United States Patent

[11] 3,582,005

[72] Inventors Frederick R. Archibald
Toronto, Ontario, Canada;
Ian H. Keith, Santo Domingo, Dominican Republic
[21] Appl. No. 741,747
[22] Filed July 1, 1968
[45] Patented June 1, 1971
[73] Assignee Falconbridge Nickel Mines, Limited
Ontario, Canada

[54] **BENEFICIATION OF NICKEL ORES**
4 Claims, 7 Drawing Figs.

[52] U.S. Cl. **241/26,** 51/313, 75/1, 75/82
[51] Int. Cl. **B02c 17/04,** C22b 23/00
[50] Field of Search .... 241/3, 26, 30, 29, 24; 51/313—316; 75/5, 82, 1

[56] **References Cited**

UNITED STATES PATENTS

Re9,053	1/1880	Hodge	241/3
679,901	8/1901	Lovett	241/3
2,363,315	11/1944	Grothe	75/1X
3,146,091	8/1964	Green	75/82
3,160,998	12/1964	Payne	51/313
3,202,502	8/1965	Lean et al.	75/1
3,231,203	1/1966	Hardinge et al.	241/24
2,906,465	9/1959	Sweet	241/26X

Primary Examiner—Allen B. Curtis
Attorney—Maybee and Legris

ABSTRACT: A process for the beneficiating of that fraction of oxidized nickel ores occurring as discrete boulders and joint blocks. The boulders and blocks treated are those which have undergone enrichment at their surfaces and decreasing degrees of intermediate enrichment inwardly from their surfaces. The boulders are tumbled in a body in rubbing contact with each other to form comminuted high-grade product and low-grade reject cores.

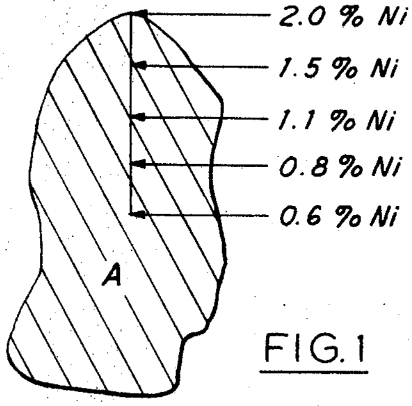

FIG. 1

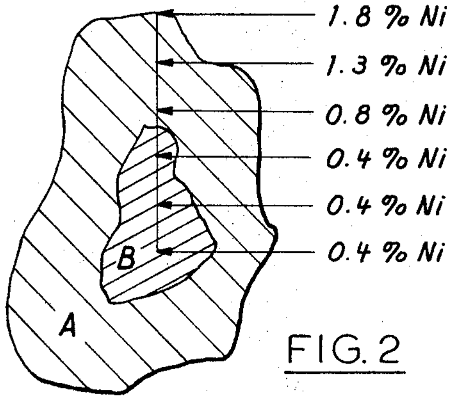

FIG. 2

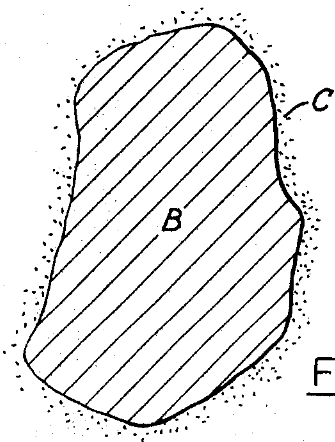

FIG. 3

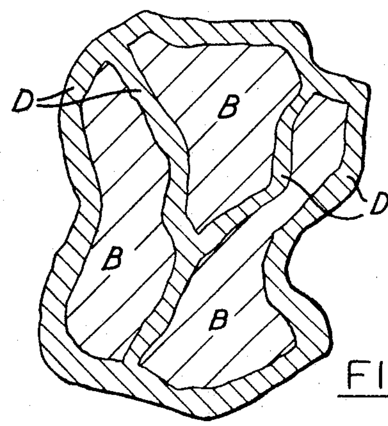

FIG. 4

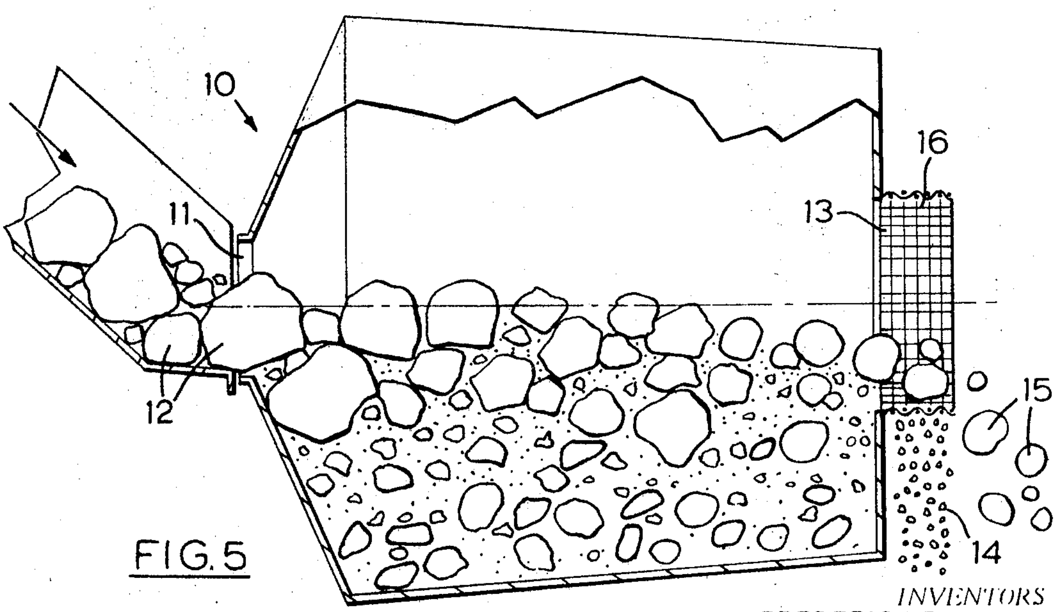

FIG. 5

INVENTORS
FREDERICK R. ARCHIBALD
IAN H. KEITH
BY
Maybee & Legris
ATTORNEYS

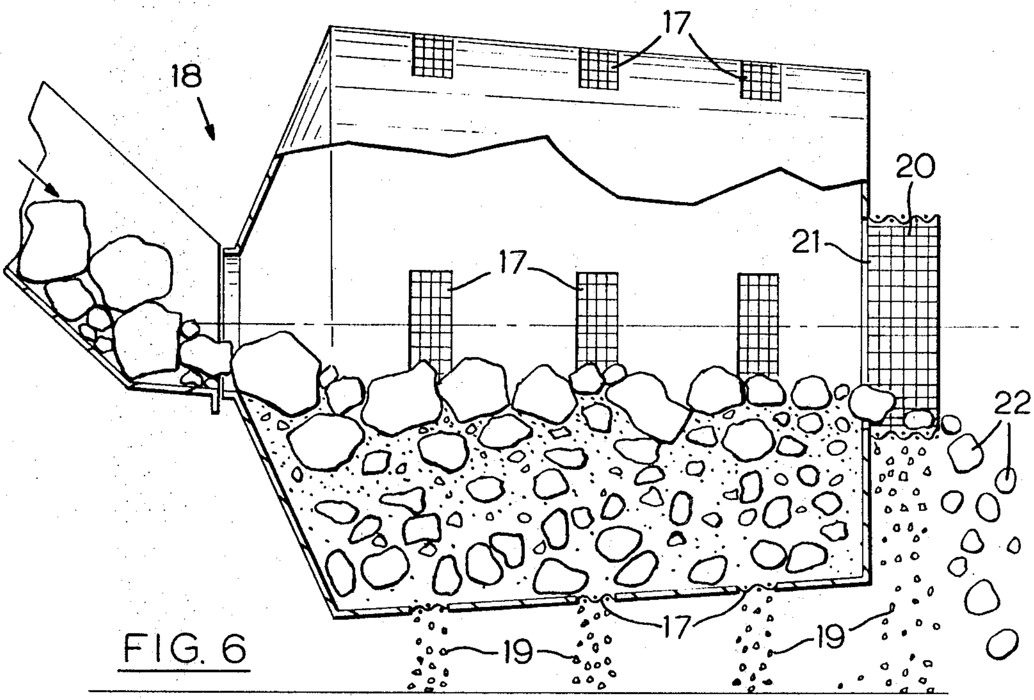

FIG. 6

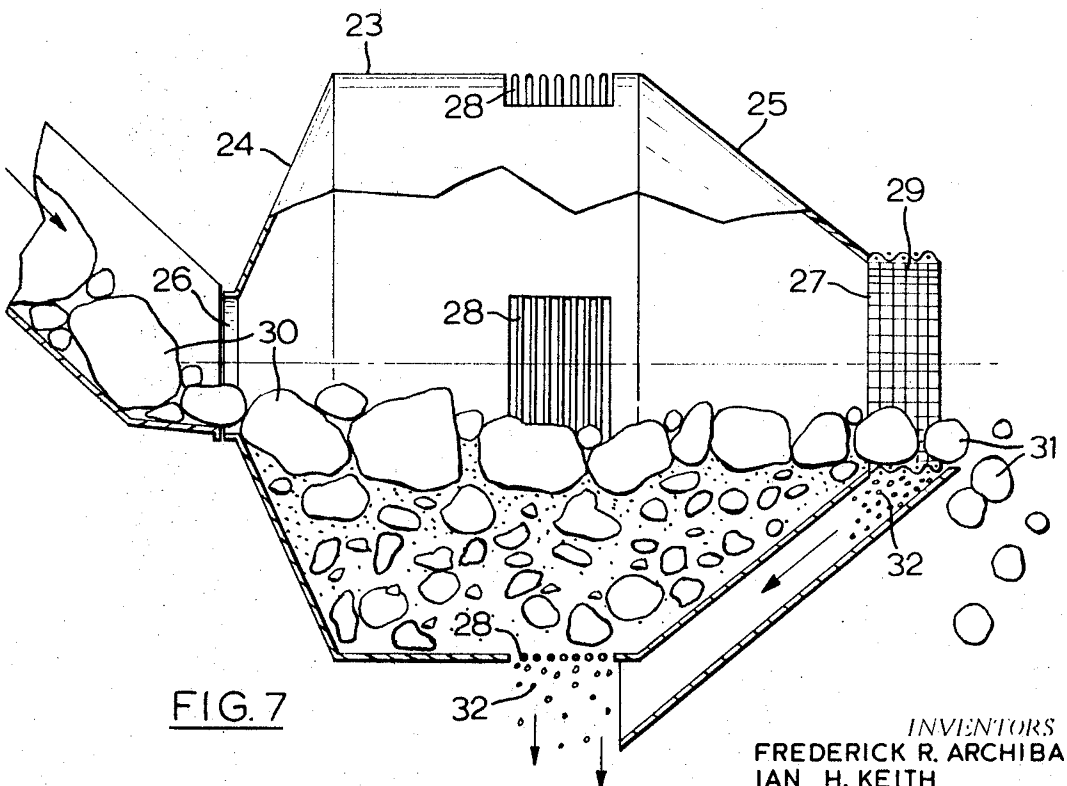

FIG. 7

INVENTORS
FREDERICK R. ARCHIBALD
IAN H. KEITH
BY Maybee & Legris
ATTORNEYS

BENEFICIATION OF NICKEL ORES

BACKGROUND OF THE INVENTION

This invention relates to the beneficiation of the type of coherent nickeliferous boulder occurring in laterite deposits which has undergone certain weathering processes resulting in a relatively high degree of nickel enrichment at its surface, a relatively minor degree of enrichment at its center, and intermediate degrees of enrichment inwardly from its surface. Such a boulder may consist of completely serpentinized ultrabasic rock in which the nickel concentration decreases continuously from the surface toward a generally central location in the boulder, or the boulder may be only partially serpentinized, in which case the nickel concentration decreases continuously from the surface only to the depth to which serpentinization has occurred. In the latter case, the nickel concentration usually levels off at some relatively low value through the unserpentinized core.

Methods of beneficiating oxidized ore have in the past been based on differences in physical properties which exist between the metal-rich and barren fractions of the ores. Such physical properties as specific gravity, electrical conductivity and ferromagnetism, for example, permit separation by such well-known techniques as tabling, electrostatic separation and magnetic separation, respectively. Another method of beneficiating oxidized ores is described in U.S. Pat. No. 2,136,726, according to which sandstone containing soft colloidal uranium-vanadium material in the interstices of the barren sand grains is subjected to dry attrition to permit separation of an upgraded product by elutriation. A similar process for upgrading low-grade ore having a sedimentary deposition containing metal values on discrete barren particles by "-scuffing" off the softer deposition is described in U.S. Pat. No. 2,906,465.

SUMMARY

Briefly stated, the present invention contemplates the beneficiation of boulders of the character described by tumbling a body of such boulders in rubbing contact with one another in a treatment zone, and controlling the intensity of the tumbling to permit a continuous abrasion of the boulders but substantially to avoid lifting, dropping and breaking them, and thereby forming comminuted high-grade product and low-grade reject cores. The invention also contemplates feeding fresh boulders into the treatment zone to displace reject cores from the zone, controlling the rate of feeding, thereby controlling the residence time of the boulders therein, and hence controlling the amount of abrasion which occurs. Although both the comminuted high-grade product and the reject cores may be together displaced from the treatment zone and separated by screening, the comminuted high-grade product is advantageously recovered from the treatment zone as it is formed.

An object of the present invention is to upgrade oxidized nickel ores containing coherent nickeliferous boulders.

A further object is to upgrade such ores without either washing or otherwise wetting them, or on the other hand, without completely drying them to the point that severe dusting occurs.

A further object is to provide a means of recovering the upgraded product in a comminuted form and of discarding a low-grade reject in an uncomminuted form. In other words, an object is to do work only on the portion of the ore it is desired to recover.

A further object is to provide means of controlling the nickel grade of the upgraded product, the nickel grade of the

reject, and the proportion of upgraded product and reject.

Other objects and advantages of the invention will be apparent from the following description taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a cross-sectional representation of a completely serpentinized nickeliferous boulder which can be treated according to the invention;

FIG. 2 shows a cross-sectional representation of a partially serpentinized ultrabasic rock occurring in a nickeliferous laterite ore deposite which can also be treated according to the invention;

FIG. 3 is a representation of a relatively barren boulder which can occur in a deposit of finely divided nickeliferous ore;

FIG. 4 represents a cross section of a boulder consisting of hard, barren portions weakly held together by layers of enriched material;

FIG. 5 is a diagrammatic representation, in a longitudinal, sectional view, of a tumbling mill in which the process of the invention may be carried out;

FIG. 6 shows diagrammatically a preferred modification of the apparatus depicted in FIG. 5, spaced peripheral discharge grates being used therewith; and

FIG. 7 is a conical modification of the apparatus of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For purposes of obtaining a full understanding of the present invention in the context of known procedures it is important to consider in some detail the various types of occurrences of boulders in nickeliferous laterite ore deposits by reference to FIGS. 1 through 4 of the accompanying drawings. Thus FIG. 1 shows a coherent nickeliferous boulder occurring in laterite deposits which has been completely serpentinized. The boulder can be imagined as divided down the middle to present a surface showing its serpentine interior A. Samples taken from the surface and from various points along an internal radius are found to analyze progressively lower in nickel as a generally central point in the boulder is approached. Thus the arrows in FIG. 1 indicate sampling points along the radius and the nickel concentration at each point, the nickel concentrations running, for example, from a maximum of 2.0 weight percent Ni at the surface to a minimum of 0.6 weight percent at the center. The coherent boulder of FIG. 1 is an example of the type of ore which can be beneficiated according to the present invention.

The partially serpentinized ultrabasic rock occurring in a nickeliferous laterite ore deposit, shown in FIG. 2, again is to be imagined as being divided down the middle to expose an unserpentinized interior core B and a serpentinized portion A. As in FIG. 1 the serpentinized portion can be seen to show progressively decreasing nickel concentration, starting at 1.8 weight percent Ni at the surface, and decreasing to 0.4 percent at the core when sampled along an internal radial path. But when the unserpentinized core B is reached the nickel concentration remains at 0.4 weight percent. The boulder of FIG. 2 is another example of the coherent ore to which the principles of the present invention are applicable.

The invention should not be confused with prior-art methods applicable to the treatment of boulders which do not have the properties described above. For example, the boulder B in FIG. 3, although being relatively barren, can occur in a deposit of finely divided nickeliferous ore C which loosely adheres, or sticks, to its surface and is removable therefrom by treatment in a log washer or other known washing device. Nor should it be confused with jaw crushing or the lifting and dropping type of breakage, which are successful in treatment of boulders shown in FIG. 4. Such boulders may consist of hard, barren portions B, weakly held together by relatively friable but adherent layers of enriched material D, which fall and crumble away from the barren portions when the boulder is subjected only to impact forces.

The nickeliferous boulders which can be treated by the present invention are seen to be coherent boulders which have been completely or partially serpentinized and which have nickel concentrations that decrease progressively and inwardly from the surfaces thereof.

A tumbling mill which may be utilized for treating boulders as depicted in FIGS. 1 and 2 by the process of the invention is shown diagrammatically in longitudinal cross section in FIG. 5. The generally cylindrical, substantially horizontally disposed mill **10** is rotatable about its longitudinal axis and has an opening **11** at one end for the introduction of boulders **12** and an opening **13** at the other end for the discharge of comminuted beneficiated product **14** and reject cores **15**. The discharge opening **13** shown is equipped with a trommel **16** for the separation of the product **14** from the reject cores **15** by sizing. In operation, rotation of the apparatus of FIG. 5, at a rate controlled substantially to avoid lifting and dropping the boulders in free fall, causes relative motion therebetween and maintains them in rubbing contact with each other. Because of this relative motion and the fact that the boulders are coherent, their action on one another is abrasive and occurs continuously in a gradual manner. Fresh boulders, fed by gravity into the feed opening **11**, displace treated material which overflows the discharge opening **13** at substantially the same rate as that at which feed is introduced. Thus, for a given rate of rotation, the amount of abrasion occurring in each boulder is inversely proportional to the feed rate.

The mill **10** is seen to provide a comminution zone for the nickeliferous boulders **12** which have variable nickel concentrations through their cross sections with relatively high nickel concentrations at their surfaces and progressively decreasing nickel concentrations toward their centers. The boulders formed in a body in the mill **10** are tumbled in rubbing contact with each other to abrade material of relatively high nickel concentration from the boulders to form the comminuted upgraded product **14** and leave the reject cores **15** of relatively low grade and in a substantially uncomminuted form. The tumbling in the mill **10** is controlled by adjusting the speed of rotation of the mill to minimize breakage of the cores and yet effect abrasion of the boulders at a steady rate.

In the apparatus shown in FIG. 6 the addition of peripheral discharge grates **17** to mill **18** permits removal of abraded beneficiated particles or product **19**, which are smaller than the grate openings, as they are formed. Further particles of the beneficiated product **19** are seen to be removed through trommel **20** located on discharge opening **21**, with reject cores **22** retained on the trommel **20** being discarded. Removal of the product in the fashion shown in FIG. 6 prevents overgrinding of the product, substantially overcomes the "cushioning" effect of the undersize which otherwise retards the abrasive action of the boulders, and by leaving more space for partially treated boulders, increases their average retention time compared to that obtained in the apparatus of FIG. 5.

The advantages of the present invention are further illustrated by the following examples:

EXAMPLE 1

Coherent serpentinized nickeliferous boulders recovered from a nickeliferous laterite deposite, were comminuted by three conventional crushing methods. The products were screened and each size fraction was analyzed for nickel to ascertain the degree of upgrading effected. Table 1 gives the nickel concentration of each size fraction.

TABLE 1.—EFFECT OF CONVENTIONAL COMMINUTION METHODS ON UPGRADING COHERENT NICKELIFEROUS BOULDERS

	Comminuted product		
Means of comminution	Size fraction	Weight percent	Percent Ni
Jaw crusher	−1 inch+½ inch		1.24
	−½ inch+¼ inch		1.30
	−¼ inch+10 mesh		1.29
	−10 mesh		1.36
	Total feed	100.0	1.29
Crushing rolls	+10 mesh	45.5	1.24
	−10 mesh	54.5	1.36
	Total feed	100.0	1.29
Impact crusher	+½ inch	3.0	1.92
	+⅜ inch	8.0	1.80
	+¼ inch	12.1	1.66
	−¼ inch	76.9	1.69
	Total feed	100.0	1.70

The data of table 1 show that little, if any, upgrading of nickel is obtained when conventional means such as jaw crushers, crushing rolls or impact crushers are used for comminution of the coherent type of boulders with which the present invention is concerned.

EXAMPLE 2

A sketch of an apparatus in which the method of the present invention was carried out is shown in FIG. 7. The apparatus consisted of a drum **23**, 6 feet in diameter and 10 feet long, with conical end sections **24,25**. The drum **23** was equipped with feed and discharge openings **26,27**, 15 inches and 24 inches in diameter respectively on its horizontal axis, and with peripheral discharge grates **28** containing slots ¼-inch wide and spaced at 90° intervals around the circumference of the drum **23**. A trommel screen **29** with ¼-inch openings was attached to the discharge end of the drum **23**.

In operation the drum **23** was rotated about its horizontal axis and coherent nickeliferous boulders **30** of the type with which the present invention is concerned and ranging in size from 1 inch to 12 inch diameter were fed thereto and a body of boulders established therein such that when fresh boulders were introduced through the feed opening reject boulders **31** were displaced through the discharge opening **27**. The rotational speed of the drum **23** was controlled at about 25 r.p.m., or about 60 percent of its critical speed, to produce the desired tumbling and abrasive action and substantially to prevent lifting, dropping and breaking. Since the charge volume of the drum was about 5 tons and feed rate was 10 tons per hour, the average retention time of the boulders was about 30 minutes. Comminuted product **32** recovered from the peripheral discharge grates **28** and trommel undersize were combined, weighed and analyzed. The results of the operation are summarized in table 2. Substantial upgrading is seen to have been attained.

TABLE 2.—UPGRADING OF COHERENT NICKELIFEROUS ULTRABASIC BOULDERS IN ROTATING DRUM EQUIPPED WITH ¼ INCH PERIPHERAL DISCHARGE OPENINGS

		Analysis percent		Product discharge ton/hr./ton
Material	Wt. percent	Ni	H_2O	volume
Feed boulders +1 in. -12 in	100	1.46	10	1.2
Comminuted product −¼ in	60	1.83	9	
Reject cores +¼ in	40	0.92	5	

EXAMPLE 3

Coherent nickeliferous ultrabasic boulders between 4 inches and 12 inches in size and analyzing about 1.0 percent Ni were continuously fed to a rotating drum similar to that described in example 2, with modifications reducing its operating charge volume to 3 tons and closing off the peripheral discharge grates. Comminuted upgraded product was discharged together with reject boulders via the ¼-inch discharge trommel where the comminuted product, or undersize, was separated from the reject, or oversize, by the trommel. Five tests were performed at decreasing feed rates. Both products from each test were weighed and analyzed for nickel to give the results summarized in table 3.

TABLE 3.—EFFECT OF RESIDENCE TIME ON DEGREE OF UPGRADING OF COHERENT NICKELIFEROUS ULTRABASIC BOULDERS IN ROTATING DRUM NOT EQUIPPED WITH PERIPHERAL DISCHARGE OPENINGS

	Feed		Residence time, min.	−¼-in. product			+¼-in. reject percent Ni	Product rate, ton/hr./ton vol.
	Percent Ni	Tons/hr.		Percent Ni	Weight percent	Percent Ni recovery		
Test No.:								
1	0.96	11.2	16	1.51	25.2	40	0.78	0.94
2	0.95	7.0	26	1.42	38.2	57	0.66	0.89
3	0.98	4.6	39	1.41	49.0	70	0.57	0.75
4	1.01	3.6	50	1.37	57.0	77	0.53	0.68
5	1.03	3.0	60	1.30	68.2	86	0.47	0.68

The results of example 3 show how the degree of upgrading of coherent nickeliferous ultrabasic boulders having an average analysis of about 1.0 percent nickel can be controlled in the practice of the present invention by controlling the average residence time of the boulders in the drum. Thus, while treatment at a feed rate of 11.2 tons/hr., equivalent to a residence time of 16 minutes, gave a product running 1.5 percent Ni and a reject of 0.78 percent Ni, reduction of the feed rate to only 3 tons per hour, or increasing the residence time to 60 minutes, gave a higher proportion of product at 1.3 percent Ni, and a lower grade reject.

Examination of the residence times and nickel recoveries indicate, however, that the rate of nickel recovery decreased with time. Thus while 40 percent of the nickel was recovered in 16 minutes at an overall rate of 2.5 percent per minute, only 86 percent was recovered in 60 minutes at an overall rate of 1.4 percent per minute. This "diminishing returns" aspect of the treatment is due to the concentration gradient of nickel in the boulders as described above and is exploited by the present process in which boulders are subjected to selective milling, the extent of which is controlled to produce not only a comminuted product that is upgraded but an uncomminuted reject containing uneconomically recoverable concentrations of nickel on which no milling work is done and which can be discarded without further handling. Thus, the present process effects milling and concentrating in one operation by separating an upgraded comminuted product from a downgraded uncomminuted reject.

The selective milling that is characteristic of this process can be effected in a continuous manner in one tumbling mill or in a stagewise manner in either a series of tumbling mills or a single mill divided into several compartments in which each compartment functions as a separate mill. Such stagewise operation is particularly advantageous in minimizing short circuiting of boulders that might occur from time to time.

As will be appreciated by those skilled in the art, circumstances such as location of the ore body and relative costs of mining, haulage and smelting of the ore will determine the degree of upgrading which will result in optimum economic benefit in the treatment of boulders of the type to which the present invention is applicable. It will also be appreciated that since boulders obtained from different ore bodies, or from various parts of the same ore body may have properties of size, shape or hardness which differ from those of the boulders used in the above examples, not only may the optimum degree of upgrading vary, but also the amount of treatment for a given degree of upgrading.

As noted above, the degree of upgrading is proportional to the residence time in the tumbling drum at a given rate of rotation. But the degree of upgrading may also be controlled by variations in the speed of rotation, whereby the rate of relative motion and abrasive action of the boulders on one another is also controlled. Thus, the degree of upgrading may be controlled at a constant feed rate by varying the speed of rotation, and at a constant speed of rotation by varying the feed rate.

Also as noted earlier, removal of the comminuted upgraded product as fast as it is formed via peripheral discharge openings in the apparatus can be seen to increase the efficiency of the beneficiation operation by comparison of example 2 with example 3. Thus, while the drum equipped with peripheral discharge openings gave a specific rate of upgraded product discharge of 1.2 tons per hour per ton charge volume, the maximum specific rate obtained in the unit not so equipped was only 0.94 tons per hour per ton charge volume.

It can be seen that the present invention provides a novel method for beneficiating coherent nickeliferous boulders, which are completely or partially serpentinized and which have nickel concentrations that decrease progressively and inwardly from their surfaces, to obtain a comminuted upgraded product and uncomminuted reject cores of relatively low grade on which no milling work has been done and which can be discarded without any further treatment thereof.

What we claim as our invention is:

1. A method for concentrating nickel values in coherent nickeliferous boulders having nickel concentrations that decrease progressively and inwardly from the surfaces thereof which comprises providing an abrasion zone and forming a body of said boulders therein, autogenously tumbling the boulders in rubbing contact with each other to abrade material of relatively high nickel concentration from the boulders to form a product of upgraded nickel content and reject cores of downgraded nickel content, controlling the tumbling to effect abrasion of the boulders continuously and gradually and to minimize breakage of the boulders and cores, recovering abraded upgraded product from the treatment zone and removing reject cores therefrom, feeding boulders to the treatment zone to displace reject cores therefrom and controlling the degree of upgrading of the product by controlling the amount of abrasion of the boulders to obtain a concentration in the abraded, upgraded product of up to 86 percent of the nickel in the boulders and leave reject cores of downgraded nickel content being not less than about 32 percent by weight of the boulders treated.

2. A method as claimed in claim **1** wherein at least a portion of the upgraded product is removed peripherally from the abrasion zone as it is formed.

3. A method as claimed in claim **1** wherein the boulders are abraded in a tumbling mill and the amount of abrasion is controlled by the rate at which boulders are fed to the mill and by the speed of rotation of the mill.

4. A method as claimed in claim **3**, wherein the tumbling mill is rotated at about 60 percent of its critical speed.