchangeably; they vary together and both indicate the degree of saprolitization. Where possible, rock content is estimated directly, but in

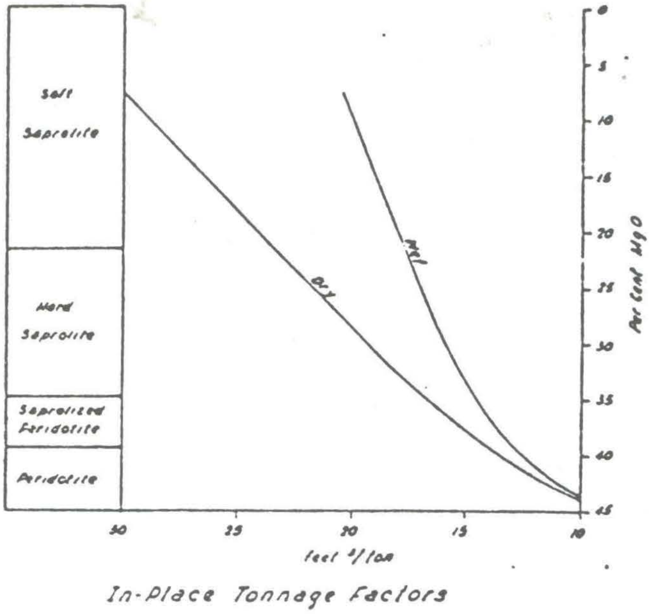


FIG. 5. "In-Place" tonnage factors of ore and rock types and relationship to MgO content.

the many places where only drill samples are available, the MgO-rock relationship is used.

The saprolites show the same kind of jointing as the peridotite from which they were derived, namely three or more sets of joint planes intersecting approximately at right angles and forming irregular blocks or rhombs. The joint planes are nearly always marked by thin films of garnierite, chalcedony, or serpentine, and the films are preserved with no sign of collapse or deformation even when all peridotite has been completely decomposed.

Normally, each joint rhomb contains a core of fresh peridotite surrounded by concentric layers of saprolitic material. A progressive chemical change can be traced from the core to the joint planes. Compared with the rock core, the outermost layers are lower in MgO and higher in SiO_2, Fe, and Ni, indicating that decomposition took place from the joint surfaces inward. Joint spacing and frequency must therefore have been important factors controlling degree of saprolitization.

Decrease in the total amount of fresh rock is paralleled in general by a decrease in size of the fresh rock residuals. This would be expected if alteration was initiated along joint surfaces. However, the size of the residuals also depends on the closeness of joint spacing in the parent rock. A highly fractured or jointed parent rock produces small-sized residual fragments regardless of the degree of saprolitization.

The density of saprolite varies considerably; the more decomposed material is less dense. As this is an important factor in making accurate ore reser estimates, a series of bulk samples of about 200 to each were collected to determine in-place tonna factors. These samples were supplemented by series of smaller samples obtained from hand du test pits. The results of the sampling program a shown in Figure 5 where tonnage factor (cu ft p short ton) is plotted against MgO and ore type the sample. The dry, in-place tonnage factor is co trolled by mineral specific gravities and by porosity the wet tonnage factor is further complicated by th degree of water saturation.

The close relationship between in-place tonnag factor and the degree of decomposition reflects th large increase in porosity which is achieved withou change in volume. Owing to the incoherent natu of the material, direct measurements of porosity a difficult to make and are usually inaccurate. However, porosity can be calculated from the dry, in-plac tonnage factor (Fd) if the true mineral specific gravity (Gm) is also known. Dry in-place tonnage facto is converted to dry, in-place specific gravity (Gi) a follows:

$$Gi = \frac{2.000}{Fd.\ 62.4}$$

Porosity (P) is then obtained from

$$P = \frac{(Gm\text{-}Gi)}{Gm} \times 100$$

A clear relationship between porosity and degree alteration is indicated by the six samples plotted Figure 6. The highest observed porosity is about 6 percent, expressed as the ratio of void volume to tot volume.

Given the moisture content and porosity of a sample, the degree of saturation (percent volume of voi filled by water) can be calculated.

% volume water

$$= \%\ \text{weight water} \times \text{wet in-place S.}$$

$$\%\ \text{saturation} = \frac{\text{volume water}}{\text{porosity}} \times 100$$

Figure 6 also shows the results of this calculati plotted against fresh rock content of the sampl used. Although the data points are few, the tre seems to be clear. As peridotite is decomposed, t in-place density decreases owing to an increase pore space. As pore space is made available, t resulting rock becomes increasingly saturated wi water because of increased permeability. The i crease in surface area available to chemical weath ing, and the increase in permeability, may have h an important effect on the rate of saprolitization.

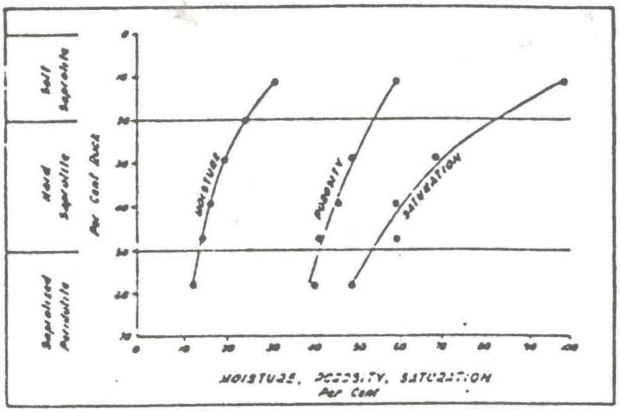


FIG. 6. Moisture content, porosity, and degree of saturation of each ore type.

Boxwork Ore.—This ore is quite distinctive as it occurs in prominent veins composed of chalcedony and garnierite group minerals, many with typical thin-walled boxwork textures. This is the highest grade, most colorful ore, and makes up about 10 percent of the ore reserve.

Boxwork ore is widely distributed throughout the saprolite ores, usually with evident structural control, as veins following joints, fractures, and faults. It is particularly prominent as the 40-foot thick vein along Rock Fault. Some of the boxwork ore, however, is in layers roughly parallel to present surface and possibly represents fossil water tables.

Not all boxwork ore has the typical boxwork texture; in places it is made up of massive or banded chalcedony veins up to 10 feet thick; breccia veins with fragments of peridotite, saprolite, and serpentine, and early chalcedony or early garnierite cemented by later chalcedony, serpentine, and garnierite are locally prominent. Polished fault planes, fault grooving, and striae also are common.

Boxwork ore is important not only because it makes up 10 percent of the ore reserve of relatively high nickel content, but also because the high silica content creates smelting problems.

Structure

Depth and intensity of saprolitization follows a pattern complex in detail but fairly simple in its broader aspects. The pattern is influenced by three structural elements, namely, former water tables, two sets of faults, and zones of intense jointing. These three elements make up the large-scale structural framework that controlled ore distribution and the degree of saprolitization.

Water Tables.—A discontinuous zone of boxwork ore, more or less flatlying and subparallel to the present surface, is found at the eastern end of the Lower Ore Body and along the southern margin of the Upper Ore Body. The boxwork ore lies just below the base of the red soil and tends to drape over the underlying structures rather than conform to them. The location of this ore in the profile is consistent with deposition of boxwork elements at a former water table or similar boundary surface. Apart from the two areas mentioned above, this type of boxwork ore is either absent or insignificant in amount.

Faults.—Faulting and jointing controlled the localization of the saprolite ore. Two major faults show a relationship to existing ore. One of these, known as Rock Fault, strikes approximately east-west through the Upper Ore Body and dips to the south at 35 to 45 degrees. (Fig. 2) The fault has been exposed by mining operations for a strike length of 2,800 feet and can be traced through surface mapping and drilling for an additional 3,300 feet. At least two other subparallel faults have been mapped above Rock Fault. These faults branch from and converge with Rock Fault, forming a fault zone in places 50 feet thick.

Rock Fault is overlain in many places by a remarkably thick boxwork, which is invariably vuggy, and in places cavernous. This implies that the boxwork was deposited in an open fracture, a condition not likely to be encountered under thrust fault conditions. In addition, the massive boxwork is cut by steeply dipping tension cracks filled with later barren chalcedony. These, too, are consistent with normal movement, and the balance of evidence suggests that movement on Rock Fault was a normal dip slip.

The footwall of Rock Fault is generally fresh peridotite, hence the name of the fault. Boxwork ore along the plane of Rock Fault is known to continue locally to a vertical depth of 260 feet below the present surface, suggesting that the fault zone acted as a major artery for the escape of mineralized ground water. Downward migrating ground water would have impinged on the footwall but clearly had little or no effect on the footwall peridotite, indicating that the footwall was sealed in some way.

Rock Fault is cut by north-south trending, steeply dipping, normal faults. Mining has exposed three cross faults cutting Rock Fault, and the existence of at least two others is suspected from drilling. Striations on the exposed cross faults pitch steeply, indicating essentially dip slip movement which resulted in horizontal offsets in Rock Fault of 10 to 220 feet.

Joints.—Joint intensity exerted a considerable amount of control on both the depth and degree of saprolitization by providing permeable avenues through an otherwise relatively impermeable rock. A relationship between joint spacing and degree of alteration can be recognized in the field. Massive, blocky peridotite with a joint spacing of about 24 inches is little altered except along the joint planes, which are usually coated with films of garnierite and serpentine. On the other hand, relict joint planes in exposures of soft saprolite show a joint spacing of the order of 2 to 6 inches.

Irregularities in the bedrock topography can be related to permeable zones produced by faulting and jointing. This is shown in plan in Figure 2, which reproduces a portion of the 200-foot level of the Upper Ore Body. In this area, the major joint zones strike north-south and dip 50 to 60 degrees to the east. They are truncated by Rock Fault on the north, and cut by a "y"-shaped fault system in the southwestern part of the area. The pattern is similar in other parts of both ore bodies, and results in a series of "ribs" of peridotite elongated in a north-south direction, and dipping steeply to the east. Saprolite ore types are not shown in the illustration because of scale limitations, but the centers of the large saprolite areas tend to be soft saprolite that grades outward into hard saprolite and saprolitized peridotite. Boxwork ore is closely related to the faults.

A typical pattern of ore distribution in vertical cross section is shown in Figure 3. In this example, two joint zones striking northeast and dipping to the southeast are cut by Rock Fault. Saprolite ore types are developed symmetrically around the joint zones. A layer of boxwork lies slightly above, but parallel to the plane of Rock Fault.

In detail, the distribution of ore types is more complex than shown in Figures 2 and 3, and day-to-day mining operations must be carefully controlled in order to provide an optimum product and to reduce stripping. The complex bedrock topography increases the problems of pit design, haulage road location, and equipment utilization.

Collection of Geologic Facts

Mine Mapping

As in all mining geology, continual mapping of the faces exposed on the mine bench levels is essential at Riddle in order to keep up to date and not miss critical data. All pit mapping is done with a 2-man team consisting of a geologist and a surveyor-helper. Plane table or transit and stadia surveys along the toe of each bench, using established survey points, are made to locate geological contacts, ore types, and structures. These are projected to the toe of the face slope (bench level elevation) and are plotted directly on the individual 50-scale maps of each bench level. All mappable geology is shown clearly with this scale. Special effort is made to map soil, rock, and ore types, and contacts or transition zones, quantity and size of residual boulders in the ore, and the presence and attitude of faults, prominent fractures, and boxwork veins. Soils are readily recognizable in the mine and are easily mapped. Occasionally, a face with complicated or obscure geology is sketched in the field notebook, but usually all data are recorded in plan.

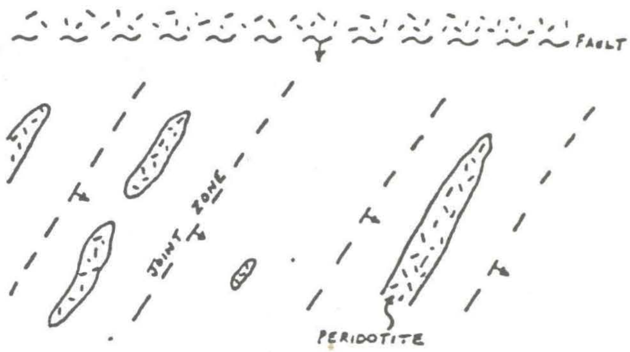


FIG. 7. Sketch map showing hypothetical pattern of rock distribution, faults, and channels of saprolitic ore as determined by drilling.

A numerical "shorthand" nomenclature is used for mapping saprolite ores to provide an accurate description of the continuous saprolite sequence. In this nomenclature the saprolite ores are recorded as a coupled number (e.g., 30/10) rather than as a rock name. The total amount of fresh rock is recorded as the first part of the number, and the amount of fresh rock greater than 6 inches in diameter is reported separately as the second part of the number.

Major boxwork veins are mapped directly by recording their location, dip, and strike. Minor garnierite joint coatings are noted symbolically. Faults, prominent fractures, and joints are mapped systematically in the usual way.

Because of the nature of the observed geology and because the technique of interpreting mappable elements differs from usual mining geology practices, the actual procedure used may be worth describing step by step in some detail.

Let us assume that before mining begins enough deep drilling has been done to determine the structural elements present. The structures are the "bones" around which the ore types are draped and they must be accurately recorded. Drilling has shown the general pattern portrayed in Figure 7.

Let us now examine in more detail a small area of the mine and illustrate the process of mapping a sequence of mining cuts on a bench level, which, though hypothetical, correspond to day-by-day operating practice at Riddle, and can be expected to approximate conditions in the root zone of nickel-laterite deposits elsewhere. The sequence of bench-level cuts is shown in Figure 8.

1st Cut.—At this stage very little direct evidence of structure is exposed in the bank. The geologist first decides where the boundaries of the various ore type units are to be plotted. He then locates these points by stadia or by a set of previously surveyed pickets. When this has been done, he goes back over the bank and estimates the amount of peridotite boulders present and the amount of rock reject to be anticipated on the 6-inch screen at the plant. This involves noting the intensity of jointing and faulting, the attitude of all the structural features visible, and the degree of alteration of each joint rhomb. In training new geologists, high, medium, and low nickel contents are estimated visually to train the eye and at times to be used as a check against the bank samples. Otherwise nickel grade is only estimated where it is thought to be anomalous, e.g., in a saprolite that has escaped supergene enrichment.

In many instances, even when the observations have been carefully recorded, the structural data may be so confusing that confident projection of ore types is not possible. This is where drill hole data and mapping of the bench directly above are most important. These data help determine the projection of structure, and ore types, and aid in deciding where the mine shovel should be scheduled to dig next.

2nd Cut.—At this stage of mine development two structural features of importance have emerged. One is the major boxwork vein striking northeast, and the other is the peridotite rock rib that also appears to strike northeast. Hopefully, these two features can be identified in nearby drill holes or on maps of the bench above. If this information fits the drilling "pattern," projections can be made with some confidence. If not, caution and reinterpretation are indicated.

3rd Cut.—At this face, the trends or strikes of the boxwork vein and peridotite rib are clear, and one can assume that the ore channel continues to the northeast. However, at this stage, knowledge of the fault to the north is confined to drilling data. Moreover, it is not known whether the eastern rock rib is separated from the fault by enough room to allow mining machinery into the area and to swing a shovel boom.

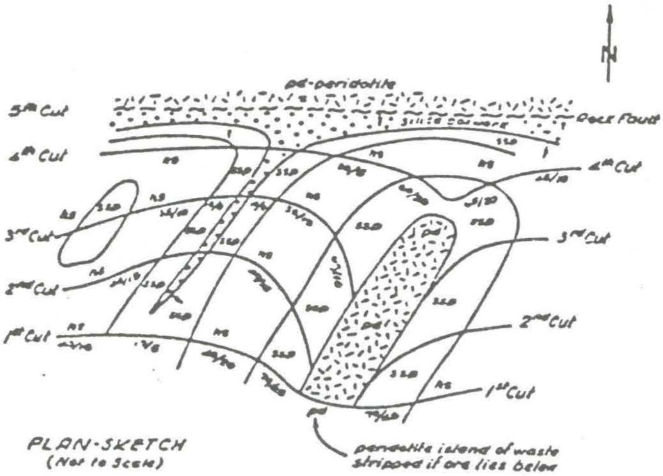


FIG. 8. Enlargement of small selected area of Fig. 7 illustrating geology as revealed by mapping of successive faces on a mine bench as mining proceeds in a series of cuts into the ore body.

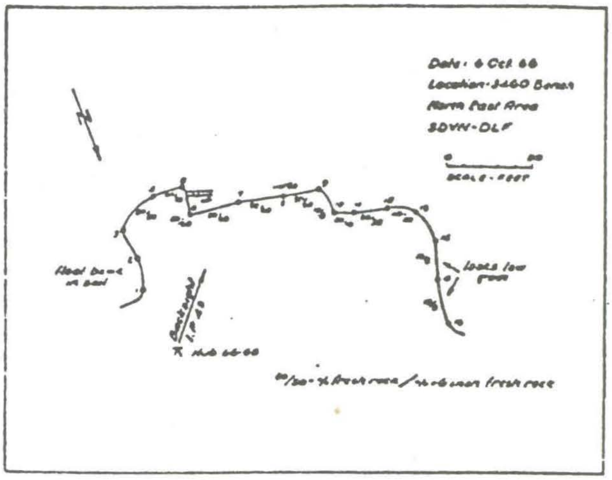


FIG. 9. Example of a typical work sheet from a mine notebook showing type of data recorded.

4th Cut.—Completion of this cut clears up the problem of mining around the north side of the rock rib. Thus, the peridotite rib can be left as an island of waste, or it can be stripped at a later date.

This cut also confirms a tendency, noted in cuts 2 and 3, for the reject content and rock content to decrease. For example, successive cuts through the hard saprolite west of the peridotite rib show a numerical change from 40/20, 40/15, 35/15, to 30/5. This is due to increased fracturing as the fault plane is approached. The joint rhombs are smaller; therefore a higher specific surface was exposed to weathering.

The small island of saprolitized peridotite to the west of the boxwork vein is an indication of peridotite below and an advance warning for the next bench.

Note that the high-grade boxwork ore lying on the major fault has not yet been cut. Again, deep drilling and adequate mapping and sampling records from higher benches give advance warning.

5th Cut.—Ore is now cut back to the fault revealing high-grade boxwork ore along the fault plane, which in places is sufficiently rich to warrant cleaning the plane of the fault with a backhoe or bulldozer to recover all of the ore.

If good records have been kept of mining on this level, they will help explain conditions on the bench below when projected down dip.

With this illustrative sequence of "cuts" it is apparent that the mine faces are studied carefully in

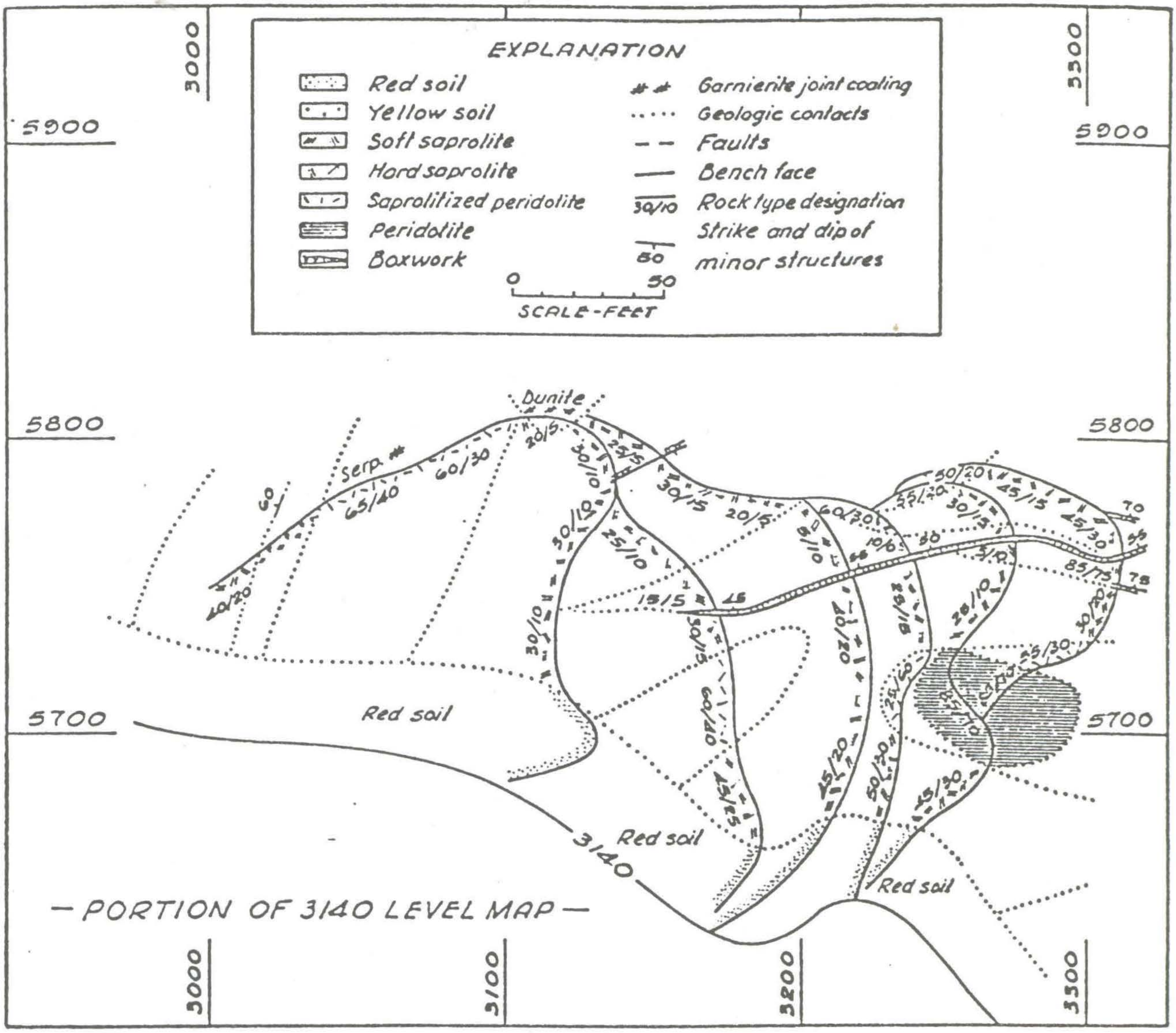


FIG. 10. Part of a typical bench map. 3,140-foot level, 50-scale.

advance of mapping, the mappable elements are selected, and preparations are made for actual recording of the important data. Figure 9 is an example of a typical mapping sheet. Note that mapping is done in plan and that it shows the type of data recorded and the side notes recorded. Figures 10 and 11 show portions of actual mapping sheets and illustrate further the method of recording ore types, the nomenclature used, and the trace of a series of mine faces or "cuts." In Figure 11, for example, at approximately 4150 East, 6725 North, the small differences in rock content that can be recorded are illustrated in the soft saprolite sequence 20/5, 15/5, 20/5, 10/0, and 10/5. All of this material is soft saprolite and the rock content varies considerably from 20 to 10 percent with the 6-inch rock content 5 percent or less.

Geological Maps and Sections

The geological mine data are plotted on a set of 50-scale level map sheets. Two sets of maps, 1 in. = 50 ft and 1 in. = 100 ft, and one set of sections, 1 in. = 50 ft, are maintained. Areal coverage of the ore body is provided by six 100-scale maps. The geological maps are constructed on 20-foot vertical intervals, corresponding to the mining benches. Detailed coverage in the active mining areas is provided by seven 50-scale base maps. On the 100-scale maps, 2 levels, each 100 vertical feet apart (5 mining benches), are plotted on the same sheet to conserve space and reduce the number of sheets.

A set of 50-scale vertical sections is used and is continually updated when new information or changes are indicated from the field mapping. These sections coincide with the 100-foot north-south mine grid and complement the 50-scale geologic maps. The sections show the observed factual geology indicated by the mapping and the projected geology as indicated in the drill hole data. Reasonable geologic projections of the factual data are then sketched on the sections. The known and projected geology plotted on the sections is compiled on 100-scale maps.

The maps and sections are complementary. The 50-scale sheets are fact maps; only known or observed data are plotted on them. Interpretations and projections are sketched in pencil on the 50-scale sections and on the 100-scale maps. This method permits a clear differentiation between factual and inferred information. Past experience indicates that highly accurate geologic projections can be made only when the data appear to be consistent with the three-dimensional view of plan and section.

Mine Drilling

Both development churn drilling and blast hole drilling are carried on in the ore zone. Development churn drilling is used to provide information on ore grade, type of ore, and structures. Blast hole drilling is primarily used for mining purposes.

Development drilling is done with a Bucyrus-Erie Model 29T churn drill with a 6-inch bit. In the mine area, holes are drilled on a 100-foot grid, whereas in the peripheral area at the margins of the ore body, holes are spaced at 200-foot centers. In the early years of the mine development, drilling was done at closer intervals and the holes were stopped at arbitrary, shallow depths. The closely spaced holes were abandoned when the fundamental structural control of the ore body was recognized and it was found that fewer but deeper holes could be used to obtain the same or better factual information.

[illegible]

Samples are taken in the drill holes in 5-foot intervals. The holes are cased continuously behind the samples. As each 5-foot sample is bailed from a hole, it is split and a one-quarter split of the sample, amounting to about 2 gallons, is saved in 3- or 4-gallon water-tight cans. The sludge color and hardness of the material penetrated (hard or soft) are noted by the driller and reported on his daily drill report. At the same time, a small split of the cuttings is saved and washed. These "cuttings" are logged and provide a fairly accurate guide to the material being drilled.

7

Drill hole samples are not completely satisfactory because, with the churn drill currently in use, the sludge samples are difficult to classify visually. Close inspection of the drilling chips, after washing away the mud, is qualitatively useful but much of the altered rock and some of the fresh rock is pulverize in drilling and so quantitative data are not available

Sludge color and the "cuttings" provide immediat information on the hole. Nickel analyses are usuall available within 24 hours. Analyses are also ru for MgO, SiO_2, Fe, and Cr; these are normally avail able within 2 to 5 days. The nickel analyses are ru at the mine laboratory and the others at the smelte laboratory.

Churn drill holes are plotted on the 50-scale geo logic sections as soon as the analyses are available Because the ore type classification is based in par on chemical analyses, final assignment of the or types cut in the hole is made at this time.

Blast hole drilling is a mining technique and produces very little additional geologic information Blast holes are confined to the hard, less decompose material which is generally of lower grade than th more saprolitized material. This drill produces a unreliable sample that cannot be used in determinin accurate grades. Cuttings from the blast holes provide some material of geologic importance but th shallow depth of the holes limits the usefulness o this information.

Applied Geology: Use of Geologic Data

The factual data collected, recorded, and interpreted by the mine geologist are used routinely for thre purposes: (1) for the estimate of ore reserves, (2) to aid in long-term mine planning, and (3) as a basis for daily grade control during mining.

Ore Reserves

Two types of estimates are made and kept up t date each year: (a) the usual tonnage-grade compu tation made in advance of mining and (b) a "cu estimate" which is a calculation of the amount an grade of ore actually mined each year.

a. The usual ore reserve estimates are made from th geologic cross sections using the grade data from th drill hole sample analyses after they have been factore to remove systematic bias in the data. Areas of th same ore type are planimetered and reduced to short ton by the usual weighted average method. Cutoff of 0.65% Ni and 0.90% Ni are used to determine true tonnage an grade figures.

Three reserve totals are calculated: (i) natural crud tons of unmined ore in place, (ii) crude dry tons c unmined ore in place using moisture correction factor and (iii) dry tons of tram product. The latter estimat is made by calculating or predicting the amount an grade of rock reject (+6 in. size) in each ore block th will be removed by the screening plant. The amount c rock reject is then subtracted from the crude ore reser to determine a "tram product" reserve, which is a estimate of the amount and grade of ore that will actuall be moved down the mountain by aerial tram and delivered to the smelter.

b. *"Cut Estimate"*: This is an annual estimate of the ore that was mined during the previous year. It is measured by the same method that is used for the total "in-place" ore reserve estimate. The results of the "cut estimate" are compared with the actual production figures and provide a yearly check on the accuracy of the ore reserve computation technique including the crude ore estimates, the rock rejection predictions, and the "upgrading" data. The yearly reduction in total ore reserves by current mining is obtained by subtracting the "cut estimate" from the total reserve.

The yearly ore reserve estimates for both natural crude ore and dry crude ore are generally made following the completion of the "cut estimate." The new estimates thus incorporate the estimate of ore removed during the preceding year as well as taking into consideration new geologic and analytical data and interpretations made during the previous year.

Mine Planning

The mine geologist works with the mine engineer and mine superintendent in planning and scheduling pit development and mining sequence. Geologic sections, engineering level or slice maps, and the pit bottom maps are used in systematic planning. Bench development, haulage roads, and ore blocks to mine are controlled in a large measure by geologic structure, distribution of ore type and grade, and pit bottoms. Temporary access road locations and other engineering installations are located in accordance with geologic conditions to provide maximum usefulness and life span. The coordinated efforts of geologist, engineer, and operator, using the knowledge and experience of all three, result in an efficient mining operation.

Grade Control

The extreme variations in the nickel content of the ore body as a whole and within the individual ore types, coupled with the necessity of providing a uniform smelter feed, necessitate close grade control during the mining operation. Both nickel and silica are critical to the smelter. In controlling grade, the objective is to provide the smelter with ore of constant nickel content with silica held to close limits. In actual practice the ore grade is controlled by blending ores from the various mine faces in predetermined tonnages.

Projected or planned grades are set on an annual basis and normally are not changed during the course of the year. Every effort is made to achieve the projected grade during each day's mining. In practice, however, the basic grading standard is a unit of approximately 8,000 to 25,000 dry tons of screened ore. The degree of success achieved in attempting to mine the grade required improves as the tonnage mined increases, so that, as a year progresses, the gap between the actual grades produced and the desired grade becomes progressively smaller.

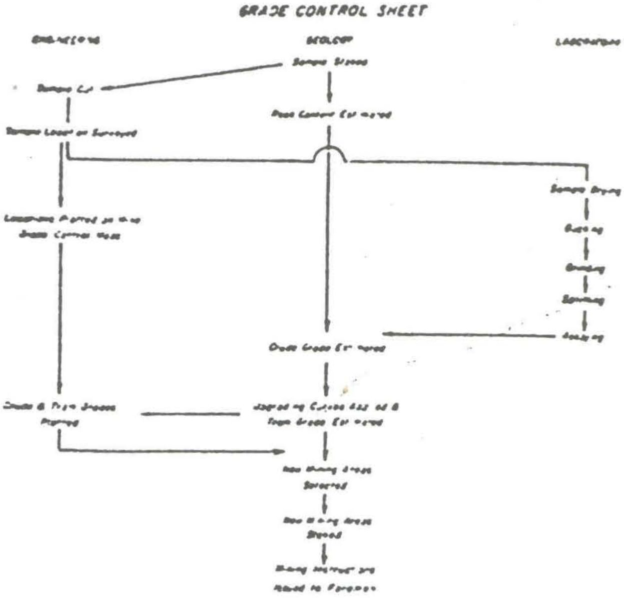


FIG. 12. Chart showing sequence of steps in grade control.

The basic technique used in controlling grade is to mine small ore blocks that have been carefully sampled and examined visually for rock reject screening characteristics. A simplified flow sheet of the grade control procedure giving the different contributions and functions of each department is illustrated in Figure 12.

The bank sampling procedure used daily in obtaining the basic data for nickel grade control and estimated amount of rock rejects is given in the appendix.

Special Studies

Special studies of problems relating to the mine or to the smelter are undertaken periodically by the mine geologist in cooperation with the mine and smelter staffs. These studies have covered a wide range of subjects and have made important contributions to the success of the operation. Among the problems studied are (a) the correlation of chemical analyses by different methods and from different laboratories, (b) the feasibility of separating higher grade boxwork ore from peridotite and lean saprolite particles by various mechanical techniques, and (c) the chemical and physical properties that govern the smeltability of the ore.

The procedure followed to investigate ore smeltability is summarized below as an example of the type of research problems studied and the kind of results obtained. Parenthetically, this also illustrates the close cooperation between mine and smelter personnel needed to reach useful conclusions.

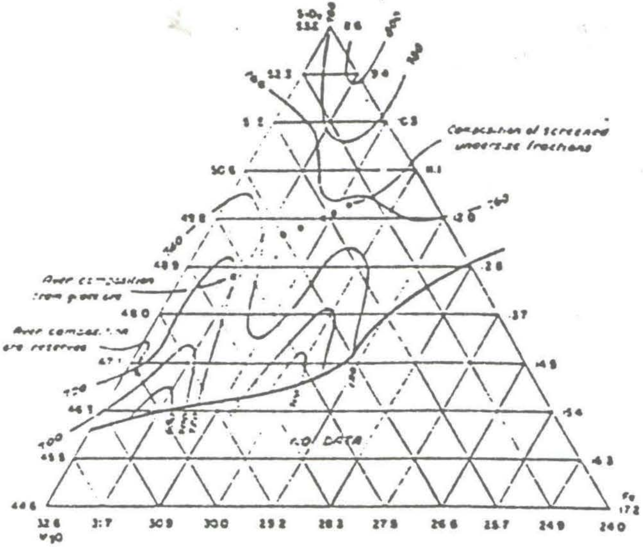


FIG. 13. Ternary diagram-system Fe-MgO-SiO_2, showing power consumption in kilowatt-hours per ton; 56 measurements contoured.

Cursory study of mine and smelter records showed that (1) smelter performance had been declining and (2) the decline was matched by a gradual change in mine product (screened ore) as mining advanced deeper into the ore body.

The primary objective of the study was to determine the smelter behavior of the various ore types and whether certain types of mine product gave better smelter results than others. It was hoped that a method of predicting and controlling smelter performance could be established.

The study interval of August, 1964, through September, 1966, was selected because of the uniformity of smelter procedures during that period. Individual tonnage units of mine product consisting of 12,000 to 25,000 dry tons each, which had been closely followed through the smelter, were used as a basis for study and comparison. One hundred and eight tonnage units that met the qualifications for testing were selected for study; all pertinent data concerning these units were tabulated from daily mine and smelter operation reports, and each unit was studied in detail as to chemical composition, power consumption (kwh per ton), ladle life, Ni losses in the slag, and normalcy of smelter operations.

When the information was assembled, a method of analyzing it was evolved. The mine product is composed essentially of three chemical components: $MgO + Fe + SiO_2 = 85.8\%$. It seemed reasonable to assume that if smelter performance varied with changes in the ore, a systematic change must take place in the ratios of the three major chemical components.

To test and illustrate this hypothesis, a triangular diagram representing MgO, Fe, and SiO_2, recalculated to 100 percent, was drawn for kwh per ton (power consumption). Points representing kwh per ton for each unit were plotted on the triangular diagram according to their MgO, Fe, and SiO_2 contents. Contours developed from these points proved to be confusing; and it was necessary to smooth out the contour lines and simplify the overall results. This was achieved by breaking the triangular diagram into a series of binary graphs which actually represent cross sections of the ternary diagram and were constructed along constant Fe, MgO, and SiO_2 lines.

Lines that best fitted the points on each binary graph were drawn, and adjusted kwh-per-ton contours were replotted on the triangular diagram (Fig. 15). This plot gave clearer and more meaningful results by eliminating some analytical and measurement errors, and by reducing the effect of daily variations in smelter operating procedures.

In a similar manner, a triangular diagram was developed to show total nickel losses in the slag (Fig. 14).

The triangular diagram of power consumption (Fig. 13) shows a decrease in power consumption with a decrease in silica content of the ore. A "ridge" of higher power consumption divides the low silica field. This produces two favorable areas of low power consumption; one in which MgO is high, corresponding to saprolite ore, and one in which Fe is high, corresponding to surface soil. Mixtures of saprolite and soil are apparently unfavorable, perhaps due to the formation of a high heat-capacity phase.

The loss of nickel in the slag decreases with decreasing SiO_2 content (Fig. 14), and a ridge of high slag losses divides the low silica field. This

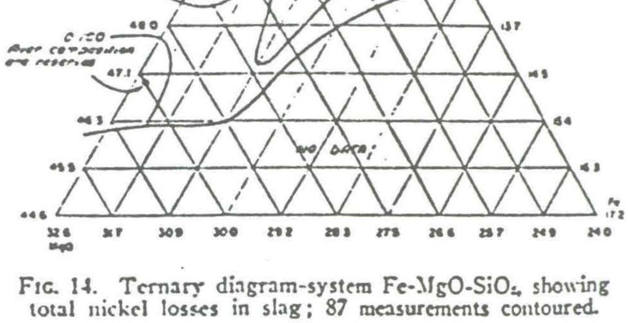


FIG. 14. Ternary diagram-system Fe-MgO-SiO_2, showing total nickel losses in slag; 87 measurements contoured.

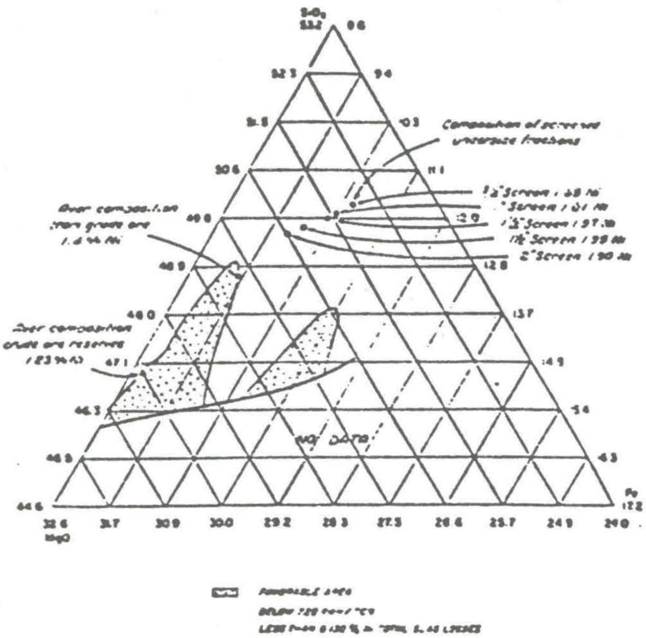


FIG. 15. Ternary diagram-system Fe-MgO-SiO_2, showing the two areas of optimum performance.

diagram is similar in shape to the power consumption diagram, but the underlying reason for nickel loss is probably the high viscosity of silica-rich melts.

With respect to power consumption and loss of nickel in the slag, two areas of optimum smelter performance were determined (Fig. 15). In these two areas, power requirements are low, and slag losses are low. Because these areas can be defined chemically, the production staff are now able to predict smelter performance within acceptable limits for any ore batch before it runs through the smelter. Trouble can be anticipated and minimized.

Neither of the two favorable areas corresponds exactly in composition with the remaining smelter feed as calculated from the current ore reserve estimates. Figure 15 shows the composition of crude ore and of ore screened on various screen sizes. Inspection shows that whereas crude ore is chemically favorable, it contains only 1.23 percent nickel. Screening on finer sizes produces an undersize product which is higher in nickel but has a less favorable chemistry. Obviously there is an economic balance point between the favorable economics of a higher nickel head grade and the benefits attending lower power costs and greater nickel recovery. When the optimum balance point had been defined, the mine geologist found ways and means of blending ore types to achieve optimum grade. The vagaries of geology, climate, and grade make this a difficult task, but the economic reward is commensurate with the effort involved.

Acknowledgments

We are indebted to Mr. E. E. Coleman, Consulting Engineer and formerly General Manager of the Nickel Mountain Mine, and to Mr. E. J. Maney, currently General Manager, and his staff for their cooperation and stimulating discussions during the work at Riddle. Mr. D. N. Vedensky, Senior Vice President of The Hanna Mining Company, has been a constant source of help, inspiration, and guidance. Dr. John G. Stone critically read the manuscript and made useful suggestions. Thanks are also due the officials of The Hanna Mining Company for permission to publish the results of our work. Our secretary, Mrs. R. E. Leibin, has patiently and efficiently typed and retyped various drafts of the manuscript.

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February 19, 1968

APPENDIX

Bulk Sampling for Nickel Grade Control

1. Shovels dig a 5-foot cut along face to be sampled.

2. A "fines" sample is collected along slough-face contact; only −3 in. material is collected. Samples are broken at 20-foot intervals or at geologic contacts. Location of sample breaks measured by transit and stadia.

3. "Fines" sample (−3 in.) is screened on a ½-inch screen.

4. Minus ½ in. material is sent to laboratory for analysis (Ni only).

5. Sample interval is inspected by grade control engineer who (a) estimates the amount of fresh rock within each sample interval and (b) estimates the percent of fresh rock that will be rejected by the screening plan (+5 − ½ in. material).

6. Nickel analysis of −½ in. "fines" plus estimate of fresh rock content and rock reject are used to calculate crude nickel grade and tram grade nickel for each sample interval.

A set of graphs which were developed over a long period of experience are used to determine the two grade estimates.

7. Crude grade of ore in place and tram grade are plotted on two 1 in. = 100 ft. daily grade control maps.

8. These maps are then used to schedule the next mining cuts. Location of cuts and amount to be taken from each face depends on the tonnage and nickel grade required for that day.

The first grade control sheet is a composite engineering map that shows the crude and tram grades for every bench face exposed in the pit. This map is posted daily so that current grade status of all exposed ore is always available.

The second grade control sheet is actually a set of engineering maps of the individual bench levels. These show the analyses of all the samples taken previously on each level.

The first composite map shows only current data for 11 benches; the second set shows the results of all previous sampling and mining on each bench.

Daily mining schedules are made using the information on these maps. Each mining shift is divided into 3-hour intervals. The schedules are arranged so that the thin slice of ore mined at each face seldom exceeds 1.500 tons; this represents an advance of 8 to 10 feet in each of the scheduled mine faces. When the predetermined ore slice has been made at one face, the shovel is moved to the next previously selected face and the process is repeated.

A sample of the tram grade ore is taken every 30 minutes so that an almost continuous record of the mine production is available and the accuracy of the ore grade predictions can be checked. If discrepancies occur, as they do occasionally, corrections can be made in the tonnage of each grade mined, and the results taken into consideration for the next round of mining.

Past experience indicates that a systemati
the tram samples occurs during the winter mo
to the increased moisture content of the
adjustment schedules have been evolved to
this divergence.

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4-10-94

meteoric water
slightly acidic

[illegible] in Nickel ore

reject this @ Nickel Mtn
New Caledonia: 1.6%Ni

LATERITE
soil

40% Fe
9% MgO

Topsoil

NC 2.6

SOFT SAPROLITE

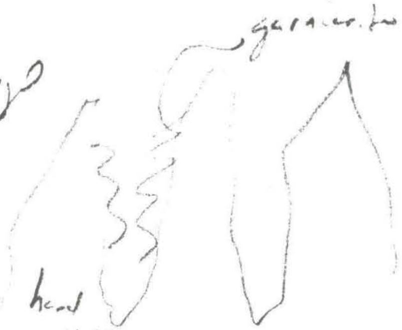
15% FeO
22-24% MgO

float & boulders

NC 1.8%

HARD SAPROLITE

10% Fe
33% MgO



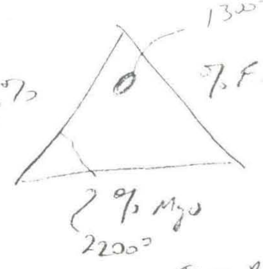
Peridotite

3-5% Fe
45-48% MgO

.25% Ni

raw ☐
MgO
SiO2
Fe

no bad dust problem from sand blasting



ferrosilicon is flux (reductant)

Jerry Reynolds died

48% MgO = 100% reject

Screen Ni-rich fines out

0.8

30% @ 0.25%
70% @ ~1.3% +
} 0.8%

More affected by European & Japanese economies than U.S.
Consumer products

U.S. Department of the Interior • Bureau of Mines

MINERAL INDUSTRY SURVEYS

Rhea L. Graham, Director
Washington, DC 20241

Nickel, Monthly

For information call:
Peter H. Kuck, Nickel Specialist Tel (202) 501-9436, Fax 501-9961, Internet: kuck@whq.usbm.gov
Barbara J. McNair (Survey Data Information) Tel (202) 501-9467
Hank Sattlethight (Survey Data Information) Tel (202) 501-9503
For MINES-DATA computer bulletin board call:
(202) 501-0373 (2400,N,8,1) for computer access
(202) 501-0406 for technical assistance
For MINES FaxBack system dial:
(202) 219-3644 from touch-tone handset of fax machine. The document number for the nickel catalog is 500100. The document number for the multi-commodity GPO publications list is 1500.

NICKEL IN DECEMBER 1994

Reported domestic nickel consumption in December, on a daily average basis, was almost identical to that of November, according to the U.S. Bureau of Mines (USBM). Production of austenitic stainless steel increased significantly, boosting demand for both scrap and ferronickel. Growing demand for pure metal in the steel sector, however, was offset by decreased consumption by (1) the electroplating industry and (2) producers of cupro-nickel and other non-ferrous nickel alloys. Daily use in electroplating dropped back to 34 metric tons (mt), the lowest level since July. Trade data for December will appear in a subsequent issue.

Glenbrook Plans To Resume Ferronickel Production in April

The Glenbrook Nickel Co. has told the USBM that it will restart its ferronickel smelter near Riddle, OR, in April. The mining and smelting complex had been on standby since August 1993. The Oregon operation is described in detail in the September 1993 issue of *Mining Engineering* (V. 45, No. 9, pp. 1139-1143). Glenbrook is a 50/50 venture of Cominco American Inc. and Cominco Resources International Ltd.

Glenbrook will continue to use lateritic ore from both New Caledonia and Nickel Mountain as feed. The New Caledonian ore imported in 1991-93 typically contained 2.2% to 2.4% Ni on a dry basis and was significantly richer than the 1.0% to 1.25% material being mined on Nickel Mountain. The first shipment of New Caledonian ore is expected to arrive in Coos Bay in late March.

The reopening of the smelter was made possible by the recent increase in the London Metal Exchange (LME) cash price. (See Table 9 of this MIS.) The LME cash price has been extremely volatile since the beginning of February and has been fluctuating between $3.24 and $4.45 per pound of nickel. Glenbrook's management decided to shut down the smelter 20 months ago when the cash price dropped below $2.50 per pound.

The company plans to produce about 8,200 mt of Ni in FeNi in 1995 and expects production to be at least 14,000 mt in 1996. (See *American Metal Market*, Jan. 23, 1995, p. 2.) The recently renovated smelter has a capacity of 16,000 metric tons per year (mt/yr). The ferronickel will contain 48% to 52% Ni and be available in both shot and ingot form.

Glenbrook is also considering reactivating its ferrosilicon

THIS ISSUE INCLUDES REVISED CONSUMPTION STATISTICS FOR 1990-92.

Prepared in the Branch of Metals and Branch of Data Collection and Coordination, March 6, 1995.

furnace, instead of buying ferrosilicon on the open market as in recent years. Ferrosilicon prices have been gradually increasing since 1992.

The ferrosilicon is added to the molten nickel ore to promote rapid reduction of the nickel, while still keeping a large part of the iron in oxide form. Addition of ferrosilicon increases production costs, but improves nickel recovery, bringing the roughly 25% Ni content of the melt up to 50% Ni.

Falconbridge Moves To Develop The Raglan Deposit in Northern Quebec

Falconbridge Ltd. has decided to develop its Raglan deposit at the northern tip of the Ungava Peninsula. Work is to begin as soon as ongoing negotiations with the Provincial Government of Quebec are completed. A few issues involving infrastructure funding, environmental permitting, and taxation still need to be resolved. Falconbridge also has to finalize its agreement with the Makivik Corp., which represents the local Inuit people. (See Falconbridge news release sent via *Canada NewsWire* on Feb. 2, 1995.)

Falconbridge is planning to spend C$486 million to bring the deposit into production by mid-1998. A sulfide concentrate will be produced on site at Katinniq and trucked about 65 kilometers to Deception Bay, QUE, where it will be transshipped by vessel to the company's smelter at Sudbury, ONT. At Sudbury, the concentrate will be converted into matte. From Sudbury, the matte will go to the company's Nikkelverk refinery at Kristiansand, Norway. The capacity of the 64,000-mt/yr Nikkelverk operation is being increased to 80,000 mt Ni/yr at a cost of C$31 million to handle the increase.

According to company officials, the Raglan deposit has 18.1 million mt of reserves, averaging 3.13% Ni and 0.88% Cu. Falconbridge is planning to produce 20,000 mt/yr of Ni in concentrate over the first 15 years of operation. The deposit was discovered in the 1930's but has been passed over on several occasions because of its extreme northern location. Falconbridge has had control of the property since 1966. For additional information, see *The Northern Miner*, v. 80, No. 50, Feb. 13, 1995, pp. 1 and 12.

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LEASE

THIS LEASE, made this 13th day of November, 1963, by and between DOUGLAS COUNTY, a body politic and corporate of the State of Oregon, party of the first part, hereinafter sometimes called "Lessor" and THE HANNA MINING COMPANY, a corporation duly organized and existing under and by virtue of the laws of the State of Delaware, party of the second party, hereinafter sometimes called "Lessee",

WITNESSETH:

WHEREAS, Lessor is the owner in fee of the following described mineral rights on lands located in the County of Douglas, State of Oregon:

> All of the mines, minerals, ores and valuable substances (excluding timber) in, on or under the West half of the Southeast quarter of Section 18; Northeast quarter of the Northeast quarter of Section 19; West half of the Northwest quarter of Section 20; and Northwest quarter of the Southwest quarter of Section 20, all in Township 30 South, Range 6 West, Willamette Meridian,

hereinafter referred to as the "mineral rights"; and

WHEREAS, in accordance with Chapter 271, Oregon Revised Statutes, the County Court of Douglas County, Oregon, has determined that the mineral rights on the above-described property are not needed for public use and has further determined that the public interest would be furthered by leasing the mineral rights to the Lessee for the term and for the purpose hereinafter set forth and that the execution of this lease has been authorized by order of the County Court of Douglas County, Oregon, duly entered in its journal and dated November 13th, 1963, and

WHEREAS, it is expressly understood that the Lessor has deeded the rights to timber and other rights in and to said premises to the Roseburg Lumber Company as more particularly set forth in deed to Roseburg Lumber Company dated May 6, 1959, recorded in Vol. 284, page 223 and 228, Deed Records, Douglas County, Oregon, subject to all minerals and mineral rights in and to the same, said minerals and mineral rights having been retained by Douglas County.

NOW THEREFORE, In consideration of the sum of one dollar ($1) to it in hand paid, and in consideration of the agreements hereinafter set forth to be kept and performed by Lessee, Lessor has let, leased and demised and by these presents hereby does let, lease and demise to the Lessee the mineral rights for such period of time and upon such terms and conditions as are hereinafter set forth.

1. The term of this lease shall be ten (10) years from and after the date hereof, provided, however, that the Lessee shall have the sole and exclusive option to renew this lease for five (5) year periods for the next thirty-five (35) years by giving the Lessor written notice of its desire for each respective renewal at least thirty (30) days prior to the first day of such renewal period, and provided further, however, that Lessee shall have the right at any time to terminate this lease or any renewal thereof as a whole by giving sixty (60) days' written notice to the Lessor of its intention so to do. On the expiration of said sixty days, this lease shall terminate and all liabilities of the Lessee under this agreement, except such liabilities as shall have then accrued, whether or not then payable, shall cease and terminate.

2. The Lessee desires to acquire the rights of said Roseburg Lumber Company in and to the said above described premises in order that it may use the surface of the above described premises for roadways, power lines, pipe lines, stockpiles, and for any other uses and purposes which shall be necessary or convenient in connection with its mining and treating operations in or on other properties.

3. The mineral rights are leased to Lessee for the purpose of enabling the Lessee to construct, maintain and use on the above described premises any or all of the facilities described in Section 2 hereof.

4. While the parties hereto expect that there is not contained in the mineral rights, a merchantable ore body, it is the desire of the Lessor that the Lessee shall verify the non-existence of a merchantable ore body in the manner hereinafter set forth prior to the use of the mineral rights by the Lessee for the construction and use of facilities on the surface thereof. The geological representatives of the Lessee, as soon as possible after the execution and delivery of this agreement, shall submit to the State Geologist of the State of Oregon, a proposed program for the exploration of the mineral rights, and when the Lessee shall have obtained the approval of said State Geologist to such proposed program, it shall cause such exploration program to be carried out. During the course of such exploration, geological representatives of the Lessee shall confer with the said State Geologist with respect to the results being obtained,

and at the completion of the exploration program, the geological representatives of the Lessee and the said State Geologist shall agree as to the existence or non-existence of a merchantable ore body on the mineral rights. The State Geologist shall thereupon make a report of such agreement to the Lessor, furnishing a copy of such report to the Lessee, and if such report shall indicate there is contained no merchantable ore body on the mineral rights, the Lessee shall thereafter, during the term of this lease or any renewal thereof, have the sole and exclusive right to use the mineral rights for the purposes herein set forth. If such report shall indicate that there is contained on the mineral rights a merchantable ore body, the said report shall also indicate the area covered by such merchantable ore body, and such area shall thereafter be excluded from the operation of this lease without any further action on the part of the parties hereto, but the Lessee shall thereafter during the term of this lease or any renewal thereof, have the sole and exclusive right to use all of the mineral rights, except the area so excluded, for the purposes herein set forth. The Lessee shall pay all costs and expenses incurred in connection with such exploration. For all purposes of this lease, a "merchantable ore body" shall be understood to be a concentration of minerals which could be mined and sold or mined, treated and sold on the market by the Lessee in the year in which such exploration is made.

5. In the event that the Lessor shall acquire at any time during the term of this lease or any renewal thereof, any interest or interests in the above described premises in addition to its ownership of the mineral or mineral rights therein, such additional interest or interests shall be automatically included herein and covered hereby with the same force and effect as if such interest or interests had been included herein on the date hereof.

6. Beginning with the date hereof and during the period this lease or any renewal thereof continues in force and effect, Lessee covenants and agrees to pay to Lessor, an annual rental, payable annually in advance, of the sum of twenty-five cents (25¢) for each acre of mineral rights covered by this lease at the time of each respective payment of rental.

7. The Lessor agrees that Lessee shall have the right to sub-lease the mineral rights or any part thereof and to contract with others to use the mineral rights or any part thereof for the purposes herein specified with the

same rights, privileges, obligations and requirements as are herein granted to and required of the Lessee.

8. The Lessee agrees during the term of this lease to pay any and all taxes of every kind and all assessments duly and lawfully made against all improvements or use of the premises as may be provided by the laws and statutes of the State of Oregon and which may be levied against that part of the mineral rights covered by this lease at the time of each levy of said taxes and assessments (excluding all of the surface thereof except that part used by the Lessee in its operations) and any and all taxes which may be assessed against the improvements placed by Lessee thereon, provided that the Lessee shall have the right to bond, in the manner provided by law, any assessments levied against any such leased property for local improvements and to pay the same in installments in the manner provided by law; provided further that only such installments of any such assessments as shall become due during the lease term shall be paid by the Lessee; PROVIDED, however, the Lessee shall always have the right to contest in the courts, or otherwise, the validity of any such tax or assessment in case it shall deem the same unlawful, unjust, unequal, or excessive, before it shall be required to pay or discharge it, or any part thereof; but all such taxes and assessments, or so much thereof as shall not have been cancelled or set aside, shall be paid by Lessee in time to prevent any sale of the mineral rights, or property or any part thereof, for said taxes and assessments.

9. The use and occupancy of the above described premises by the Lessee, and all of its operations hereunder shall be conducted in strict compliance with all laws applicable thereto, and with all rules and regulations promulgated, adopted and published by any commission or other governmental body having jurisdiction in the matter.

10. Lessor reserves and shall have a lien upon all machinery, implements and personal property of Lessee that may be on mineral rights as security for the payment of any annual rental that may have accrued under this lease, and for all unpaid taxes and assessments on the mineral rights and for any and all liabilities of Lessee. Any such unpaid annual rental or taxes or liabilities shall be deemed to be and be treated as a balance or balances of unpaid accounts under this lease, and such lien thereof may be enforced under the laws of the State of

Oregon by action or otherwise. Such lien, however, shall not follow any of said property after it has been shipped or removed from within the boundaries of the State of Oregon, and nothing herein contained shall prevent the removal of any or all of said property at any time when the Lessee shall not be in default hereunder, and the above referred to lien shall not, in case of sale of such property to third parties, be deemed to follow the same as against said third parties.

11. The grants of Lessor as contained herein are subject, however, to the express condition, that in case, and as often as Lessee shall make default in the performance, or by the violation of, any of the several agreements expressed herein to be kept and performed on its part, and such default shall continue uncorrected or unsatisfied for the period of ninety (90) days after written notice specifying the default complained of shall be given to Lessee by Lessor, then and in such case Lessor shall have the right to enter in and upon the mineral rights and to have and possess them again as of its first and former estate, and to exclude Lessee and all parties claiming under it.

12. The Lessor hereby represents and covenants to and with the Lessee that, at the time of the execution hereof, it owns the mineral rights in fee simple, and that the same are free and clear from all encumbrances and that (the Lessee keeping, performing and carrying out all of the covenants, promises and agreements, on its part to be kept, performed and carried out) the Lessor will, during the term aforesaid or until the termination of this lease as herein provided, warrant and defend the Lessee in the quiet and peaceable possession of the mineral rights and privileges herein granted, against all persons and corporations whomsoever, and the Lessor further covenants that at the beginning of the term hereunder, it will turn over and deliver the mineral rights to the Lessee in such condition that nothingtherein or thereon shall constitute a continuing nuisance, or a continuing menace to adjacent property.

13. Lessee agrees that whenever this lease is terminated, Lessee shall peacefully surrender the mineral rights to Lessor, provided that Lessee shall be entitled and permitted to remove within ninety (90) days after such termination all buildings, structures (including milling and treatment plants), engines, tools, machinery, railroad tracks, pipe and power lines, improvements, and other property

which may be erected or placed or made on the mineral rights by the Lessee, either before or after the date hereof. It is expressly understood however, that Lessee shall leave all roads, complete with culverts and bridges necessary for their usefulness intact for the use of the Lessor upon expiration or termination of this lease.

Lessee further agrees to peaceably surrender the leased premises or the governmental descriptions affected thereby, as the case may be to the Lessor with all caves and openings properly fenced, filled or protected as may be required by any laws or proper regulations of any duly constituted governmental authority then in effect and in good order and condition, ordinary wear and tear in use and deterioration from and damage by the elements excepted.

Lessee agrees that when this lease terminates, it will, at the request of Lessor, enter or cause to be entered a certificate of that fact upon the proper books of record in said Douglas County, Oregon, provided this lease shall have been recorded there.

14. Any difference or controversy which may arise between Lessor and Lessee, as to the construction or carrying out of this lease, or the rights of Lessor or Lessee under it, shall not interrupt or suspend Lessee's right to use the mineral rights for the purposes herein set forth, provided Lessee shall duly pay the annual rental herein provided for at the time or times and in the manner stated in this lease.

15. It is mutually covenanted and agreed that in case any controversy or disagreement shall arise between the Lessor and the Lessee relative to the due observance and fulfillment of the terms and obligations hereof by either party, then such controversy or disagreement shall be determined by arbitration in the manner herein specified. Either Lessor or Lessee may within thirty (30) days after such controversy or disagreement arises demand arbitration thereof and the party or parties making such demand shall in writing to be served upon the other in the manner herein specified for the service of notice, specify the matter to be submitted to arbitration, and at the same time choose and nominate some competent and wholly disinterested person to act as an arbitrator; thereupon within ten (10) days after the receipt of such written notice, the other shall in writing choose

so chosen shall forthwith select a third arbitrator giving written notice to Lessor and Lessee of the choice so made and fixing a place and time for a meeting not later than ten (10) days thereafter, at which Lessor and Lessee may appear and be heard touching such controversy or disagreement. The arbitrators shall then make a decision as to the controversy or disagreement within thirty (30) days, which decision of said arbitrators shall be made in writing, and when signed by a majority of them, shall be final and conclusive upon all parties and the award so made shall be forthwith complied with. In case either Lessor or Lessee shall fail to choose and nominate an arbitrator, after notice as aforesaid from the other party, or in case the first two arbitrators selected fail to agree upon a third arbitrator within ten (10) days, then such arbitrator or arbitrators may, upon application made by either Lessor or Lessee, after ten (10) days written notice thereof given to the other, be appointed by any judge of the federal court having jurisdiction within the federal judicial district in which the mine is located. The expense of any such arbitration, including reasonable compensation for the arbitrators, shall be paid by the party against which the award shall be made, unless otherwise provided in the award of the arbitrators.

16. Any request or notice which either party may desire to give hereunder shall be properly served on the other party or parties only when reduced to writing placed in an envelope, sealed, stamped, registered and deposited in any United States Post Office addressed as follows, to wit:

County Court, Douglas County
County Courthouse
Roseburg, Oregon

Hanna Mining Company
1300 Leader Building
Cleveland 14, Ohio

Either party hereto may upon written notice to the other party (which shall be served as herein provided for service of notices generally) change the address to which notices to such party may be sent, or designate a new party with the same or a different address to which such notices may be sent.

17. In the event Lessor, in any instance, shall waive any default by Lessee or waive any provision hereof, such waiver shall not constitute a waiver by Lessor of any other default or, as to any other instance, of any provision hereof.

If any provision of this Lease or the application of such provision to any circumstance shall be held unlawful, the remainder of this lease shall not be affected thereby.

18. It is further agreed that the covenants, terms and conditions of this Lease shall both bind and benefit the heirs, executors, administrators, successors and assigns of the Lessor and the Lessee.

IN WITNESS WHEREOF, the parties hereto have executed or cause this agreement to be duly executed as of the day and year first above written.

DOUGLAS COUNTY

By V T Jackson
County Judge

____
County Clerk

E R Metzger
County Commissioner

Ray E Doerner
County Commissioner

THE HANNA MINING COMPANY

By R.W. Whitney
President

S A Engel
Secretary

Signed, AND sealed~~, and acknowledged~~
in the presence of:

J. M. Corbeil

Charles T. Myers

THE HANNA MINING COMPANY
RIDDLE, OREGON

Mining Property Preliminary Questionnaire

Explanation - More mining prospects are being brought to our attention than we are, at present, able to examine. In order to determine whether your prospect warrants a field examination, it is essential that we have the most complete information possible on the prospect. If you will please fill out the following form as completely as possible, it will help to indicate what steps should be taken by our Company.

Date Questionnaire was sent ______________________

Name of Property ____

Mining District ____________________ County ____________ State ______

Section __________ Range _____ Township _____ Meridian ___

Principal Metals or Minerals ______________________________

Owner or Representative ___________________________________

Address ____

CLAIMS:

How many claims _____ Lode or Placer ____________ Where Recorded ____________

When Located ____________ Locater ________________ Recorded At ______________

Who owns Claims _________________________ Who represents Owner ______________________

TERMS:

Give your suggestions as to basis on which we might work out an agreement to lease or purchase the property.

____

____

____

HISTORY OF PROPERTY:

Tell us what you can of the property's past history. (Use another sheet if necessary).

____

____

____

____

____

PROSPECTING INFORMATION:

What is nearest town ______________________ Miles ___________

Condition of road to property ______________________________

Can property be examined at any season of year ______________

What rock occurs mainly in region __________________________

Is property a vein, lode or blanket _________________________

Ore Minerals - what minerals are considered valuable ________

____

Gangue Minerals - What minerals are considered worthless ______

What are the dimensions of the mineralized zone, Length _______

Width ________________ Thickness __________________

What mine workings have been driven ________________________

____________________ Can they be entered ___________________

Have any exploration drill holes, trenches or pits been sunk in the

prospect ________________ . Who did this work ________________

__________________________ When ____________________

What were the results ______________________________________

____

____

If you have any assay or analytical returns list them, give length

or height of sample ____

____

Do you have any copies of maps or reports of Engineers' examinations

________ . Who made them ________________________ At what Date _______________

A map or sketch, no matter how crudely drawn is always of value.

If none exist, try to draw a sketch of the property.

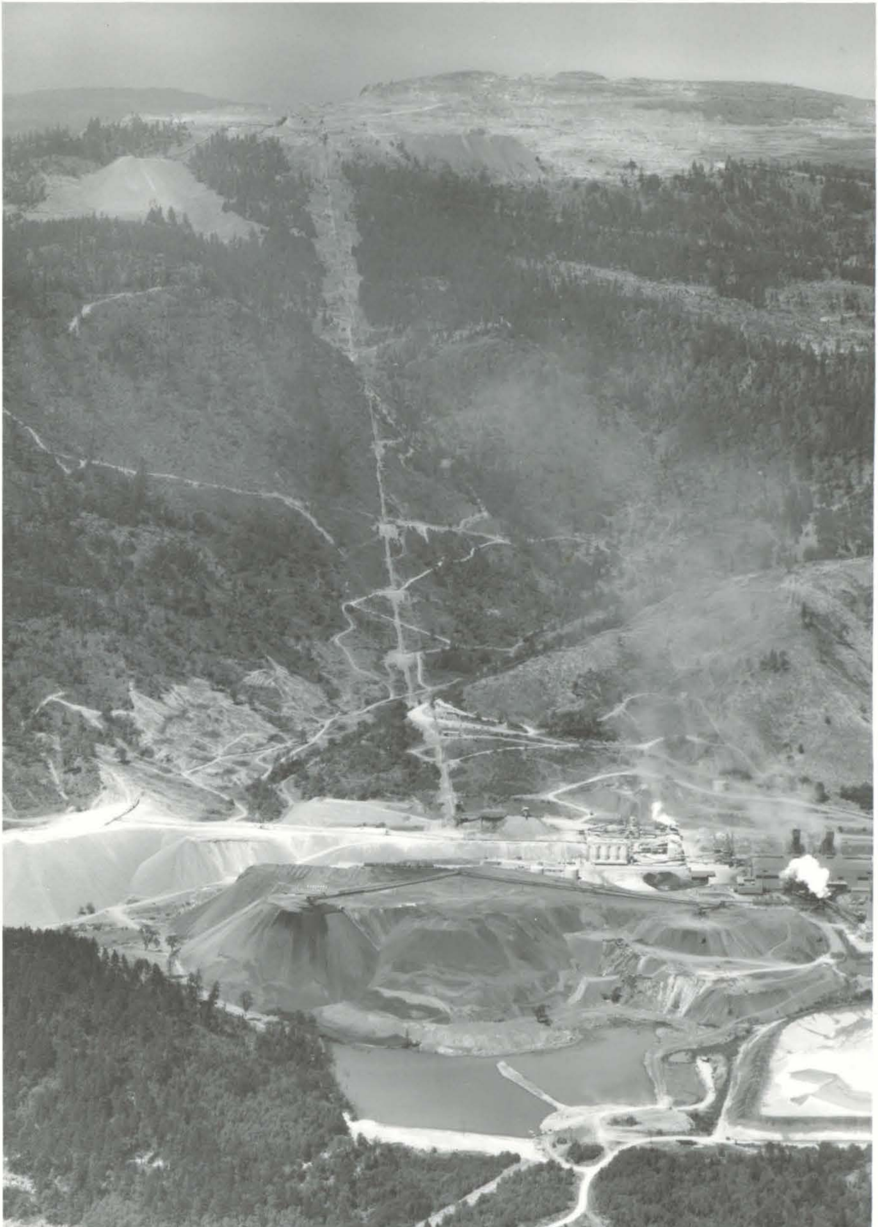
Your Name ______________________

Address ______________________

____

____

Date



'A Conspicuously Successful Case'

Statement by

George M. Humphrey

Honorary Chairman
The M. A. Hanna Company

Before the

Senate Armed Services Stockpiling Subcommittee

THE abrupt adjournment on August 17 of the Senate Stockpiling Subcommittee hearing left questions, and some degree of confusion, in the minds of many outside observers.

Since only partial reports of our initial testimony were published in the news media, we have printed Mr. Humphrey's opening statement before the Committee on August 16. This contains the basic information regarding the nickel transaction, of which, as Mr. Humphrey characterized it, both Hanna and the Government should be justly proud. We believe you will find his statement interesting and informative.

Sincerely yours,

W. A. Marting, *President*
The Hanna Mining Company

August 24, 1962

Statement by George M. Humphrey Before Senate Armed Services Stockpiling Subcommittee

I appreciate the opportunity to make this statement to you today, setting forth the facts with respect to Hanna's connection with the sale of nickel to the Government.

I would like to begin my statement with a short summary of exactly where both the Government and Hanna stand today as a result of this transaction, and then I would like to go back to the beginning and explain in detail just how this result came about and my own connection with it.

The net result of all of the transactions between the United States Government and all of the Hanna companies relating to all of the nickel contracts can be summarized as follows:

When the contracts are all completed, the Government will have on hand an inventory of 94,700,000 pounds of nickel at a total cost to it of $67,200,000, which is a cost of 71¢ per pound, as compared with the current market price of about 75¢ per pound.

Included in this total cost are the amounts used to repay in full to the Government its advances of $25,600,000 for the construction cost of the smelter plant and for working capital, and $4,800,000 of interest at 5% on these advances. This total cost also reflects the cash bonus of $1,722,000 paid to the Government by Hanna when the operation of the nickel plant was taken over for its account as well as the profit of $4,200,000 realized in cash by the Government from the sale of 30,300,000 pounds of Hanna nickel to others.

In addition to the foregoing items reflected in the cost of nickel, the Government has also received income taxes paid to it by Hanna of $5,800,000, withholding taxes of $2,000,000 for its employees at the nickel operation, and approximately $7,000,000 for power from the Bonneville Dam.

As compared with this, Hanna has sold one-quarter of its best nickel ore reserves, has realized a total net profit of $7,535,000 from all sources for the seven years of operation. Hanna now owns and is operating the smelting plant, the cost of which has been repaid to the Government in full with interest and cash bonus.

The results of these transactions are further summarized in the following table:

SUMMARY OF FACTS RELATING TO HANNA NICKEL CONTRACTS

		Amount
Sales to Government to August 14, 1962		
Cash payments to Hanna		$72.6 Million
Credited against loans to Hanna		25.6
Total cost for 108.0 million pounds of nickel		$98.2 Million
Less following amounts received by Government:		
Sales to others of 30.3 million pounds at a profit of $4.2 Million	$34.5 Million	
Cash from Hanna—bonus payment for plant	1.7	
Interest on advances credited	4.8	41.0 Million
Price paid for present inventory of 77.7 million pounds of nickel		$57.2 Million
17 million pounds to be delivered before June 30, 1965		10.0 Million
Total price paid by Government for 94.7 million pounds of nickel*		$67.2 Million
		Cost per Lb.—$.7102
Other amounts received by the Government		
Federal income and withholding taxes paid by Hanna		$ 7.8 Million
Sales to Hanna of power from Bonneville Dam		7.0 Million
		$14.8 Million
Net profit to Hanna from entire transaction		$ 7,535,000

*Sources: Report on Borrowing Authority dated December 31, 1961, submitted to the Congress by the General Services Administration pursuant to Section 304 (b) of the Defense Production Act as amended, and, Audit Report of Comptroller General of The United States dated April, 1961, covering Contracts DMP 49, 50, and 51.

Personal Participation Limited, Mistrusted Crash Program

I will now return to the history of the transaction and my connection with it.

My own personal participation in the nickel undertaking was very limited. The fact is that during the latter months of the Truman Administration, while the Hanna nickel contracts were being negotiated, I personally was engrossed in the negotiation and development of a very much larger project, embracing the building of a 360-mile railroad, opening of several iron mines, building of a shipping port, and construction of two good-sized towns, involving a total expenditure of something over $300,000,000 in Quebec and Labrador. Under these circumstances, I had very little time to spend personally on this nickel project of so much lesser importance, and the part I played was to advise from time to time with my associates who were conducting the negotiations. As a matter of fact, I was always doubtful about Hanna's undertaking the project in the way the Government proposed. The Labrador development, which was many times larger and more important to the national economy to supplement the dwindling iron ore supplies from the Mesabi Range, was straining the executive and technical capacity of our organization to the full, and I did not want that interfered with in any way. I also mistrusted the wisdom and practicability of the crash basis on which the Government felt it must go ahead with the nickel plant. And I am sure now that if we had proceeded on our own in an orderly, businesslike way without acceding to the Government's urging for a crash program, we would have been able to supply nickel in greater quantity at an even earlier time. The contracts were under negotiation by my associates long before I had the slightest idea I might ever become an officer of the Government, and they were finally signed and delivered just before I took office.

When I was nominated as Secretary of the Treasury in January, 1953, I brought out, in my confirmation hearing in the Senate Finance Committee, the fact that these contracts had been negotiated and recently signed with representatives of the Truman Administration (see Print of Hearing before the Committee on Finance, United States Senate, Jan. 19, 1953, p. 22). As Secretary of the Treasury I had of course no occasion to take and did not take any action affecting them. As I told the Senate Committee (see Hearings p. 6) one of the first things I did when entering the Treasury was to issue a flat order that any questions of any kind that might thereafter arise affecting in any way any company with which I had been previously associated should go directly to an Under Secretary for attention, with full power to act without any reference of it to me. When I left the Treasury in July, 1957, I returned to the Hanna Company only as a director, without salary, and not as an operating officer of Hanna, and have had only general familiarity with the project since then until the hearings of your Committee prompted my recent, very careful review of the entire matter, on which I have just spent a good deal of time and effort.

This statement is based, therefore, upon my general familiarity with the origins and development of the nickel project and the careful review I have just made, and there are here today responsible officers of The Hanna Mining Company, who participated in the negotiations and directed the operations, to answer your detailed questions as to both.

For more than thirty years, the Hanna Company has spent an average of more than a million dollars a year in geological and geophysical work, in drilling, and in research into metallurgy and into various methods of beneficiation, to find, seek out, acquire and develop metal mining projects anywhere in the western hemisphere and in a number of other, more distant places. Over the years there has been a high percentage of failures and losses, but there have been sufficient successes with profit enough to offset them so that, by and large, the Company has been repaid for its large expenditures, and grown and prospered.

Government Pressed Hanna To Open Nickel Deposit

In 1948, a mining prospect known as Nickel Mountain, near Riddle, Oregon, was brought to Hanna's attention. It was prospected and drilled, and enough ore proved to warrant a mining operation, but there was no known way of working out the metallurgy. Control of the property was acquired, and Hanna technicians went to work with their research. By the spring of 1952, Hanna's research and laboratory work indicated that a satisfactory process to make ferronickel out of this ore might be worked out, and Hanna was prepared to carry the project to the pilot plant stage of development.

The United States was then in a shooting war in Korea. The economy was controlled under wartime powers. Jet propulsion fighter planes were just coming into greater use and were of rapidly growing importance in the strategy of our defense effort. The construction of a great fleet of jet fighters would require substantially increased use of nickel, which was already in extremely short supply. There was then no nickel production within the borders of the United States. It all had to be imported. Small and large nickel users were almost desperate in their search for nickel and were paying as much as $2.25 or more per pound in order to maintain their supply of this very essential element. The Government had been for some time pressing Hanna to open the only known domestic source of supply. For example, on February 3, 1951, then Senator Lyndon B. Johnson, Chairman of the Preparedness Subcommittee of the Committee on Armed Services wrote me as follows:

> Dear Mr. Humphrey:
>
> In its report on nickel, the Subcommittee recommended that the appropriate Government agencies, in cooperation with private industry, intensify efforts to develop American nickel ore deposits such as those in Douglas County, Oregon.
>
> I note from recent press reports that your company has taken an option on nickel deposits near Riddle in Douglas County, Oregon.
>
> I should greatly appreciate receiving from you a report on your program for the development of these deposits, including an estimate of the time which may be required for both the development of the mining processes and the treatment of the ores, an estimate of the amount of nickel recovery which you presently expect to be available, and what aid, if any, you may require from the Government.
>
> Sincerely,
> /s/ Lyndon B. Johnson
> *Lyndon B. Johnson*
> Chairman
> Preparedness Subcommittee

As a matter of interest, I attach a series of statements on the subject of the urgency of the nickel shortage from reports of various Congressional Committees from this time until the end of 1957. (See reports following this statement.)

Risks Not Justified For Commercial Development

The Government wanted crash action. But Hanna was being asked to enter a business that was entirely new and wholly untried, and Hanna was reluctant to go forward without pilot plant proof of the feasibility and economics of its process and a test of the marketability of its product in an orderly, businesslike way. This would have taken at least a year or more, but the greatest speed is often made by proven practical methods. The risks involved in a crash program were justified only for defense requirements, which might suddenly be changed. They were not justified for a commercial development. I was insistent with our own people that Hanna should not take the risks involved in an unbusinesslike crash program and in the immediate expenditure for the development of a mine and the construction of a plant under those circumstances. Through negotiations to overcome this situation, a plan was proposed which was finally accepted by both parties:

> Hanna agreed to immediately invest, in addition to all past expenditures for acquisition, drilling, research and proving of the mining property and its process, up to $3,800,000 of Hanna's own money to open, equip and develop its own mine with no Government assistance of any kind. Hanna then agreed to meet the Government's request and make a plain, straight, firm sale under a long-term contract to the Government of the entire production of nickel ore from its own mine for a period of nine years estimated at

about 4,000,000 tons of ore at an agreed fixed price of $6 per ton subject to adjustment for nickel content and escalation.

The Government agreed to advance to a corporation formed for the purpose by Hanna but wholly financed by the Government sufficient funds (approximately twenty-two million dollars) to immediately build a full-scale commercial plant of Hanna's design, but with no profit to Hanna, and thus gain time, which the Government desired. If the process turned out not to be feasible, Hanna could convey the plant to the Government in satisfaction of the advances. And in consideration of turning over all its research and technical knowledge to the Government without any payment to Hanna, Hanna had the right at any time to acquire full title to the plant by paying off all unpaid Government advances, plus a bonus of 7½% of the original cost. Hanna agreed to not only design and construct, but also to operate the plant to produce ferronickel for sale to the Government at cost, with no profit to Hanna from its operation until the plant had produced the full tonnage of nickel then desired by the Government and contracted for at cost. Hanna received a flat fee of $100,000 a year toward the expense of providing the salaries and costs of its organization.

Both parties realized that the plant had no value except to operate on ore from this particular mine.

The Results — For the Government

Now, how did this work out, for the Government and for Hanna? The Government acted here in three capacities —first, as banker, advancing the funds to build the smelting plant and the working capital to run it; second, as customer, purchasing the ore from the mine to run the plant to make nickel for the stockpile through operation of the plant at cost; and third, as the agency responsible for national defense, to broaden the mobilization base by creating the one and only source of domestic capacity to produce a material in critically short supply.

First, as banker, the Government advanced approximately $22,300,000 to build the smelter and $3,300,000 for working capital and has been repaid the whole amount, plus 5% interest.

Nickel Cost Government Less Than Present Market Price

Second, as customer, the Government has now bought 108 million pounds of nickel, has 17 million more due under contract at less than market, and has sold 30 million pounds at a profit of $4,153,000 during the period of acute shortage. When deliveries are completed, the Government will have acquired an inventory of 95 million pounds of nickel for the stockpile at a cost per pound of about 71¢. This cost per pound reflects the Government's total outlay, reduced by the $4,153,000 of profit which the Government got for the 30 million pounds it sold and by the $1,700,000 of bonus that Hanna paid it on transfer of the smelter, and also by the $4,799,000 of interest already paid to the Government on its loans. For purposes of comparison, the market price of ferronickel has ranged recently from 77¢ to 75¢ per pound.

Third, toward its objective of broadening our mobilization base, the Government has by this transaction stimulated the creation of the only United States facility for the production of nickel, with a capacity of 20-22 million pounds per year. The Government's total net outlay to accomplish this is the acquisition of the 95 million pound inventory at a cost per pound less than the present market price, with every cent of additional Government expenditure fully repaid with interest. There was an obvious strategic advantage in creating the capacity in the United States; but the economic advantages were also very important. The Government's alternatives were limited to Cuba and Canada. Any Cuban capacity would now be lost to us. If a contract of the same dimensions had been made with a Canadian company, more than $100 million would have been spent outside instead of inside the United States for the purchase of nickel, with an adverse effect of that amount on our balance of payments, and the loss of millions in taxes, payrolls, and other benefits to our own economy. Those familiar with the nickel expansion program, I am sure, will agree that, of all the transactions the Government made for this purpose, the Hanna contracts involved the most efficient use of the least Government money, either per pound of nickel bought or per pound of capacity created, and it is surely one of the comparatively few cases where every cent of its expenditure has already been fully repaid to the Government with interest.

The Results — For Hanna

The result from Hanna's standpoint is this: In addition to all of its previous exploration expense, Hanna has invested $3.6 million of its own money in its own mine, and during the period to April 1, 1961, it has produced and sold to the Government 4.4 million tons of its best ore. It also designed and built the smelter, perfected the process, and operated the smelter at cost. During this period, it made a net profit on the operation of its own mine of $7,535,000 over a period of seven years, after paying Federal taxes of $5,820,000 to the Government.

In addition, Hanna has taken over for its account operation of the smelter, having repaid the Government loans and having made the additional payment of $1,722,000 of bonus in cash on the basis provided for in the original contract.

Now, what of the future for Hanna? Hanna has now mined and sold about one-fourth of its best ore. The balance remains. It owns the mine and the plant. Through Hanna's own successful efforts, plus the loan from the Government, which has been fully repaid with interest, Hanna has introduced ferronickel, a product previously new to the American steel industry, for which Hanna is proceeding to try to develop a broadened market. If its efforts continue successful, a new commercial operation has been created that gives employment, pays taxes, supplies a needed material, and continues as the only source of nickel production within the borders of the United States.

Government Should Never Speculate In Commodities

Now, what is the real value of the Government's nickel stockpile? That is wholly dependent upon what the Government itself does from now on. The original purpose was to cover a deficiency in the supply of nickel required to meet the Government's essential requirements for war and for defense.

If the Government now changes its mind and wishes to dispose of its stockpile, it can sell it on the market, disturb normal nickel prices, operations and employment, and cause great losses, both to the Government itself and to the entire nickel industry. That is one reason why in a strong, free-market economy, the Government should never speculate in commodities.

If, however, this stockpile or any part of it is to be resold in spite of the possible consequences involved, some plan should be worked out for long-range, orderly, careful distribution when market demands are strong and commercial requirements are high, in ways and under circumstances that will least affect normal market operations. That is the only way in which the Government's own values in the stockpile can be protected and preserved.

In recent weeks, one foreign nickel producer has already cut the price of refined nickel two cents per pound. The market is sensitive, and the Government's own action will affect the degree of pressure placed upon it.

But that is only part of the story. Beginning during a shooting war the Congress and three successive Administrations have approved and carried on this strategic stockpile program. The Truman Administration started it and contracted for the greater part of the total now in stockpile. The Eisenhower Administration carried it on with vigor and belief in its desirability, and the Kennedy Administration has continued to increase it right up to this day. Whether it was really wise to start it or not is no longer debatable. We have it on hand, paid for during the past decade.

Those commodities now in stock which will not deteriorate, which must be imported and are not available in this country when required and which in the event of world disturbance are essential to our economic life or safety, should be kept intact. They are assets we should hold on to for Government use when needed. They were bought to protect our national safety. They may well be required again for that same purpose, and they should not be frittered away now, either to help the current budget or possibly disturb sensitive commodity markets. They should remain tightly held as a matter of permanent policy, subject only to considered Congressional control in the event any of them become clearly useless for Government use or national protection as time goes on if obsolescence should develop.

Conspicuously Successful Case; Both Parties Should Be Proud

In conclusion, this entire arrangement with Hanna was carried forward, not under the provisions of the Strategic Materials Stockpile Act, but under the terms of the Defense Production Act of 1950 which authorized the President to make commitments to purchase metals, minerals or other raw materials, and had as one of its purposes, as stated in its declaration of policy "the expansion of productive facilities . . . " Thus, through the Government's proper participation, as clearly designed and provided for by the Defense Production Act, and through Hanna's successful efforts, the Government is now protected not only with a stockpile of essential material for future use in any emergency, but a new industry has been created which may be successfully carried forward commercially and help to provide employment, taxes, and additional protection for the Government's possible future critical requirements in case of another emergency.

This is a conspicuously successful case, in which the objectives of the Congress have been fully realized, of which both Hanna and the Government should be justly proud.

FOURTH REPORT OF THE PREPAREDNESS SUBCOMMITTEE OF THE SENATE COMMITTEE ON ARMED SERVICES

January 8, 1951

"The current shortage has resulted from the collision of a rapidly increasing civilian and military demand for nickel with the relatively fixed supply produced by Inco. The foreseeable shortage, however, is even more serious. Nickel has important alloying qualities which are indispensable in steel making and the production of certain types of aircraft engines. The large increases in the production of these industries, which have now become basic to our survival as a free nation, depend substantially on a similar increase in nickel production." (page 1).

"It is reported that the M. A. Hanna Co. is engaged in a metallurgical study of certain ores in Douglas County, Oreg. According to a report by the Geological Survey, published in 1942, these deposits contain some 6,600,000 tons of ore, most of which have a nickel content of 1 percent or more. The report concluded as follows:

> The deposit can be mined by power shovels at low cost, but a new method of treating silicate ores or a great increase in the price of nickel would be required to make mining of the deposit profitable.

"In the present emergency, this deposit should not be overlooked and, accordingly, the subcommittee recommends that the Bureau of Mines and other interested agencies expedite efforts to develop this source." (page 14).

FOURTH ANNUAL REPORT OF THE ACTIVITIES OF THE JOINT COMMITTEE ON DEFENSE PRODUCTION

January 5, 1955

"At the suggestion of Arthur S. Flemming, Director of ODM, the committee held an executive hearing on March 8, 1954, to review the nickel situation and discuss its effect on our national defense and to the domestic economy as a whole. The committee also invited Charles S. Thomas, Assistant Secretary of Defense for Supply and Logistics, to present the latest military requirements; Edmund F. Mansure, Administrator GSA, to report on the actions being taken under the nickel resources expansion program to speed up new development and production; and Sinclair Weeks, Secretary of Commerce, to discuss the impact which the stockpile acquisitions is having on the civilian economy.

"While most of the information and data discussed at this meeting is 'classified for security reasons', it was made crystal clear by each of the responsible officials that the most serious problem facing this Nation today in its preparedness program, is to develop new nickel deposits and at the same time substantially increase the production capacity at existing sources.

"Your committee strongly urged each agency to make a further effort to explore every potential source and technical process to overcome this critical bottleneck. In view of the essential use of this metal in the production of certain top priority items, it was further agreed that costs should be considered secondary to our Government's security until such time as the projected needs for both the military and civilian economy were more definitely in sight." (page 15).

FIFTH ANNUAL REPORT OF THE ACTIVITIES OF THE JOINT COMMITTEE ON DEFENSE PRODUCTION

January 25, 1956

"In view of the supply-demand imbalance that is currently forecast for months to come, and the strategic need for meeting stockpile objectives, your committee continues to urge that ODM and other Government agencies exert every effort to expedite the Nicaro expansion, increase the productive capacity of all other sources of supply available to the United States, and to make acquisitions of nickel at an aggressive rate for delivery to the stockpile until our defense position with respect to nickel is substantially improved." (page 38).

SIXTH ANNUAL REPORT OF THE ACTIVITIES OF THE JOINT COMMITTEE ON DEFENSE PRODUCTION

January 22, 1957

"In view of the critical shortage of nickel which currently exists, and the anticipated shortage which is forecast for many months ahead, your committee urges that the responsible Government agencies make a determined effort to increase the nickel supply as has been recommended by your committee repeatedly." (page 37).

SEVENTH ANNUAL REPORT OF THE ACTIVITIES OF THE JOINT COMMITTEE ON DEFENSE PRODUCTION

January 16, 1958

"With respect to supply, use, and distribution of nickel, the Department of Commerce made the findings which follow:

> "1. The supply of primary nickel available to the United States will not meet the Nation's full requirements for several years. Expansion of the free-world supply now underway or definitely planned, may not meet fully the needs of the United States by 1960-65, when such expansions are due to materialize. If additional projects for expansion of the total supply now under discussion with the General Services Administration with respect to governmental assistance are actually undertaken in the near future, it appears that the supply that would be available at the end of 5 or 6 years will be adequate for our needs at that time." (page 14).

Reduction of nickel and iron is accomplished by the Ugine Process, which consists of adding a reducing agent containing metallic silicon to an oxide ore in the presence of molten, ferrous metals and using vigorous mixing action for good contact of reductant and ore. In Hanna's smelter, crushed 48% ferrosilicon is used as the reductant, the ferrosilicon being produced in a separate electric furnace in the smelter. After the vigorous mixing cycle, the ferronickel is allowed to settle to the bottom of the ladle, after which the slag is skimmed off and granulated with high pressure water jets.

Refining

As the reducing reactions continue, ferronickel accumulates in the ladle. At regular intervals, a portion of this product is removed, or "thieved," and transported to one of two identical small electric steel furnaces. Here the impurities, predominantly phosphorous, are removed by suitable refining slags, after which the ferronickel is cast into pigs weighing approximately 28 pounds.

Samples from each cast are taken for complete chemical analysis and an accurate record of all casts is available for consumers. The ferronickel pigs are packaged on 4,000 pound pallets, with the exact weight and analysis stamped on each pallet. It has proven to be a very desirable product for the major stainless steel manufacturers of the United States.

RIDDLE NICKEL DEPOSIT

By

W. A. Foster*

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RIDDLE NICKEL DEPOSIT

The Riddle nickel deposit is located in southwestern Douglas County in Oregon, four miles west of the town of Riddle, which is inland from the Pacific coast approximately fifty miles and north of the California border about seventy miles. The deposit was discovered in 1864. Since then much prospecting and preliminary development work has been done on the property, but no ore was shipped for other than metallurgical tests until Hanna Coal & Ore Corporation started mining operations in 1954.

The ore mineral is largely garnierite. It occurs as a lateritic concentration in an intricate meshwork of iron- and nickel-stained chalcedony boxwork in sheared and weathered peridotite. In its fresh state the peridotite contains about .2% nickel. The major axis of the ore body strikes northeast and exploration so far has shown it to be roughly 6000 feet long and 3000 feet wide. The concentration ranges in thickness from a few feet to a maximum of 250 feet. It consists of three general layers; a top, brick-red soil layer, an intermediate thick, yellow, limonitic layer with some quartz-garnierite boxwork, and a root layer composed of quartz-garnierite boxwork in nearly fresh bedrock that is a transition between weathered material and fresh peridotite.

The favorable condition of shearing and fracturing of nickel Mountain peridotite made possible the formation of the quartz boxwork and garnierite. The nickel is believed to have been derived from olivine in the peridotite by decomposition during lateritic weathering which probably took place in late Tertiary time prior to uplift and canyon cutting. The Nickel Mountain deposit is an erosional remnant that escaped destruction, and under present climatic conditions, the original laterite has been altered resulting in quartz boxwork and nickel-rich garnierite.

Exploration of the deposit is being accomplished by churn drilling and trenching. A few test shafts were put down for the purposes of studying the ore in place, determining volume and moisture factors, and gathering bulk samples for pilot plant and smelter tests. In churn drilling, 6-inch casing is driven down every two or three feet behind the drill bit and bottomed at each 5-foot interval. All the sludge for each cased 5-foot interval is dumped through a splitter and one-eighth is saved and analyzed. Churn drill holes are stopped after going through the ore zone and penetrating fresh peridotite in which the nickel content is less than .5%.

For estimative purposes we have used conservative factors as follows:

Cubic feet per short ton in place - 17

Moisture - 21%

Grade - 1.5% Ni.

Mining of the ore is done by open pit methods, utilizing 2-1/2-cubic-yard diesel shovels and 22-ton diesel trucks. The mining plan being developed at the property consists of a series of level benches, with a twenty-foot maximum height and a fifty-foot minimum width. Each bench is intersected at several points by access roads, for moving the ore from the benches to the crushing and screening plant. The mining operation can be divided into three phases, (1) mining and hauling, (2) crushing and screening, and (3) shipping.

The ore is dug from the face of a twenty-foot bench by a 2-1/2-yard-shovel and loaded into 22-ton trucks. The ore is hauled from the benches to a stockpile area in front of the screening plant. The truck loads average about 17 tons and using one shovel it is possible to handle 2500 tons per shift. Because of the fractured state of the ore in place, practically no blasting is necessary.

In the second phase of the operation the ore is screened and crushed and deposited by conveyor belt into a conical shaped surge pile of 25,000-ton capacity to await shipment. The ore is pushed by bulldozer into a hopper which feeds a 54-inch wobbler feeder. This feeder consists of thirteen rotating eliptical manganese bars spaced at 5 inches. Over the length of the feeder, the minus 5-inch portion of the ore passes between the wobblers and into a bin from which it is fed by a 42-inch apron feeder onto the 30-inch belt going to the surge pile. The plus 5-inch portion of the ore is carried over the length of the wobbler feeder by its rotating action, and passes down a chute into a 30 x 42 jaw crusher set at 5 inches. The crusher product can either be placed on top of the wobbler undersize on the 30-inch belt to the surge pile, or on the 24-inch conveyor belt going to the reject pile. The decision to waste or save the crusher product is made by the engineering staff. The ore on the belt from the plant to the surge pile is sampled at regular intervals as a part of the grade control procedure.

Transporting the ore from the surge pile on the mountain to the smelter stockpile at the foot of the mountain is accomplished by means of a continuous aerial tramway. In a concrete tunnel under the surge pile, the ore is fed by an apron feeder onto a 30-inch conveyor belt which deposits the crushed material in a 100-ton bin where it is stored before being loaded in the tram cars. The ore is weighed and sampled on the 30-inch belt between the surge pile and the storage bin. A 42-inch apron feeder, electrically controlled, places a measured quantity of ore from the bin, into the loader, the door of which is tripped by the moving cars. Once in the car, the ore travels a distance of 8,306 feet, and drops 2,000 feet in elevation before being deposited at the smelter stockpile. The 50-cubic-foot capacity cars each carry approximately 2-1/2 tons of ore down the mountain at a speed of 500 feet per minute. The cars, spaced 260 feet apart by a two-inch connecting cable, travel loaded on 2-inch track cables and return inverted and empty on 1-1/2-inch track cables. The tramway is held to constant speed by two 300-horsepower induction generators, which when the tram cars are fully loaded, generate 500 horsepower in the form of 375 Kilowatts of electricity being returned to the power source. Two 30-horsepower electric motors are utilized in the starting of the tramway to overcome inertia and friction in the system when the cars are empty. Hydraulically controlled brake bands acting on the drive wheel, effectively bring the tramway to a stop when loaded or empty.

A major problem in the operation of the mine is controlling the grade of ore going to the smelter at 1.5% nickel on the daily basis. Since the formation shows no continuity the exploration drill holes can be used only for depth, rather than the sample values being projected horizontally. Daily grade control is presently being attempted by horizontal bank sampling of shovel cuts, visual classification of the banks, limiting the width of the shovel cuts to ten feet. Using these methods it is necessary to have many cuts available for mining because of the length of time necessary to dry, prepare, and analyze the bank samples. A large number of digging faces are necessary also because of the wide variation in nickel grade over the property. Several areas must be available to make up an average daily shipment.

Since mining operations were started, a little over a million tons of ore has been delivered to the smelter.

October 1953 Portland, Oregon

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THE NICKEL MOUNTAIN PROJECT*

Introduction

A very important event in Oregon mining history occurred on January 16, 1953, in Washington, D.C., when the Defense Materials Procurement Agency signed contracts with the Hanna Coal and Ore Corporation and the Hanna Smelting Company, both subsidiaries of the M. A. Hanna Company, Cleveland, Ohio, for the production of nickel from the Nickel Mountain deposit near the town of Riddle, Douglas County, Oregon. In addition, signing of the contracts marked the opening of an important chapter in the domestic mining industry since no nickel has ever been produced in this country on a commercial scale from ore mined in continental United States (a total of a few hundred tons is recorded as a by-product in smelting copper ores). We have always depended on Canada for our nickel. Start of nickel production at Riddle will make the United States partly independent of outside sources of this very strategic metal.

Because of the importance of the Nickel Mountain project, it seems desirable to assemble background descriptive material as a record.

Geography

Nickel Mountain is about 5 miles northwest of Riddle, an incorporated town in Douglas County, as shown on the accompanying index map. Elevation of the summit of the mountain is 3533 feet. The nickel deposit, occupying much of the upper part of the mountain, may best be reached from the Hanna plant site which is about 3½ miles west of Riddle. The Hanna Company has constructed a new road more than 2 miles long extending from the plant to the deposit at the summit. Because of the hazard of meeting heavy trucks on this road, permission to drive over it must be obtained at the Hanna Company office, at present in Riddle. A gatekeeper is stationed at the entrance to the new road and a pass is required to enter.

Riddle, at an elevation of about 700 feet, is on the Southern Pacific Railroad about 220 miles south of Portland and 25 miles south of Roseburg. It is about 4 miles west of US 99, the main north-south highway in western Oregon which bypassed Riddle when it was built. Population in 1940 was reported to be 214. In 1950 it was 634, the increase caused by the lumbering boom. The main support of the population in recent years has been from a plywood mill and several sawmills together with accompanying logging. A small amount of income is received from farming. Population has increased further since the start of the nickel project but no exact record is available.

History

The town of Riddle, erroneously called Riddles, was named after William H. Riddle who, with his family, was the first settler in that part of Cow Creek valley.

In April 1851, the William H. Riddle family (including the son George who later became Judge of Douglas County) left their farm near Springfield, Illinois, and joined a party of pioneers headed for Oregon. The Riddle's outfit consisted of three wagons, each drawn by three yoke of oxen, one large carriage or "omnibus" for the family (the omnibus was abandoned at the Platte River), and about 40 head of cattle, cows, and heifers. They came into Oregon by the southern route, arriving, after 5 months of arduous travel, at what is now known as Canyonville. Here they met the first settler

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*By Department staff.

they had seen in Oregon, namely Joseph Knott, who had located the first donation land claim in the Cow Creek valley. Joseph Knott showed Riddle the Cow Creek valley, and Riddle, impressed by the beauty of the valley and the splendid range for cattle, selected a site near what is now the town of Riddle. Here he immediately cut and laid the first four logs of his cabin, this being sufficient in those days to hold a land claim.

Early in the spring of 1852, other settlers began to arrive in Cow Creek valley. One of these was John Smith, from South Bend, Indiana, who located a donation land claim embracing the present site of the town of Riddle. After establishing the claim, Smith returned to his home in Indiana, but sent his daughter and son-in-law, J.Q.C. Vandenbosch, out to take over the claim. The Vandenbosch family thereby were the first owners of the townsite of Riddle, and their name appears on all abstracts of title to Riddle town property. In 1866, Vandenbosch sold his claim to Abner and J. B. Riddle.

In 1882, the Oregon and California railroad (later the Southern Pacific railroad) began extending its line south from Roseburg and soon reached Cow Creek. Abner and J. B. Riddle donated land for a town site, and a depot was located on it. The little town which sprang up was named Riddle, sometimes called Riddleburg, and for 8 months it was the southern operating terminus of the railroad. Stages left from this point for Redding, California. A. G. Walling, in his "History of Southern Oregon," published in 1884, reports that during the time that Riddle was the railroad terminus, "the place was 'lively' in the broadest significance of the term, and its like the peaceful citizens of Cow Creek valley hope never to witness again." With the extension of the railroad, and the departure of "the horde which infested the terminus," Riddle became a subdued but thriving village and shipping point for a small but prosperous community. There were two hotels, a store, a warehouse, a saw mill, and a school house. Placer mines were being extensively worked and "a nickel mine was being worked with good results on a neighboring mountain called 'Old Piney.'"

The deposit of nickel was first discovered by sheepherders in 1865 and was thought to be tin. In the excavations the prospectors found green ore which they supposed was copper. Samples of the rock were sent to Mr. William Q. Brown, a mining expert, who was then mining on Althouse Creek in Josephine County. An analysis showed the ore to be not copper or tin, but nickel, and the sample contained 6 percent nickel.

According to a newspaper clipping dated January 17, 1908, Mr. Brown and associates purchased the property in 1882 and ran open cuts, tunnels, and shafts. More than 3,000 tons of the ore was piled on the dumps, showing an average of 5 percent nickel, the value of which at that time was about $150,000 (the price of nickel varied from 40 to 60 cents per pound). The mine was then placed on the market for sale at prices ranging from $400,000 to $1,000,000 but no purchasers were secured. In 1891, Mr. Brown and J. B. Riddle sold 200 acres of the property to the International Nickel Mining Company, of Chicago. The Company expended over $100,000 in surface improvements, including a hotel, houses for workmen, a large Corliss engine and boilers, and a saw mill. A complete smelting plant of 150 tons capacity was purchased but was never erected. The newspaper stated that the stockholders got into litigation, and the machinery for the smelting plant was still stored on the railroad at Riddle. Mr. Winslow of Chicago had become owner, and Mr. W. Q. Brown still held some of the original property. Both properties were idle in 1908, and the International Nickel Company had 60 acres in prunes, then a thriving industry in the Cow Creek valley.

Sometime during the latter part of the last century the Adams family of Oakland, California, acquired ownership in the nickel area, and early in the present century Edson F. Adams emerged as the owner of the land containing the deposit.

In the late 1930's and early 1940's at least two important groups examined the deposit. A few churn drill holes were put down, mainly on the lower deposit. It seems likely that some metallurgical testing work was done on the nickel ore at this time but the investigations were conducted quietly and no publicity was given to the field work or results obtained.

In 1941 Freeport Sulphur Company negotiated a lease with Mr. Adams and in 1942 carried on extensive exploration work. Besides geological studies, some 50-odd diamond drill holes were put down with the principal attention given to the upper deposit, which contains much the greater amount of nickel. Metallurgical testing work was done along with the drilling.

In 1943 Freeport relinquished the lease, mainly because of the seeming difficulties of economic treatment of the ore. (The market price of nickel was then 35 cents per pound.) Moreover the company had acquired the Nicaro nickel property in Cuba and put it in production under a government contract so that interest in the Oregon deposit waned. The area containing the deposit, as well as some adjoining land which had been acquired by Freeport, was turned back to Mr. Adams.

After World War II, the M. A. Hanna Company of Cleveland, Ohio, became interested in the Nickel Mountain property. Negotiations were carried on, first with Mr. Adams and then, after his death in 1947, with his estate and a deal was finally transacted. Geological work and extensive metallurgical testing were begun. This was supplemented by churn drilling, shaft sinking for testing purposes, and bulldozing deep trenches during the succeeding three years. The culmination of all the exploratory work was the signing of the government contract early in 1953.

Geology

1. General geology and geologic setting

Nickel Mountain is in the northwest part of the Siskiyou Mountains a few miles east of their juncture with the Tertiary rocks of the Coast Range. Approximately 30 miles to the northeast the Tertiary volcanics of the Cascade Range overlap the continuation of the rocks that are found in the vicinity of the nickel deposit at Nickel Mountain.

The summit of Nickel Mountain and the host rock of the nickel deposit is peridotite, an ultrabasic rock consisting chiefly of olivine and enstatite. All the peridotite is serpentinized to some extent - fresh specimens being rare. A band of serpentine several hundred feet wide divides the peridotite into two parts. Serpentine is an altered ultrabasic rock and in this area it may mark a zone of intense shearing and considerable movement within the main peridotite body. Feldspathic and quartzose dikes of small areal extent occur in the serpentine and metavolcanic rocks. The ultrabasic rocks are probably late Jurassic or early Cretaceous in age and are intrusive into metavolcanic and metasedimentary rocks of late Jurassic age. The metavolcanic rocks are greenish colored and were originally lavas or pyroclastic igneous rocks. They have undergone varying degrees of change and some may even be classified as schists or phyllites. The metasedimentary rocks are graywackes and shales with minor chert and conglomerate and belong to the Jurassic Dothan formation.

Sedimentary rocks belonging to the late Jurassic Knoxville formation, early Cretaceous formations, and the mid-Eocene Umpqua formation occupy a minor structural basin developed in the old terrain of the Klamath Mountains after the mountain-making period which followed or accompanied the intrusion of the ultrabasic rocks. The Knoxville and early Cretaceous formations are well indurated grayish-colored rocks. Graywacke type sandstones predominate in both but conglomerates composed almost entirely of chert pebbles from $\frac{1}{2}$ inch to 2 inches in diameter mark the Knoxville formation while shales are characteristic of the early Cretaceous formations. The jointing in the Knoxville formation is more pronounced than in the early Cretaceous rocks. It is most noticeable in the chert conglomerates where the fracture planes through the pebbles form smooth surfaces. The Umpqua sediments are lighter in color than the Mesozoic sediments. A yellowish sandstone is the most common material of this formation but a pebble to boulder conglomerate is found near the base and dark-colored, thin-bedded shales are found in the valley floor. The conglomerate is composed largely of pebbles derived from the metavolcanics and metasediments of the ancient Klamath Mountains. Chert pebbles are not as prominent as in the Knoxville conglomerate and the jointing is so poorly developed that the rock generally breaks around the pebbles rather than through them as in the Knoxville conglomerate. Fossils, the basis on which the age of these formations has been determined, are fairly common in the Umpqua and early Cretaceous formations, less common in the Knoxville formation and very rare in the Dothan formation.

The Dothan and metavolcanic formations generally have high dips to the southeast with a strike to the northeast. The peridotite and serpentine form a discontinuous band which can be traced for nearly 35 miles from Cow Creek near the mouth of Salt Creek northeastward to Little River near Peel. The Knoxville and younger formations have attitudes which suggest a basin in the Riddle area. All contacts of the serpentine and peridotite with the other rocks are faults, consequently when the younger formations are found lying next to the ultrabasics the otherwise low attitudes found near the middle of the basin are distorted and frequently quite steep. The contact between the Dothan formation and the volcanics appears to be gradational although in many places serpentine occurs between the two, indicating a fault. Differences in attitudes between the Knoxville, early Cretaceous, and Umpqua formations mark unconformities. The unconformity between the Knoxville and early Cretaceous formations is more pronounced than the one between the Cretaceous and the Eocene formations, while the unconformity between the Knoxville and older formations indicates that the most severe orogenic disturbances took place at that time.

2. Geology of the deposit

The nickel mineralization is confined to the area of the peridotite. The serpentine band separating the peridotite is barren.

The ore mineral is a nickel-bearing hydrosilicate. The name garnierite is generally applied to this light to dark green mineraloid but as pointed out by Pecora (Pecora, Hobbs, and Murata, 1949)* garnierite is not a single mineral but a mixture of at least two and possibly three hydrosilicates.

The source of the nickel was the olivine and enstatite, the main minerals of peridotite. Both olivine and enstatite are compatible to having nickel concealed in their structures. An analysis of olivine from Nickel Mountain showed 0.26 percent NiO while an analysis of bronzite (the alteration mineral of enstatite) showed 0.05 percent NiO (Pecora and Hobbs, 1942). According to Rankama and Sahama (1949), during weathering ultrabasic rocks are converted into magnesite by the carbon dioxide-bearing weathering solutions; the magnesite goes into solution as magnesium bicarbonate in the uppermost weathering zone, and only silica, hydrosilicates of nickel and magnesium, and iron oxide remain as a residue. Also, according to Rankama and Sahama, "Contrary to Fe^{2+} and Mn^{2+}, Ni^{2+} is very stable in aqueous solutions and is accordingly able to migrate for considerable distances under proper circumstances."

The deposit can be divided into three zones that conform well with this data. The upper zone is a brick-red soil layer from 0 to 10 feet thick that was formed under lateritic conditions. In this zone silica nodules are common but the boxwork structure of the underlying zone is lacking. Small round pellets of red iron oxide and the brick-red soil are characteristic. The green nickel-bearing silicate is not found and the mineral which contains the nickel is not known. Pecora and Hobbs (1942) give a nickel content for this zone from 0.61 percent to 1.10 percent on four composite samples. The second or medial zone is characterized by a preponderance of silica in the form of a limonite-stained boxwork. Garnierite also stains the boxwork, imparting to it a pleasing mint-green color. Boulders of peridotite which contain garnierite veinlets are common in this zone. The lower zone is referred to as the root zone by Pecora and Hobbs. Here garnierite veinlets are found filling fractures within the peridotite. The limonite-stained silica boxwork is missing, indicating that the waters depositing the nickel were relatively lower in silica and iron than those which formed the medial or boxwork zone. Undoubtedly the garnierite of this lowest zone is confined to the more permeable shear zones within the peridotite. Shearing has fractured the peridotite and localized the nickel-bearing solutions to definite zones to impart a rootlike shape. The depth to which this zone extends is not known but distances of over a hundred feet may exist. All three zones will grade into one another and the depth to which economic mineralization will extend will also probably be gradational as well as variable.

The age of the mineralization is directly related to the period of laterization. It is thought that this is Tertiary, probably early Tertiary, but until the topographic development

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*Bibliography at end of this report.

of southwestern Oregon has been more accurately dated a more precise dating is not readily assignable. Probably the mineralization of the medial and lowest zones owes a great deal of its enrichment to leaching of the lateritic horizon. This suggests that mineralization in these zones has been continuous since laterization and may possibly extend to the present.

Government-Hanna contract

According to the contract between the Defense Minerals Procurement Agency and the Hanna Nickel Smelting Company and Hanna Coal and Ore Corporation, the Hanna Nickel Smelting Company will produce from 95 million to 125 million pounds of nickel in ferronickel to contain at least 25 percent nickel and not more than 75 percent iron. The government will pay not more than 79.39 cents a pound for the first 5 million pounds and 60.5 cents a pound thereafter. DMPA agrees to advance 24.8 million dollars for construction of smelting facilities and all but 2.4 million dollars will be spent on construction of the smelter. The loan will be written off under a mortgage for 24.8 million dollars recorded in Douglas County on June 25, 1953. The mortgage calls for liquidation by June 30, 1962.

The Hanna Coal and Ore Corporation contracts to develop the mine on Nickel Mountain at its own expense to cost approximately 4.3 million dollars. It is provided that ore from the deposit will be sold to the government at $6 a ton. In turn the government will sell the ore to the Hanna Nickel Smelting Company at the same price.

Plans have been made for transportation of the ore from the mine down the mountain to the smelting plant, a distance of about 1½ miles, by means of an aerial wire rope tramway. It is reported that the smelter will have four primary furnaces, one refining furnace, and two auxiliary furnaces. The company has obtained the rights to use the process of Societe D'Electro-Chimi, D'Electro Metallurgie et des Acieries Electrique D'Ungine. This process has been used successfully in treating New Caledonia ores having characteristics similar to the nickel silicate ore on Nickel Mountain.

At the time the DMPA announced the contract between the government and the company, it was stated that the ore to be treated would have an average grade of 1.5 percent nickel and that the ore would be mined by surface methods, put through a primary crusher and then conveyed to the smelter. A contract for construction of facilities was let to the Bechtel Corporation and construction has been underway since early in the spring. At the plant site furnace construction is well underway as well as numerous buildings. A railroad spur has been run from the Southern Pacific main line to the plant site, a distance of about 2½ miles. A pipe line and other water supply facilities have been installed. Sources of water will be Cow Creek and Rail Creek. Foundations for the tramway have been poured and the new first-class road from the plant to the mine has been completed. Timber is being logged off the ore body, some stripping has been done, and an office building erected at the mine. It is reported in the Mining World that production of ferronickel from one furnace will be started before September 30 of next year and that the remaining three furnaces will be installed by the end of 1954. The General Manager at Riddle is Earl S. Mollard and E. Emmons Coleman is Plant Manager. Mr. D. N. Vedensky, metallurgist, is Director of Hanna's Research and Development department.

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RIDDLE NICKEL WILL HAVE LONG LIFE

Under a Roseburg October 18 dateline the Oregon Journal published facts about the Hanna nickel project quoting Mr. Earl S. Mollard, General Manager of the project. Mr. Mollard stated that about 400 employees would be needed when the plant gets into production in the summer of 1954. It is expected that nearly all employees will be hired in the State. There will be five electric furnaces, four for the production of ferronickel and one for ferrosilicon. About 65,000 kilowatts of power will be required. The ore from the open pit mine will probably yield about 25 pounds of nickel to the ton of ore. The plan is to mine about 1800 tons of ore per day. The plant is expected to run three shifts a day for seven days a week, and ore reserves are sufficient for 30 to 40 years of operation at the capacity now planned, assuming that the operation is economic after the government contract is completed.

Mr. Mollard stated that the furnaces would not be able to refine anything but nickel. Some other elements in the ore would go to the slag pile and tests are being made to determine uses for the slag.

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PHIL BROGAN NOW ASSOCIATE EDITOR

Phil Brogan, who has been on the Bend *Bulletin* staff for 30 years since graduating from the University of Oregon, has been named associate editor of the *Bulletin*, by Robert W. Chandler, the new owner. Brogan has been the geologists' spokesman in Oregon for many years, and a great many people look forward to his weekly article on Oregon geology in the *Oregonian*. He is chairman of the Oregon Geographic Board, member of the Legislative Interim Committee on Historical Institutions, member of the Geological Society of the Oregon Country and the Bend Geological Society.

* * *

MINING CLAIMS ABANDONED

The Bureau of Land Management, under William C. Guernsey, Regional Administrator, is trying cooperation with mining claimants in a new approach to administering the mining laws. The BLM sent letters to about 400 persons holding 890 mining claims on O & C land. These letters reminded the claimants that they had not filed the required notice that assessment work on the mining claims had been performed during the 1952-1953 assessment year. Replies have been received by BLM that 126 mining claims have been abandoned. Mr. Guernsey stated that he felt encouraged by the cooperation of mining claimants, and he urged those who have received a letter concerning lack of assessment work and have not replied to do so at once so that the status of the claim may be cleared.

Holders of mining claims on O & C lands must file an affidavit of proof of labor showing that annual assessment work has been done. This proof must be filed in the United States land office as well as the office of the county recorder of the county in which the claim is located.

* * *

OIL AND GAS CONSERVATION LAW HEARING HELD

On September 15, 1953, the Governing Board of the State Department of Geology and Mineral Industries, which administers the new oil and gas conservation law (Chapter 667, Oregon Laws 1953), held a public hearing in the auditorium of the State Office Building in Portland. The Board had previously compiled rules and regulations as required by the law and presented these rules for approval at the hearing. Minor changes were suggested by representatives of the industry and these have been taken under consideration by the Board. The final draft of rules and regulations is now being prepared.

* * *

NEW CHROME CONCENTRATOR

The Thompson Milling and Manufacturing Company owned by L. H. Thompson and Lawrence Wilson of Ashland, Oregon, has constructed a concentrating mill on the south bank of Bear Creek near the end of Oak Street in Ashland for the purpose of concentrating chromite ore. It was put into operation October 6, 1953. The mill, powered by Buda Diesel engine, includes a 12-inch jaw crusher, a 32 x 48 Denver ball mill, and a Deister table. The owners plan to enlarge the mill by addition of another ball mill and two tables. Most of the ore is from deposits on the Klamath River in California under lease to Thompson and Wilson. Ore is also being shipped from three properties near Red Mountain which is nearly 30 miles southwest of Ashland on the Mt. Ashland road. One deposit on patented ground in sec. 32, T. 40 S., R. 1 W., has been leased from Larry Basey. Another in sec. 3, T. 41 S., R. 1 W., near Red Mountain Creek has been leased, and the third property is a claim adjacent to Basey's claim located by L. H. Thompson.

* * *

C.C.D.
BUSINESS DEVELOPMENT CORPORATION
ROSEBURG, OREGON

PROPOSAL

ALTERNATIVE USE STUDY
NICKEL MOUNTAIN SMELTER FACILITY

PB - 153
MAY, 1987

HATCH ASSOCIATES CONSULTANTS, INC. CONSULTING ENGINEERS

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1.0 - INTRODUCTION

The mine and smelter at Nickel Mountain, four miles west of Riddle, Oregon, that is owned by M.A. Hanna of Cleveland, Ohio has been permanently closed. The C.C.D. Business Development Corporation has requested a formal proposal for an "Alternative Use Study". The objective of this study will be to identify ways by which the assets of the smelter plant can be used to create jobs thereby maximizing the value of the facility both to the community and to the M.A. Hanna Company.

On May 11, 1987 Richard W. Wilson, President, Hatch Associates Consultants, Inc., Walter D. Atchison, a consultant and formerly Sales Manager for M.A. Hanna accompanied H.D. Wedge of the M.A. Hanna Company on a tour of the smelter plant. Mr. Wedge said that layout drawings, together with specifications for major equipment, are available and he provided assurance that the study team will receive full cooperation from the M.A. Hanna Company.

The smelter plant was shut down in an orderly fashion. The plant is clean but the electrical equipment is not being rotated nor is there any ongoing maintenance program in place. Apparently the owner is in the process of disposing of the physical assets to used equipment dealers and salvage companies.

On May 12th we met with representatives of C.C.D. Business Development Corporation, a representative of the Albany Research Center of the Bureau of Mines and other interested parties. During this meeting various concepts for utilizing the smelter facilities were discussed. The proposed ferrochromium smelter plant that is in the planning stage at Coos Bay Port was also discussed. In one of the newspaper articles describing the Coos Bay project, it was stated that chromite ore from the Klammath Mountains in southern Oregon and northern California would be smelted to produce ferrochromium. The second concept that was discussed was one proposed by W.D. Smiley, Consulting Scientist, who suggests that chromite which can be mined on the shelf off-shore terraces in the vicinity of Coos Bay could be smelted in the Nickel Mountain smelter.

It was proposed that the initial study be restricted to identifying various alternative uses for the plant. The most likely concept that results from this study would then become the subject of a full scale feasibility study. At the stage when a feasibility study is initiated, it is important to have the proposed investor also involved.

It was agreed that the Alternative Use Study would have a budget not to exceed $50,000. Assuming that detailed information on the plant facilities is readily available and we are given authority to proceed by June 1, 1987, the final report should be completed by August 7, 1987.

2.0 - OBJECTIVE

The objective of this study is to identify the use or variety of uses for the physical assets that are in place at the smelter plant located at Nickel Mountain, four miles west of Riddle, Oregon. The assets associated with this facility ranges all the way from the availability of heavy industrial labor to state-of-the-art roasting, smelting and melting equipment and includes the availability of low cost power, modern pollution control equipment and transportation facilities. It is intended that priority concepts identified during this study will be those that use the entire plant whereas some only take advantage of small sections of the plant.

It must be emphasized that an alternative use study should not be confused with a comprehensive feasibility study. An alternative use study such as this must concentrate on identifying all of the manufacturing processes that can conceivably be carried on in the subject plant. This study will address only the key feasibility elements.

The final report for this project will prioritize the various concepts for alternative uses developed by the study team. It will describe the various feasibility elements that must be explored and expanded in a comprehensive feasibility study.

3.0 - SCOPE OF WORK

The initial task will be to catalog all of the assets and characteristics of the plant and of the region. The schematic flow diagram for the smelter plant shown in Figure 1 identifies much of the major equipment that will be evaluated. The specifications of all major equipment will be collected and the space and structural limitations of buildings will be shown. Information relative to the existing utility contracts, labor availability and transportation facilities will be reviewed.

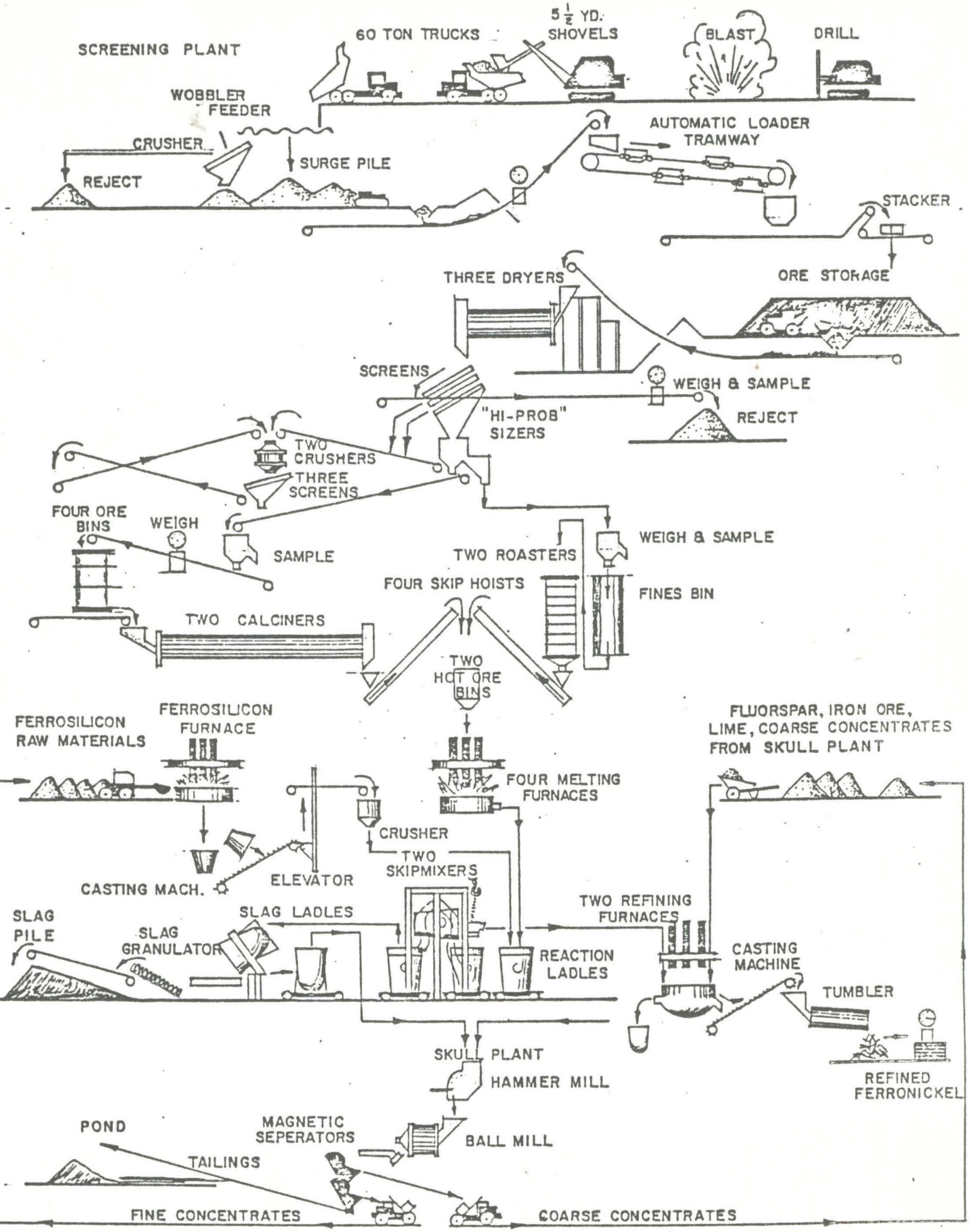
The study team will take advantage of the Hatch Associates' in-house information relative to a variety of processes that can be considered as alternative use plans. The concepts reviewed in this proposal are intended to be examples of those that will be explored.

3.1 - Ferrochrome From Black Sands

Dr. W.D. Smiley, Consulting Scientist, submitted a letter proposal to the C.C.D. Business Development Corporation on May 8, 1987. In this proposal Dr. Smiley states that there are black sands that are rich in chromite and ilminite occurring in on shore terraces, and on the shelf off shore terraces in the Coos Bay region to Cape Blanco area of southwest Oregon. He further states that these sands can be concentrated to produce a chromite suitable for smelting.

The market for ferrochromium remains depressed and is dominated by imports. There are, however, certain considerations that may make a project such as this worthy of consideration. During 1986 there was a total of 348,000 tons of ferrochromium imported which included 214,000 tons from South Africa. Our country is obviously dependent upon imports for this strategic material.

The most serious problem that we see in considering ferrochrome from black sands as a high priority alternative use for the subject smelter is that the feasibility of obtaining chromite from black sands has not been established. It may be more difficult to prove the economic feasibility



FLOW DIAGRAM

THE HANNA MINING COMPANY
HANNA NICKEL SMELTING COMPANY

FIGURE 1

of using the black sands as a source of chrome units than it will be to find an alternative use for the smelter.

3.2 - Sherwood Project (Coos Bay Port)

The newspaper in article in Coos Bay World dated April 11, 1987 describes the construction of a $24 million low carbon ferrochromium smelter plant that is in the planning stage for Coos Bay Port. It appears from the article that the site at Coos Bay was selected because the port facilities are important to the economic success of the project. It may be, however, that certain facilities currently in place at the Nickel Mountain smelter may be used in conjunction with this plant.

3.3 - Production of Stainless Steel Slabs

In mid-1982, Hatch Associates conducted a study to determine the feasibility of producing high carbon ferrochromium from chromite concentrates that originated from a North American ore source. It was determined that the subject chromite concentrates could be used to produce ferrochromium by any of the established smelting processes and that the product would be acceptable to domestic consumers. Unfortunately it was found that the concentrates could not be economically converted to ferrochromium because of the low prices that prevailed and still prevail in this depressed market.

An alternative scheme for developing domestic chromite deposits into a viable source of chromium units might be to build a plant that would convert the chrome units into stainless steel slabs or billets. An integrated plant such as this, constructed in an area where there are both raw materials and electrical energy, would have a cost advantage over competitive producers.

The flow sheet shown in Figure 2 illustrates the concept of converting low grade chromite concentrates into continuously cast slabs. This particular flow sheet was developed to illustrate the production of 400 series stainless slabs that do not contain nickel. Naturally, the

CONCEPTUAL FLOWSHEET FOR MANUFACTURE OF STAINLESS STEEL FROM LOW GRADE CHROMITE CONCENTRATES

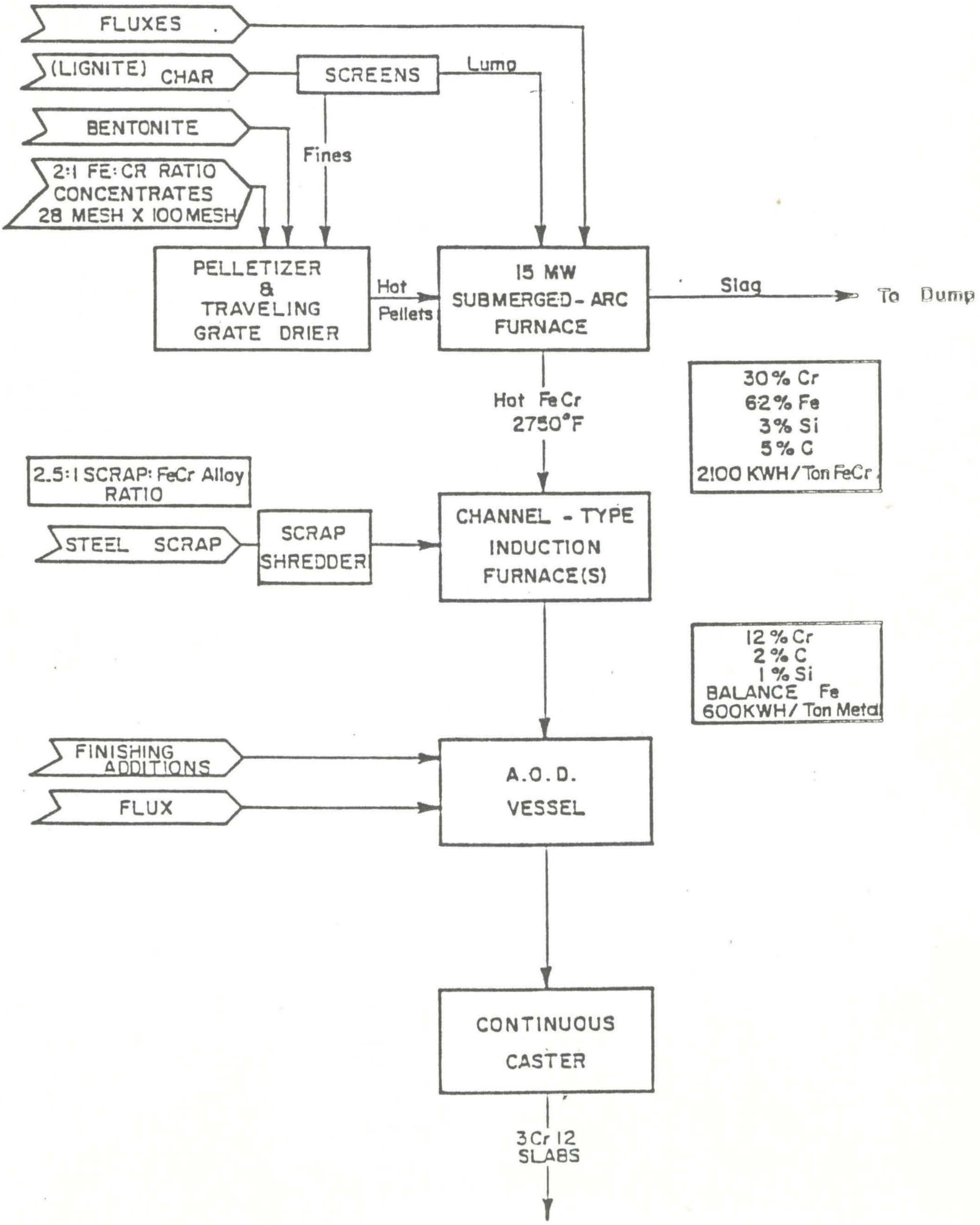


FIGURE 2

process could also be used to produce 300 series stainless containing both nickel and chromium. It should be noted on this flow sheet that a pelletizer and a dryer is required to prepare the pellets for feed to a submerged arc furnace. These major pieces of equipment are all in place in the Nickel Mountain smelter. The channel type induction furnace shown on the figure could also be replaced by the two arc furnaces installed in the smelter. Major equipment required that is not currently in place in the smelter would be the AOD vessel and the continuous caster.

We readily admit that this alternative use concept is a "long shot" because of the depressed condition of the specialty steel industry in the United States. It is, however, worthy of investigation because it has many advantages to the region in that natural resources and energy would not be shipped out in the form of raw materials but rather they would be shipped as semi-finished products; many more local jobs would be created.

3.4 - Specialty Alloys For Remelt

The two refining arc furnaces that have the capability of pouring molten metal directly into casting machines that feed their pig cast product into a tumbler, could be used for the production of a variety of specialty alloys. The raw material for this series of products would be scrap generated by the aircraft companies and other manufacturing firms located along the west coast. The product would be sold to induction melters located along the west coast.

We would not consider this to be a high priority alternative use because it would only utilize a very small part of the plant. It could, however, be used in conjunction with the slab casting process described in Section 3.3.

3.5 - Metals from Fly Ash

The Electric Power Research Institute (EPRI) has sponsored a program to evaluate the recovery of metals from fly ash. Based upon studies to date, the Direct Acid Leach Process appears to be the preferred route.

EPRI is looking for support on a $600,000 mini plant to pilot their process which has only been examined on a laboratory scale. The process flow sheet is shown in Figure 3.

The quantity of coal consumed by the power companies in the general region of southwest Oregon is shown in the following table:

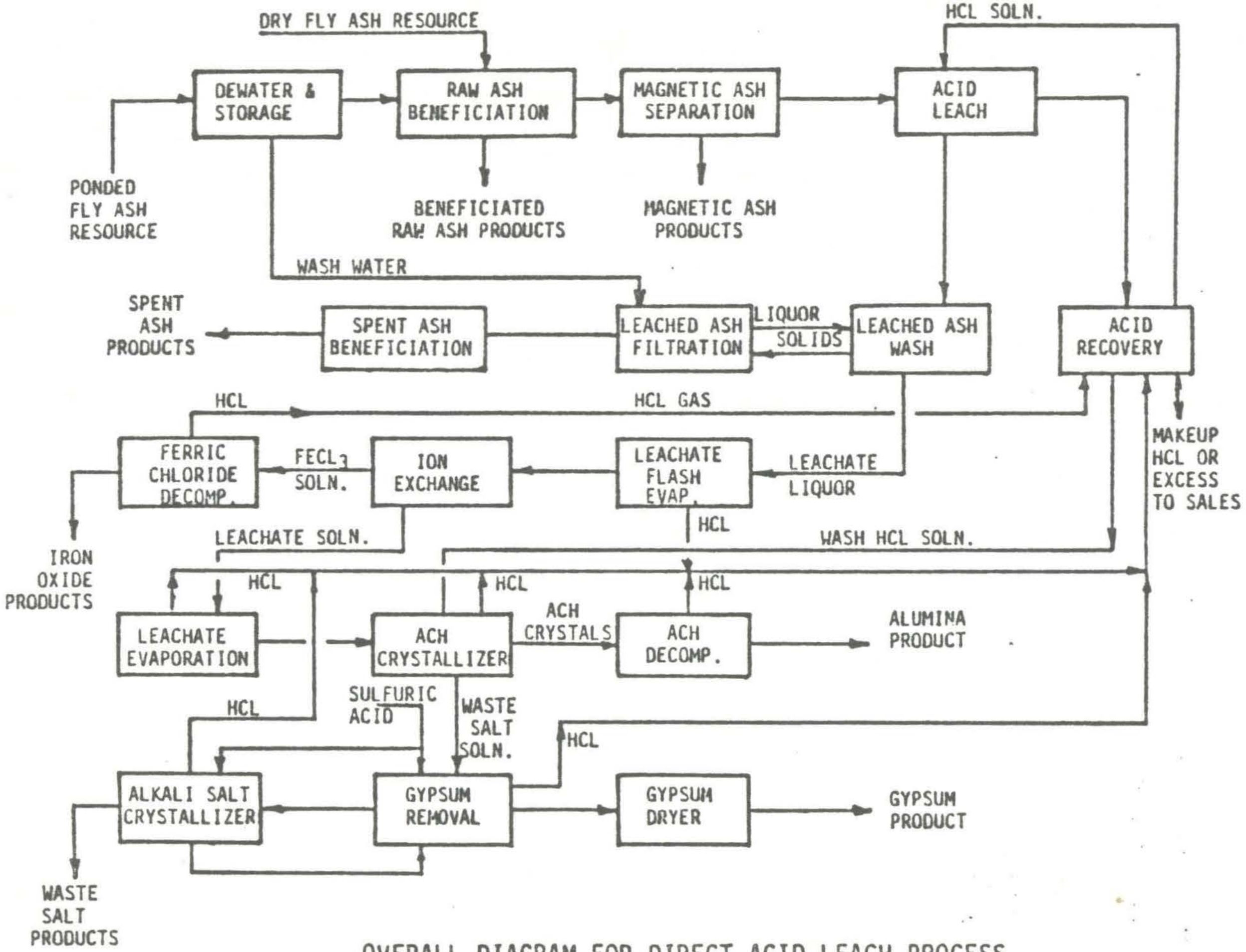
COMPANY	LOCATION OF OPERATIONS	COAL CONSUMPTION (NTPA)
Pacific Power & Light	Oregon	18.2×10^6
Southern California Edison	Nevada	$3.9 \text{ X } 10^6$
Portland General Electric	Oregon	1.1×10^6
Idaho Power	Idaho	1.4×10^6
Sierra Pacific Power	Nevada	0.3×10^6
TOTAL COAL CONSUMPTION		25.4×10^6

We assume that there is 10% ash in the coal. The total fly ash produced by these five power companies each year totals more than 2.5 million tons.

3.6 - Hazardous Waste Destruction

Soils containing extremely low levels, expressed in parts per million (ppm) of polychlorinated biphenyls (pcb), and/or even lower parts per billion (ppb) levels of dioxins or furans are deemed to be hazardous and become subject to environmental restrictions. These hazardous contaminants may enter the soil as a result of leaching chemical disposal dumps.

Emerging technologies are being developed to collect the hazardous components using heat, distilling them from the soil. While the economics may be more favorable for a mobile processing concept, the use of a fixed facility may be feasible if there are sufficient hazardous waste sites in the area.



OVERALL DIAGRAM FOR DIRECT ACID LEACH PROCESS

FIGURE 3

This alternative process would utilize some of the roasting and calcining equipment in the smelter plant.

3.7 - Recycling of Electric Arc Furnace Dust

The steel industry generates large quantities of dust that is collected in filters. The dust quantity represents several percent of the steel produced. Since the dust consists mainly of metal oxides, it will be preferable to recycle the dust in the steel process but unfortunately today's processes do not generally allow an economic recycling. Much of the dust is therefore dumped or stockpiled, frequently causing environmental problems when heavy metals leach into the ground water.

Hatch Associates Consultants, Inc. has been a consultant to SKF Engineering, a Swedish based company, for the past two years. This consulting has been in connection with the application of plasma technology to both chrome smelting and to recycling of electric arc furnace dust. SKF is presently operating a plasmadust plant which converts 70,000 tons of dust per year that is located in southern Sweden. This plant converts virtually all of the electric arc furnace dust generated in Europe.

The plasmadust plant located near Riddle, Oregon would receive EAF dust from steel plants located in Seattle, California and possibly as far away as Utah. The plasmadust process is very energy intensive and it may be that the low cost electrical energy in Oregon will offset the high cost of freight.

4.0 - PROFESSIONAL STAFF

Hatch Associates offers comprehensive engineering services to the process industry, including all phases of steel and non-ferrous operations from ore processing to finished products. The company is particularly well known for its ability to work with client's top management in the planning and execution of projects involving the scale up of process technology, implementation of innovations and following through engineering, construction and start-up. Since its formation in 1955, the firm has grown to a staff of over 450, including approximately 200 engineers.

The process group is responsible for feasibility studies, new process development, pilot plant investigations, process design, environmental control projects and start-up of major industrial facilities. The group consists of over 50 chemical, environmental, metallurgical and mining engineers with many years of research, development and plant operations experience. Most of the personnel in this group have advanced degrees.

This alternative use study will require concentrated effort of a few dedicated professionals who will have the support of a variety of specialists from the Hatch organization on an as-required basis. Richard W. Wilson, President, will be Principal in Charge of the project. Paul O'Shaughnessy, Supervising Process Engineer, will be Project Manager and will be assisted by Walter Atchison and Tom Kaveney. Resumes of these key members of the project team together with resumes of various other staff members who are expected to participate in the study, are included in Appendix A.

We have contacted Dr. W.D. Smiley, Consulting Scientist, who is retired in Salinas, California. Dr. Smiley has some experience with the black sands along the coast of Oregon and he has indicated that he will be available for consultation on this project.

5.0 - PROJECT BUDGET

The scope of work may not be limited to the alternative use concepts listed in Section 3.0 of this proposal. The project team may also find that some of the concepts listed will be rejected. The project team will be in a better position to firm up the list of concepts after they have completed cataloging the facilities which is the initial phase of the project.

The not-to-exceed budget has been established at $50,000. We estimate that approximately $10,000 of the budget will be expenses, leaving $40,000 for professional fees. Based upon previous studies of this type, this equates to approximately 65 mandays of effort.

We estimate that the time required to complete the study together with the final report will be 10 weeks. It is possible that the project can be completed in less time but the wide range of concepts being considered requires a large amount of information to be gathered. In some cases the information is not readily available, thereby causing a delay.

The professional fees and terms of payment are provided on the schedule of rates included in Appendix B.

THE
HANNA NICKEL
OPERATION

THE HANNA MINING COMPANY

HANNA NICKEL SMELTING COMPANY

RIDDLE, OREGON

JUNE 1, 1970

P.S.M. Technologies Inc.

Head Office:
880 - 789 West Pender St.
Vancouver, B.C. V6C 1H2
Tel: (604) 669 3614

Subsidiary:
U.S. Chrome Inc.,
U.S. Nickel Corp.

PRECIOUS
STRATEGIC
METALS

"PROJECT CHROMIUM SMELTER"

To Produce Low Carbon Ferro Chromium

The Company is pleased to announce that on April 11th, 1987, the corporate structure of SHERWOOD Pacific Limited was initiated. This company is formed to construct and operate a Chromium Smelter in Coos Bay, Oregon, to produce low carbon ferro chromium.

P.S.M. Technologies Inc. has a 31.5% interest in the project and has the exclusive right to supply all raw materials required.

The Board of SHERWOOD was elected as follows:

SIR MONTE FINNISTON
F.Eng. FRS Phd. Metallurgy
Retired, C.E.O. British Steel
Deputy Chairman Nuclear Research Centre,
Harwell U.K.
As Chairman of the Board

JOSEPH B. HOWE
BS Physics MS Physics
Group Vice-President Radio Corporation of America
Oversees two plants in New Jersey
As Director and Secretary

GEORGE E. KRUGER
BS Geology Dartmouth
MS Economic Geology U. of Minnesota
AMP Harvard Business School
20 years as Senior Vice-President of Chase Manhattan
Bank in charge of Mineral, Metal Development
Division of the Bank.
As Director.

WILLIAM G. WOOD
President of P.S.M. Technologies Inc. 30 years experience
in exploration and development of natural resources.
As Director.

PATRICK J. WOODING
BS E "Eng Lond", C.Eng Fifmech E,FIEE
Past Director of Engineering, Lectromelt, President of
Consarc and has been responsible for many of the
advanced melting projects in the United States and
overseas for the past 25 years.
As President and C.E.O.

The accumulated years of total experience of the Board of SHERWOOD with regard to their respective endeavours and expertise is 173 years.

Technical, financial and business administration are all well simulated and the Board of SHERWOOD is dedicated to one objective -- success!

Pacific Power and Light Company is funding the project in the amount of \$2,000,000 (U.S.) in preferred equity. An incentive electrical supply agreement has also been negotiated subject to the approval of the Oregon Public Utility Commission. This agreement provides a price discount as well as funding for transmission, substation and other electrical facilities in the amount of approximately \$4,000,000 (U.S.). This smelter will use 25/50 Megawatts of energy.

Oregon Governor Neil Goldschmidt, working in concert with the State Economic Development Department, under the direction of Chairman Roger Smith, will co-ordinate the state's major financial contribution to the project. Both Governor Goldschmidt and Chairman Smith have been extremely co-operative in bringing this new industry to Oregon.

The Oregon International Port of Coos Bay is also making a major financial contribution in the form of a fully-serviced site, including a deep-water dock on very attractive terms for the first six years. Much of the credit for this goes to Mr. Frank G. Martin Jr., the Port's General Manager, who has worked for months to bring the project to Coos Bay.

WOODING, a New Jersey corporation, headed by P. J. Wooding, an international leader in the metal melting industry, will license to SHERWOOD all patents, patent applications, and technology and will construct the smelter. The prototype primary melter was installed at full scale in one of Arbed's plants in Luxembourg and operated successfully for 18 months.

P.S.M. Technologies Inc. will provide \$10,000,000 (U.S.) in equity and will have the exclusive right to supply raw material to the project. For this, it will receive a 31.5% interest directly in SHERWOOD. Initial raw material will come from Southern Oregon and Northern California properties, which P.S.M. Technologies Inc. owns or has under option from Del Norte Chromium and Asamera Metals (U.S.) Inc.

Thirty thousand tonnes of L.C.F.C. have been presold on a take or pay basis through two major metal companies for ten years. The smelter construction will be completed in August, 1988, and commissioned October, 1988. Total sales in the first full year of production will be \$45,000,000 (U.S.) increasing to \$60,000,000 (U.S.) in ten years with a gross profit of 35%.

Funding for this project will commence with a private placement. This financing will be announced as soon as the price has been agreed upon.

ON BEHALF OF THE BOARD

Wm Wood.

WILLIAM G. WOOD, PRESIDENT

CCD BUSINESS DEVELOPMENT CORPORATION

JULY 30, 1987

MEETING

ALTERNATIVE USE STUDY-NICKEL MOUNTAIN SMELTER FACILITY

1.0 INTRODUCTION

2.0 ALTERNATIVE PROCESSES

3.0 RECOMMENDATIONS FOR FURTHER INVESTIGATION

LIST OF ALTERNATIVES

1) STAINLESS STEEL
2) ZINC RECOVERY FROM EAF STEELMAKING DUST ✓
3) METALS FROM FLY ASH ✓
4) SCRAP CATALYST PROCESSING ✓ (Horsehead →)
5) FERROSILICON
6) CENTRAL HAZARDOUS WASTE PROCESSING FACILITY
7) FERROCHROMIUM
8) NICKEL SLAG PRODUCTS ✓

STAINLESS STEEL

-- COMPETITIVE HOT METAL COSTS AT 50,000 TPA INGOTS.

-- PROCESS UTILIZES HANNA FACILITY AND ASSUMES ZERO COST FOR REJECT NICKEL ORE.

-- WEST COAST STAINLESS IMPORTS TOTAL APPROXIMATELY 50,000 TPA BUT THERE ARE MANY PRODUCT TYPES.

-- ONLY ONE EXISTING STAINLESS PRODUCER ON WEST COAST-JORGENSEN IN SEATTLE.

\- STAINLESS POWDER MARKET IS 5,000 TPA AND COMPETITIVE.

ZINC RECOVERY FROM EAF STEELMAKING DUST

-- EAF DUST HAS BEEN RECLASSIFIED BY EPA AS HAZARDOUS AND LANDFILLING WILL BE BANNED AS OF 8/8/88.

-- SEVERAL PROCESSES HAVE BEEN DEVELOPED TO PROCESS DUST TO RECOVER THE VALUES (WHICH ARE THE HAZARDOUS COMPONENTS) AND DISCARD AN INERT PRODUCT.

-- DISCUSSIONS WITH NINE (9) STEEL PLANTS HIGHLIGHTED THEIR CONCERNS ABOUT THE EPA REGULATIONS AND THE HIGH COST OF DISPOSAL.

-- OF 500,000 TPA DUST GENERATED IN THE UNITED STATES, ONLY 35,000 TPA COMES FROM PLANTS FROM COLORADO WESTWARD.

-- HORSEHEAD RESOURCE DEVELOPMENT (HRD) IS THE ONLY FULLY COMMERCIAL OPERATOR RECOVERING ZINC FROM EAF DUST, HAS ONE OPERATING PLANT IN PENNSYLVANIA, ONE DUE TO START IN CHICAGO, AND IS LOOKING FOR OTHER SITES.

-- HRD MAY BE ABLE TO USE SOME EXISTING EQUIPMENT; EXPRESSED CONCERNS RELATIVE TO ASSUMING EXISTING ENVIRONMENTAL LIABILITY.

METALS FROM FLY ASH

-- EPRI HAS DEVELOPED A DIRECT ACID LEACH (DAL) PROCESS ON A BENCH SCALE TO RECOVER:

- ALUMINA
- IRON PRODUCTS
- GYPSUM
- ALKALI SALTS

AND THE RESIDUE HAS APPLICATIONS AS A FILLER IN PLASTICS.

-- FLORIDA PROGRESS CORP. DEVELOPED THEIR OWN DAL PROCESS ON A PILOT SCALE AND PATENTED SOME ASPECTS NOT COVERED BY EPRI.

-- POZZOLANIC NORTHWEST HANDLES 3 MILLION TPA FLY ASH FROM SOURCES IN WASHINGTON, OREGON, WYOMING, COLORADO, NEVADA AND ALASKA AND SELLS MATERIAL AS A CEMENT SUBSTITUTE WITH SHIPPING DISTANCES UP TO 1,500 MILES.

SCRAP CATALYST PROCESSING

- TOTAL AVAILABILITY IS 50,000 TPA MAX.
- GULF CHEMICAL & METALLURGICAL AND CRI-MET ARE LOCATED ON THE GULF COAST AND HAVE COMBINED CAPACITY OF 70,000 TPA.
- NI/CO RESIDUE FROM GULF COAST PLANTS IS SHIPPED TO EUROPE AS WELL AS CANADA, AUSTRALIA AND JAPAN.
- CATALYST SCRAP GENERATION ON WEST COAST IS SMALL COMPARED WITH GULF COAST.
- CHEVRON IS LANDFILLING Ni/W AND Ni/Sn SCRAP BECAUSE THERE IS NO ECONOMIC PROCESS AVAILABLE TO RECOVER THE METALS.
- TRANSITION METALS TECHNOLOGY'S PROPOSAL SEEMS TO ASSUME A LARGER SCRAP CATALYST AVAILABILITY.

FERROSILICON

- THE HANNA FESI FURNACE IS SUITABLE FOR FESI50% PRODUCTION BUT MODIFICATIONS FOR FESI75% PRODUCTION MAY EXCLUDE THIS ALTERNATIVE PRODUCT.
- UNITED STATES FESI FURNACE CAPACITY IS UNDERUTILIZED.
- THE UNITED STATES IMPORTS 20% OF FESI50% REQUIREMENTS AND 70% OF FESI75% REQUIREMENTS, AND EXPORTS ARE SMALL.
- HANNA'S PROJECTED PRODUCTION COSTS FOR FESI50% ARE GREATER THAN PREVAILING MARKET PRICES AND THERE IS LITTLE OPTIMISM FOR SIGNIFICANT UPWARD PRICE MOVEMENT BECAUSE OF WORLDWIDE OVERCAPACITY.

CENTRAL HAZARDOUS WASTE PROCESSING FACILITY

-- EPA HAS MADE DATA AVAILABLE ON 226 IDENTIFIED SITES IN OREGON.

-- THE LIST INCLUDES LANDFILLS AS WELL AS GENERATORS.

-- PLATING OPERATORS ARE NOW PROCESSING THEIR WASTES ON-SITE.

-- A CENTRALIZED INCINERATOR [illegible] CAN ONLY PROCESS WASTES GENERATED IN OREGON AND ADJACENT STATES

-- A NEW PROCESS WOULD TAKE EXTENSIVE STUDY AND REVIEW TIME, PARTICULARLY FOR PREVIOUSLY UNDEMONSTRATED TECHNOLOGIES.

FERROCHROMIUM

-- THE "WOODING" DEVELOPMENT REQUIRES A DEEP WATER PORT BECAUSE RAW MATERIALS MAY BE FROM OFF-SHORE AND MARKETS WILL BE WORLDWIDE.

-- OREGON BEACH SANDS COULD BE A SOURCE OF CHROMITE CONCENTRATES AND AN EXPLORATION PROGRAM IS BEING PLANNED BUT FINANCING HAS NOT BEEN SECURED.

-- THE "PROCESS" IDENTIFIED BY DR. SMILEY MAY BE BETTER LOCATED AT COOS BAY RATHER THAN RIDDLE.

NICKEL SLAG PRODUCTS

-- NICKEL SLAG IS CURRENTLY BEING USED AS AN ABRASIVE FOR SANDBLASTING AND AS THE BACKING GRANULES ON SHINGLES.

-- NICKEL SLAG HAS BEEN FOUND UNSATISFACTORY FOR HEAD LAP GRANULES ON SHINGLES; QUARRIED MATERIAL IS PREFERRED.

-- THERE IS A LIMITED MARKET FOR COLORED GRANULES IN THE NORTHWEST WITH COMPETITION IN CORONA (NEAR L.A.) AND RANCHO CORDOBA (SACRAMENTO).

-- UP TO 18 COLORS ARE CURRENTLY BEING MARKETED.

-- CAPITAL COST FOR COLORING PLANT COULD BE SEVERAL MILLION DOLLARS.

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

DEVELOPED PROCESS

-- HORSEHEAD RESOURCE DEVELOPMENT

PROCESSES NEEDING DEVELOPMENT

-- SCRAP CATALYST PROCESSING WITH CHEVRON.

-- METALS FROM FLY ASH WITH POZZOLANIC, EPRI AND FLORIDA PROGRESS.

-- NICKEL SLAG PRODUCTS (COLORED GRANULES) WITH GAF OR 3M.

	MAJOR FEED MATERIAL				SALEABLE PRODUCTS				
Process	Type	Quantity	Operating Costs ($/yr)	Capital Cost	Types	Revenues ($)	Demand Power (MW)	Employment (No.)	
(1) DAL Leach	Fly Ash	540,000 TPA	11 Million	$162 Million	Magnetic Ash Alumina Gypsum Plastic Fillers	41 Million	6	200	
(2) Elkem Dust	EAF Dust	30,000 TPA	3 Million	$ 2 Million	Zinc Lead	5 Million	4	40	
(3) Horsehead Resource Development (N.J. Zinc)	EAF Dust	25,000 TPA	4 Million	$ 15 Million (Max.)	Zinc Concentrates Aggregate	5 Million	<1	25	
(4) Stainless Slab	Reject Nickel Ore Domestic Chromite	520,000 TPA 45,000 TPA	40 Million	$ 5 Million	300 Series Stainless Ingot	50 Million	25	130	
(5) Metal Recovery from Scrap Catalyst	Ni/W and Ni/Sn Catalyst	[illegible]0,000 TPA	Not Known	Not Known	W and Sn Alloys with Ni Residue	2 Million	<1	20	
(6) Slag Recovery Process	Nickel Slag	75,000 TPA	2 Million	$ 0.5 Million plus for coloring plant	Colored Granules	3 Million	<1	20	del from study

BPA assignment of Power contract with Hanna Ni.

may consider the 7(b)3 charges to be "otherwise unrecoverable costs" under the terms of the power sales agreement. On this theory, they might assert that charges that would have been collected from Hanna if it were a customer can be collected as costs of termination. This position would have to be based on the contract rather than the statute since the charges are limited to "customers" under the statute.

At the meeting we simply asserted that 7(b)3 charges do not apply once Hanna ceases being a customer of BPA. The staff said they would informally respond to this position within a week. We can develop a more formal statement of position later if it appears the staff is going to be adamant in asserting that 7(b)3 charges can be imposed following termination. In the meantime it seems to make sense to work with them on an informal basis.

4. Transfer Charges Under the PP&L Agreement. We discussed the transfer charged of approximately $6,000 which BPA must pay to PP&L under its transfer agreement. Hanna bears the responsibility for these charges which continue until the time of termination. We do not see any way these charges can be avoided.

5. Other Indirect Costs. The staff did not know of any other indirect costs that can be imposed under the terms of the power sales agreement. However they said they would give the matter some additional thought and respond within the next week.

Assignment Issues.

We had an extensive discussion of the possibility of assigning the power sales agreement. The staff explained that BPA does not have a "formal" policy outlining the circumstances under which a power sales agreement can be assigned and in fact does not have any memos on this point. They did indicate that BPA is very interested in maintaining as much load as possible during the current surplus and therefore will be willing to read as much flexibility into the Regional Act and power sales agreements as possible. They specifically indicated that an assignment to a new location and to a related industry might be possible. They suggested Hanna compile a list of all products which were ever produced at Riddle even if production of one of those products was not the primary purpose of the facility. They concluded that Hanna ought to bring any possible assignment to BPA for further review.

A/S OLIVIN

A Success Story Which Illustrates How Demand can be Generated to Meet Supply

LEN,
HAVE YOU SEEN
THIS ARTICLE ? HOW
DID THE OLIVINE
SAMPLES YOU TOOK
ON NICKEL MOUNTAIN
TURN OUT ?
Herb

Peridotite is made
of ± 90% olivine.
Any use for olivine
in the US.
VMM

A/S Olivin is a Norwegian company which currently supplies almost half the world's 4½ million tonne per year demand for olivine sand. All this comes from a single deposit at Aaheim on the west coast of Norway. It was not always so. As recently as 1975 production was as little as 150 000 tonnes a year but research and clever marketing have opened up new uses for olivine and production has now reached 1.7 million tonnes a year. Its main use today is as a slag conditioner in iron and steel making.

Olivine is a magnesium silicate mineral made up of a solid solution of Fayallite ($FeO.SiO_2$) and Forsterite ($2MgO.SiO_2$). Chemically it assays 48 to 50% MgO, 41 to 43% SiO_2, and 6.1 to 6.6% FeO with minor quantities of chromite, alumina, nickel and manganese oxides. It is light green in colour, has a specific gravity of 3.25 and a hardness of 6.5 on Moh's scale. Olivine is a very common mineral being a component of many rocks, but it rarely occurs in exploitable deposits. There are several olivine deposits in the ultrabasic rocks of Norway but those at Aaheim are the largest and purest. Geologically the rock at Aaheim is a dunite. It consists of 90 to 95% olivine mineral with minor quantities of pyroxene, chlorite and other minerals. The deposits cover an area of 6½ km^2 and are surrounded by massive gneiss. The quality of the deposit is very consistent although there has been some serpentinisation of the olivine along the contact with the gneiss. Serpentine is a hydrated magnesium silicate formed by the action of steam on the olivine at the time of its emplacement. The water of crystallisation thus absorbed makes the serpentinised olivine unacceptable as a refractory. The gemstone peridot is a pure crystalline form of olivine.

An interesting fact from the geological point of view is that wherever the olivine outcrops the ground is covered with pine forest. Where there is no olivine, birch and other deciduous trees predominate. The conformation of the orebody can thus be clearly seen from the vegetation.

A/S Olivin, which is wholly owned by the Norwegian government, began operations in 1948 and slowly increased production to meet the demands of the traditional markets of blast cleaning and foundry sands. At the low production level of around 100 000 tonnes a year however operations were barely economic, and it was realized that a truly profitable operation could only be achieved by developing new uses in order that production could be increased and unit costs reduced. The lower costs would then hopefully further foment olivine use. The strategy has been highly successful, with production increasing more than tenfold in the ten years since 1975.

Uses

One of the traditional uses of olivine has been as foundry sand where its high melting point of 1760°C, good thermal conductivity, high heat capacity and low coefficient of expansion make it ideal as a casting medium. It has the additional advantage that there are no health hazards associated with its use as there are with silica sand, since the silica in olivine is chemically bonded to the magnesium. There is therefore no risk of workers developing silicosis.

Main photograph:-
The mobile crushing plant at the new pit with Lokomo double deck vibrating screen and G3210 gyratory crusher.

Bottom left:—
Inside the processing plant. Two of the four secondary crushers are shown, a Lokomo G3210 gyratory crusher and S21 cone crusher.

Top left:-
A/S Olivin processing plant and dock on the fjord.

Another traditional use is as a blast cleaning agent. Olivine sand has a hard angular grain of high density which acts as an excellent scourer. There are no health risks associated with its use since no free silica is released to the air.

The use which has accounted for the tremendous increase in production in recent years is as a slag conditioner in iron and steel making. The usual fluxing agents in steel making are dolomite or limestone, together with silica to lower the melting point. Since olivine contains both magnesia and silica the melting point of the charge is reduced and the viscosity of the slag lowered. This makes olivine an excellent substitute for dolomite when treating low silica ores. Olivine at 49% MgO also has a higher magnesia content than dolomite, so fewer tonnes are required and less slag is produced. The olivine is either mixed with the iron ore fines and fed to the sinter plant, mixed directly with the iron ore for the production of olivine pellets, or added to the blast furnace in lump form. In sinter plants the substitution of dolomite by olivine has been found to increase sintering capacity by 13 to 14%. This has been achieved through sintering temperatures about 100°C lower than before, a 20% reduction in coke consumption, and the production of a tougher sintered product, which has meant less recycle of fines. About one million tonnes a year of olivine are supplied for sinter feed with a further 250 000 tonnes a year for pellets and 250 000 tonnes a year of lump olivine for direct blast furnace feed.

Among the other uses to which olivine is being put is the manufacture of refractory bricks for ladles, torpedo tubes, and night storage heaters. The proximity of Aaheim to the North Sea oilfields and the high specific gravity of olivine has created a demand for it as ballast for oil platforms and for covering undersea pipelines.

Mining

Prior to 1970 production came from five or six different open pits. These were consolidated into a single operation and this pit is now being extended to avoid going into deeper and harder strata. A second open pit was recently started a few kilometres away.

Although olivine is a hard mineral it is quite a soft rock from the excavation point of view. Because the deposit is almost pure olivine, with little or no other minerals, there is no cementation between the individual crystals and the rock breaks easily along the grain boundaries. These characteristics make the rock resilient and elastic which causes problems when blasting. Much of the explosive shock is dissipated through the natural fractures and explosive consumption is therefore high.

Mining is on 15-m benches in the conventional manner, 102-mm holes 16-m long being drilled by hydraulic drills. Slurry gel type explosive is used with Nonel detonation and about 40 000 tonnes are produced with each blast. The explosive gel is prepared at a mixing station on the dockside and transported to the mine in tankers. Gel type explosive is used because of the fractures in the rock and the wet holes. It is extremely safe to use as it does not become an explosive until it has set. The blasted ore is loaded into trucks by two CAT 988 loaders and a Broyt 52 hydraulic excavator for transport to the primary crusher at the edge of the pit. The Broyt 52, which weighs 45 t and has a 4.8-m^3 bucket, is unusual in that it has no traction. It is fitted with two solid iron wheels and two rubber wheels and moves itself over short distances by leverage on the bucket boom.

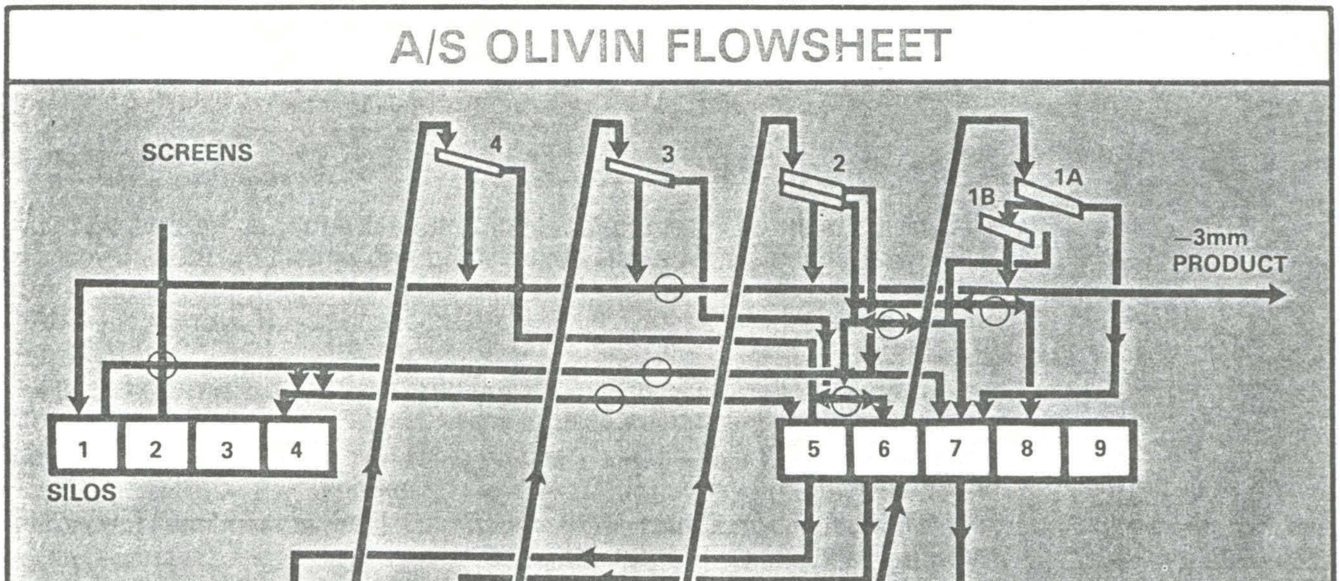
The primary crusher is a Lokomo MK120 jaw crusher which has 2½-m long jaws and is set at 300 mm. Crusher discharge goes to a conical covered stockpile and loading point. Primary crushed ore is transported to the treatment plant on the coast 7 km away by a fleet of Scania trucks with three axle trailers. The 34-t trailers are made of aluminium lined with rubber panels. The mine is currently in the process of replacing these 34-t trucks by 50-t versions.

Ripping proves an alternative to blasting

The soft nature of the rock, particularly close to the surface, led to discussion as to whether it would be feasible for excavation to be done by ripping instead of drilling and blasting. Trials at the new pit using a contracted D9L bulldozer with a single ripping tooth have been very successful, and the mine has placed an order for its own Komatsu 375 dozer. The shank of the single tooth is mounted on four hydraulic cylinders at the rear of the D9L. Ripping to a depth of about 600 mm is always done downslope. The technique is to start by tilting the dozer forward on its front axle with the tooth angled back in order to gain penetration. Once penetration has been achieved and the dozer is level, the hydraulic cylinders are actuated to force the tooth into the vertical position. The dozer makes several parallel rips and then uses its blade to push the material down the slope to the crusher. The method gives very good fragmentation, about half the production being reduced to the final size range. Olivin estimate that they will be able to remove the top 25 or 30 metres by this method. Below this the rock becomes harder and blasting will be necessary. One third of the 9000 tonne per day production is now coming from this new pit, the majority of it excavated by ripping.

Mobile Crushing Plant

The crushing plant at the new pit has been made as two mobile units so that it can be easily moved to a new site in the future. It consists of a feed hopper, grizzly, and Lokomo C125 jaw crusher as one unit, and a Lokomo double deck vibrating screen with G3210 gyratory crusher as the second unit. The jaw crusher is set at 120 mm and the G3210 gyratory at 20 mm. Gyratory discharge is recycled to the screen. Both the jaw crusher feeder and double deck screen are driven by hydraulic motors which give accurate speed control, and the gyratory crusher is mounted on rubber feet to isolate its motion from the frame.


A/S OLIVIN FLOWSHEET

A/S OLIVIN EQUIPMENT LIST

Crusher No.	1	Lokomo	G4214	Set	50mm
"	2	"	G3210	"	20mm
"	3	"	S21	"	6mm
"	4	"	S21	"	6mm
Screen No.	1a	Siebtechnik		Set	40mm
"	1b	"	HF	"	3mm
"	2	"		"	50/20/3mm
"	3	"		"	3mm
"	4	"		"	3mm
Silo No.	1	Size of Product			−3mm
"	2	"	"		4-30mm
"	3	"	"		Not in use
"	4	"	"		+40mm
"	5	"	"		3-40mm
"	6	"	"		3-40mm
"	7	"	"		+40mm
"	8	"	"		10-40mm
"	9	"	"		10-40mm

For transport the unit is raised on hydraulic jacks and a low-bed driven underneath. The steelwork and connecting conveyors for this installation were built locally by A/S Haahjem. This mobile crusher installation produces 150 t/hr of minus 4 mm product.

Processing

Since the mineral occurs in its almost pure state processing is largely a matter of producing the right size distributions. The main products are:

0 to 3 mm	for sinter plant feed.
0 to 6 mm	for sinter plant feed.
10 to 40 mm	for blast furnace feed.
1 to 5 mm	for refractory purposes.
3 to 7 mm	for refractory purposes.
Foundry Sands	— complete range in AFS grades 20 to 120.

Quality control is of paramount importance and begins with analysis of the samples from each blast hole. The most important parameter for a refractory mineral such as olivine is the "loss on ignition", or water content. This must be below 1%. Analysis for loss on ignition, chemical content, hardness and size distribution is carried out at regular stages from mining through to shipping.

The huge increase in production that has occurred over the past ten years has meant that the processing facilities have been in an almost continuous state of modification. A new plant with a capacity of 3 million tonnes a year has just come on stream but the old plant is being retained for the production of the more specialised products. The new plant has been designed for the maximum flexibility with four main crushing and screening circuits, reversible conveyors, and nine silos for final and intermediate products. Flexibility is extremely important to allow production of the different grades to be tailored to demand, and to accommodate special orders such as coarse ballast material for North Sea oil platforms.

Ore from the mine is dumped into a 1000-t feed hopper from where it is transported by belt to a Lokomo G4214 gyratory crusher set at 50 mm. All material passes through this crusher which operates in open circuit with two Siebtechnik screens. The upper screen removes the +40-mm material which goes to an intermediate silo while the −40-mm material passes to a Siebtechnik high frequency curved screen to remove −3-mm material. This forms one of the final products. The other three crushing circuits all work in closed circuit with screens and are used to produce the full range of products through a network of silos and conveyors. The crushers are a Lokomo G3210 gyratory and two Lokomo S21 cone crushers. The latter have a diameter of 2.1m and can be fitted with different liners for either coarse or fine crushing, thus eliminating the need to have both a standard and short-head crusher. All the screens are provided by Siebtechnik.

The following design features deserve a mention. The main vibrating feeders under the hopper can be quickly isolated by a hydraulically operated gate for maintenance purposes. The feed conveyor in the underground tunnel section is supported from the roof instead of the floor so that spillage can be easily cleaned up. Both the gyratory crushers are small enough to be mounted on rubber feet but the S21 cone crushers are solidly fixed. In order to save space and obtain a good distribution of the −40 mm material over the curved high frequency screen, a short conveyor of the same width as the screen has been installed beneath the primary 40-mm screen so that the entire feed stream travels the full length of the HF screen.

The fine size fractions to be used for foundry sand, blast cleaning and casting, are crushed, dried, screened on Mogensen sizers and a series of Rotex screens, and air cleaned to reach AFS specifications. Because of the need to dry certain fractions all crushing is done dry which can cause considerable problems in achieving the desired throughput. This is particularly so in winter when it is frequently freezing at the mine site and just above zero at the plant on the coast.

The olivine rock is very hard and abrasive but is brittle and crushes easily. Hardness and resistance to attrition are important in many applications and to achieve attrition resistance final products are not usually made on the first pass. Stage crushing and screening ensure that when producing an intermediate product like −40 +10 mm it contains only the most resilient stone since the more fragile material will have been broken up on earlier passes.

Abrasion is a serious problem in the crusher plant as the rock breaks so easily that the manganese crusher liners do not become properly work hardened. A typical bowl and mantle set will last about 4500 hours. To counteract the abrasion rubber is used for all the coarse screen cloths and polyurethane for the rest.

Refractory Production

A/S Olivin makes refractory bricks in a highly mechanised operation. One robot automatically transports the bricks from the hydraulic press to waggons for firing, and a second robot is on order to increase production. A third robot is planned, for handling the burned bricks from the waggons to pallets.

Shipping

The plant is situated right next to the dock where ships up to 80 000 tonnes can be loaded. Most of the production is shipped in bulk but some of the dry products are shipped in bags.

Conclusion

The market orientation of A/S Olivin has been responsible for its success in exploiting their unique deposit. Supply is no problem as reserves are almost limitless; what makes the business is quality, consistency, delivery dates, and a continual effort to find and develop new uses for this rather special mineral. ■

FERROCHROMIUM

-- THE "WOODING" DEVELOPMENT REQUIRES A DEEP WATER PORT BECAUSE RAW MATERIALS MAY BE FROM OFF-SHORE AND MARKETS WILL BE WORLDWIDE.

-- OREGON BEACH SANDS COULD BE A SOURCE OF CHROMITE CONCENTRATES AND AN EXPLORATION PROGRAM IS BEING PLANNED BUT FINANCING HAS NOT BEEN SECURED.

-- THE "PROCESS" IDENTIFIED BY DR. SMILEY MAY BE BETTER LOCATED AT COOS BAY RATHER THAN RIDDLE.

CENTRAL HAZARDOUS WASTE PROCESSING FACILITY

-- EPA HAS MADE DATA AVAILABLE ON 226 IDENTIFIED SITES IN OREGON.

-- THE LIST INCLUDES LANDFILLS AS WELL AS GENERATORS.

-- PLATING OPERATORS ARE NOW PROCESSING THEIR WASTES ON-SITE.

-- A CENTRALIZED INCINERATOR ~~[illegible]~~ CAN ONLY PROCESS WASTES GENERATED IN OREGON AND ADJACENT STATES

-- A NEW PROCESS WOULD TAKE EXTENSIVE STUDY AND REVIEW TIME, PARTICULARLY FOR PREVIOUSLY UNDEMONSTRATED TECHNOLOGIES.

FERROSILICON

-- THE HANNA FESI FURNACE IS SUITABLE FOR FESI50% PRODUCTION BUT MODIFICATIONS FOR FESI75% PRODUCTION MAY EXCLUDE THIS ALTERNATIVE PRODUCT.

-- UNITED STATES FESI FURNACE CAPACITY IS UNDERUTILIZED.

-- THE UNITED STATES IMPORTS 20% OF FESI50% REQUIREMENTS AND 70% OF FESI75% REQUIREMENTS, AND EXPORTS ARE SMALL.

-- HANNA'S PROJECTED PRODUCTION COSTS FOR FESI50% ARE GREATER THAN PREVAILING MARKET PRICES AND THERE IS LITTLE OPTIMISM FOR SIGNIFICANT UPWARD PRICE MOVEMENT BECAUSE OF WORLDWIDE OVERCAPACITY.

SCRAP CATALYST PROCESSING

- TOTAL AVAILABILITY IS 50,000 TPA MAX.
- GULF CHEMICAL & METALLURGICAL AND CRI-MET ARE LOCATED ON THE GULF COAST AND HAVE COMBINED CAPACITY OF 70,000 TPA.
- NI/CO RESIDUE FROM GULF COAST PLANTS IS SHIPPED TO EUROPE AS WELL AS CANADA, AUSTRALIA AND JAPAN.
- CATALYST SCRAP GENERATION ON WEST COAST IS SMALL COMPARED WITH GULF COAST.
- CHEVRON IS LANDFILLING Ni/W AND Ni/Sn SCRAP BECAUSE THERE IS NO ECONOMIC PROCESS AVAILABLE TO RECOVER THE METALS.
- TRANSITION METALS TECHNOLOGY'S PROPOSAL SEEMS TO ASSUME A LARGER SCRAP CATALYST AVAILABILITY.

METALS FROM FLY ASH

-- EPRI HAS DEVELOPED A DIRECT ACID LEACH (DAL) PROCESS ON A BENCH SCALE TO RECOVER:

  - ALUMINA
  - IRON PRODUCTS
  - GYPSUM
  - ALKALI SALTS

AND THE RESIDUE HAS APPLICATIONS AS A FILLER IN PLASTICS.

-- FLORIDA PROGRESS CORP. DEVELOPED THEIR OWN DAL PROCESS ON A PILOT SCALE AND PATENTED SOME ASPECTS NOT COVERED BY EPRI.

-- POZZOLANIC NORTHWEST HANDLES 3 MILLION TPA FLY ASH FROM SOURCES IN WASHINGTON, OREGON, WYOMING, COLORADO, NEVADA AND ALASKA AND SELLS MATERIAL AS A CEMENT SUBSTITUTE WITH SHIPPING DISTANCES UP TO 1,500 MILES.

ZINC RECOVERY FROM EAF STEELMAKING DUST

-- EAF DUST HAS BEEN RECLASSIFIED BY EPA AS HAZARDOUS AND LANDFILLING WILL BE BANNED AS OF 8/8/88.

-- SEVERAL PROCESSES HAVE BEEN DEVELOPED TO PROCESS DUST TO RECOVER THE VALUES (WHICH ARE THE HAZARDOUS COMPONENTS) AND DISCARD AN INERT PRODUCT.

-- DISCUSSIONS WITH NINE (9) STEEL PLANTS HIGHLIGHTED THEIR CONCERNS ABOUT THE EPA REGULATIONS AND THE HIGH COST OF DISPOSAL.

-- OF 500,000 TPA DUST GENERATED IN THE UNITED STATES, ONLY 35,000 TPA COMES FROM PLANTS FROM COLORADO WESTWARD.

-- HORSEHEAD RESOURCE DEVELOPMENT (HRD) IS THE ONLY FULLY COMMERCIAL OPERATOR RECOVERING ZINC FROM EAF DUST, HAS ONE OPERATING PLANT IN PENNSYLVANIA, ONE DUE TO START IN CHICAGO, AND IS LOOKING FOR OTHER SITES.

-- HRD MAY BE ABLE TO USE SOME EXISTING EQUIPMENT; EXPRESSED CONCERNS RELATIVE TO ASSUMING EXISTING ENVIRONMENTAL LIABILITY.

STAINLESS STEEL

-- COMPETITIVE HOT METAL COSTS AT 50,000 TPA INGOTS.

-- PROCESS UTILIZES HANNA FACILITY AND ASSUMES ZERO COST FOR REJECT NICKEL ORE.

-- WEST COAST STAINLESS IMPORTS TOTAL APPROXIMATELY 50,000 TPA BUT THERE ARE MANY PRODUCT TYPES.

-- ONLY ONE EXISTING STAINLESS PRODUCER ON WEST COAST-JORGENSEN IN SEATTLE.

\- STAINLESS POWDER MARKET IS 5,000 TPA AND COMPETITIVE.

LIST OF ALTERNATIVES

1) STAINLESS STEEL

2) ZINC RECOVERY FROM EAF STEELMAKING DUST ✓

3) METALS FROM FLY ASH ✓

4) SCRAP CATALYST PROCESSING Horsehead →

5) FERROSILICON

6) CENTRAL HAZARDOUS WASTE PROCESSING FACILITY

7) FERROCHROMIUM

8) NICKEL SLAG PRODUCTS ✓

CCD BUSINESS DEVELOPMENT CORPORATION

JULY 30, 1987

MEETING

ALTERNATIVE USE STUDY-NICKEL MOUNTAIN SMELTER FACILITY

1.0 INTRODUCTION

2.0 ALTERNATIVE PROCESSES

3.0 RECOMMENDATIONS FOR FURTHER INVESTIGATION

	MAJOR FEED MATERIAL				SALEABLE PRODUCTS			
Process	Type	Quantity	Operating Costs ($/yr)	Capital Cost	Types	Revenues ($)	Demand Power (MW)	Employment (No.)
(1) DAL Leach	Fly Ash	540,000 TPA	11 Million	$162 Million	Magnetic Ash Alumina Gypsum Plastic Fillers	41 Million	6	200
(2) Elkem Dust	EAF Dust	30,000 TPA	3 Million	$ 2 Million	Zinc Lead	5 Million	4	40
(3) Horsehead Resource Development (N.J. Zinc)	EAF Dust	25,000 TPA	4 Million	$ 15 Million (Max.)	Zinc Concentrates Aggregate	5 Million	<1	25
(4) Stainless Slab	Reject Nickel Ore Domestic Chromite	520,000 TPA 45,000 TPA	40 Million	$ 5 Million	300 Series Stainless Ingot	50 Million	25	130
(5) Metal Recovery from Scrap Catalyst	Ni/W and Ni/Sn Catalyst	10,000 TPA	Not Known	Not Known	W and Sn Alloys with Ni Residue	2 Million	<1	20
(6) Slag Recovery Process	Nickel Slag	75,000 TPA	2 Million	$ 0.5 Million plus for coloring plant	Colored Granules	3 Million	<1	20

DOUGLAS COUNTY
INDUSTRIAL DEVELOPMENT BOARD

744 S.E. Rose Street – Roseburg, Oregon 97470
Telephone (503) 672-6728

OREGON STABILIZATION & CONVERSION FUND
FEASIBILITY STUDY APPLICATION:
NICKEL MOUNTAIN SMELTER--ALTERNATIVE USE STUDY

II. Project Information

6. Describe the facility (including type of construction and construction sector, pertinent features, current value, building sq. ft., land area and ownership)

The mine and smelting facility are described in some detail in an attached brochure. Since the brochure was written, rapidly increasing supply and especially power costs in the face of declining selling prices of FeNi during 1981 and 1982 resulted in a 19-month closure of the facility in April 1982. Events preceding closure are described in a copy of Hanna's pre-filed testimony at the Bonneville Power Administration rate case hearing. Subsequently, relying on an amendment in the Northwest Regional Power Bill which provided that the Bill should not adversely affect industries using materials indigenous to the region, Hanna worked out the techniques necessary to operate on an "off peak" form of power which was sold to them at $0.007 per KWH. Off-peak operations reduced costs by more than 30% but sales prices by 1984 were 10% less than production costs.

In a further attempt to regain economic operations, a modification costing approximately $12 million was made. The modification provided for recovery of an ore concentrate by a process of wet screening and separating the high grade fine fractions of ore at approximately 100 mesh size. Only economic ore was processed, melted and reduced to FeNi while the lower grade size fractions were rejected from the process as soon after mining as possible.

After construction in 1985 the new facility was tested during the end of that year and during early 1986. Approximately 70,000 tons of ore concentrate was produced, dewatered, agglomerated and stock piled. Smelting tests during June through August 1986 indicated that many unestimated advantages would be realized but that costs could not be reduced to a level roughly half of 1980 levels. The tests to produce the concentrate revealed that the $3 million wet screening and classification system required additional equipment to increase its capacity by about 60% to the 650,000 to 675,000 tons per year of concentrate needed to supply the smelter on the 104 hour per week "off peak" operating basis.

After completion of testing in August 1986, an indefinite shutdown of facility was declared. This was converted to a permanent shutdown in January 6, 1987 and plans were made to dismantle and salvage the equipment. Estimates of salvage value range from $7 to $10 million.

The land area involved includes approximately 5,200 acres of which nearly 4,000 acres is owned by M.A. Hanna Co. The balance is mostly BLM land on which Oregon Nickel and Wright leases have unpatented mining claims. Hanna has surface rights to their land but, although unmineralized, Douglas County has mineral rights. Nearly 2000 acres of the Hanna land is probably tillable.

7. Describe the most recent activity employed at the facility.

The most recent activity at this facility was the production of low carbon ferronickel and testing of the new equipment.

8. Based on available information, describe the prospects for a re-start and/or conversion of the facility.

The prospects for restarting are very remote. The equipment will be dismantled and the land sold unless an economic alternative use can be found. Even then, the equipment would most likely be sold to prospective users since, as a result of a major policy change, mining and metals are outside Hanna's corporate objective for use of new funds.

9. Please attach the facility's past three years financial statements (if available).

Financial statements are not available, but it is public knowledge that losses from Nickel Mountain operations were as follows:

FYE Sept. 30	Pre-Tax Operating Loss (000)
1982	($8,101)
1983	($5,321)
1984	($4,435)
1985	($2,228)
1986	($9,866)

The 1986 jump in the loss was due to the combination of new facility costs and a precipitate decline in nickel prices. A table showing sales prices and a graph of nickel prices for 1986 are attached.

10. Describe the facility's existing or last markets and customers for its product(s). Describe these products.

See the next to last page of the enclosed Hanna brochure for a brief description of product and markets. It is to be emphasized that an evaluation of uses of the facility <u>other</u> than the production of nickel are the subject of the current grant application.

11. Identify the level of employment during the last twelve months, and over the past three years.

<u>Employment history</u>

1987 Jan.- April	4	employees
1986 Dec.	9	"
1985 Dec.	59	"
1984 Dec.	277	"
1981	550-600	"

12. Describe the potential product mix for the facility.

See enclosed proposal from Hatch Associates

13. Describe any impediments to successful operation of the facility.

The equipment design is early 1950 vintage. It has been well-maintained and modernized where possible but modern equipment is larger by a factor of 3 to 4 and takes advantage of economy of scale.

It is somewhat difficult to speculate about other impediments prior to selecting an alternate use. For many (but not all) possible uses, the site's relative isolation and distance from major markets could be a significant impediment.

14. Describe the elements and an estimate of the cost of the feasibility study. Include specific costs for such study components as market research, asset appraisal and production cost analysis.

The Alternative Use Study will be generally as delineated in the enclosed proposal from Hatch Associates.

Hatch has been asked to provide additional information regarding:

- Definition of end-product, and likely scenario of next steps following submission of a positive report.
- Rough outline and schedule of work, with proposed review-and-reconfirm points.
- Breakdown by study component of probable type and level of effort for the not-to-exceed-$50,000 total.

15. List all individuals and/or organizations you believe are qualified to perform the feasibility study.

We are informed by former Hanna personnel that this study is sufficiently technical in nature that very few firms are qualified to undertake it. Hatch Associates is perhaps the only firm among them (others would be Bechtel Corporation, Ralph M. Parsons, Davey-McKee) who could be described as "medium" sized and who would be, in all likelihood, interested in bidding on this comparatively small project.

Hatch, whose brochure is enclosed, is perhaps uniquely qualified to perform this "Phase I" study because a) they are experts in both the iron and steel and the non-ferrous metals industries, b) they have done similar studies, currently performing a study for the State of Pennsylvania to determine alternative uses for closed steel mills in and around Pittsburgh, c) they offer an excellent potential for bringing potential investor/operators to the table in the event one or more of the alternative uses appears profitable, and d) they are available to do the study immediately, a significant factor in view of Hanna's plan to sell off the facilities (see enclosed letter from CCD Business Development Corporation to Hanna dated June 1, 1987).

16. List those individuals and community organizations supporting this application and re-starting the facility. Attach any letters of support.

Re-establishing some form of meaningful manufacturing activity at the Nickel Mountain site has virtually universal support throughout south and central Douglas County. A news article is enclosed, describing the effect of the loss of local property taxes on the local community.

The loss of the Hanna payroll, and of the trade and service jobs that the Hanna payroll supported, are if anything more dramatic. Metals industry jobs are family wage jobs--historically slightly outstripping even lumber and wood products.

In response to testimony from the neighboring communities of Canyonville and Myrtle Creek, the Douglas County Economic Strategy Committee named the $50,000 Nickel Mountain Alternative Use Study a priority project even though the primary focus of their (draft) strategy is tourism.

17. Attach a commitment letter for the 25 percent matching funds source for the feasibility study.

The Douglas County Industrial Development Board were handed the Hatch proposal on May 22. The results of their discussion are summarized in CCD's letter to Hanna of June 1. As soon as Hatch has responded to the questions listed in item 14 above, the DCIDB will reconvene and formalize its commitment. This is expected in the next two weeks.

3/16/87
Hanna

Hanna - peddle wear (w/ specs) (rather than Cr alone)

EDD - track along + be informed

- Lynn Youngban (EDD) has memos etc. (Lens contact)
- (Jim Haights contact also)

Wedge will write a memo

Deadlines for future action

6mo start + 2yr completion

overview memo to file

statement of possibilities

Hanna deadlines

Richard Hahn
(216) 589-4040
100 Erieview Pl
Cl. Ohio 44114

Jim Haight - 208000 tons drilled - refractory grade 22% Cr_2O_3

= actually was pursuing
a broader coalition

- Establish closer liaison with EDD

⓪ Hanna feasibility statement

Plan

Need internal deadlines + strategic plan

① sales brochure - Hanna ①
② deadline - Hanna
③ Tax break from county - state (or loophole)
④ specific leads - EDD ②

concurrently

Regional economic goal setting should include
⑤ bind counties one w/ other to give two payoffs

Hanna File

Len, Don, John B, Ralph Natzinger 4/1

Must attempt to retain expertise
John Day Ore @ $100/ton to product vs $65/to on open market. JD are better for local refractory brick making

$ payoff is .76% × $1.50/lb → $22/ton for nickel payout

1 yr time frame min. w/ smelter to be scrapped last. (furnaces @ $6.3M inc $600K heel)

Wedge is doing feasibility study in which plant upgrade is a part & for which EDD $ could be available

"Wooding" - ferrochrome Coos Bay option (sort of pie in the sky)
or "Bill Wood" - interested in natural gas / virgin iron contab in April at Chicago - gas as reductant would take place of coal or ferrosilicon

diff eyes + ears + can make contacts etc. for takeover individuals

volume est. not provided for ferrochrome options

$$Fe^{+} + Ni^{?} + e^{-} \rightarrow FeNi$$
$$Fe^{+} + Cr^{+} + e^{-} \rightarrow FeCr$$

gas
coal
other

Upgrade needed to be competitive in any scenario

Stainless Steel market presently depressed

Need feasibility study with a look at the market first and the technology second. through SRI, Bechtel or whatever for ferro-nickel.

generic + non site specific in nature

As part of regional economic dev strategy