39/85

IN THE PRIVY COUNCIL NO. 28 of 1985

ON APPEAL
FROM THE COURT OF THE SUPREME COURT OF WESTERN AUSTRALIA

B E T W E E N :

HAMERSLEY IRON PTY LIMITED — **Appellant** (Respondent) (Plaintiff)

- and -

1. **THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED,**
2. **LANGLEY GEORGE HANCOCK,**
3. **ERNEST ARCHIBALD MAYNARD WRIGHT,**
4. **HANCOCK PROSPECTING PTY LTD,**
5. **WRIGHT PROSPECTING PTY LTD AND**
6. **L.S.P. PTY LTD**

Respondents (Appellants) (Defendants)

RECORD OF PROCEEDINGS

PART II
VOLUME III

Ince & Co.
Knollys House
11 Byward Street
LONDON, EC3R 5EN

SOLICITORS FOR THE APPELLANT (RESPONDENT) (PLAINTIFF)

WALTONS & MORSE
PLANTATION HOUSE
31-35 FENCHURCH STREET
LONDON, EC3M 3NN

SOLICITORS FOR THE RESPONDENTS (APPELLANTS) (DEFENDANTS)

IN THE PRIVY COUNCIL NO.

ON APPEAL

FROM THE FULL COURT OF THE SUPREME COURT OF WESTERN AUSTRALIA

B E T W E E N :

HAMERSLEY IRON PTY LIMITED	Appellant (Respondent) (Plaintiff)
- and -	
LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, HANCOCK PROSPECTING PTY LTD, WRIGHT PROSPECTING PTY LTD AND L.S.P. PTY LTD AND THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED	Respondents (Appellants) (Defendants)

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HAMERSLEY IRON PTY LIMITED — Appellant (Respondent) (Plaintiff)

\- and -

LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, HANCOCK PROSPECTING PTY LTD, WRIGHT PROSPECTING PTY LTD AND L.S.P. PTY LTD AND THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED — Respondents (Appellants) (Defendants)

RECORD OF PROCEEDINGS

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PART II

EXHIBITS

DOCUMENTS NOT TRANSMITTED TO THE PRIVY COUNCIL

IN THE SUPREME COURT
OF WESTERN AUSTRALIA

No. 2313 of 1982

IN THE MATTER of an Agreement between LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, WRIGHT PROSPECTING PTY. LTD., HANCOCK PROSPECTING PTY. LTD, two other companies and HAMERSLEY IRON PTY. LIMITED

B E T W E E N:

HAMERSLEY IRON PTY. LIMITED	Plaintiff
AND	
LANGLEY GEORGE HANCOCK	First Defendant
ERNEST ARCHIBALD MAYNARD WRIGHT	Second Defendant
HANCOCK PROSPECTING PTY. LTD.	Third Defendant
WRIGHT PROSPECTING PTY. LTD.	Fourth Defendant
L.S.P. PTY. LTD.	Fifth Defendant
THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED	Sixth Defendant

AFFIDAVIT

I, EARL CONRAD HERKENHOFF of 151 Warfield Drive, Moraga, California in the United States of America, Mining and Metallurgical Engineer, make oath and say as follows:

1. (a) I hold the degrees of Bachelor of Science in Mining Engineering, New Mexico School of Mines (1936) and Master of Science in Metallurgical Engineering, University of Idaho (1937). I am a registered Professional Engineer in the States of Connecticut and California. I am a member of the American Institute of Mining and Metallurgicial Engineers. I hold a number of United States patents in mineral beneficiation. I am the author of approximately 15 technical papers on various mineral dressing processes.

EXHIBIT "23" - Affidavit of Earl Conrad Herkenhoff dated 29.8.1983

(b) I have worked continuously in the fields of mining (both underground and open pit) and mineral dressing, including iron ore beneficiation, for 46 years. My experience spans the basic steps of sampling mineral deposits, conducting laboratory bench scale tests on those samples, pilot plant testing of larger samples, flow sheet design, engineering design and equipment selection, and operation of the completed production facilities.

(c) I spent 7 years from 1948 to 1955 on the Iron Ranges of Minnesota and Michigan. In that time I was Field Engineer for American Cyanamid Co. (who were technical representatives for the Heavy Media Processes worldwide) and then Assistant Chief Metallurgist for Pickands Mather and Co. in Hibbing, Minnesota on the Mesabi Range. My direct responsibilities were for the design, construction and technical performance of 3 major iron ore washing and beneficiation plants, two having each a capacity of 700 tons per hour. These plants incorporated crushing, washing, sizing, heavy media treatment of coarse fractions and cyclone heavy media separation of finer fractions.

(d) From 1956 to 1963 I was concerned with the development of beneficiation procedures for the multi-million ton complex iron ore 2
deposits on the coast of Peru known as the Marcona Mines. The production plant capacity ultimately reached 10 million tons of product per year. The processes included crushing, screening, washing, scrubbing, heavy media, jigging, spiraling, grinding, magnetic separation and pelletizing. My positon in 1963 was Vice President of Technical Services for Marcona Mining Company.

(e) From 1963 to 1967 I was Vice President - Engineering and Development for Minera Bayovar S.A. in northern Peru where a large phosphate rock deposit was being studied. Processing involved selective mining, crushing, washing, intensive scrubbing, desliming 3
and froth flotation, all using sea water. I was also Vice President - Operations for Texada Mines Ltd. of Vancouver, British Columbia (Texada Mines owned Minera Bayovar S.A.). Texada

produced sinter feed iron concentrates and by-product copper concentrates from complex iron ores mined open pit and underground utilizing crushing, screening, magnetic cobbing, grinding and froth flotation of the sulfides.

(f) From 1967 to 1969 I was Vice President - General Manager for Pickands Mather International in Sydney and acted as technical adviser to the Managing Director of Savage River Mines in Tasmania. This operation produced 2 million tons per year of high grade oxide pellets by crushing, grinding and wet magnetic separation. The iron ore concentrates were transported to the pelletizing plant on the coast by slurry pipeline. Impurities in the ore such as nickel, titania and vanadium were held to rigid buyers' limits in the pellets.

(g) From 1969 to 1971 I was Technical Adviser - Senior Mineral Engineer to the Executive Vice President of the Specialty Metals Division of Kaiser Aluminium and Chemical Co. in Oakland, California. I then became Consultant to the Southern Peru Copper Corp. (from 1971 to 1975) in connection with the 40,000 tons per day Cuajone copper project in southern Peru. The project capital cost was US$740 million and involved mining, milling, smelting, thermal power and other infrastructure.

(h) In 1975 and 1976 I was Manager of Technical Development for A.G. McKee Corp. in their design offices in San Mateo, California. In 1977 and 1978 I became Consultant - Mineral Projects to both Kaiser Engineers and A.G. McKee, located in the San Francisco Bay area.

(i) After two years as Engineering Director for Phillips Uranium Corp. in New Mexico I returned to consulting work on phosphate rock for Zellars-Williams in Lakeland, Florida and Lima, Peru. During 1982 I was consultant to Minero Peru on base metal projects and to Hierro Peru for cobalt recovery at the Marcona deposits.

E C Herkenhoff

EXHIBIT "23" - Affidavit of Earl Conrad Herkenhoff dated 29.8.1983

2. I have been asked to advise the Plaintiff in relation to these proceedings and I have read and ask leave to refer to the Affidavits of Colin Roy Langridge sworn on 2nd September, 1982 and 24th May, 1983, the Affidavit of Niles Earl Grosvenor sworn on 27th October, 1982, the Affidavits of Peter Forbes Booth sworn on 27th October, 1982 and 30th June, 1983, the Affidavit of Christian Frederick Beukema sworn on 22nd June, 1983, the Affidavit of Alban Jude Lynch sworn on 22nd May, 1983, the Affidavit of Arthur Noel Pritchard sworn on 24th May, 1983, the Affidavit of Desmond Evered Wright sworn on 30th May, 1983, the Affidavit of Douglas Frederick Tompsitt sworn on 24th May, 1983 and the Affidavit of Robin John Batterham sworn on 25th May, 1983 all filed herein. I have also examined the exhibits (other than samples of feed) to each of those Affidavits, including the Agreement which is "Exhibit CRL 1". I inspected the Plaintiff's facilities at Tom Price on 26th August, 1983.

3. There are two broad reasons for beneficiating iron ores: first, to increase the iron content and improve the physical structure by crushing oversize particles and removing excessive fines; and secondly, to remove or reduce the content of undesirable elements such as alumina, phosphorus, silica, titania, sulfur, copper, zinc, nickel, alkalis and excessive moisture in order to provide steel companies with an iron ore feed, either in blast furnace size or sinter feed size, that will meet and maintain their specifications and tonnage requirements.

4. I agree that the treatment of the ore that takes place prior to and on the screens in the washing and screening house in the concentrator at Tom Price includes a scrubbing function, but the process would more likely be referred to in the iron ore industry in North America both now and in 1962 as "washing" because that term better describes the cleansing effect of the water. The water by itself significantly improves the purity of the hematite by removing adhering fines and slime particles and is an essential pre-requisite to later heavy media separation. "Screening" now connotes and in 1962 connoted a process of sizing without more. That is the process which a screen without washing attributes performs. To say that a washing process like that at Tom

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EXHIBIT "23" - Affidavit of Earl Conrad Herkenhoff dated 29.8.1983

Price which itself beneficiates the ore is included in the term "screening" is incorrect.

5. I am confident that paragraph 4 accurately describes industry usage in North America both now and in 1962. Now produced and shown to me are:

   (a) "Exhibit ECH 1", a true copy of Chapter 10 from Taggart's Handbook of Mineral Dressing (1945) referred to by Mr. Booth in paragraph 4 of his second Affidavit. This text recognises both "washing" and "scrubbing" as forms of treatment in their own right.

   (b) "Exhibit ECH 2", a true copy of an extract from the Bulletin of the University of Minnesota, Mining Directory Issue (Minnesota, 1963), in which "washing" is recognised as a process distinct from "screening". All the references to "Crushing and Screening" and to "Crushing, Screening" are to crushing and screening without the addition of water. The references to "washing", include plants where water is added to the ore feed prior to and on the screens, just as at Tom Price.

   (c) "Exhibit ECH 3", a true copy of extracts from Economic Aspects of Iron Ore Preparation (United Nations, 1966) in which "washing" is regarded as part of concentration and again as a process distinct from "screening".

6. I ask leave to refer in particular to paragraph 12 of Mr. Grosvenor's Affidavit and to paragraph 6 of Mr. Beukema's Affidavit. I disagree with the suggestion implicit in those paragraphs that the common description for the process is "wet screening". In North America the process would normally be described as "washing" or "washing and screening". When the term "wet screening" is used it is a reference to both aspects of a dual process. Its use would immediately inform a person in the iron ore industry that cleaning by washing was included. The term "screening" standing on its own does not include that dual process, whether it is described as "washing and screening" or "wet screening".

EXHIBIT "23" - Affidavit of Earl Conrad Herkenhoff dated 29.8.1983

7. Contrary to the seventh sentence in paragraph 12 of Mr. Grosvenor's Affidavit, the purpose of adding water is to wash the ore and increase the iron content of the coarser fractions thus "beneficiating" the ore. Washing is particularly relevant to the removal of alumina and sulfur. Where washing assists the sizing on the screen, that is a desirable but secondary effect.

SWORN by the said EARL CONRAD HERKENHOFF at Perth in the State of Western Australia this 29th day of August 1983.)

Earl C. Herkenhoff

Before me:

~~A Justice of the Peace~~

[illegible]
A C[illegible] of the Supreme Court
of Western Au[illegible] for taking Affidavits.

Filed on behalf of the Plaintiff.

EXHIBIT "23" - Affidavit of Earl Conrad Herkenhoff dated 29.8.1983.

EXHIBIT "23ECHI" - Extract from "Handbook of Mineral Dressing" by A.F. Taggart

HANDBOOK
OF
MINERAL DRESSING

ORES AND INDUSTRIAL MINERALS

BY

ARTHUR F. TAGGART

VINTON PROFESSOR EMERITUS OF MINING, SCHOOL OF MINES
COLUMBIA UNIVERSITY

CONTRIBUTORS

HENRY A. BEHRE
CHARLES H. BREERWOOD
JOHN M. CALLOW
DORR CO. ENGINEERING STAFF
FRANCIS E. FINCH
T. A. FRANKISH
HARLOWE HARDINGE
MENELAOS D. HASSIALIS
DONALD F. IRVIN
EDWARD K. JUDD
PERCEY F. SMITH
E. J. TOURNIER
PAUL M. TYLER

JOHN WILEY & SONS, INC.
NEW YORK · LONDON · SYDNEY

EXHIBIT "23ECHI" - Extract from "Handbook of Mineral Dressing" by A.F. Taggart

SECTION 10

WASHING AND SCRUBBING

Scrubbing and washing are the counterparts of crushing and concentration respectively, as applied to the treatment of crudes which are geologic residuals. Such crudes nor- 1(
mally comprise rock that is more or less unconsolidated, in which the important mineral species differ markedly in grain size and bulk hardness. Particle size alone is ordinarily, but not necessarily, the property upon which separation is based. Water is the usual separating medium, but air is sometimes used. The names carry over from parallel familiar household activities and imply the same actions, *viz.*, soaking, rubbing, pounding, agitation, spraying, and the like in the presence of water, and removal of the water from the larger solid, carrying the smaller solid in suspension. By these means clay is washed from harder and more coarsely crystalline minerals and rocks generally; sand from aggregate, fine sand from coarse sand, loam from fine sand; sand from shell; decomposed blue-ground from diamondiferous sand and gravel; silica sand from lump hematite, phos- 2
phate, barite and the like; and slimy limonite from associated granular material.

SCRUBBING

Definition. Scrubbing is disintegration effected by forces which are relatively light, judged by ordinary standards of comminution, but are sufficient to break down soft unconsolidated material such as clay, or to sever the bonding brought about between grains by precipitates of salts and the like. Scrubbing is usually effected by rubbing the larger and harder grains together, as by tumbling the mass, but in some cases the force of a water jet playing against a mass of crude backed by a rigid surface is sufficient. Scrubbing normally precedes washing, but the two may proceed simultaneously.

1. PRINCIPLES OF SCRUBBING 3

The materials to be scrubbed, the form and character of the material to be removed by the scrubbing, and the results demanded determine the method and apparatus to be employed. If, as in the preparation of lump limestone for burning in shaft kilns, the finished material is the lump stone and the impurity to be washed away is adhering clay picked up in quarrying, the method indicated is one in which the lumps of relatively hard stone are rubbed against each other in the presence of water; the degree of tumbling required depends upon the resistance of the clay to disintegration and upon the purity demanded. If the clay is tough, adhesive, and water resistant, and if standards of purity are high, the stone must be tumbled until most of the surface concavities are eliminated, since only thus can such clay be removed. On the other hand, the clay bonding in many so-called cemented gravels containing well-rounded smooth boulders may be removed by even such light rubbing as is involved in passage through chutes and over vibrating 4
screens, particularly if subjected to vigorous sprays. In general the smaller the fragments to be scrubbed the more irregular their surfaces, and the softer they are the more difficult it is to scrub them.

Materials subjected to scrubbing may be classified on the basis of the form of the soft component, since this determines the method of scrubbing. NODULAR MATERIALS are those in which the harder grains, ranging in size from very small to massive, are

EXHIBIT "23ECHI" – Extract from "Handbook of Mineral Dressing" by A.F. Taggart scattered through a matrix of clay or clay-bound sand. The important characteristic of this type of material from the standpoint of scrubbing is that the material to be disintegrated is massive and frequently tends to form rounded lumps (CLAY BALLS) which are highly resistant to disintegration. CEMENTED MATERIALS are those in which the harder particles predominate, but in which there is sufficient intergranular cementing material to form a substantially continuous interstitial filling; cemented gold gravels and some tin gravels are typical. COATED MATERIALS are usually fine grained, relatively unconsolidated, but coated, and, perhaps, lightly cemented, by films of decomposition products, precipitates such as iron oxides, and the like.

Methods of scrubbing are (1) jet-impact, (2) tumbling, (3) stirring. Each may, sometimes advantageously, be preceded by soaking. Additionally, in difficult cases, modifications of standard methods of crushing and/or grinding are employed.

2. JET SCRUBBING

Jet-impact scrubbing is used for primary disintegration of both nodular and cemented crudes, and in final scrubbing of gravelly aggregates and, less frequently, of sands. The underlying principle is subjection of the solid to the mechanical impulse of the jet, at the same time supporting it against a rigid or semi-rigid backing so as to utilize as much of the jet energy as possible in setting up internal stresses in the lump, rather than in effecting transport. The size and velocity of the jet to be employed depend upon the size of the material and the method of backing. If the lumps move as a mass under the impulse of the jet, energy is being wasted. If the material being jetted is submerged, so that a part of the force of the jet is expended in moving the submerging water, energy is again wasted. If the material is moving toward the jet as it is struck thereby, the force of the impact is increased. It follows that jet scrubbing is most effective when material is held in place, as in a gravel bank sufficiently steep to permit rapid runoff of water, or when it is moving down a steep chute (again permitting rapid runoff), or is supported on (and preferably moving toward the jet over) a rigid perforate surface.

Hydraulicking is employed in mining many nodular crudes and cemented gravels and sands, not only because such excavation and transport are relatively cheap, but also because the full impact of powerful jets can thus and only thus be brought to bear on the finer sands. For methods and costs of hydraulic mining see *Peele*; for sluicing see Sec. 11, Art. 26.

Monitors are nozzles, usually 1-in. diameter or larger, supplied with water at pressures of 50 to 150 lb. per sq. in. and upward. They are used in the plant on lump crudes of nodular or cemented character, the crudes normally being supported on a grizzly sloping toward the nozzle stand. A typical simple arrangement is shown in Fig. 1 (*21 IMM 250*).

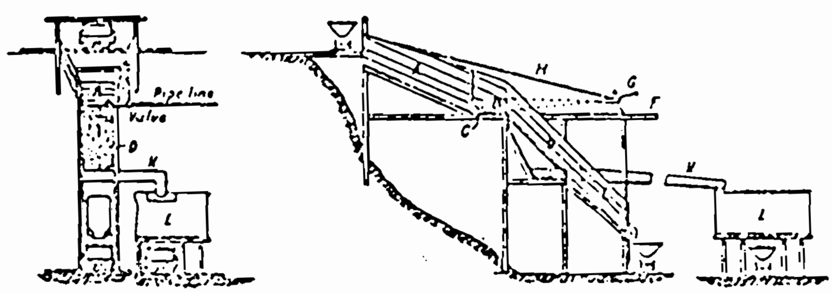

FIG. 1. Monitor washing plant.

The ore was delivered on an upper track, dumped into a chute *A* and brought to a washing platform *B*, where it was disintegrated by means of a stream from a nozzle *C*. Disintegrated material flowed over a grizzly *D*, washed oversize was collected in a bin *E*, and undersize flowed through launder *K* to a settling tank *L*. See also Sec. 2, Fig. 135.

At CHARLESTON MINING Co., Mt. Pleasant, Tenn. (*44 #9 RP 27*), clayey muck from steam-shovel mining is disintegrated on a grizzly with 110-lb. water from hydraulic guns, adding 1,500 g.p.m. (for 125 t.p.h. of solid); grizzly undersize then passes to an 8 × 25-ft. blade mill and thence to 3/16-in. Low-head screens.

A modification of monitor scrubbing was used at MONROE SAND & GRAVEL Co., Monroe, La. (*41 #9 RP 40*). A cemented gravel containing about 20% clay was excavated by steam shovel and transported by side-dump cars to the shore of a lake, where it was dumped. A header with a plurality of

EXHIBIT "23ECHI" - Extract from "Handbook of Mineral Dressing" by A.F. Taggart

jets under 25-lb. pressure was carried along above the dump, and the dump was washed into the lake by the jets. The material was then picked up by a suction dredge and washed and sized in the usual fashion (Sec. 3, Art. 38). The lake served both for storage and to soften and disintegrate small lumps of clay by soaking.

Water consumption for jet scrubbing is substantially impossible to estimate. A 1 1/2- or 2-in. monitor under 60- to 100-lb. pressure will effect rough disintegration of a relatively large tonnage of material per hr., sufficient to permit passage through a 1 1/2- or 2-in. grizzly, and the water therefor is readily calculable, e.g., for a 2-in. nozzle at 100-lb., 1,100 to 1,200 g.p.m. is required. Thus if extensive monitor scrubbing is contemplated, a large supply of cheap water is necessary.

Jet scrubbing on screens. See Art. 6.

3. TUMBLING SCRUBBERS

Tumbling scrubbers are rotatable cylindrical shells, set more or less horizontally, with end closures sufficient to maintain a body of liquid within them, and with internal projections that serve to tumble the load on rotation. They operate, usually, at speeds well below critical (Sec. 5, Art. 2) and thus depend for their scrubbing action primarily on rubbing between the lumps of hard material in the feed, supplemented by such impact as occurs in cascading (see Sec. 5, Art. 2). At the usual low speeds the forces are insufficient to break material as soft as the ordinary pebble phosphates, but may disintegrate barite (Sec. 3, Art. 3) or nodular manganese oxides. Ordinary clays disintegrate relatively completely, if the harder material is 2-in. lump or larger, and the pulp is kept thin; tough clays, small lump, and thick pulps all tend toward the production of clay balls, which tend to float through without disintegration. The remedies are higher speeds to cause definite cataracting, introduction of a light load of steel tumbling media, and thin pulp; one or more being applied according to circumstances.

Drum scrubber in its simplest form (Fig. 2) is a cylindrical welded-steel shell, 5 to 7 ft. diameter by 8 to 25 ft. long, with plane or conical ends. It is mounted, with axis horizontal, on tires and rollers, and revolved 10 or 12 r.p.m. (170 to 190 f.p.m. peripheral speed) by spur gear. It is lined with chilled cast-iron or manganese-steel blocks, usually in alternate courses of smooth and lifter types, the lifters being set at an angle so as to both elevate and convey settled material from feed to discharge end. Water and suspended fines flow through, either concurrent or countercurrent, by reason of difference in diameter of feed and discharge openings. Lifters of spiral or radial types on the discharge head may be used to lift the scrubbed rock to the discharge opening (see Sec. 5, Art. 8). Weight complete is from 20,000 to 85,000 lb. over the size range 5×8- to 7×24-ft.

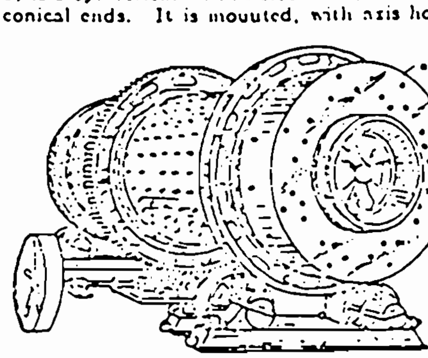

FIG. 2. Drum scrubber (*after Allis-Chalmers Mfg. Co.*).

Operating conditions. FEED SIZE for standard construction is usually 4-in. limiting. Larger lumps, 6- to 10-in., require larger feed and discharge openings and redesigned discharge-head lifters. CAPACITY is a matter of conveying rate, which depends upon the projection and inclination of the lifters and upon the coarseness of the feed. Manufacturers' ratings for 5-ft. drums are 20 to 75 t.p.h., for 6-ft. from 75 to 125 t.p.h., and for 7-ft. from 200 to 300 t.p.h., the lower values at each size corresponding, of course, to the higher and tougher clay contents of the feeds. POWER CONSUMPTION varies with the amount and specific gravity of coarse material in the feed, and upon the hardness of the sand and its resulting tendency to lift the load. Motor sizes recommended range from 10-hp. for a 5×8-ft. drum to 40-hp. for a 6×20-ft. and 125 hp. for the 7×24-ft. size. WATER CONSUMPTION depends upon the service, but is roughly within the range of 1 to 4 tons per ton of solid feed.

Blade mill; paddle mill (Fig. 3) is essentially a drum-type conflow scrubber with log-washer teeth *a* of adjustable angularity (Art. 4) and without an inside wash spray. In one form, it is trunnion-mounted, with trunnions capable of passing 12-in. lumps, and is fitted with a large gravity-feed hopper, a lifter-type discharge for coarse material, and a trunnion drum (see Fig. 4) having annular retaining rings to aid in maintaining level with a surging feed. It is built in the belief that the higher blades (as compared with the simple drum-type scrubber) will be more effective in disintegrating clay balls, by reason

EXHIBIT "23ECHI" - Extract from "Handbook of Mineral Dressing" by A.F. Taggart

of a cutting action; and that control of time-factor may be effected by adjustment of the pitch of the blades. Sizes are 6- and 7-ft. diameter by 16- to 30-ft. length. Performance data are not available but makers' ratings are 200 to 300 t.p.h.

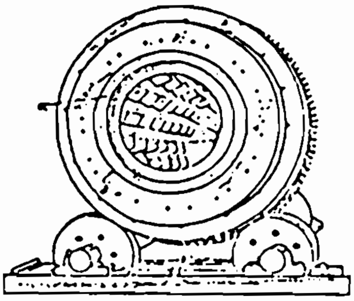

FIG. 3. Blade mill (*after McLanahan & Stone Corp.*)

Cone-ended scrubber is a cylinder with 30° conical ends and spiral lifters carried up into the discharge-end cone to aid in discharging coarse material. It is effective for easy scrubbing, such as for lump limestone; it is doubtful whether it would be effective for difficult work.

Super-scrubber is used for refractory feeds that require intense tumbling for disintegration. 1 LIFTERS are given more projection and the inclination toward the discharge end is decreased or eliminated. SPEED is increased to between 80 and 90% of critical so that there is much cataracting of the charge. POWER requirement is thus more than doubled. CAPACITY is decreased by reason of the decrease in conveying thrust. More good rock is crushed and broken. The machine should be heavier and more rugged generally to withstand the heavier duty.

Counterflow scrubber is designed to remove clay and fine sand from gravel and stone 2 during the scrubbing operation. One form is shown in Fig. 4. It comprises a cylindrical shell with dished ends, trunnion mounted, with cylindrical axis horizontal. The feed end is lined with spiral lifters *a* directed toward the discharge end, so that material is heaped up beyond the inner ends of the lifters and thereafter flows by gravity to and through the discharge trunnion. The remainder of the cylinder is lined with lifter liners *b*, the ridges *c* parallel to the shell axis. A grate *d* at the feed end forms a perforate annulus around the feed chute, holding back the coarser material, but permitting egress of fines. Liquid flow toward this end is induced by making the diameter of the discharge opening smaller than the outside diameter of the grate and feed-trunnion opening. 3 Spray pipe *e* with deflector jets (Fig. 9) projects into the discharge end as indicated. Speed is such that, with the lifters, the load is largely cataracted, and the low-level discharge minimizes cushioning. Counterflow acts to decrease in-load cushioning by removing much fine material shortly after entry; it also does final washing of product with the cleanest 4 water. Usual diameters are 5 to 7 ft. and lengths from 1- to 1 3/4-times diameter. Outside screen (TRUNNION TROMMEL) *f*, bolted to the discharge spout, is used when close sizing of coarse products is unnecessary.

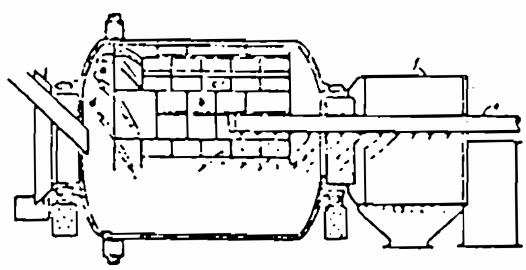

FIG. 4. Counterflow scrubber (*after Allis-Chalmers Mfg. Co.*).

In another form, with plane instead of dished ends, a chute projects adjustably into the discharge opening and the lifters are carried to the end of the shell; the combination serves to elevate and drop scrubbed material into the chute, and the extent of washing may be varied by the inward projection of the latter.

Screen scrubber is an imperforate section, usually at the head of a revolving screen 5 washer (Art. 6). The cover sections are steel plate or manganese-steel castings, usually unlined, with longitudinal lifters, and, normally, an annular baffle at the end to increase time-factor somewhat and to make the falling load slightly heavier than otherwise. The action of a screen scrubber is much lighter than that of the drum-type machines above described; correspondingly, less thorough disintegration is demanded. For further detail of construction and operation see Sec. 7, Art. 5.

4. STIRRING SCRUBBERS

Stirring scrubbers are essentially stirring devices in which thick pulps, ordinarily too fine or too soft to be scrubbed effectively by tumbling, are treated. Some of them, such 6 as the pug mills and mulchers, depend upon moving blades to actually cut through soft

EXHIBIT "23ECH1" - Extract from "Handbook of Mineral Dressing" by A.F. Taggart

clay lumps; the majority, however, attempt by thorough stirring to produce repeated rubbing together of hard-particle surfaces in order to rub off adherent films of softer materials.

Pug mill (Fig. 5) consists of a horizontal trough *a* in which is mounted a shaft or shafts *b* carrying blades *c*, usually set at a sufficient angle to the shaft to impart to the pulp some longitudinal movement. Diameter of blade-tip circle ranges from 10 in. to 3 ft. according to the duty. Speed ranges from 10 to 50 r.p.m. The apparatus is used for soft clays containing relatively small amounts of small granular materials. CAPACITY depends upon the amount of disintegration necessary and the difficulty in effecting it; each case is more or less special, and can be decided only on the basis of test and experience. Form C, Fig. 5, represents a mixer in a revolving barrel and is used when the charge tends to be sticky and not travel through the normal type of mill.

FIG. 5. Pug mills.

Log Washer

A log washer has two functions, *viz.*, (*a*) to disintegrate clay and clay-bound sand matrices, and (*b*) to separate disintegrated fines from lump material. Both disintegration

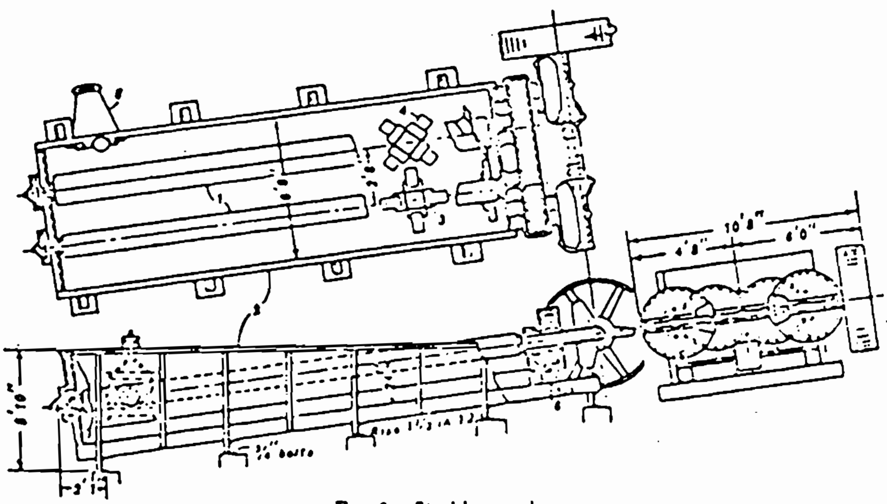

FIG. 6. Steel-log washer.

and transport of the coarser material are performed by blade-bearing inclined revolving LOGS, which agitate and turn over the feed in water in a box and at the same time push the settled lump material up an inclined bottom by reason of the spiral positioning of the blades. Discharge of fines is effected by overflow, in suspension in water, at the lower end of the box.

Description. Log washers (Fig. 6) comprise essentially one or two heavy inclined members or logs (*1*) mounted rotatably on a slope of 0 to 2 1/2 or 3 i.p.f. in a rectangular or round-bottomed trough (*2*), with bottom on the same slope. Logs were made originally (and still are in small, crude plants) of 12- to 18-in. sticks, shod full length with iron straps, and fitted with chilled-iron gudgeons (Fig. 7), the lower gudgeon or both gudgeons passing through a stuffing box and carried in a thrust bearing. In modern forms the bearings are outside, roller-type, and the lower (drive) end of the shaft passes through a water-sealed stuffing box. In the modern apparatus figured, the logs are made of 8 × 8 × 3/4-in. angles welded to form an 8 × 8-in. box girder. Base plates (*3*) for holding reversible alloy-steel blades (*4*) are welded to the logs in such spacing (about 4 per ft.) and

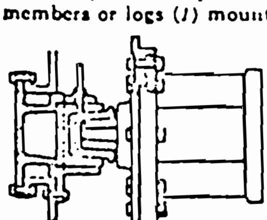

FIG. 7. Gudgeon, chilled-iron thimble and step bearing for wooden log.

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position that the blades form an interrupted spiral with a pitch angle of 65 to 70° and a diameter of 20 to 40 in. Logs are made in 20- to 35-ft. lengths; in 2-log machines rotation is in opposite directions, rising in the center. Boxes are normally of steel, but often of wood, with adjustable overflow (*5*) and sand-discharge spout (*6*). Clearance between blade-tip circle and box bottom should be greater than the largest lump of feed. The upper 8 to 10 ft. of the box is usually sprayed. Normal speed range is 140 to 190 f.p.m. peripheral, the higher figure corresponding to the greater blade-tip circle; speeds up to 240 f.p.m. are shown in Table 1.

Table 1. Performances of 2-log washers on stone and gravel (*After Amos and Patterson*)

Feed material	Size, in.	Feed, tons per hr.	Box	Washer: Length of logs, ft.	Washer: Diam tip circle, in.	Washer: Pitch of blades, deg.	Washer: Speed, r.p.m.	Power, hp.: Installed	Power, hp.: Consumed, Total	Power, hp.: Consumed, Per ton of feed	Water, tons per ton of feed	Reject, tons per hr.
Limestone *a*	<2 1/4	24.7	Wood	25	36	22 1/2	21	60	59	2.4	0.7	4.2
" *b*.	2 1/2~1 1/2	25 *c*	Wood	25	36	22 1/2	.....	100	91	3.6 *c*	4.0 *c*	....
" *d*.	<1 1/4	58 *c*	Wood	25	36	22 1/2	20	80	64	1.1	2.2	13
Gravel *f*....	<1 3/4	42	Wood *h*	25	36	....	25	100	.....	2.0 *i*	3.0	9.5
" *f*....	1 3/4~1/4 *g*	60 to 70	Wood	25	36	....	25	100	......	1.5 *i*	0.8 *k*	10 to 20
" *l*....	*m*	80	Steel	25	36	25 *n*	25	40	......	0.5 *i*	2.5	8 to 10
" *o*....	<3-in.	....	Steel	25	36	25	16	60	......	......	*p*	......
"	1 1/2~1/4 *q*	45 *c*	....	20	....	....	19.5	55	...	......	....	......

a Cost (1935), 4.6¢ per ton of washed product, of which power was 63%. Labor, 1 man to 2 machines.
b Foreign material, red clay in balls and coating the stone.
c Washed product.
d Refuse from hand loading at quarry face; includes loam and clay balls 1 to 6 in. diam.; also some clay-smeared larger rock.
e Easier washing than material in first line of table because clay had somewhat weathered. Repairs and maintenance, 0.17¢ per ton of feed.
f Cemented. Owing to increasing cementation a rotary washing screen with scrubber section would no longer clean the product sufficiently.
g Through 2-in. ring, on 1/4-in. vibrating screen.
h Slope, 1 i.p.f.
i Estimated.
k Minimum operable with this feed. Supply limited.
l Cemented.
m Pit run.
n Repairs estimated at 1 to 2¢ per ton of finished product.
o Clay-coated.
p 400 g.p.m.
q <1/4-in. removed by vibrating screens.

Turbo washers are log washers with perforated false bottoms through which water is forced under pressure. They wash the lump material more thoroughly than the ordinary log washer does.

Operation. LENGTH of machine affects time that material is subjected to the action of the logs and therefore the extent of disintegration and cleaning of sand, but it does not affect rate of sand movement and, therefore, has no effect on capacity. SLOPE affects the run-back rate from the sands; the steeper the slope the better the cleaning, all other things being equal. Within small limits, also, slope affects rate of sand travel and thus controls capacity. SPEED affects the force of the blade blows and thereby the disintegration; higher speed, however, increases transport rate and correspondingly decreases time-factor; usual range is 20 to 25 r.p.m. for the larger machines. Slow speeds must be used for difficult washing. WATER CONSUMPTION varies according to the amount of solid to be carried over; figures range from 1 to 8 tons per ton of feed. The larger quantities are required with sandy and loamy material; with stiff clay thicker pulp aids disintegration, and when coarse material is to be overflowed a thick pulp is necessary for buoyancy. Unless draining is necessary, spray water should be added as near the upper end as possible, at pressures of 20 or 30 lb. or more. Extra water added to increase volume of overflow should be introduced in the corners at the discharge end in order to give a counterflow effect. POWER required is from 15 hp. for a small single-log machine to 100 hp. for a large double-log machine; the requirement is generally lower the higher the clay content; consumption figures as low as 0.5 hp.-hr. per ton are reported. FEED is introduced on the upcoming side of a single log or between double logs and, in order to save power and wear, as near the head end as will produce a clean product. When the feed varies widely in amount of dirt, it should be brought in high enough above the washer to permit the actual feed point to be changed with the duty demanded. Maximum size of feed is usually about 3-in., but 4-in. stone can be handled in large logs. Large rock tends to work down-slope and jam in the lower end of the box; this can be prevented by feeding over a grizzly, with oversize delivered farthest up-slope.

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Concentrating action in a log washer. Apart from the classifying action, which is simply a rough sizing, a log washer forms a stirred bed in which reverse classification, aided by the lifting action of the paddles, keeps the coarser material at the top, where it is most readily transferred up-slope. If the feed is a mixture of minerals of different specific gravities, the coarse particles of lower gravity simply float on the bed. The coarse particles of higher gravity are prevented from sinking in it by the stirring. The finer material not in suspension, which percolates, stratifies according to specific gravity; a part of the lighter can then be forced to overflow, while the heavier bottom material is carried up-slope by the conveying action of the logs. If the log is overfed, both scrubbing and washing decrease markedly; if the pulp is too thick, fine light material is carried into a heavy-mineral log product.

Capacity. Maximum capacity is determined by the transport ability of the logs acting as a blade conveyor. Manufacturers' ratings of this capacity at blade-tip speeds of 200 to 225 f.p.m. range from 60 to 80 t.p.h. for a 36-in. tip circle on material of 2.7 sp. gr. Performance figures are in this range. Maximum capacities for smaller sizes may be estimated from these on the proportion of the squares of the diameters of the tip circles. Total capacity is the raking capacity plus the discard. When washing is difficult, speed must be reduced; then reduce estimated raking capacity proportionately. For material of high specific gravity, increase tonnage estimates proportionately. An oversize allowance of 25 to 50% should be made to take care of surges.

Performance. At the Coleraine plant of OLIVER IRON MIN. Co., washing hematite ore at <2-in. ring, 36-in. X 25-ft. turbo-type double-log washers at 14 r.p.m. received 160 t.p.h. each and made 40 tons of concentrate. Overflow was sent at the rate of 107 t.p.h. each to 20-in. X 16-ft. 2-log turbo machines at 9 r.p.m., which made 32 tons each of concentrate. Both concentrates averaged 55% Fe and 10% SiO_2. In Alabama (*105 P 455*) log washers are used to wash clay and gravel from nodular limonite. Usual capacity of 36-in. 2-log machines, 20 to 30 ft. long, at 12 to 15 r.p.m. is 50 to 75 t.p.h. with 8 to 25% of the feed being raked up as concentrate carrying 40 to 45% Fe. Maximum size of feed is about 3-in. Treating manganese ores (*Bul 734 USGS 63*) a double 25-ft. log making 12 to 15 r.p.m. treated 40 to 50 tons per 24 hr. with a water consumption of 50 to 75 g.p.m. and 20 to 25 hp.

Performances at a number of installations washing limestones and gravels are given in Table 1 (*129 A 145*). For use in mills see Secs. 2 and 3.

Character of products. Log washers are largely sizers so far as the coarse product is concerned and this must usually, therefore, be further concentrated. The ordinary means are picking, jigging, or sink-float separation. There is some differential settling of fine material, but overflow cannot be considered finished tailing except for low-cost mineral, or for one not further concentratable.

Screw washer (Fig. 8) is a modification of the log washer designed for light scrubbing and washing of coarser sand. It comprises an inclined tank with sides built up at the lower end to accommodate a pool, the depth of which is controlled by means of an adjustable overflow weir at *a*. The screws *b*, usually 16 to 20 in. diameter, are cast or sheet-steel spirals carried in bearings outside the tank. Provision for thrust is made in the lower bearings, and the stuffing box at the lower end is water-sealed. Usual speed range is 20 ± 5 r.p.m., and should be an operating adjustment. Feed is introduced into the pool at a limiting size usually $^1/_8$- to $^1/_2$-in.; the location of the feed point is nearer the high end the coarser the feed. Spray water is introduced on the upcoming side of a single spiral, or between oppositely rotating double screws near the high end, the location of the topmost jet being a compromise between requirements for cleanliness and dryness of sand. LENGTH is usually 15 to 20 ft. PITCH is 3 $^1/_2$ to 4 $^1/_2$ i.p.f., usually increasing with length. CAPACITY ranges from about 10 t.p.h. for a 16-in. single screw doing difficult cleaning and making a relatively dry sand to 70 t.p.h. when making an easy separation in a 20-in. 2-screw machine. Double-screw capacity for a given speed is substantially twice that for a single screw; capacity is directly proportional to speed and to the square of the diameter of spiral. Provision may be made to introduce bottom water near the shallow end of the pool; this tends to make a cleaner sand.

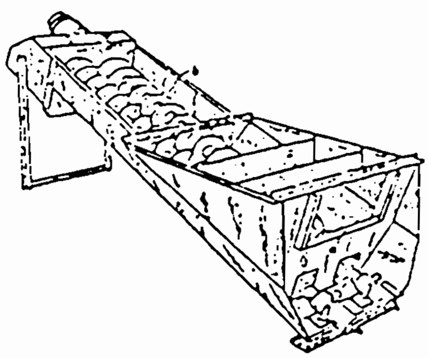

FIG. 8. Double-screw sand washer.

Modified log washer for sand washing, used at P. J. WEIRTZ, INC., Corona, Calif. (*41 §8 RP 65*) in production of glass sand, had alternate radial and 45° blades, 13 $^1/_2$-in. radius, mounted on a 1 $^{15}/_{16}$-in. shaft in a horizontal tank. The squeezing effected by the radial blades is reported to have been effective in disintegrating small clay balls (see Sec. 3, Fig. 64)

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5. SAND SCRUBBING

Sand scrubbing is essentially removal of films or coatings, *i.e.*, disintegration of clay masses or the like is normally not involved. The method employed depends upon the refractoriness of the coating.

Scuffing is a name recently applied to a form of scrubbing, the object of which is, in general, to remove fine-grained crumbly or particulate incrustations from sandy materials. Thus clay and fine phosphate slimes are removed from pebble-phosphate particles prior to oiling for table flotation (Sec. 12, Art. 30; Sec. 3, Figs. 51, 54); decomposed feldspathic material is removed in preparing spodumene for froth flotation (Sec. 12, Art. 53); and fine powdery hematite is rubbed from quartz grains in treatment of the oölitic hematites of the southern U. S.

The methods employed for scuffing depend upon the difficulty of the job. Tumbling mills (Sec. 5) with light loads of rods or balls are used in phosphate and hematite treatment; chaser mills are used for some glass sands, tumbling mills with a load of slugs for others (*43 § 1 RP 103*); vigorous stirring in a thick pulp in a beater box such as the agitation compartment of an agitation-froth machine (Sec. 12, Art. 27), with a dispersant present to prevent redeposition (Sec. 12, Art. 7) is sufficient in other cases.

Separation in scrubbing is never clean. When cleanliness is desired the scrubbed material must be subjected to some further form of washing or other method of concentration.

WASHING

Washing is, properly, separation on a size basis between particles differing so widely in size that the smaller are readily suspended in a fluid current which fails completely to suspend the larger. The term is applied also, however, to classification, particularly in the sand and gravel industries and in those concentrating operations in which the crude separations possible in classifiers are sufficient, *e.g.*, for certain iron ores, manganese ores, phosphates, and the like.

Washing usually involves more or less scrubbing. This is particularly true with crudes which require light scrubbing only, such as crushed stone, dredged shell, and many sands and gravels.

The principal apparatus used for washing are screens for sizes coarser than 1/8-in.; sand tanks, mechanical classifiers and hindered-settling hydraulic classifiers for separations in the range from 10- to 100-m.; and hydro-bowls and air classifiers in the finest range.

6. SCREENING WASHERS

A washing screen is an ordinary screen provided with more or less powerful water jets playing on the oversize material, suitably housed to lead away liquid undersize and confine splash.

Rotary washing screens are used when a considerable amount of disintegration, usually of clayey material, is necessary, when tumbling and some resultant breakage of oversize are not harmful, and when separation is to be made at sizes not finer than 1/8-in.

The greatest development of rotary washing screens has been in connection with gold and tin dredging. In this service single-jacket screens up to 9 ft. in diameter and 50 ft. long, usually with a scrubbing section, have been built. See Sec. 2, Art. 20, for details of construction and operation in gold and tin dredging. See Sec. 7, Art. 5, for the forms ordinarily used in treating industrial minerals. Such screens when used for washing differ from those used for screening alone in the fact that they are normally equipped with lifters, they have internal sprays, and may have retarding rings to thicken the bed and thus cause a certain amount of in-load rubbing.

Rotary screens without lifters have been widely used for light washing and sizing crushed stone and gravel. They have been largely displaced, however, by vibrating screens in most modern installations of this type, particularly when but little disintegration is required, or where heavy scrubbing is done separately (Art. 1). The only sacrifice in such substitution is loss of the transport and distribution to bins effected by the usual rotary. This loss is more than compensated for by the smaller weight, greater compactness, and higher capacity and efficiency of the vibrating type.

Rotary screens are pre-eminent in washing dredged shell. In this service there is considerable marl to be dislodged from the shell cavities and tumbling is essential to present both faces of the shell repeatedly to the washing jets. The accompanying sand

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is fine so that screening, even at somewhat under 1/8-in. on the outer jacket, is easy, and the shell is a cheap enough commodity to make it unnecessary to reduce aperture to effect the highest possible shell recovery.

Chains of heavy rod, hung in loops from the lifters, have been proposed for material that requires considerable scrubbing and is deficient in coarse heavy lumps. The chains are to be hung in the scrubbing and/or coarse-screening sections. It is difficult to see how they could aid; any slap that they might exert would be on the downcoming side, which carries no bed; on the upcoming side the tendency would be to swing out and dislodge material from the lifter shelves at a lower elevation than otherwise, thus decreasing impact.

Capacity depends upon the requirements as to cleanliness of oversize, the size at which separation is made, and the amount of near-mesh material present. For broken rock and not more than 50% of oversize to any given screening surface, a base rate of 1 ton per 24 hr. per sq. ft. of screen surface per mm. of aperture is safe; this rate may be increased 100 to 200% in the case of the finer apertures (3/8- to 1/8-in.) owing to the presence of plentiful wash water. For loose free-running and generally rounded gravel of long uniform range, add 20 to 25%. For bulky, irregular materials such as shell, apply a factor proportional to the decrease in bulk weight, and a further multiplier which may be 0.25 or smaller for blinding tendency. If considerable proportions of near-mesh material are present, apply a half-size factor *H* of the general order of magnitude given in Sec. 7, Art. 9. If high washing efficiency is necessary, a final efficiency factor, depending on the roughness and fines-holding nature of the surface and the adhesive character of the fine material, must be applied; this will be a divisor, the magnitude of which may be as great as 10, if, as in the case of oyster shell for making high-purity lime, the surface has recessed roughness and if the shell has been dug from a deposit containing considerable clay.

Shaking-screen washers have been installed on a few dredges (Sec. 2, Art. 21). They have been extensively used in washing pebble phosphate, and, following this practice, have been employed in treatment of similar ores such as barite and manganese. They have also been used as the exclusive means for screen washing of anthracite.

The philosophy underlying the use of the shaker in phosphate washing was that separation had to be made at a fine mesh, disintegration had already been effected in log washers (Art. 4), the shaker was as efficient as the trommel, had much higher capacity per square foot of floor space and of fine-screen surface, and was cheaper to install. The modern trend is toward vibrating screens, which actually have most of the advantages attributed to the shakers.

Sprays for phosphate washing are reported to have been most effective with 50-lb. pressure; light loads on the screens are essential for good washing.

Washing of anthracite on shaking screens is, except for the bull screen, entirely secondary to sizing; the screens were and are selected for this latter service because they cause the least breakage of any screen available.

For construction and operation of shaking screens see Sec. 7, Art. 6.

Vibrating screens are used for most modern sizing and washing of rock, gravel, and the like down to 1/8-in. sizes when the scrubbing requirements are light. The types of screen which can run on low slopes are preferable if scrubbing must be done, and, in general, the cleaner the oversize product required, the flatter the screen chosen. The screens should be operated so as to produce a relatively thin bed and high activity of oversize, since turning of oversize for subjection of all sides to water is desirable.

Capacities may be reckoned on the basic rates given in Sec. 7, Art. 9, with the additional factors discussed under *Rotary washing screens* (*ante*).

Wash sprays. Various forms of spray nozzles have been devised to produce effective jets and spray streams. Two forms are shown in Fig. 9. Item *a* clamps to the header so as to hood a drilled orifice therein, the deflector being shaped to produce the form of jet desired. Item *b* is welded or clamped in position. The inner surface of the deflectors is polished in all cases to eliminate undirected spray. Spray water should be applied under at least 25-lb. pressure. The headers are run above the screen box, transversely to the flow; they should be close enough to the bed of material to impinge as sheets rather than as spray, and should be so spaced as to form a continuous sheet of water across the screen box at the level of the upper surface of the bed. The number of cross headers depends upon the amount of washing required; spacing is sometimes as close as 6 or 8 in. between headers. Spray pipes should be assembled, if possible, so that the entire assembly can be lifted to permit screen change.

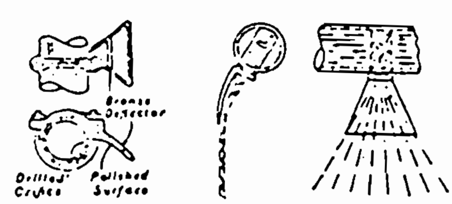

Fig. 9. Spray nozzles.

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Vibrating scrubber (Fig. 10) is a modified eccentric-drive vibrating screen with the screen box rebuilt to form two separate transverse deep pockets *a* with hoppered screen bottoms. Fishtail sprays are provided above each pocket. Independent feed streams are brought to each trough at the back side of the screen box in the figure, and the scrubbed material discharges through the screen-box wall at the front. The device is effective, at any economic capacity, only when the amount of scrubbing necessary is very small, since the superincumbent load is light and turnover is slight, if any, and almost wholly undirected and accidental, while the spray is effective on the particles in the upper layer only.

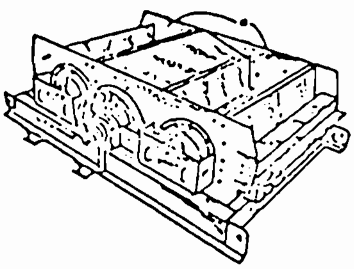

Fig. 10. Niagara scrubber.

A. E. Reed (*PC*) reports that 2 @ 2×6-ft. scrubbers handle up to 90 t.p.h. each of $\frac{1}{16}$–$\frac{1}{4}$-in. stone to make satisfactory removal of clay; and that a pebble phosphate containing 35% clay is fed at 100 t.p.h. to 3 @ 2×6-ft. scrubbers in series, with intermediate screening on 20-m. Hum-mers, producing a washed pebble cleaner than was made on log washers, with less loss, and with a saving of 66% in power and 50% in maintenance.

Stationary-screen washers must ordinarily be set on such a steep slope that insufficient time is available for even the most cursory washing.

At Lawrence Stone & Gravel Co., Blenheim, S. C. (*45 69 RP 44*), an 8×10-ft. stationary screen, on 5° slope, with 6-in. aperture, forms the bottom of the dump box for a 10-in. dredge line. A blank plate parallel to and about 1 1/2 in. below the screen causes the undersize and water to surge up and down through the screen, both washing the gravel and preventing screen blinding.

7. CLASSIFIER WASHERS

The classifiers used for sizing coarse and intermediate sands are, in order of decreasing use: (*a*) sand tanks, usually of automatic-discharge types; (*b*) whole-current and surface-current settlers; (*c*) launder- or trough-type; (*d*) mechanical classifiers; and (*e*) hindered-settling hydraulic classifiers.

Sand tanks are usually of the continuous type with automatic control of sand discharge. See Sec. 8, Art. 8, for description and discussion of the forms commonly used in concentration practice.

Tilting tank. Fig. 11 shows a form of tilting tank widely used in cleaning concrete sands. Tank *a*, which is pyramidal, with a minimum side slope of 50° (better 60° or 65°)

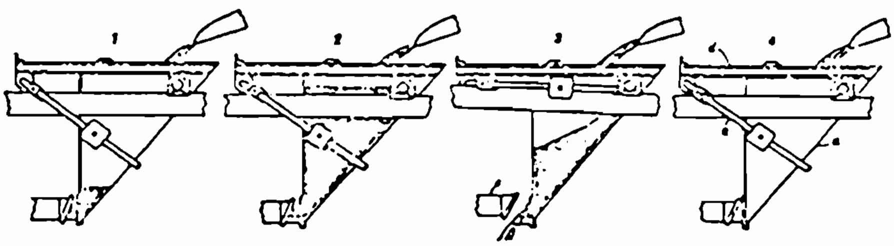

Fig. 11. Cycle of a tilting sand tank (*after Stephens-Adamson Co.*)

is supported near the back on knife-edge pivots, and is counterbalanced by the swinging arms *c*, carried at the outer ends of the cantilever frame *d* attached to the box, the mechanism being so arranged that as *d* tilts downward to the left, counterweight *c* is raised as shown in item 3, and the sand spigot opens by falling away from the fixed stop *e*. When the tank has emptied itself of sand, and has correspondingly decreased in weight, the counterweight *c* restores it to position with the spigot opening pressing against the closer stop. This may be a piece of rubber belt or softer rubber, suitably backed for stiffness, or a flatly conical rubber, wood, or metal plug.

Many forms of tilting tanks have been built. Sensitivity is increased by placing the counterweight on the opposite side of the fulcrum, increasing the horizontal projections of the distances from weight and counterweight to the fulcrum, and by lowering the latter toward the center of gravity of the system, but crankiness increases at the same time.

Fig. 12 shows a form of tank pivoted at *A* in which the counterweight arm *C*, pivoted at *B* on *D*, is so connected through arm *E* and bell crank *F* to valve plate *H* that as the

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tank tilts and raises *C*, the bell crank swings up and out and the valve opening is thus increased over that caused by simple swing of the tank as in Fig. 11. Counterweight is set so that with the tank filled as indicated the weight of the small amount of additional sand necessary to cause water to back up on the feed side of baffle *K* and of the water backed up tilts the tank slightly; the relatively large valve opening permits rapid discharge and fall of sand with release of backed-up water, whereupon the valve again closes.

The cycle of the apparatus starts with the tank partly filled with settled sand and overflowing water and suspended material as in item 1, Fig. 11. Sand continues to build up (and the overflow tends to become coarser) until at, say, the condition shown in item 2, tilt occurs and a thick mixture of sand and water discharges as in item 3 until the counterweight restores at some condition as in item 1 before break-through of thin pulp occurs. The shorter the fluctuation of top-of-sand, *i.e.*, the more frequent the tilts for a given sand flow, the more uniform the product.

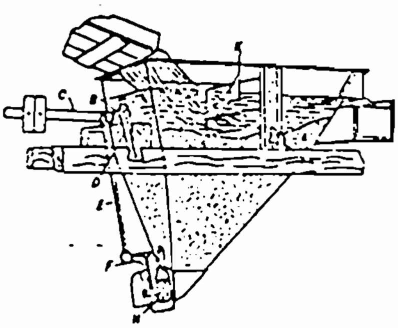

FIG. 12. Tilting sand tank with lever valve (*after Smith Engineering Works*).

Capacity of a tank depends upon the quantity of water overflowing, the separating mesh, and the dimensions at overflow level. For all practical purposes, all of the water entering can be considered as overflowing vertically, which gives a rising water velocity $V = Q/A$, where A is the tank cross-section at overflow level, Q is the volume of water flowing per unit of time, and V is velocity, the units being chosen to correspond. Settling velocities of the sands normally treated may be considered as lying in the Newton range (Sec. 8, Art. 1), and the equations for falling velocities there given apply. The determining sand size is that of the separating mesh. Free-settling prevails. Hence the maximum liquid volume that can be sent to a tank of a given size is that which will give an overflow velocity not to exceed that of the settling velocity of the grain of separating mesh; excess liquid will carry over coarser sand, a deficit in liquid will permit finer sand to settle.

Shaw (*44 \$4 RP 47*) reports capacities as about 0.3 to 0.35 cyd of coarse sand per hr. per cu. ft. of tank volume, and capacity for fine sands as 55 to 60% of those for coarse. Water capacity when catching coarse sand ranges from 10 g.p.m. per sq. ft. for 5-ft. tanks to 20 g.p.m. per sq. ft. for 12-ft. tanks; for fine sand, water capacity is about 75% of these figures.

Baffles. It is apparent that without some means of adjustment in overflow area, the character of the sand from such a tank will vary widely under the fluctuating conditions of stream flow normally prevailing. This may be compensated to a certain extent by installing a cross baffle (Fig. 12, item *K*) adjustable in its distance from the overflow lip. Only that part of the tank on the overflow side of the baffle is now to be figured for rising current, whence it follows that the rising velocity for a given water flow increases as the baffle is moved toward the overflow lip. If, at the same time, sensitivity is increased to the point that the fluctuation in top-of-sand is small, scour under the baffle enters as an element in determining size of overflow (see Sec. 8, Art. 8), and the cone becomes substantially automatic for a given setting of the baffle over a considerable range in feed volume. Adjustment in depth of baffle permits some control of sharpness of separation.

Spigot density of sand cones is given by Shaw (*44 \$1 RP 37*) as ranging from about 30% water by weight for fine sands to 25% for coarse sands.

Spigot discharges at the above densities are at the rate of about 200 lb. solid per min. per sq. in. of spigot area for diameters of 2 1/2 in. or larger (*43 \$10 RP 41*); discharge rate falls rapidly for smaller sizes (Sec. 8, Art. 12 and Fig. 41). Shaw (*43 \$6 RP 49*) recommends that in calculating sizes for rougher-pocket spigots, an additional area of 20% over that required to discharge an equivalent volume of water under the same head be allowed to compensate for the sand content.

Whole-current classifiers in the form of sloughing-off boxes or V-tanks are useful for sand settling when rough sizing of the settled sands is desired. Action therein and design requirements and equations are given in Sec. 8, Art. 8. Usual sizes are 6 to 8 ft. wide at the top and 15 or 20 to 40 or 50 ft. long, with gates of slide or molasses type at about 5-ft. intervals. The shorter boxes are sometimes used as receiving boxes for dredge-pump lines, but the sizing that they effect is a disadvantage in this service, since the gate products must usually be mixed again for further treatment, and incomplete mixing results in uneven feed to the subsequent apparatus.

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Surface-current classifiers are used for desliming fine sands, and at the same time effecting a size separation of the deslimed material. Analysis of action and design equations are given in Sec. 8, Art. 9. A form reported by Dull (*43 EG RP 29*) is shown in Fig. 13. Spigots *a* are made of rubber hose with pinch clamps and are long enough to enable them to be swung over any one of the three dewatering conveyors *b*, thus permitting almost any desired blending.

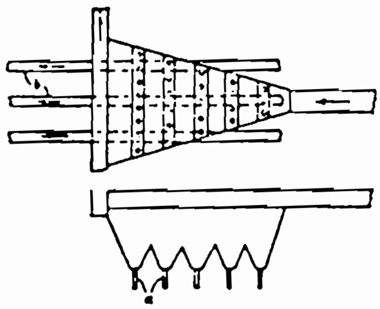

FIG. 13. A multispigot surface-current classifier (*after Dull*).

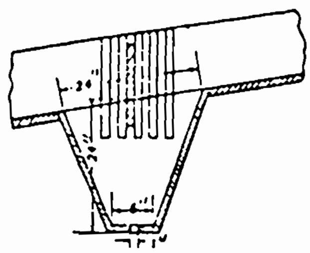

FIG. 14. Launder pocket for coarse or medium sands (*after Shaw*).

Launder classifiers are frequently used for bleeding off sands from flumes. The usual arrangement is one or more roughing pockets with adjustable baffles (see Sec. 8, Arts. 10, 11, 12) and a transverse slot in the bottom of the pocket (Fig. 14); if hydraulic water is used, a pressure pocket with spigot discharge is placed below the roughing pocket (see Sec. 8 as above). Dull (*43 EG RP 29*) describes such an apparatus with 8 or 10 pockets along a length of launder such that all were visible to an operator centrally stationed; spigot discharges were regulated by molasses gates operated by means of levers from the station. Dull (*ibid.*) also describes an adjustable slicer (Fig. 15) for drawing off coarse sand; he recommends riffling a short distance ahead of the slicer in order to throw the sand into suspension and so withdraw only the quickest-settling material. See also Art. 20, Sec. 3.

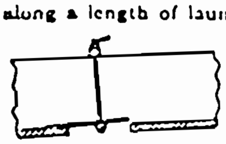

FIG. 15. Launder sand slicer (*after Dull*).

Scrubbing in flumes. Any flume or launder carrying coarse material causes a certain amount of rubbing together of the coarser, rolling lumps, and thereby does a certain amount of scrubbing. The action is accentuated by transverse riffling and by drops in the line (see Sec. 11, Art. 20).

At HEDRICK GRAVEL & SAND CO., Lilesville, N. C. (*45 EE RP 48*), 200 t.p.h. of crude gravel with 20% clay and 2,000 g.p.m. is transported in an unriffled 2×250-ft. flume, on a 13% grade. Normally, sufficient disintegration is thus effected. If it is insufficient, provision is made for detour through a 6×24-ft. drum scrubber, the discharge of which re-enters the flume.

Sizing in flumes. Long-range products of one specific gravity stratify on a size basis in flumes, irrespective of the velocity of flow, but when the flow rate is such that the larger particles are never in suspension, the nature of the stratification is different according to the nature of the bottom of the flume. If the bottom is smooth, the large and flat grains form a slow-moving bottom layer, dragged along on the water-lubricated and substantially sand-free flume bottom by the frictional pull of the overlying material. This is the action in the trough washers used to remove flat slate and bone from the more rounded coal. The more rounded particles stratify more or less according to size above this lower layer, and progress by a combination of rolling and sliding. If, however, the bottom of the trough is riffled sufficiently to force rolling of the settled coarser particles, reverse classification (Sec. 11, Arts. 2, 20) occurs, and the material not in actual suspension stratifies with coarse on top and fine beneath. Thus by suitable combinations of bottom character, water velocity, and skimming arrangements, it is possible to use a flume to make rough cuts on long-range feeds of one specific gravity between flat and rounded coarse material, between intermediate sands and the remainder (an undercurrent, Sec. 11, Art. 26), between slime and the remainder, or between fine sand and slimes and the remainder.

Mechanical classifiers (Sec. 8, Arts. 2 to 7) are used both for grading and dewatering industrial sands (see Sec. 3), and for making a rough gravity-size separation of iron and manganese ores (Sec. 2). Their advantage over sand cones lies in the saving in sand fall

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through the machine, a possible larger capacity per unit of mill volume, drier sands, and no possibility of choking of sand discharge. On the other hand, a sensitive automatic cone, well operated, probably makes a closer cut at the separating mesh, particularly with fluctuating feed.

Sizing test of one of the more siliceous concentrates made by a bowl-rake classifier on Mesabi ore is given in Table 2.

Table 2. Sizing-assay test on rake product of a bowl-rake classifier treating wash iron ore (*After De Vaney and Coghill, RI 3148*)

Mesh	Percentages			Distribution, %	
	Weight	Fe	Insol.	Fe	Insol.
4	3.6	31.8	52.6	2.6	5.5
6	1.0	36.0	46.1	0.8	1.4
8	1.3	38.0	43.6	1.1	1.6
10	1.5	42.2	38.1	1.4	1.6
14	2.2	43.3	36.2	2.1	2.3
20	4.3	43.5	36.1	4.2	4.5
28	8.0	40.5	40.5	7.2	9.4
35	12.0	39.4	42.2	10.6	14.7
48	16.4	42.0	38.9	15.4	18.4
65	18.0	45.7	33.1	18.3	17.2
100	16.1	49.9	27.0	17.9	12.6
200	12.5	58.3	15.6	16.3	5.6
<200	3.2	29.1	56.2	2.1	5.2
Totals	100.1	44.8	34.5	....	....

Dorr ore washer consists essentially of a combination of a standard rake classifier and a wash trommel. The trommel is mounted transversely above the classifier pool, at such a height that a lower segment is submerged, and material therein is, therefore, subjected to underwater scrubbing. Oversize is lifted to a discharge chute above pool level by a scoop device similar to that used in the discharge head of a grate ball or tube mill (Sec. 5, Fig. 56). The manufacturer reports that a 16×30-ft. machine has the capacity in iron-ore washing of 2 @ 6×25-ft. 2-log washers making 65-in. overflow, and a test on wash iron ore at Minnesota School of Mines is reported (*Bul C MSM*) in which the washer made 90% recovery against 85% in a log washer, and delivered a higher grade of concentrate. The data given in Table 3 are reported from Mabon and Counselman (*130 J 619*).

Table 3. Performance of Dorr washer at Mesebi Chief

	Percentages					
	Weight, dry	Iron		SiO_2	H_2O	Recovery
		Dry	Natural			
Crude....................	100.00	42.68	38.92	36.03	8.80	....
Washing barrel concentrate..	31.38	51.33	48.76	22.73	5.00	....
Rake concentrate..........	33.98	55.08	51.22	18.19	7.00	....
Total concentrate..........	65.36	53.28	50.06	20.37	6.05	81.61
Tailing..................	34.64	19.03	....	70.83	....	....

Shovel and sand wheels are used to a considerable extent for rough washing and dewatering. Typical forms are described in Sec. 15, Art. 1.

Dorrco sand washer comprises a shallow circular tank with flat bottom inclined at a slope of 4 i.p.f., and a slowly revolving wheel equipped with peripheral buckets, just clearing the tank bottom. Sand is picked up by the buckets, carried above water level onto an inclined drainage deck and is discharged therefrom through a chute. Excess water overflows a peripheral lip on the lower wall of the tank. The 12-ft. (diam.) unit has a rated capacity of 150 to 200 t.p.h. of sand. Rough separations are claimed possible at any mesh between 20 and 100, and it is asserted that the machine may be operated to deliver a sand product containing not more than 1 to 5% <100-m. fines. Moisture content of sand is higher than that obtained in drags and mechanical classifiers.

Hindered-settling hydraulic classifiers are used both for making multiple splits of industrial sands at meshes from 10 to 100, and also for desliming. Multiple-spigot machines, usually of the automatic-discharge type (Sec. 8, Art. 11), are used in grading service (Sec. 3) and for concentration (Table 5); hydro-bowls (Sec. 8, Art. 7) are used widely in desliming (Secs. 2, 3).

Performance of an 8-spigot automatic-discharge classifier making asphalt sand (*45 #7 RP 21*) is shown in Table 4. Further data on performances of such classifiers are given in Sec. 8, Tables 36 to 39.

Character of classifier-washed products. A hydraulic classifier puts together in the various spigot products the bulk of the equal-settling grains in the feed which are fairly presented to the spigot and capable of settling against the rising current therein, plus any more rapid-settling grains carried past the preceding spigots and now fairly presented, plus some grains too small to settle normally against the nominal rising current in the spigot, but which settle nevertheless because of entanglement in a crowded mass of heavier

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Table 4. Sizing tests of feed and products of an 8-spigot automatic-discharge hindered-settling classifier on a single-gravity natural sand

Screen, mesh	Weight retained, %								
	Feed	Spigot No. [a]							
		1	2	3	4	5	6	7	8
>8	0.7	8.5	0.5	......	......	......	......	......	......
10	1.5	12.8	1.1	0.1	......	......	......	......	......
16	6.2	50.6	20.4	3.1	0.2	0.1	0.1	......	......
20	5.2	22.5	37.2	13.8	2.2	9.8	0.3	0.2	0.1
30	9.8	4.5	38.1	42.9	22.1	19.0	1.9	0.2	0.1
40	19.9	0.4	2.2	36.2	59.4	61.4	28.4	10.5	0.6
50	22.2	0.2	0.1	1.3	14.8	18.0	59.3	67.1	23.4
80	14.3	0.1	0.1	1.9	0.2	0.1	8.9	18.1	65.6
100	7.4	0.2	0.1	0.5	0.7	0.4	0.9	3.5	9.1
200	9.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	1.0
<200	3.6	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1

[a] Overflow not sampled.

grains, or because of eddies in the sorting column. This distribution for a single-gravity feed to an 8-spigot hindered-settling classifier is shown in Fig. 16. For any given mesh size, grains of that size appear in a number of spigot products. Thus there are 28-m. grains in all spigot products; material amounts in *2* to *6*, some 4 or 5% in spigot *1*, and fractional percentages in the others. There are even fractional percentages of 200-m. reported in all, but this is probably due to abrasion in screening, at least in the coarser products.

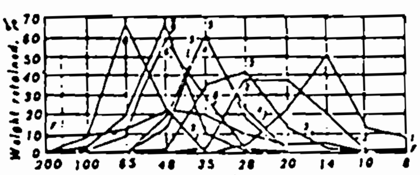

Fig. 16. Size distribution by an 8-spigot Fahrenwald sizer treating a single-gravity feed.

The 28-m. grains in spigot *1* are largely accidental, carried down by eddying and entanglement, since the current in this spigot was set for a 14-in. split. Even so, they average the most nearly spherical 20-m. particles in the feed, plus a few particles of heavier impurity. The 28-m. grains in spigot *2* and a majority of those in spigot *3* are substantially equiaxed; there is no prominent shape difference between them, but close examination shows that those in spigot *3* are somewhat flatter than those in spigot *2*. The 28-m. grains in spigots *4* and *5* are definitely flattened and/or elongated. These two spigots (as was also true of spigots *6* and *7*) were set to substantially the same rising currents in order to take care of the large amounts of 35- and 48-m. sands in the feed, hence there is not a great deal of difference in shape as between the two. The 28-m. grains in spigots *6* and *7* are mostly thin conchoidal shell-like fragments. A similar variation in shape of the grains of a given mesh size in successive spigot products holds all along the line, and is characteristic of closely classified products.

When the material classified contains grains of two (only) specific gravities, sizing curves of the products, plotted as in Fig. 16, show two humps, separated by a valley that is more or less deep and broad according respectively to the efficiency of the classification and the difference between specific gravities. With respect to either mineral, however, overlapping occurs as with a one-mineral feed.

When the feed is a natural primary ore containing free grains of both minerals and middling grains of all intermediate specific gravities, the curves lose the peaked character of Fig. 16, and become broad rounded bumps with marked increase in overlap.

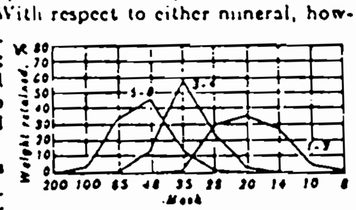

Fig. 17. Sizing tests of combined products of the classifier of Fig. 16.

If the number of spigots is decreased the magnitudes of the overlaps between successive spigots increases. Thus the products plotted in Fig. 17 were made by combining spigots *1* and *2*, *3* and *4*, and *5* to *8* of the products of Fig. 16 and dewatering, with a certain amount of fines rejection, in rake classifiers. Thus the *1–2* and *3–4* products of Fig. 17 both contain 25 to 30% of 28-m., and *3–4* and *5–8* both contain 30 to 35% of 40-m. Percentages of such magnitude go far toward setting the average sizes of the products of which they are parts.

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Table 8. Concentration of a wash iron ore in a Dorrco sizer (*after Dorr Co*).

Mesh	Feed		Spigot 1		Spigot 2		Spigot 3		Spigot 4		Spigot 5		Spigot 6		Overflow	
	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %	Wgt., %	Fe, %
6	11.4	59.8	43.7	61.8	16.7	58.0	...	...	...	...	...	...	...	...	...	...
8	11.8	58.5	31.9	62.3	26.7	59.8	8.8	50.2	...	...	...	...	...	...	...	...
10	8.9	59.4	14.9	62.3	22.5	60.5	11.6	54.2	...	...	...	...	...	...	...	...
14	8.4	55.7	6.3	64.1	18.3	62.0	19.2	56.2	...	...	...	...	...	...	...	...
20	8.3	58.7	...	...	10.6	63.6	26.3	60.9	14.7	43.5	...	...	...	...	...	...
28	11.3	57.3	...	...	...	...	25.2	64.3	33.0	56.9	...	...	...	...	...	...
35	13.0	56.7	...	...	...	...	...	...	41.1	62.7	13.8	35.2	14.8	27.1	...	...
48	9.7	56.2	...	...	...	...	...	...	...	...	35.6	50.8	26.0	39.9	...	...
65	5.4	57.6	...	...	...	...	...	...	...	...	36.5	62.0	22.8	53.5	...	...
100	2.8	57.8	...	...	...	...	...	...	...	...	...	...	14.9	54.7	...	...
150	1.3	47.3	...	...	...	...	...	...	...	...	...	...	7.4	46.1	...	...
200	1.3	35.4	...	...	...	...	...	...	...	...	...	...	7.4	33.8	...	...
<last	6.3	30.5	3.0	57.8	5.2	59.4	8.9	63.2	11.2	65.7	14.0	65.6	6.7	26.2	...	...
Totals	99.9	56.2	99.8	62.0	100.0	60.5	100.0	59.3	100.0	58.3	99.9	54.7	100.0	42.4	100.0	31.8
% Fe, cum.	56.2		62.0		61.3		60.7		60.2		59.7		57.7		31.8	
Recovery, cum. %	100.0		23.4		43.3		62.5		77.7		89.8		96.9		100.0	
Wgt. recovery, cum. %	100.0		21.2		39.7		58.0		72.7		85.0		94.5		100.0	

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Nonhydraulic classifiers making two products only, such as the sand tanks and mechanical classifiers, show even greater overlaps. Thus if such a classifier is run for, say, a 100-m. split with not over 2% of <100-m. in the sands, there will be considerable amounts of 48-m. and probably, even, some 35- or 28-m. material in the overflow. If, on the other hand, <100-m. overflow is the aim and not over 2% >100-m. therein is allowable, the sands will contain 20 to 50% of material finer than the separating mesh (see Sec. 8, Arts. 4 to 8). This explains the necessity of placing a hydro-bowl or other sand settler as a guard behind mechanical classifiers in sand plants when there is a deficit of fine sands, and the advisability of desliming ahead of the mechanical machines when clean sands are wanted.

8. MISCELLANEOUS SCRUBBING AND WASHING

Many problems encountered in beneficiating ores and industrial minerals by scrubbing and washing methods are not solved by the standard apparatus and methods previously discussed. For these cases appeal is usually had to standard ore-dressing machines of other types, or to simple modifications of these.

Clay balls are formed when tough clays, resistant to penetration by water, are tumbled. Such clay masses tend to float on the balance of the material in tumbling and not to be nipped and subjected to the disintegrating forces. A number of methods have been tried to deal with them, none too successfully. These include crushing in smooth rolls (*41 #8 RP 34*), in corrugated rolls, or in toothed rolls, in each case preferably operated with only one roll driven so as to subject the material to a tearing force; special three-roll machines in which adjacent roll faces move in opposite directions, designed to accentuate the tearing effect; impact mills of the hammer type; pug mills (*41 #8 RP 34*); soaking, usually accompanied by the use of monitors or a plurality of high-pressure jets; or, as an acknowledgement of failure, separation on a screen and discard, together with any and all of the wanted material that they may have rolled up in their travels. Such discard is usually economical when the concentrate has low unit value, *e.g.*, phosphates; it is certainly questionable when the concentrate is tin or gold. The nearest to a satisfactory solution reported is a hammer mill with a slow-moving breaker plate, independently driven (*34 #10 PQ 62*).

At Virginia Limestone Corp., Ripplemead, Va. (*43 #12 RP 26*), clay balls were disintegrated by passing the crushed stone, before final washing and sizing, through a 1,000-cyd. bin, 40 ft. deep, through which about 100 g.p.m. of water from washing screens trickled. The bin was kept reasonably full, and the pressure and working of the mass in moving toward the outlet, together with the water, were effective.

Unsound stone is ordinarily eliminated to a satisfactory extent by log washing or by light crushing and rescreening; if it is of sedimentary character, *i.e.*, shale or soft sandstone, which tends to form flat particles in gravels, it can be removed by jigging in the coarser sizes and tabling in the finer (*43 #1 RP 67*). These apparatus also float over chip stone, clay balls, and wood. Some decrease in the content of flat stone is also possible by rescreening over slotted screens, but the separation is relatively crude. Use of an impact crusher is reported (*44 #2 RP 40*) to have reduced rattler loss from 45% to 30 or 35% in one case.

Iron, if it is a problem at all, is usually a serious one because of low tolerances in specifications. Iron in glass sands, if in the form of metallic iron, or magnetite or ilmenite grains, is readily removed from dried sized sands by magnets; if the grades have been prepared by classification, the iron-bearing grains are usually sufficiently finer than the prevailing size to screen out. Hematite grains are usually removed by wet tabling, but dry tabling and electrostatic methods are both applicable. Iron-bearing incrustations can sometimes be reduced somewhat by vigorous scuffing, but are usually best removed by acid leaching and subsequent washing.

Dry scrubbing consists in tumbling material in a dry state, usually on a revolving screen.

At Granite Rock Co., Watsonville, Calif. (*43 #7 RP 33; ibid. #8, 22*), 1 @ 4×12- and 1 @ 4×10-ft. 2-deck vibrating screen were used for rescreening an average flow of 160 t.p.h. Newly crushed dry gravel sizes contained about 0.25% dust, but the fine sizes (1/2~1/4-in., 3/8~1/8-in., and 1/4~1/8-in.), when taken from stockpiles (which never dried out), contained up to 2.5% dust after rescreening. Substitution of wet washing brought the <200-m. in washed products down to a trace.

EXHIBIT "23ECH1" - Extract from "Handbook of Mineral Dressing" by A. F. Taggart

EXHIBIT "23ECH2" - Extract from Bulletin of the University of Minnesota- Mining Directory 1963 Issue 1963

BULLETIN of the UNIVERSITY OF MINNESOTA

Mining Directory Issue

Minnesota, 1963

By

MILDRED R. ALM

INSTITUTE OF TECHNOLOGY

A. F. SPILHAUS, Dean

SCHOOL OF MINES AND METALLURGY

MINES EXPERIMENT STATION

JAMES E. LAWVER, Director

EXHIBIT "23ECH2" - Extract from Bulletin of the University of Minnesota- Mining Directory 1963 Issue 1963

TABLE 8

LIST OF BENEFICIATION PLANTS ON MINNESOTA IRON RANGES—1963

Name of Plant	Superintendent	Company	Location	Type of Plant
		MESABI RANGE		
Arcturus	K. F. MacAlpine	Oliver Iron Mining Div.	Marble	Washing, Hi-d, Spirals, Cyclones
Babbitt (Inactive)	———	Reserve Mining Co.	Babbitt	Taconite Concentration
Bennett	C. E. Lerick	Pickands, Mather & Co.	Keewatin	Crushing, Washing, Hi-density
Canisteo	W. M. LeClair	The Cleveland-Cliffs Iron Co.	Coleraine	Washing and Hi-density
Canisteo Fines	W. M. LeClair	The Cleveland-Cliffs Iron Co.	Coleraine	Fines treatment
Coons-Pacific	Jack Durham	Coons-Pacific Co.	Clinton	Crush'g, Wash'g, Jigg'g, Hi-density
Danube	L. M. Becker	Pickands Mather & Co.	Bovey	Crush'g, Wash'g, Jigg'g, Hi-density
E. W. Davis Works	J. Reynolds-D. Cooksey	Reserve Mining Co.	Silver Bay	Taconite Concentration
Duncan	L. T. Kreuz	Douglas Mining Co.	Chisholm	Washing, Hi-density, Cyclone
Embarrass	H. J. Stetson	Pickands Mather & Co.	Biwabik	Crushing
Erie Prel. (Inactive)	———	Pickands Mather & Co.	Aurora	Taconite Concentration
Extaca	M. E. Johnson	Oliver Iron Mining Div.	Virginia	Taconite Agglomerating
Hanna Pilot	W. T. Rule	Butler Bros.	Cooley	Wash, Hi-d, Mag.Roast, Mag.Sep
Harrison	L. D. Clover	Butler Bros.	Cooley	Wash'g, Hi-d, Cyclone, Spirals
Harrison B	L. D. Clover	Butler Bros.	Cooley	Fines Treatment (Spirals)
Hawkins Fines	———	International Harvester Co.	Nashwauk	Fines treatment
Hill Annex	J. A. Strande	Jones & Laughlin Steel Corp.	Calumet	Cr'g, Scr'g, Wash'g, Hi-d, Spirals
Hill Annex	J. A. Strande	Jones & Laughlin Steel Corp.	Calumet	Semi-taconite (Grinding, Spirals)
Hill Annex	J. A. Strande	Jones & Laughlin Steel Corp.	Calumet	Fines treatment (Spirals, [illegible])
Hill-Trumbull	R. B. Pearson	The Mesaba-Cliffs Mining Co.	Marble	Washing and Hi-density
Holman-Cliffs	R. B. Pearson	The Mesaba-Cliffs Mining Co.	Taconite	Washing and Hi-density

TABLE 8—(Continued)

LIST OF BENEFICIATION PLANTS ON THE MINNESOTA IRON RANGES—(Continued)

Name of Plant	Superintendent	Company	Location	Type of Plant
		MESABI RANGE—(Continued)		
Hoyt Lakes	J. H. Healy	Pickands Mather & Co.	Aurora	Taconite Concentration
Hull-Rust (Inactive)	———	Oliver Iron Mining Div.	Hibbing	Crush'g, Screen'g, Wash'g, Hi-d
Hunner	A. C. Nelson	Hanna Iron Ore Div.	Coleraine	Wash'g, Hi-d, Spirals, Cyclones
Jessie	L. R. Sewell	Jessie H. Mining Co.	Coleraine	Washing
Julia	Roy Amundson	Pittsburgh Pacific Co.	Virginia	Washing and Hi-density
Lind-Greenway	A. E. Seaberg	Jones & Laughlin Steel Corp.	Gr. Rapids	Cr'g, Scr'g, Wash'g, Jigg'g, Hi-d
Longyear	W. Ball	Jones & Laughlin Steel Corp.	Hibbing	Crushing, Screening, Washing
Mahoning	E. R. Tyler	Pickands Mather & Co.	Hibbing	Crushing, Washing, Hi-density
Mariska	Wm. Kinnunen	W. S. Moore Co.	Gilbert	Cr'g, Wash'g, Jigg'g, Hi-d, Spirals
Mary Ellen	———	Pittsburgh Pacific Co.	Biwabik	Washing and Hi-density
Meadow	Frank Grebene	Pittsburgh Pacific Co.	Aurora	Crushing, Screening, Washing
Mesabi Chief	R. M. Cross	Hanna Ore Mining Co.	Keewatin	Washing, Hi-density, Hydrosizer
Morton	L. J. Morgan	Morton Ore Co.	Hibbing	Washing
North Uno	L. J. Morgan	Hanna Ore Mining Co.	Hibbing	Crushing
Patrick A	L. D. Clover	Butler Bros.	Cooley	Washing, Hi-density, Spirals
Pierce	L. M. Bredvold	Hanna Ore Mining Co.	Hibbing	Wash'g, Hi-d, Spirals, Cyclones
Pilotac	D. Hartley	Oliver Iron Mining Div.	Mt'n Iron	Taconite Concentration
Plummer	K. F. MacAlpine	Oliver Iron Mining Div.	Coleraine	Washing, Spirals, Cyclones
Rouchleau	M. E. Johnson	Oliver Iron Mining Div.	Virginia	Crushing, Screening, Sizing
St. Paul	———	Pacific Isle Mining Co.	Keewatin	Crush'g, Wash'g, Hydro., Spirals
Schley	A. W. McWilliams	Jones & Laughlin Steel Corp.	Gilbert	Cr'g, Scr'g, Wash'g, Spirals
Scranton	———	W. S. Moore Co.	Hibbing	Crushing and Washing
Security	T. Hartikka	Rhude & Fryberger, Inc.	Eveleth	Drying

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TABLE 8—(Continued)

LIST OF BENEFICIATION PLANTS ON THE MINNESOTA IRON RANGES—(Continued)

Name of Plant	Superintendent	Company	Location	Type of Plant
		MESABI RANGE—(Continued)		
Sherman	N. G. Helland	Oliver Iron Mining Div.	Chisholm	Crush'g,Scr'g,Wash'g,Hi-d,Spirals
South Agnew	L. J. Morgan	South Agnew Mining Co.	Hibbing	Washing
Stephens	I. H. Rubow	Oliver Iron Mining Div.	Aurora	Crushing, Screening, Sizing
Susquehanna	S. V. Smith	Susquehanna Ore Co.	Hibbing	Crushing and Screening
Trout Lake (Inactive)	———	Oliver Iron Mining Div.	Coleraine	Washing, Hi-d, Spirals, Cyclones
Troy	H. Swartout	Rhude & Fryberger, Inc.	Eveleth	Washing, Jigging, Hi-density
Uno	———	Pacific Isle Mining Co.	Hibbing	Crushing and Screening
Virginia	Frank Skubic	Edwards Mining & Milling Co.	Eveleth	Crush'g,Scr'g,Jigg'g,Hi-d,Spirals
Wacootah	R. J. Lacke	Pacific Isle Mining Co.	Mt'n Iron	Crushing and Screening
Wanless	———	The Cleveland-Cliffs Iron Co.	Buhl	Crushing
Webb	T. J. Barker	Snyder Mining Co.	Hibbing	Washing
Webb	T. J. Barker	Snyder Mining Co.	Hibbing	Crushing and Screening
Weggum	L. M. Bredvold	Philbin Mining Co.	Hibbing	Washing
West Hill	L. M. Becker	Pickands Mather & Co.	Coleraine	Crushing, Washing, Hi-density
Whiteside	T. J. Barker	Snyder Mining Co.	Buhl	Crushing and Screening
		VERMILION RANGE		
Pioneer	F. D. Hoover	Oliver Iron Mining Div.	Ely	Screening and Washing

TABLE 8—(Continued)

LIST OF BENEFICIATION PLANTS ON THE MINNESOTA IRON RANGES—(Continued)

Name of Plant	Superintendent	Company	Location	Type of Plant
		CUYUNA RANGE		
Huntington	J. A. Gemert	The Hanna Mining Co.	Ironton	Crushing
Manuel	———	Pittsburgh Pacific Co.	Crosby	Crushing, Screening, Washing
Maroco	J. A. Gemert	The Hanna Mining Co.	Trommald	Wash'g, Hi-d, Cyclones
Portsmouth	J. A. Gemert	Hanna Iron Ore Div.	Crosby	Washing, Screening, Sintering
Rabbit Lake	L. M. Becker	Pickands Mather & Co.	Cuyuna	Crushing
Virginia	———	Pittsburgh Pacific Co.	Ironton	Wash'g,Jigg'g,Hi-density,Cyclone
		FILLMORE COUNTY		
Hadland	C. A. Pedersen	The Hanna Mining Co.	Ostrander	Washing
Schroeder	I. Nading	Schroeder Mining Co.	Chatfield	Washing

Note: The above list does not include a number of crushing and screening plants of small size or of a temporary nature.

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EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

UNITED NATIONS

ECONOMIC ASPECTS OF IRON-ORE PREPARATION

Prepared by the
SECRETARIAT OF THE
ECONOMIC COMMISSION FOR EUROPE

GENEVA, 1966

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Sweden

United States of America

The following symbols have been used throughout the present study:

.. = figure not available
— = nil or negligible quantity
* = secretariat estimate
N. A. = not applicable

Unless otherwise specified, tonnages are in metric tons.

NOTE ON TERMINOLOGY AND SOURCES

In this relatively young industry, a world-wide terminology has not yet had time to establish itself and the same terms can have a slightly different meaning from one country to another.

In the present study, including the contributions by countries, the terms used have the following meaning:

By "preparation" is meant the total of all processes which may be applied to a run of mine ore in order to render it suitable for the blast furnace. In some cases this term may cover only crushing and screening, or hand sorting, whilst in others it may include roasting, blending and any processes of concentration and agglomeration which may have to be used.

The term "ore dressing" is used synonymously with the term "ore preparation".

"Concentration" covers all processes which will increase the iron content of the ore, i.e. "upgrade" the ore, and eliminate some of the undesirable elements. It does not apply to such very simple processes as the screening out of fine materials from a run of mine ore. It is generally achieved through the "separation" of the undesirable elements out of the ore by means of "separators" or

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"concentrators" from which a "concentrate" of purified and "upgraded" ore is recovered and the waste material is eliminated as "tailings". It can also be achieved in "flotation cells", "jigs" and by various other methods.

The first stage of concentration, which gives only a rough, impure, product, is sometimes termed "cobbing".

"Agglomeration" covers those processes—sintering, pelletizing, briquetting—which, by or with the application of heat, transform ore fines or concentrates unsuitable for use in the blast furnace in their natural state because of the small size of the constituent particles, into a product in which these particles have been bonded or fused together into increments of a suitable size.

In the pelletizing process, the application of great heat is termed "firing" or "burning", and during this stage the pellets are "sintered", this should not be confused with the distinct process of "sintering" as applied directly to ore fines.

"Beneficiation" is a general term which covers both "concentration" and "agglomeration", taken separately or together as the case may be for a given ore.

One of the first processes of "ore preparation" or of "ore dressing" prior to or concurrent with "beneficiation" is "comminution", which comprises "crushing" or breaking the ore to a coarse size, and "grinding" or "milling" to reduce the ore to a fine powder.

This operation is usually combined with a division of the ore into a range of lump sizes. This is termed "grading" or "sizing" the ore, and is frequently achieved by the use of a screen, or of a succession of screens, in which case the process is termed "screening".

Frequently, the crushed ore, generally after "grading", undergoes a process of "homogenization" prior to further "beneficiation" or to its use in the blast furnace. This is done to eliminate any irregularities in the physical and chemical composition of the ore, and frequently to mix this ore with other ores or other materials which it may be found desirable to add. This "homogenization" is termed "blending" and is often carried out with special "bedding" or "layering" equipment, in which case the ore is said to have been "bedded" or "layered".

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Apart from current technical literature, an important source of information for the present study was constituted by material submitted in response to a questionnaire which was sent by the secretariat of the Economic Commission for Europe, in April 1963, to all Governments participating in the work of the Commission. Material and information were also kindly communicated by the Governments of Australia, Canada, India and Japan and by the secretariats of the regional economic commissions for Africa, Asia and the Far East and Latin America. Unless otherwise indicated, the country reviews in part II of the study are based on the material communicated by Governments in response to the questionnaire.

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The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of the frontiers of any country or territory.

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CHAPTER II

Methods of iron-ore preparation

As has been said in chapter I, the reasons for preparing iron ore for use in the blast-furnace may be summarized as follows:

(*a*) To improve the physical and mechanical properties of the ore, by crushing and screening it, and to remove the fines;

(*b*) To obtain an ore which is uniform in its chemical composition, especially as regards the content of iron and of the main slag-forming components;

(*c*) To raise the iron content, i.e. to obtain "concentrates" rich in iron; to remove the impurities, and in some cases to recover valuable components of the ore other than iron;

(*d*) To agglomerate the fines or concentrates.

Ore preparation may aim at one or more of the above objectives.

This chapter gives a description of the different methods of iron-ore preparation as follows:

— crushing, grinding and screening;
— blending;
— concentration methods;
— agglomeration.

Examples of the application of the above methods to various types of ore are also given.

SECTION 1—CRUSHING, GRINDING AND SCREENING

Ore is prepared for concentration by crushing, grinding and screening.

Crushing can be either a basic or a preparatory operation.

It is a basic operation when the crushed ore does not undergo concentration and is merely crushed to produce a lumpy product of the optimum size. One unavoidable drawback of the operation is the formation of fines (−8 or −6 mm) which are unsuitable for direct use in the blast-furnace and have to be agglomerated.

The optimum size of ore prepared for the blast-furnace depends on its density and reducibility. It tends to be higher for porous ores which are easily reducible, and lower for close-grained ores which are difficult to reduce. The optimum size for brown hematite blast-furnace ores is about 20-100 mm, and for magnetite ores 10-50 mm. For high-grade steelmaking ores it is 20-40 mm.

Crushing is used as a preparatory operation in the case of compact ores requiring further treatment.

The final size to which the ore will have to be crushed depends on the grain size of the constituent minerals and on the qualities demanded of the concentrate. The finer the ore is crushed, the more completely the ore grains will be separated from the waste rock and the richer the concentrates obtained will be.

The smallest lump size obtainable with existing crushers varies between 20 and 15 mm; but the only ores which can be effectively beneficiated at this size are some coarse-grained and relatively high-grade ores. In a few cases, ores crushed to 20 mm can undergo preliminary concentration; but in most cases concentration to produce a rich product with a high metal recovery cannot be undertaken until the ore has been reduced to a size of less than 1 mm, or sometimes (in the case of fine-grained quartzites, for instance) to 0.1 mm or smaller. In these cases, crushing is followed by grinding.

Crushing and fine grinding consume a great deal of energy and are expensive. For fine-grained ores, expenditure on crushing and grinding may amount to as much as 70% of the total expenditure on the whole preparation cycle. It is always essential, therefore, never to overgrind the ore and to extract the tailings or the finished concentrates as soon as they can be separated at each successive stage of the process.

The maximum lump size of mined ore varies considerably. The usual range in a mechanized mine is 0.9-1.2 m for open-pit operations and 0.4 to 1.2 m for underground mining.

Modern ore crushers are designed to deal with lumps of this size; but for most crushers the extent to which the size of the ore can be reduced—that is, the difference between the maximum size of the mined ore and that of the largest pieces of the crushed product—is fairly small. Crushers can only reduce the lumps to a quarter or an eighth of their original size, or, in the case of soft ores, to a tenth by using hammer crushers. The ore may therefore have to be crushed in several stages. Multi-stage crushing has the advantage of producing a smaller proportion of fines.

The number of stages which will be required depends on the maximum size of the ore as mined, on the size required for the crushed product, and on the physical properties of the ore, hardness, moisture content, clay content, etc.

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When a crushed product of −25 or −20 mm is required, hard ores have to be crushed in three or four stages. Four-stage crushing may be necessary for extremely hard ores, especially for those which tend to form lumps in the shape of flagstones.

Hard ores are generally crushed in gyratory or jaw-crushers. Softer ores, for instance brown hematites, can be crushed with impact-type crushers. Crushers of this kind are common in France and in Western Germany.

There are two methods of grinding ore, wet and dry.

Wet grinding is used in the vast majority of cases because of lower energy consumption, the absence of dust and the convenience of transporting the product after it is ground. It is also used for very damp raw materials or when it is followed by wet concentration.

Dry grinding is used in conjunction with dry concentration. The consumption of metal per ton of ore ground is lower in dry grinding than in wet.

The commonest type of grinding mill is the tube mill, in which the ore is ground by steel rods or balls. In recent years, however, there has been an increasing tendency to use autogenous mills, in which large lumps of the ore itself are used as grinding elements. The advantages of this latter type of mill include the much lower specific consumption of metal per ton of ore ground and in some cases a certain selectivity in the grinding process. The risk of the ore grains being crushed as they are disengaged and exposed is less than it is in the conventional mill. It thus diminishes the risk of overgrinding the ore grains, which can have an adverse effect on further beneficiation.

The optimum size of crushed ore fed to a tube mill is 15-20 mm, and to autogenous mills 250-300 mm.

In tube mills the ore can be ground in one or more stages. Single-stage grinding is rare, and is only used for ores which can be adequately concentrated at a size of 1-2 mm.

When a finer product is required, multi-stage grinding is used. The advantages of this procedure compared with single-stage grinding are, firstly, that the proportion of material overground is smaller, energy consumption is lower and there is less wastage in the form of tailings which are unsuitable for beneficiation, and secondly that it is often possible to combine multi-stage grinding with certain other intermediate operations and to extract some of the tailings or of the finished concentrates from the grinding circuit.

The number of times the ore is ground depends on the size of the material at which the first stages of beneficiation can be undertaken, and also on the size of the final product at which the ore grains are sufficiently liberated and a concentrate of the required quality can be obtained. It also depends to a certain extent on the hardness of the ores. In practice, compact ores (magnetites and hematites) are usually ground in two, three or even four stages.

In multi-stage grinding, rod mills are generally used for the first stage and ball mills for the subsequent stages.

To ensure that the product is uniform in size and that none of it is overground, the mills usually operate in a closed circuit with size-grading equipment (screens, classifiers or hydro-cyclones). This extracts the material which has been sufficiently ground whilst material requiring further grinding is returned to the mill.

One exception is the rod mill, which is often operated in open circuit.

Autogenous mills always operate in closed circuit—wet mills with screens, and dry mills with pneumatic separators.

Section 2—Blending

The purpose of blending ores is to ensure that the ore component of the blast-furnace burden is uniform in its chemical composition, and to prevent fluctuations in the composition of ores intended for further concentration or agglomeration.

Ores can be blended to ensure a uniform content of one or of several components, iron, sulphur, lime, etc.

Another object of blending, for ores containing several minerals which have to be beneficiated in a multi-stage flowsheet, is to even out variations in the ratio in which the different components (such as magnetite and hematite) are present, and thus to level off the load on the various kinds of equipment used in the beneficiation process.

The need for blending and the extent to which it has to be carried out depend, on the one hand, on the composition and natural properties of the ore in question and on the methods used to extract it, and, on the other hand, on the maximum permissible variations in the composition of the prepared ore as required for further beneficiation or for smelting.

Ore can be blended during mining or during the preparation process.

During mining it is blended by mixing the output from different workings containing ores of different compositions.

In the preparation process, it can be blended:

(*a*) Either by using the normal storage facilities (piles or bunkers) which are provided at the ore preparation plant or at the mine to level out the variations in the amount of feed and to distribute an even load throughout the plant as a whole or throughout its individual sections;

(*b*) Or by providing special blending piles or bunkers, equipped for mixing the ores. Such special piles can also be used as intermediate storage capacity.

Normal intermediate storage, such as piles or bunkers, to which the ore is delivered by belt conveyor and dump trucks and from which it is removed by gravity flow on to a conveyor is not very satisfactory for blending purposes, as the material passing through the pile or bunker is not properly mixed and there is no way of controlling the mixing process.

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When normal intermediate storage is used it is impossible to determine in advance how widely the amounts of the critical components present in the blended product may fluctuate.

Special blending piles are of two kinds. The simplest type is a pile to which the ore is fed by conveyor and from which it is removed by an excavator.

The efficiency of blending carried out in piles of this type depends largely on the differences in the external characteristics of the various ores received for blending. Given suitable conditions, this kind of blending can reduce variations in the iron content of the blended product to as little as ± 0.5%, starting from variations in the run of mine of 3 to 5% (in the Magnitogorsk combine in the USSR, for instance).

A more advanced type of blender is the Robins-Messiter storage yard which consists of an even number of piles with the ore delivered to each pair of piles by a conveyor equipped with a stacker—i.e. a mobile tripper fitted with short transverse conveyors which spread the material evenly over the top of the piles.

The ore is removed from the ends of the piles by travelling reclaimers which rake off the material evenly over the whole end of the pile and feed it onto a belt conveyor.

Whilst ore is fed to one pair of piles, blended ore is removed from the other pair.

Blending yards of this type are found at many plants. Such blending is highly efficient and can in theory be pursued to any extent. The greater the capacity of the individual piles, the more completely the ore can be blended.

Excellent results have also been obtained with the special ore-blending equipment which has been designed and installed at the Witkowice iron- and steel-works in Czechoslovakia, and it has been decided to install a similar unit—but with an even higher capacity—in the iron- and steel-works at Kuncice.

Good results have also been obtained at an ore-blending plant at Eagle Mountain in California where the crushed and screened ores are deposited on four piles with a combined weight of up to 1,000 tons, each of the piles containing up to 1,000 layers.

SECTION 3—CONCENTRATION

A. *General comments*

Concentration is a treatment aimed at obtaining a product (or products) considerably richer in useful constituents (in this instance iron) than run of mine ore.

Absolute concentration would result in a complete separation of the useful, i.e. metallurgically valuable, minerals contained in the ore from those which are useless or harmful.

Methods of ore concentration are based in practice upon the differences in the physical and physico-chemical properties of the ore minerals. Those most frequently used for iron ores are the specific weight and the magnetic and surface properties, which find their application in gravity concentration, magnetic separation and flotation.

The optimum concentration technique will be determined by the combination of all the properties of the ore, such as its mineral composition and distribution, grain size, hardness and other characteristics as well as by the characteristics required of the end product.

The over-all concentration process may comprise the use of one or of several concentration methods.

The final choice will be determined by an economic estimate of the various operations envisaged and of the corresponding improvements in the metallurgical values of the products.

Other factors which may have to be taken into account in the economic estimates of concentration are the possible cost of transportation per unit of iron over long distances and the possibilities of finding a local use for the waste products.

B. *Magnetic separation (or concentration)*

Magnetic concentration is of two kinds—first, concentration in low-intensity separators (500-1,200 oersteds) which are used for recovering highly magnetic minerals, i.e. for magnetite ores, and secondly, concentration in high-intensity separators (12,000-22,000 oersteds) to recover weakly magnetic minerals such as hematite, siderite and iron hydroxides.

(a) *Low-intensity magnetic separation*

Magnetic separation can be used both for lumpy material up to 60 mm and for fine-grained ores. The efficiency of the process depends on the magnetically recoverable iron content of the ore, on the size and distribution of the constituent minerals and on the quality of the product it is desired to obtain.

Magnetite ores can be concentrated by a number of different single- and multi-stage processes, in which concentration is combined with crushing, grinding and screening. The choice of the process and the number of stages will depend on the nature of the ore, and on the qualities required of the concentrate.

The maximum iron content which it is technically possible to achieve in magnetite concentration depends not only on technical improvements or on the qualities required of the end product, but also on the composition of the magnetite itself. The iron content of magnetite rarely reaches the theoretical figure of 72.4%, because the natural mineral usually contains a certain amount of isomorphous admixtures—normally Mg and Ti—which cannot be separated from the ore by concentration. In many ores, moreover, the magnetite has already

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undergone partial oxidation (martitization). Consequently, even if a technically perfect process were feasible and the magnetite grains were completely liberated so that the concentrates did not contain a particle of waste, the iron content of the concentrate would still be lower than 72.4%.

In order to reduce the cost of crushing and grinding, magnetic separation is usually applied as soon as the ores have been reduced to a size at which usable concentrates or tailings can be extracted from them.

Ores above 6 mm can be concentrated only by dry magnetic separation. Ores from 6 to 0.1 mm can be concentrated by either dry or wet magnetic separation. Ores below 0.1 mm can only be concentrated by wet magnetic separation.

Dry magnetic separation can only be used when the ore has a low moisture content and when it does not contain any argillaceous or viscous substances.

Dry magnetic separators work more efficiently if the material fed to them is already screened. With lumpy ores, the material should first be graded as closely as possible—for example, 40-20 mm, 20-6 mm, etc.

Wet magnetic separation has the following advantages: the products obtained from wet grinding can be fed directly to the separators; separator capacity is high; the initial feed is easy to distribute and the products are easy to collect and transport; sampling of the initial, intermediate and final products is also a simple operation.

The main advantage of dry magnetic separation, compared with the wet separation process, is that the concentrates obtainable from fine-grained (−0.1 mm) material are somewhat richer. The disadvantages of dry magnetic separation include the need to pre-dry the material, the difficulty of distributing the feed, particularly when several machines are installed in parallel, and the need for dust control.

Many concentration plants use wet magnetic separation for ores smaller than 6 mm. Dry methods are occasionally used to complete the concentration obtained by wet separation; but a major Canadian plant with a capacity of 5.5 million tons of fine high-grade concentrates a year commenced production in 1964, using spirals and electrostatic separators in preference to wet magnetic separation.

Wet magnetic separation is usually carried out in drum separators, which are either electro-magnetic or fitted with permanent magnets. Separators with two drums or more—enabling a number of successive operations to be carried out on the same machine—are now fairly common.

Usual flowsheets used on magnetite ores are the following:

(i) Dry magnetic separation of lumpy ore (+5 mm) to produce concentrates and tailings, without concentration of the fines (−6 mm);

(ii) The same as (i), but with wet magnetic concentration of the fines;

(iii) Dry magnetic separation of the lumpy ore, with the waste tailings (and sometimes the concentrates) and the intermediate product removed for concentration at a later stage by wet magnetic separation, after further grinding;

(iv) Wet magnetic separation of the whole ore, after crushing and grinding (i.e. −5 mm and smaller);

(v) The same as (iii) and (iv), but with the wet separation concentrates further treated, after drying, by dry magnetic separation;

(vi) Spirals and electrostatic separators.

Flowsheets of types (i) and (ii) are used for relatively high-grade, fine-grained ores. Type (i) flowsheets are very simple to set up and equip, but they have a disadvantage in that the iron content of the unconcentrated fines is at most only slightly higher (not more than 1 to 3%) than that of the mined ore. They are therefore used rather infrequently—usually only as a temporary measure when a new plant is just coming into operation. At a later stage, the fines are concentrated and the type (i) is converted into a type (ii) flowsheet.

Type (iii) flowsheets are often used for concentrating ores of irregular structure. This type of flowsheet is used at the Malmberget concentrating plant (Sweden). Type (iv) flowsheets are used for all fine and evenly grained ores, particularly magnetite quartzites (taconites). Grinding and concentration are usually carried out in two or three—sometimes four—stages, depending on the hardness of the ore and the type of mineralization. Rod mills are normally used for the first stage of grinding. Some examples of plants using type (iv) flowsheets are Silver Bay and Hoyt Lake—the largest plants in the United States—the plants operated by the Southern Mining and Beneficiation Combine and the New Krivoi Rog Combine for treating quartzitic ores from Krivoi Rog in the USSR, and the Sydvaranger plant in Norway.

Other processes occasionally used for magnetite ores in conjunction with magnetic separation, include deslurrying of the comminuted ore to remove the very small size fractions (10-20 microns and less) which are often low in iron. In other cases, the magnetic separation concentrates are recleaned by flotation to produce a particularly high-grade product with an iron content of more than 67%. This treatment is also applied to remove the apatite which is present in certain ores. For the same reason, but only in cases where an exceptionally high grade (more than 70% Fe) and phosphorus-free product is required, the concentrates are further treated in a solution of nitric acid. This method is used at the Grängesberg beneficiation plant, in Sweden, to produce a concentrate containing 71.3-71.5% Fe and less than 0.01% P.

(b) *High-intensity magnetic separation*

Industrial applications of this method are at present limited to ores which have been thoroughly dried; the possibilities of treating wet ores are being investigated

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The maximum acceptable size of the mineral grains is 3 mm. If the material contains over 50% of grains below 40 microns difficulties occur, owing to adhesion between the various mineral grains.

This method requires the use of very powerful electromagnets. The capacity of each separator is 2 tons of feed per hour for limonitic ores, rising to 6 tons per hour for specularite.

C. *Gravity methods*

Methods of gravity concentration commonly used on iron ores comprise jigging, heavy-media separation and tables. In recent years, too, concentration in spiral separators has been more and more widely practised.

(a) *Heavy media*

In this method the crushed ore is passed through a liquid with a specific gravity intermediate between that of the lumps or grains rich in iron and that of the lumps or grains in which waste predominates. It can only work with grains above 2 mm in size, but preferably above 4 mm.

The heavy-media liquid is a suspension of finely powdered ferrosilicon or magnetite in water; the media is kept from settling by the action of the circulating pump. Waste is eliminated as an overflow, whilst the concentrate is collected as an underflow. The concentrates and waste are then washed to recover the media which they have carried away with them.

Very high outputs can be achieved by this method.

(b) *Jigging*

In this method the feed is classified vertically, according to the weight of the individual grains and other physical factors. The weight of each grain is dependent on its specific gravity and its size; for the method to work properly, the feed must therefore be sized between very narrow limits. The classification is achieved by putting the feed into motion in water.

Very many kinds of jig are in existence, adapted to take different sizes and different types of ore. The output of an individual jig is always very low.

(c) *Tables*

This method is now little used in the concentration of iron ores. It is generally applied to the recleaning of very fine concentrates.

The investment and operating costs are high; the output of each table is very low.

(d) *Spirals*

This process has been widely applied to iron ores only in recent years. It is now becoming more and more popular.

The initial investment is high because the output of each individual spiral is low, and because the desired concentration can only be achieved in several stages; but operating costs are low because no power is required and maintenance is small.

The best size range for treatment by this method is between 0.1 and 1.5 mm.

D. *Flotation*

Till recently, concentration by flotation has been used much more rarely than other methods, sometimes as a basic, sometimes as an auxiliary, process; but there are grounds for believing that, with the present tendency to subject the ore to several stages of concentration in order to obtain a high-quality product, flotation methods will be adopted more extensively, particularly for fine-grained hematites and mixed ores.

The present situation and prospects regarding iron-ore flotation have recently been described and discussed in the West German technical press.[1] Detailed information is provided on the various flotation reagents used, and on the particular features of this technique. It is stated that the only countries where iron-ore flotation is now widely practised are China (mainland), the USSR, and the United States of America, and that the annual output of concentrates obtained by this method is about 4.5 million tons. The fine flotation concentrates are pelletized, but in some cases they have to be previously reground because the reagents used are liable to modify their surface tension.

In the present stage of development of this process, both direct and reverse flotation are used. Direct flotation has been used for the recovery of ore contained in magnetic separation tailings, and reverse flotation for the final treatment of magnetic concentrates. The concentration flowsheets used with direct flotation usually include two to four re-washings of the concentrates, whilst two to three re-washings of the froth product are carried out with reverse flotation.

In some areas the only water available is highly mineralized, and this must be taken into account in selecting the flotation reagents.

Talloil is the most common reagent used in the direct flotation of iron. Recently this reagent has been mixed with sundry surface-active substances, such as fatty acids of various molecular weights and structures, high-molecular spirits, alkylsulphides, etc. Such additives are very effective in hard-water flotation, which must be carried out in a weakly acid medium ($pH = 6.5$) obtained by the introduction of sulphuric acid or sodium fluosilicate.

When water with a low mineral content is used, the ores from many deposits can be satisfactorily floated in either a weakly acid or a weakly alkaline medium. In the latter case, sodium carbonate must be added.

In recent years new reagents have been used, such as the heavy fraction of ligneous tar from gas producers,

[1] Burghardt Otmar: *Stand und Aussichten der Eisenerzflotation* Iron-ore flotation: situation and prospects), *Erzbergbau und Metallhuttenwesen* 1964, No. 4, 173-180.

EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

and various products containing fatty acids, such as fish fat or synthetic fatty acid distillation residues, etc.

For reverse flotation, talloil or cationic reagents are used as collectors.

The economic advantages derived from the flotation of magnetic tailings are shown by the following examples:

(*a*) Flotation used for extracting the hematite from magnetic tailings in concentration plants at Gubkin, one of the main deposits on the Kursk magnetic anomaly, gave the following results: The Fe content of the magnetic tailings was reduced from 14-16% to 9-10%. The iron recovery in the concentrate was increased by 6-8%, for the same quality of concentrate; and the cost of the concentrate was reduced by 20-25%.

(*b*) The flotation of magnetic tailings in the experimental section of one of the Krivoi Rog plants gave additional flotation concentrates at half the cost of the magnetic re-concentrates.

(*c*) Similar results have been achieved on non-magnetic tailings at various other plants.

Flotation concentrates with a 68-70% Fe content can be obtained from various magnetic concentrates containing 60-64% Fe.

E. *Other processes of concentration*

Washing

Certain natural ores can be enriched by simple washing, which removes soft clay, sandy material and fines in the stream of water.

Roasting

Roasting is used separately only on rare occasions, for ores such as siderites or brown hematites which do not require true concentration but which contain a considerable amount of volatile substances (CO_2 and H_2O) which are thus driven off. It is done in shaft furnaces, grates and rotary kilns. Roasting is also used in combination with other concentration methods.

It is extensively used to recover the sulphur from pyrites.

Magnetizing roasting

The magnetizing roasting process consists in the reduction of the ore to magnetite at high temperature (600-800 °C), followed by low-intensity magnetic separation. It was first suggested for the concentration of weakly magnetic ores more than forty years ago. In the post-war years cheaper methods were preferred but this method is now the object of further studies.

Magnetizing roasting has great advantages, owing to its universality and high technical efficiency, but it is costly. It is applied on an industrial scale at Krivoi Rog, using rotary kilns.

Efforts to reduce the cost of the process have borne mainly on ways of roasting the ore in a fluidized bed using a cheap fuel such as natural gas. When this method has been perfected, the furnaces (reactors) will be less bulky and will have a higher capacity than the rotary kilns, and specific fuel consumption should be lower.

F. *Electrostatic separation (or concentration)*

Till recently, electrostatic concentration has not been used to any great extent for iron ores; but a new Canadian plant has now introduced this method to refine spirals concentrates.

It has also been used as a preparatory step prior to magnetic separation in order to remove the dust and to classify the material after dry-grinding.

The development of electrostatic separation has been hampered by the high voltages required at the electrodes (35-80 kV) and by the low capacity of the individual separators.

The electrostatic separators most commonly used at present are the crown-type drum and chamber units, which can be used for concentrating, classifying or de-dusting various ores.

Crown-type drum separators can be used for concentrating fine-grained and lean magnetic and non-magnetic iron ores which contain both conducting ore minerals such as magnetite, hematite and martite and non-conducting minerals such as quartz, etc.

The electrostatic separation process does not depend on the magnetic properties of the ore minerals, and only requires relatively low-temperature drying (compared with the high-temperature treatment necessary for magnetizing roasting).

Electrostatic separation extracts all the iron minerals from the ore as one concentrate, which distinguishes it from other concentration methods. Furthermore, it eliminates from the concentrate harmful minerals such as apatite, biotite, hypersthene, etc.

Electrostatic separation of quartzites from the Olyenegorsk deposits, ground to a size of 0.074-0.15 mm, has produced concentrates containing 68.6% Fe and tailings containing 6.8% Fe from an ore containing 38.5% Fe; it has also produced rich super concentrates containing 68.8% Fe from concentrates containing 60% Fe from the Olyenegorsk beneficiation combine.

Ore concentrates at 69.4% Fe have been economically obtained by electrostatic separation from ore of the Grensberg deposits in Canada, containing 55% Fe and ground to a size of 0.075-0.3 mm.

In the case of ores whose fines fraction is richer in iron than the run of mine, rich concentrates can be obtained by separating these fractions in crown-type chamber separators.

The combination of electrostatic and magnetic separation usually improves the efficiency of both processes. To give an example, when iron-ore fines are concentrated by combining electrostatic screening with magnetic separation, the concentrates obtained are 5-6% richer in Fe, and the tailings contain 5-13% less Fe, than when magnetic separation is used alone.

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Chapter III

Economic efficiency of various methods of preparing iron ores for smelting

Preparation of the blast-furnace burden, and particularly of its ore component, has had, at every stage of its development, a considerable effect on the technical and economic results of blast-furnace operation; each new advance in preparation methods, in the widest sense of this term, has been accompanied by improvements in blast-furnace performance.

The following economic evaluation of the iron-ore preparation methods which are used on a wide scale has been compiled in the light of the present situation and of the data supplied by various countries. The economy of certain competing techniques, such as sintering and pelletizing, is compared, and some methods of determining the metallurgical value of iron ores are given.

The economic efficiency of iron-ore preparation for smelting is assessed by the savings achieved during the reduction process, excluding the preparation costs but including the differences in transport costs. The estimates which follow are therefore given both in terms of the actual preparation costs (crushing, grading, blending, concentration and agglomeration) and in terms of the resultant savings achieved during the reduction process.

Blast-furnace efficiency is generally increased both through better ore preparation and through improvements in the blast-furnace process; not only do these two factors complement one another, but they must often be combined to give good results. It is often difficult to determine the extent to which each of these factors has influenced the end result. The efficiency of ore preparation methods must therefore be estimated on the basis of data obtained from various studies and special calculations, and this is the approach that has been used here. As differences in price structures and currency units of various countries make it difficult to compare costs, the efficiency of the different preparation methods is expressed, wherever possible, in natural or relative values; only in certain cases is it given in terms of actual values, and this only in respect of those countries which submitted the required information.

Section 1—Evaluation of various iron-ore preparation methods

A. *Crushing and screening*

These preparation methods have become an essential part of modern iron-ore utilization. Their economic justification has been proved by numerous studies in various countries, has been amply confirmed in industry, and is no longer in any doubt.

The following applications must be distiuguished:

(*a*) The crushing of friable ores many of which were previously used in run-of-mine form;

(*b*) The crushing of compact ores to smaller particle sizes;

(*c*) The separation of fines for their subsequent agglomeration;

(*d*) The division of marketable ores into two or more size ranges.

The economic advantages of crushing friable ores was recognized in the western European countries in the 1920s, even before sintering was used on a wide scale. It was found for instance that, in spite of a marked increase in the proportion of fines, the need for greater blast-furnace pressure and a 50% increase in the make of flue dust, crushing "minette" ores to −80 mm resulted in economies in the coke rate and improvements in the blast-furnace performance which left no doubt as to the desirability of crushing.

In the case of compact, high-grade ores crushed by one process or another, reduction to optimum particle size is not, generally speaking, a costly process. It is now generally recognized that the final size to which the ore should be crushed is determined by the methods which will later be used to improve its reducibility during the smelting process.

The next step in the development of ore preparation methods once sintering began to be used was the separation of fines for their subsequent agglomeration. Extensive research into the economic value of this method was carried out in the United States and in western Europe in the 1930s, and led to the use of sintering on a wide scale.

The improvements which can be achieved by removing fines can be seen from the results of tests on Krivoi Rog ores, carried out in a blast-furnace at an iron- and steel-works in the south of the USSR, and given in table 14.

This table shows that, in the first period, average daily output was low and the coke rate high, in spite of the high proportion of iron in the burden and the extremely

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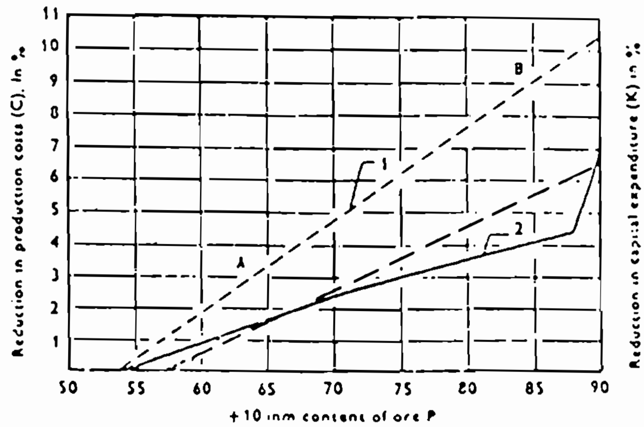
Table 14 — Effect of percentage content of the +10mm fraction in the ore on blast-furnace performance

Index	Period			
	1.I-55 31.I-56	1.II-31.XII-56	1.I-31.XII-57	1.I-31.XII-58
1	2	3	4	5
+10 mm % content in the ore	54.25	71.36	88.20	89.17
Saving of coke (kg/ton iron)	—	58	77	90
Blast temperature (°C)	605	611	616	630
Flue dust (kg/ton pig-iron)	254	241	187+	137
Average daily output (%)	100.0	106.5	109.5	110.0
Furnace volume utilization factor (m^3/ton/day)	0.918	0.865	0.840	0.834
Coke-burning rate (tons/m^3/day)	1.140	1.190	1.220	1.230

Source: Information submitted by the Government of the USSR.

Figure 7 — Iron costs (2) and specific capital expenditure (1) as a function of the +10 mm content of the ore.



Source: Information communicated by USSR government organizations.

high iron content of the ore (not shown in the table). The dust loss was also high and irregular. Once the fines had been eliminated and ores of a larger lump size were used, furnace output increased by 10%, even though other conditions were not as favourable, and the coke rate dropped by 5.4-8.7% to 58-90 kg/ton of iron.

The result was, on the one hand, lower blast-furnace operating costs through savings in coke, reduced consumption of ore and fluxes per ton of iron produced owing to lower flue dust losses, and reduction in the assumed constant overheads in production costs per ton of iron as a result of the higher productivity rate, and on the other, an increased expenditure in respect of sizing the ore and sintering the fines, which amounted to 35% of the total ore used. The situation as regards the capital expenditure per ton of iron produced remained unchanged.

The results of these tests were used to establish the following quantitative relationships between the cost of iron, the specific capital investment and the +10 mm content of the ore, in the conditions prevailing at this particular plant:

$$C = 0.197 \quad P_k - 11.29 \quad \text{and} \quad K = 0.285 \quad P_k - 15.925,$$

where

C = the reduction in costs, in per cent;

K = the reduction in specific capital expenditure on blast-furnace production and related operations, in per cent;

P_k = the proportion of +10 mm fraction in the ore, in per cent.

These relationships are illustrated in figure 7.

It was found that, from the point of view of the total expenditure ($C + 0.20\ K$), the savings achieved in blast-furnace production were about three times greater than the additional cost of ore sizing and sintering of the fines.

The effect on blast-furnace performance of removing fines from the burden is also illustrated by the following more recent data.[1] In May 1962, blast-furnace B at the Bethlehem plant of the Bethlehem Steel Co. produced 83,201 tons of iron for a useful volume of 1,424 m^3. In February 1963, blast-furnace D, of similar size but equipped with better blast heaters, and using the same burden, produced 2,653 tons/day for a coke rate of 579 kg/ton and a blast consumption of 3,400 m^3/min., limited by the blower (1.75 gauge atm. in the blast main). The pellets contained 7-8% of −6 mm material. The elimination of these fines would have made it possible to increase output, but, for economic reasons, this was unnecessary. In July 1963 the pelletizing plant was closed down for repairs and, for several months, pellets were drawn from stock and it was then decided that they should be crushed. The use of crushed pellets reduced blast pressure by 0.14-0.21 gauge atm., as a result of which blast consumption increased to 3,680 m^3/min. During this month, output amounted to 85,120 tons. The following month, when use was made of pellets from which the fines had been removed, daily output was 2,956 tons. Coke was charged in two sizes, namely +38 mm and 13-38 mm, by separate feeders. The particle size of coke, sinter and pellets at the plant was approximately the same, but the particle size of pellets in the hoppers (according to two 5-ton samples), before and after the removal of fines, varied considerably. The pellets in the hoppers contained 10% of −6 mm material before the removal of fines in August and September 1963 and 7% at the time of their shipment from the plant. It can be assumed that output rose by 9.2% as a result of the removal of fines.

Depending on the price of coke, etc, the relationship between savings and extra expenditure can vary according to circumstances but it is always positive. Ungraded ore is, therefore, very rarely smelted in modern practice, and then only because of organizational or technical difficulties and not for economic reasons.

The advantage of classifying ore into several sizes was also discovered some time ago, and extensive

[1] Nitchie : " S. M. Fines Aren't Fine ", Blast Furnace and Stee Plant, 1964 New York, pp. 331-333.

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research has been done on this subject in a number of countries since the 1930s. It was found that, if a blast-furnace is charged in layers with ore of different sizes, the gas permeability and reducibility of the burden improve considerably, with the result that the thermal and chemical energy of the fuel is used more fully (decrease in coke consumption and increase in the CO_2 content of the top gas) and blast-furnace output rises.

Table 15 illustrates the quantitative effects of separate charging on blast-furnace performance.

Table 15 — The quantitative effects of separate charging on blast-furnace performance

Item	CO_2 content of the top gases (%)	Coke rate (kg/ton iron)
Mixed ore	11.0	1,180
Ore sized into two categories	12.1	1,070
Ore sized into three categories	16.1	960

Source: C. C. Furnas, Blast Furnace, vol. 29, 1941.

The following information regarding the effect of burden sizing on blast-furnace performance was also published recently:[2]

(*a*) In 1926, output at the Irontown plant of the Colombia Steel Co. rose by 20% and coke consumption declined by 18% when ore was crushed to −50 mm, screened into three sizes and charged in separate layers.

(*b*) In 1950, output at the Fontana plant of the Kaiser Steel Corp. was raised and coke consumption dropped by 14% when the maximum particle size of ore was reduced from 38 to 25 mm. It was further found that the removal of fines from the burden improved its gas permeability and promoted the uniform distribution of gases in the shaft.

(*c*) In 1934, the influence of particle size on the gas resistance of the charge was determined. Resistance increases considerably when the charge consists of particles below 6 mm and becomes even more marked in the case of particles below 3 mm. Particle sizes over 10 mm have little effect on the resistance of the burden. The maximum effect is therefore achieved by the removal of the −6 mm or −10 mm fractions.

(*d*) In 1945, at the Edgar Thompson plant of the United States Steel Corp., the removal of the −6 mm fraction and its agglomeration, which increased the +6 mm content of the burden from 38% to 67%, led to a 14% rise in output and an 8% drop in coke consumption.

(*e*) Two years later, the screening and sintering of the −6 mm fines, which increased the proportion of the +6 mm fraction in the burden from 40% to 62%, raised output by 21% and reduced coke consumption by 15%.

[2] W. R. Trognitz: "Effect of Burden Sizing on Blast-furnace Performance", Blast Furnace and Steel Plant, 1964, No. 4, pp. 315-319.

(*f*) As a result, the proportion of sinter in the burden rose from 25% to 45% during the 1957-1962 period in the United States.

(*g*) Better sizing of the burden helped to improve blast-furnace performance. Output at the Fairless plant of the United States Steel Corp. rose by 46% when the burden was improved as follows (see table 16):

Table 16 — Improvements in the sizing of the burden at the Fairless plant

Period	Burden composition (%)			Fines content of the burden (%)	
	Run-of-mine ore	Graded ore	Self-fluxing sinter	−0.833 mm	−10 mm
I	70	30	—	26	53
II	—	60	40	7	56

(*h*) In 1957, the use of pellets in which the +6 mm fraction had been increased from 54% to 74% raised output at the Middletown plant of the Armco Steel Corp. by 17%.

(*i*) Tests at the Appleby Frodingham plant in 1959 showed that blast-furnace output can be raised considerably by screening the sinter. When the +10 mm content of the sinter was increased from 65% to 95%, output rose by 30%.

(*j*) When the +6 mm content of the sinter used at the Port Kembla plant of the Australian Iron and Steel Company was increased from 65% to 89% by screening, output rose by 12% and a furnace with a hearth diameter of 8.34 m produced 2,825 tons/day. Iron output per square metre of hearth area was practically the same as at the Middletown plant, where pellets were used.

(*k*) Blast-furnace performance is similarly affected by the classifying of coke, fluxes and other charge components.

(*l*) The best results are obtained by grading all charge components, but the advantages of such an improvement may be to some extent offset if unprepared open-hearth slag, scale, etc. are also added. The particle size of such additives must be approximately the same as that of the sinter and ore.

(*m*) Published figures indicate that a 10% increase in the +10 mm content of the ore, sinter or pellets raises blast-furnace output by 10%, ensures that the blast-furnace operates more evenly, and improves the quality of the iron.

According to a large number of sources, the saving in the coke rate as a result of classifying the iron ore into two or more classes is 50-100 kg/ton of iron.

An analysis of blast-furnace performance at two plants in the southern part of the USSR showed that when the ore is graded and charged separately, output is 10%-12% higher than when ungraded ore is used and that, when fines of −6 mm are removed from the burden, output increases still further.[3]

[3] Information supplied by USSR government organizations.

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None of the many industrial tests or analyses of performances of iron and steel plants have brought to light cases in which the classifying of ore into two or three sizes was economically undesirable. At the present time, the bulk of the lump iron ores consumed in the world are previously sized.

According to data from the USSR, the total cost of the supplementary preparation of lump iron ores (reducing lump size, separation and sintering of fines, screening) is generally three to five times smaller, in terms of production costs, than the corresponding savings achieved in the blast-furnace operation. They are two to three times lower in terms of specific capital investment per ton of iron, depending on the type of ore used and on local economic conditions.

Substantial economic advantages are achieved by careful grading in the case not only of lump ores but also of agglomerates. For example, high blast-furnace output was achieved at the Middletown plant of the Armco Steel Corp. in recent years only when the resistance to attrition of pellets was improved and the amount of fines thus reduced. Pellets by themselves were found to be a valuable blast-furnace raw material because they consist of particles of uniform size.

Former publications had shown the importance of and the economics realized by preparing the blast-furnace burden,[4] these have been confirmed in recent years by tests carried out by the Association of German Iron and Steel Manufacturers at plants in Duisburg-Ruhrort and Huckingen (Western Germany).[5]

An excellent example of the great technical advantages achieved by crushing ore to an optimum particle size and then grading it is given by the tests carried out at the Ougrée works in Belgium.[6] Under normal conditions, all ore at this plant is crushed and screened to three sizes, +50 mm, 50-10 mm and −10 mm, the last-mentioned fraction being sent for sintering.

The trials were carried out on No. 5 blast-furnace, blown in August 1959, with a hearth diameter of 6,000 mm. The timing was governed by the following factors: crushing and screening the ores started in May 1960, the sinter plant started up on 17 June 1960 and April 1960 was the last month when No. 5 blast-furnace was operated on unprepared ores. September 1960 was the first month in which the furnace operated on a fully prepared charge and May 1961 was the last trial month which, for reasons connected with the length and conditions of the tests, could be regarded as fully representative for purposes of forecasting performance figures in long-term operation.

The particle size of the two basic ores used is shown before crushing, in figure 8, and after crushing, in figure 9.

The only variable factor during the three trial periods was the composition of the burden; all other operating conditions remained unchanged. As the figures for each test relate to one month of operation, it is interesting to compare them. They are shown in table 17.

The table shows that the coke rate was reduced by 215 kg/ton of iron when crude unprepared ores were replaced by prepared ores, and by a further 41 kg/ton of iron after further improvements in the operation of the sinter plant and of the blast-furnace itself. Furnace productivity increased by 64.4%, owing to an increase in the coke burning rate of 21% and a decrease in the

[4] G. Heynert, P. Ischebeck and W. von Spee: "The effect of burden preparation" *Arch. Eisenhüttenwesen* 6 (1932/1933) S.129/36. Mintrop, R.: *Stahl und Eisen* 78 (1958) S.633/46.

[5] *Stahl und Eisen*, No. 19, 1962; No. 23, 1963, and No. 19, 1964.

[6] Journal of the Iron and Steel Institute, 1961, No. 3, pp. 253-258.

Figure 8 — Granulometric composition of raw iron ore.

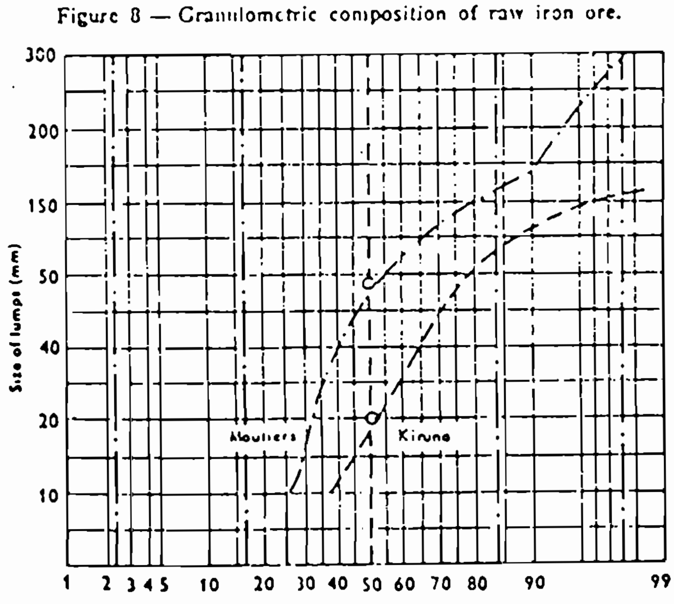
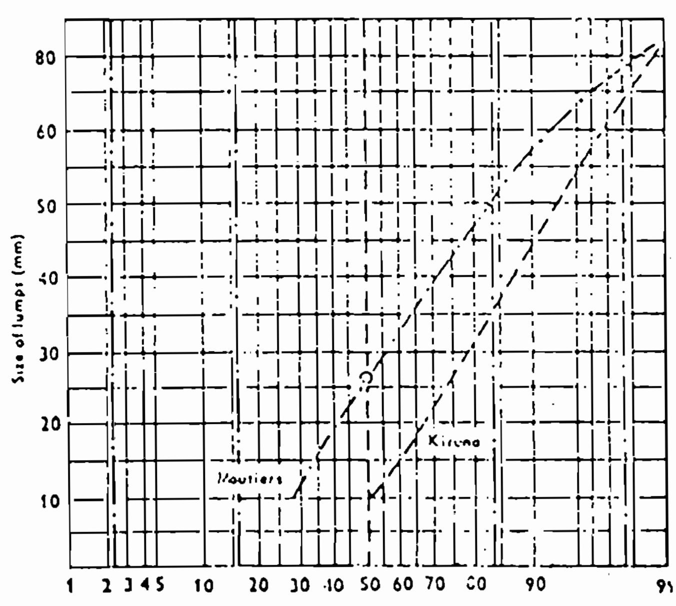


Figure 9 — Granulometric composition of iron ore after crushing.



Source: Jean Roland. "Increase in productivity of blast-furnace operating on mixed ore burdens". Journal of the Iron and Steel Institute. November 196 pp. 253-258.

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Table 17 — Tests at the Ougrée works in 1960/1961

Indicator	Furnace operating with unprepared burden, April 1960	First month of operation with a fully prepared burden, September 1960	Last trial month, May 1961
Iron production (tons/day)	495	708	815
Coke consumption, (tons/day)	478	531	578
Coke rate (kg/ton of iron)	965	750	709
Net iron content of charge (%)[a]	45.9	46.5	47.3
Slag volume (kg/ton of iron)	618	676	671
Flue dust make (kg/ton of iron)	131	58	33
Blast temperature (°C)	811	798	838
Top gas temperature (°C)	319	159	179
Coke burning rate ($kg/m^2/h$)	706	783	852
Slag basicity, CaO/SiO_2	1.46	1.43	1.43
Iron analysis (%):			
Si	0.29	0.32	0.40
S	0.043	0.025	0.027
Mn	0.75	0.75	0.80
C	3.35	3.70	3.65
Coke analysis (%):			
H_2O	1.22	1.65	1.08
C	88.27	88.15	88.79
A (ash)	9.62	9.30	9.26
S	0.89	0.90	0.87
Top gas analysis (%):			
CO_2	9.1	12.3	13.3
CO	31.6	28.3	27.7
H_2	2.3	2.1	1.8
N_2	57.0	57.3	57.2
Calorific value ($kcal/N\,m^3$)	1 014	909	883
Indirect reduction (%)[b]	54.45	58.78	61.7
Charging cycle	CC/OO/CC	CO/CC/SO/CS	OC/SC/CO/SC/OC/CS

[a] Corrected value for flue dust losses.

[b] Indirect reduction = CO_2 in gas — CO_2 in solid.

coke rate of 36%. Flue dust fell from 131 kg/ton of iron in April 1960 to 58 kg/ton of iron in September 1960 and 33 kg/ton of iron in May 1961, in spite of the higher driving rate. This indicates a better distribution of the burden and of the gases in the furnace shaft.

In conclusion it is suggested that, under conditions prevailing at the Ougrée works, hematite ores should be crushed to a size of −50 mm, magnetite ores to −25 mm, and hydrated and carbonated ores to −10 mm, for subsequent sintering. In the final analysis, the extent to which the ores are crushed will depend on the price of coke and sinter. Whatever the ore, it is always necessary to eliminate the fines in order to obtain a regular distribution of the gas-flow, thus increasing productivity without detriment to the cost of the iron.

Iron-ore preparation initially included drying. The economic advantages of drying cannot be demonstrated in terms of improvements in iron- and steel-making. Hygroscopic moisture is removed from the ore during the smelting process in the upper part of the blast-furnace by the heat of the waste gases; the removal of such moisture outside the blast furnace will require additional fuel. Drying is therefore carried out only in the event of serious difficulties, such as freezing of the ore in winter, whose disadvantages outweigh the extra cost of drying.

B. *Blending*

The technical importance of blending has been shown on a number of occasions; its advantages are now fully recognized and it plays a vital part in modern iron-ore preparation. For a number of reasons it is, however, difficult to estimate the economic influence of blending in iron-ore preparation.

Firstly, in order to reduce the undesirable effects of the variations in the chemical composition of the burden, the blast-furnace must build up a thermal reserve and the burden must contain an excess of chemical bases, which can only be created by a supplementary consumption of fuel and fluxes. Furthermore, the interruptions in blast-furnace operation which occur when a burden of this kind is used will affect the quality of the iron. It is, however, difficult to express the concept of a "smooth" or an "irregular" furnace operation in terms of quantitative and economic values.

Secondly, it is usually difficult to calculate the total cost of blending since, in modern practice, this operation often begins as soon as the ore leaves the mine and continues until it is charged into the blast-furnace.

For these reasons, the optimum economic degree of blending has not been determined and it is impossible to say what expenditure would be justified on reducing variations in the chemical composition of an ore from ±1.0% to ±0.5%, for instance. On the basis of extensive practical experience, however, a blast-furnace running on a burden the iron content of which varies by ±0.5% is considered to be operating normally and this figure is, as a rule, the target of the various blending processes applied.

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Lump ores are blended both by the supplier and by the consumer. Blending by the supplier is common in the case of large iron ore mines, or groups of mines with large stocks of ore at transloading points or ports, as for example the ore stocks at Narvik (Norway). Blending by the consumer is typical of iron and steel plants which use ores from a number of suppliers, such as the United Kingdom plants and many plants in the United States and other countries.

Owing to the high cost of building specialized blending plants, the general tendency is to carry out blending on ore stocks which have also been built for transport purposes, such as transhipment stocks, or stocks for seasonal shipment. For example, the blending practices at many plants in the United States are influenced by the necessity of creating large ore stocks to cope with the seasonal nature of supplies by water from the Lake Superior area.

Very thorough blending such as that achieved by Robins-Messiter ore yards, is applied at plants which use a multi-component burden containing ores whose iron content varies by 10% or more and when the ores contain varying proportions of slag-forming minerals. In such cases, the increased expenditure on blending is justified.

Tests carried out at one USSR plant showed that blending, which kept the variations in the iron content of 70% of all samples to between 55.5% and 55.8% Fe, increased blast-furnace output by 7% and reduced the coke rate by 4%. At the same time iron costs dropped by 2.5%, and calculations showed that capital savings amounted to 4.5% as compared with furnaces using unblended ore.[1]

The results obtained at the iron and steel plant at Witkowice by the blending of the iron ore prior to sintering are as follows:

(*a*) A 3.5-4.0% drop in the specific coke rate in the blast-furnaces;

(*b*) A 5-7% increase in blast-furnace output;

(*c*) Fewer variations in the chemical composition of the iron, resulting in more economical steel smelting operations;

(*d*) An increase of 10-15% in sinter plant output;

(*e*) Better organization of operations in the ore yard.

C. *Concentration*

Concentration is the iron-ore preparation method which alters the most radically the quality of the ore from the point of view of its iron content and of its slag-forming and harmful components. Unlike physical ore preparation methods such as crushing and grading, optimum concentration is not always technically feasible and is invariably limited by economic considerations.

The economic efficiency of iron-ore concentration is always difficult and often impossible to determine on the basis of the type of ore or of the concentration processes alone.

Concentration makes use of differences in the properties of the ore and of the waste material, physical differences such as specific gravity, magnetic, electrostatic and other properties, physical and chemical properties such as flotation characteristics, or purely chemical properties. But none of these properties, which will determine the technique to be adopted, can, in itself, govern the economics of concentration. For instance, the cost of concentrating coarsely grained soft ores will be quite different from that of concentrating similar fine-grained hard ores.

It must also be noted that there exists a wide variety of possible concentration methods and that, frequently, a number of different methods are applied successively to the same ore (combined concentration flowsheets).

The economics of concentration are considerably affected by factors governing the production, consumption and transport of iron ore. Furthermore, they cannot be considered independently of mining conditions and costs, on the one hand, and of agglomeration methods and metallurgical techniques on the other.

The wide range of natural properties which can influence the choice of concentration methods makes it essential to carry out a special technological study for each deposit, and for each type and variety of ore, whilst the multiplicity of economic factors involved calls for similar economic investigations which will include a calculation of the optimum degree of concentration.

Although technical and economic results will differ in each individual case, concentration is nevertheless subject to certain general laws which can give an approximate economic estimate of certain factors and relationships involved.

The main purpose of concentration is the removal from the ore of the maximum possible amount of slag-forming components, which, if smelted, would have a considerable bearing on the consumption of coke and fluxes as well as on blast-furnace output. The higher iron content of the ore achieved by concentration, which generally reflects the degree to which the process has been applied, is a function of the diminution in the amount of slag-forming components contained in the ore.

Other things being equal, the reduction of iron from its oxides takes place more rapidly when richer ores, sinters or pellets are smelted. At the same time, less furnace energy is expended on slag formation. It is generally recognized that a decrease in slag volume of 100 kg/ton of pig-iron reduces coke consumption by 20-25 kg and increases furnace output by 5-6%. The same result is obtained if 40-50 kg of the silica is removed from the ore, in which case the amount of limestone required drops by 120-130 kg.

The above results, which correspond to the removal of the basic or acid gangue from the ore, can lead to

[1] *Stal* No. 9, 1945

EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

a number of conclusions which, other things being equal, are valid in most cases:

(*a*) Concentration is very advantageous and the best metallurgical results are achieved when it is applied to ores associated with an acid gangue;

(*b*) Concentration is most effective when the basicity of the gangue improves as the gangue content of the concentrate declines. This is achieved in the flotation of iron ores, for instance;

(*c*) Concentration is not effective, or is the least effective, when it consists primarily in the elimination of the basic oxides (CaO, MgO) and, only to a lesser degree, in the removal of silica.

For the reason given in (*c*) above, it is considered undesirable to concentrate certain lean ores, easy to treat, such as the magnetite ores of the Teisk deposit in Siberia which contain 38.5% Fe. In other cases, the optimum degree of concentration, as regards the iron content of the concentrate, is kept below the level that it is technically possible to attain. Such cases include the skarn magnetite ores from certain deposits in the Urals and Siberia, from which it is technically possible to obtain concentrates containing 66-69% Fe but for which it is economically desirable to obtain concentrates containing not more than 62-65% Fe.

The economic advantages of concentrating iron ores for blast-furnace operation depend to a great extent on coke prices. Approximate current prices for coke in various countries are as follows: in the United States $17.5-18.0, in the United Kingdom $20.0-22.0, in the Common Market countries $23.0-25.0 and in the USSR (from January 1965) $28.6. Coke prices vary greatly within the same country, according to region.

Against the metallurgical advantages of the improved quality of the concentrate must be set the cost of concentration. This expenditure varies considerably per unit of crude ore and of concentrate, depending on a number of factors, amongst which the toughness of the ore and its grain characteristics, the degree of iron recovery in the concentrate and the cost of the concentration process itself are the most essential.

The material submitted by many countries contains little information on the industrial costs of iron-ore concentration. In some countries this information is given in costs, in others by ore-processing operations, whilst others supply only isolated data. A few countries provide fuller information.

Table 18 gives data on the cost structure of the various types of iron-ore beneficiation process at two plants, in the USSR and in Western Germany, respectively.

This table shows that, in the concentration of friable ores (brown hematites), provided the ore concentration is not based on drying, the bulk of the expenditure is accounted for by the ore concentration itself and only a smaller proportion by the preparatory operations such as crushing and grinding. In the concentration of tough, finely grained ores, on the other hand, the main part of the cost is accounted for by the preparatory operations, which in some instances amount to 65-70% of the total outlay. This second type of cost structure applies in the case of most ores at present concentrated throughout the world, for which the cost of preparatory operations amounts to some 35-60%.

The cost of the final operations, thickening, filtering, storage and removal of the concentrates, is, as a rule, relatively small; the cost of transport and storage for the tailings varies in each individual case and ranges from small values to 15-20% of the total concentration cost.

The main concentration processes, in ascending order of cost per ton of run-of-mine feed, can be listed as follows with a fair degree of accuracy:

1. Magnetic separation and Humphrey spiral separation;
2. Washing, jigging, concentration on tables and heavy-media separation;
3. High-intensity magnetic separation and flotation;
4. Magnetic roasting.

The economics of iron recovery in the concentrate will depend on the type of ore, on its mineralogical composition, on the concentration method used and on the complications of the concentration flowsheet; this can be expressed by the following general formula:

$$C = \frac{\beta}{\alpha} \times \frac{(D + O)\,100}{\epsilon}$$

C = cost of 1 ton of concentrate;

β = iron content of the concentrate, %;

α = iron content of the ore as mined, %;

D = cost of 1 ton of ore, including transport to the beneficiation plant;

O = cost of processing 1 ton of ore in the beneficiation plant;

ϵ = iron recovery in the concentrate, %.

This formula disregards the differences in the cost of the removal and storage of 1 ton of tailings, on the one hand, and of de-watering, filtering, storage and unloading of 1 ton of concentrate, on the other, since in practice these costs are often similar.

The formula shows that, other conditions being equal, the value of the recovery index increases the higher the cost of the ore and the greater the outlay on its concentration. The degree to which the capital investment on the mine is made use of and the availability of iron-ore resources in the area or country concerned, must also be taken into consideration.

In concentration one always seeks to obtain the highest possible recovery but, in a number of instances, this complicates the concentration process to such an extent as to make the extra effort uneconomic. Where the cost of iron-ore mining is relatively low and resources are plentiful, the tendency in iron-ore preparation is not to try to obtain the highest possible recovery. This is illustrated by the concentration of the taconites of the Lake Superior area (United States), of the iron quartzites of Krivoi Rog and of the brown hematites of the Kerch deposit (USSR). On the other hand, where mining is

EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

Table 18 — Cost structure of iron-ore concentration in accordance with the types of ore and the concentration methods adopted

No.	Designation of characteristics and indices	Units of Measurement	Calbecht plant	Pegnitz plant	Olenyogorsk plant USSR	NKGOK plant USSR*
			Western Germany			
1	2	3	4	5	6	7
1.	Type of ore	—	Brown hematite	Brown hematite	Magnetite-hematite ore	Magnetite iron quartzites
2.	Concentration method	—	Washing, heavy-media separation and high-intensity magnetic separation	High-intensity magnetic separation	Low-intensity magnetic separation and gravity separation	Low-intensity magnetic separation
3.	Ore-output capacity of plant	(1,000 tons/day)	18.0	1.5	22.5	30.8
4.	Iron content of ore	%	30.0	30.0	32.0	33.0
5.	Iron content of concentrate	%	37.8	39.0	61.3	62.5
6.	Iron recovery	%	91.0	..	78.5	70.0
7.	Final size to which ore is ground	0.074 mm	..	..	55-65	90-95
8.	Cost of operations:					
	Coarse crushing of ore	%	11.9	6.8	5.2	8.0
	Drying of ore	%	—	32.2	—	—
	Average crushing	%	3.7	4.7		
	Fine crushing	%	—		10.6	16.0
	Grinding	%	—	18.0	34.8	51.0
	Washing	%	23.2	—	—	—
	Screening and dehydration	%	17.4	—	1.0	—
	Heavy-media concentration	%	12.6	—	—	—
	Magnetic separation	%	15.4	25.1	6.2	8.1
	Gravity separation on tables	%	—	—	8.4	—
	Dehydration and filtering of concentrate	%	—	—	4.2	7.0
	Drying of concentrate	%	—	—	9.5	—
	Storage and removal of concentrate	%	—	—	4.5	3.7
	Transport and storage of tailings	%	—	7.2	16.6	6.2
	Other expenses	%	6.2	1.0	—	—
	Overheads	%	9.6	5.0	—	—
	Total costs	%	100.0	100.0	100.0	100.0
9.	Cost per ton of ore:					
	Electric power	kWh	8.7	18.9	14.2	16.9
	Water	m^3	2.5	0.13	2.97	3.9
10.	Number of workers	Men	293	80	715	829

Source: Information submitted by the government authorities of the Federal Republic of Germany and the USSR.

* NKGOK: New Krivoi Rog Mining Combines.

costly—as in the case of deep underground mining and in unfavourable mining conditions—there is a marked tendency to achieve a high recovery even at great cost; this is the case, for instance, in Western Germany. As far as the economics of the process are concerned, the history of the development and the present state of iron-ore concentration in various countries are therefore largely governed by three main factors: the cost of mining, the cost of the preparatory operations (liberation of the ore grains) and the method of concentration, which will determine the desirable recovery of iron and the quality of the concentrate. A favourable combination of these three factors can often provide advance information as to the efficiency which can be expected of iron-ore concentration. An example of such a situation can be found in the ores of some of the Labrador deposits with open-cast workings, relatively soft coarse-grained ores, and cheap concentration by spiral separators.

Although considerable technical advances have been made in recent years in the crushing, grinding and processing of fine materials, ores having been ground in some instances to 80-90% below 0.044 mm, grinding remains the most costly item in iron-ore concentration.

Concentration is therefore cheapest when the metallic and non-metallic minerals are coarsely grained or the individual grains are coalesced into nodules, thus making it possible to separate a substantial part of the waste from the ore by some method at each crushing stage (magnetic separation, heavy-media concentration, washing or jigging) and to obtain a finished concentrate. The iron-ore reserves to which such "summary" concentration methods can be applied are, however, relatively rare.

The best method of lowering the cost of beneficiation in the case of fine-grained iron ores remains multi-stage grinding and concentration. The treatment of low-magnetic and mixed ores by this method involves the use of special concentration techniques after each stage of grinding (combined concentration flowsheet) so that as much of the material as possible is withdrawn from the circuit, having undergone the least costly beneficiation techniques, whilst the more costly processes (flotation, high-intensity magnetic separation) are applied only to a small proportion of the material.

A major advance in the preparatory operations was the advent of ball-less grinding, which lowered processing

EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

costs for many ores and improved both the recovery and the quality of the concentrate; the scope of ball-less grinding and its economic efficiency are, however, still under study in a number of cases.

As has already been said, the economics of iron-ore concentration must be determined on the merits of each individual case and do not lend themselves to a general analysis. Nevertheless such analyses have occasionally been attempted, as shown in the following examples;

In 1955, iron-ore concentration in Western Germany removed a total of about 1.5 million tons of silica, which, with a slag basicity of 1.3, corresponds to 3.5 million tons of slag in the blast furnace. The removal of silica within the blast furnace is about three times more expensive than its removal by ore beneficiation.[8]

In 1963, a total of 47.5 million tons of waste rock, including 32.7 million tons of silica and 6.6 million tons of basic oxides, was removed in USSR beneficiation plants. At a slag basicity of 1.2, this eliminated the need for smelting 80.2 million tons of slag in the blast furnaces and reduced the consumption of limestone by 62.0 million tons. The economy achieved in the blast furnace exceeded by nearly 300% the total expenditure on ore concentration, on the sintering of the concentrates plus the cost of the metal lost in the tailings of the concentration plants (21.8% of the cost of the ore mined).[9]

Such analyses, albeit conclusive, are, however, hardly applicable to the present purpose. They would be valid only if, in the absence of concentration, the same ores were always fed to the furnaces. In fact, however, use was made not only of low-grade ores, but also of ores brought in from outside, of high-grade ores difficult to obtain and of medium-grade ores, which could be more advantageously used than unconcentrated low-grade ores. The efficiency of iron-ore concentration must, therefore, be estimated with reference to at least two cases.

The first case is when medium- or low-grade ores are used crude in the blast furnace, and the question arises of improving their quality by concentration. In this case, the method of estimating described above can be applied, and the following instance may serve as an example: In the Krivoi Rog iron-ore area (USSR), a project has been prepared for the construction of a large plant which is to concentrate hematite-martite ores containing on an average 55% Fe, which are at present marketable ores. It has been calculated that an increase in iron content of these ores by beneficiation to an average of up to 62.5% will enable the industry to economize an amount exceeding the additional outlay on ore preparation by 60-70% as regards operating costs and by 2.0-2.2 times as regards capital outlay, if the allied production branches are taken into account. The flowsheet for the concentration of these ores is at present being tested in a pilot plant.

The second case is when low-grade ores which cannot be used in their crude form are concentrated to such an extent that they become economically competitive with other marketable metallurgical raw materials. In this case, the economics of concentration cannot be measured by the amount of waste rock removed from the ore; they can only be judged by the degree to which concentrated ore has become competitive in the market, but their true value must be viewed from a still broader angle covering the expansion of national or local iron-ore resources, a longer life for the mining industry and other consequences which cannot always be evaluated.

The foregoing appraisals of the economic advisability of concentration immediately raise a practical problem: the determination of the maximum and minimum iron contents between which concentration will be economically justified. This, once again, will have to be determined strictly in accordance with local conditions in each instance. All that can be done here is to give certain practical examples.

As a practical example of the concentration of relatively rich ores, Sweden can be cited, where, in a number of cases, ores with an Fe content of 55% and even 60% are concentrated. Another, similar example is the above-mentioned project for the construction of a beneficiation plant in the Krivoi Rog area, for ores with an Fe content of 55%.

As a practical example of the concentration of ores with a low iron content, mention can be made of the beneficiation plant at the Kachkanarsk Ore Beneficiation Combine in the Urals (USSR), the first section of which was brought into operation in 1964. This plant processes titanomagnetite ores with an Fe content of 16%. The favourable economics of working the Kachkanarsk deposit are due to a conjunction of a number of circumstances: open-pit mining, with about 10 m of stripping, the possibility of putting in a large-capacity plant (36 million tons of ore per year), the favourable chemical composition of the ore (high basicity, very low sulphur and phosphorus, the presence of other useful elements in addition to iron), the ease with which the ore can be concentrated (coarse graining and cheap magnetic methods), the high quality of the sinter and the possibility of using the waste products.

D. *Agglomeration and its effects on blast-furnace performance*

From a process solely imposed by blast-furnace technology, agglomeration has in many instances become desirable and economically justified in itself. In addition to its immediate function of correcting the size of fine ores and concentrates, agglomeration also continues certain functions of concentration, such as the removal of impurities, and assumes some of the work of the blast-furnace, such as the removal of moisture, and the separation of carbonates. The high technical level of

[8] *Stahl und Eisen*, 1957, pp. 549-552.

[9] Information submitted by the government authorities of the USSR.

EXHIBIT "23ECH3" - Extract from "Economic Aspects of Iron Ore Preparation" prepared by the Secretariat of the Economic Commission for Europe, 1966

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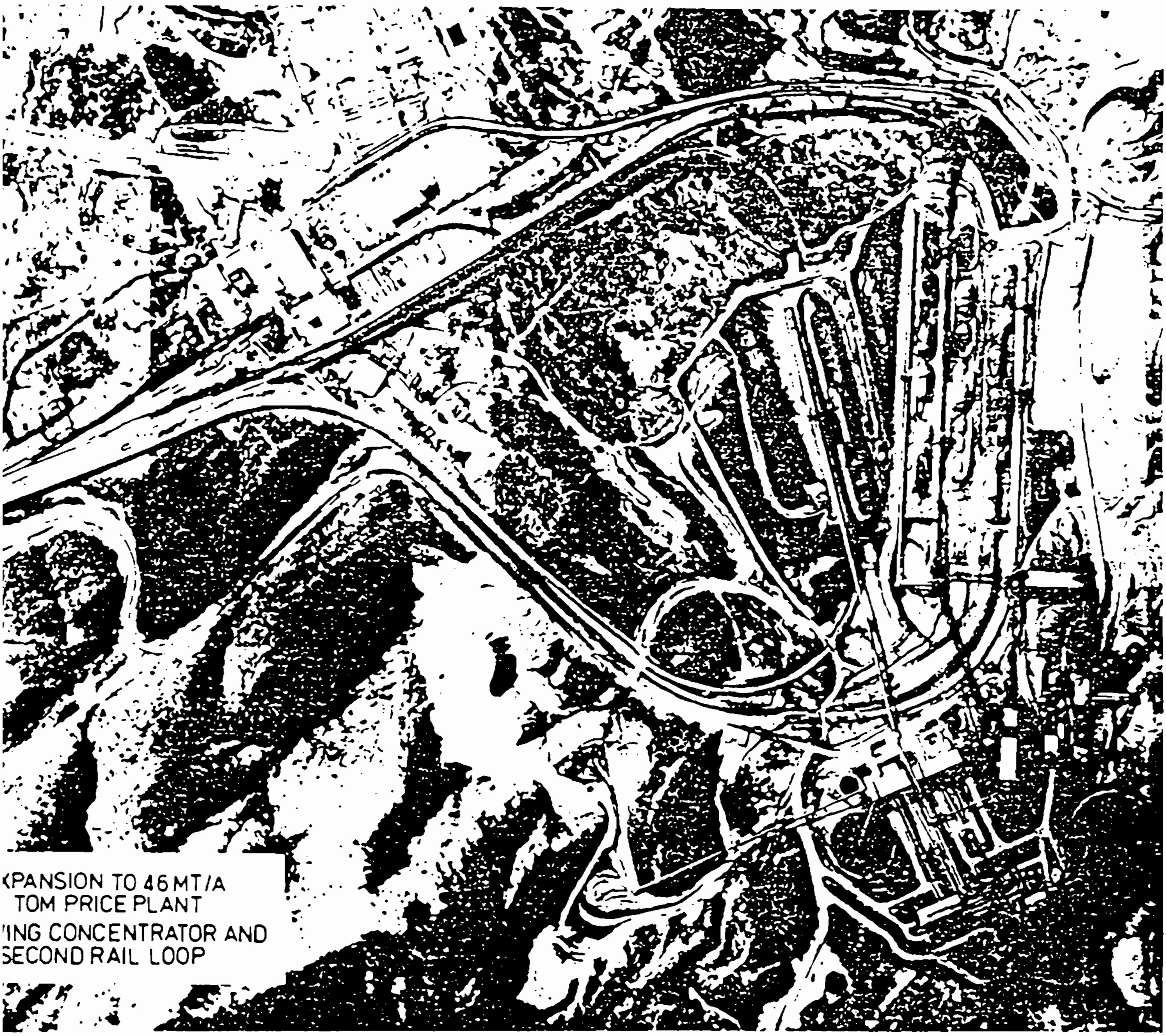


Aerial view of Mt. Tom Price mine showing new low grade iron ore concentration plant superimposed in lower right.

Hamersley's Low Grade Iron Ore Concentration Project

EXHIBIT "24" -Reprint from Volume 66 No. 47
Skillings Mining Review entitled "Hamersley's
Low Grade Iron Ore Concentration Project"1977

Hamersley's Low Grade Iron Ore Concentration Project

New facility for start up in late 1978 at Mt. Tom Price mine

MITCHELL COTTS PROJECTS (Australia) Pty. Ltd. has been active in Australia since 1968 making available to the mining industry its expertise in mineral beneficiation and in particular its wide experience in heavy media separation. The company has built more than 80 heavy media plants in various parts of the world and this year is managing, designing, constructing or commissioning eight heavy media separation concentrators treating a variety of ores.

Mitchell Cotts recently brought on line an 18,000,000-metric ton per year heavy media separation complex at South African Iron & Steel Industrial Corp. Ltd.'s Sishen-Saldanha iron ore project. This is the largest such concentrator in the world. Presently the Mitchell Cotts consortium, headquartered in Perth, Western Australia, is joint manager of Hamersley Iron Pty. Ltd.'s concentrator project.

Hamersley, one of the world's larger iron ore producers, is conducting an expansion program to increase capacity from 40,000,000 to 46,000,000 metric tons of saleable ore a year. The expansion, costing about A.$375 million, will be completed early in 1979. Hamersley operates two open pit iron ore mines situated at Mt. Tom Price and Paraburdoo in northwestern Australia. The mines are linked to the export harbor of Dampier by a 250-mile railroad.

TREATMENT OF LOW GRADE ORE IN PLANT

The expansion program will involve the installation of a concentration plant at the Mt. Tom Price mine to treat low grade material. The nature of the orebody is such that large quantities of shaley low grade material occur, and these have to be removed separately during mining operations. Since operations commenced, at least 30,000,000 metric tons of low grade ore have been stockpiled at Mt. Tom Price. Additional large quantities of low grade ore have been delineated and will be mined during the extraction of high grade direct shipping ores.

Following extensive investigations, metallurgical evaluation completed during 1975 confirmed that the low grade ores could be beneficiated by heavy media separation and wet high intensity magnetic separation.

Heavy media separation is the practical commercial application of the standard sink-float technique, where the separation of a mixture of solids of different specific gravities is achieved by a heavy liquid, the density of which has been adjusted to lie between the specific gravities of the two solids. Wet high intensity magnetic separation is based upon the differences in magnetic properties of solids, non-magnetic particles being flushed through the magnetic field while particles with even feeble magnetic permeability are held in the adjustable high intensity magnetic field.

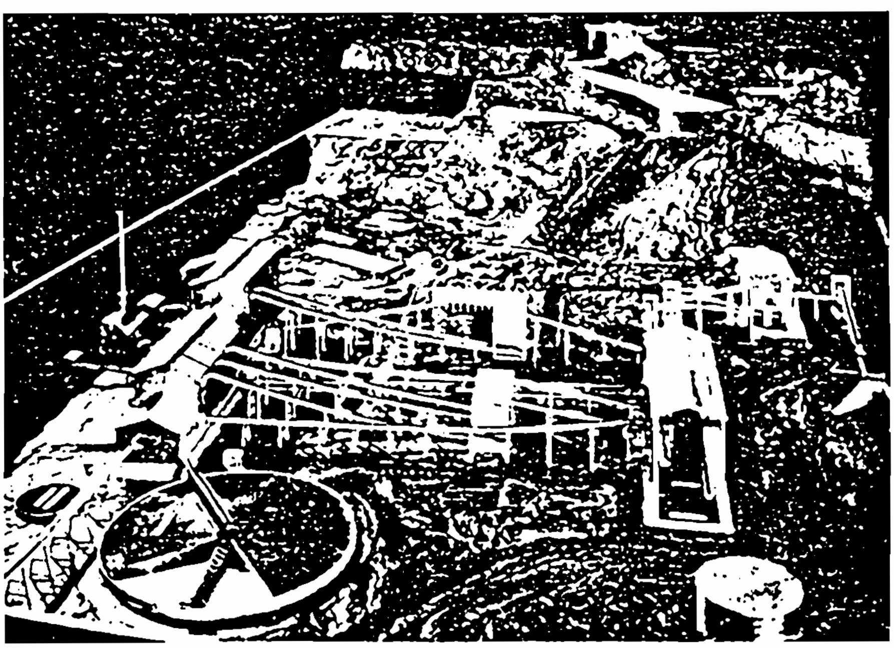
By March 1976 detailed engineering and process design studies had confirmed the technical and economic feasibility of the Mt. Tom Price low grade iron ore concentration project. Mitchell Cotts at that stage mobilized its project team in a joint venture with Minenco Pty. Ltd. in Perth.

The contract for the design and project management was awarded by Hamersley Iron to the Mitchell Cotts-Minenco joint venture during Dec. 1976. At the same time contracts also were awarded for the expansion of Parker Point at Dampier, the power station and power distribution systems, the railroad expansion, the housing expansion, loadout tunnel at Tom Price, and Tom Price water supply. The total value of these contracts is about A.$375 million.

COMMISSIONING OF PLANT LATE IN 1978

Plant commissioning is scheduled for late in 1978, and by early in 1979 the concentrator should be achieving full production rates. This will be the Pilbara region's first commercial wet iron ore beneficiation plant and introduces a new era for the iron ore industry in Australia. This expansion will lift Hamersley's annual production capacity to 46,000,000 metric tons of iron ore per year.

Concentrator feed ore is essentially a mixture of the iron minerals hematite and goethite and of shales of relatively low iron content. The nature of these shaley low grade ores is such that liberation occurs at coarse sizes and the higher Fe values are concentrated in the



Model of low grade iron ore concentrator being built at Mt. Tom Price mine.

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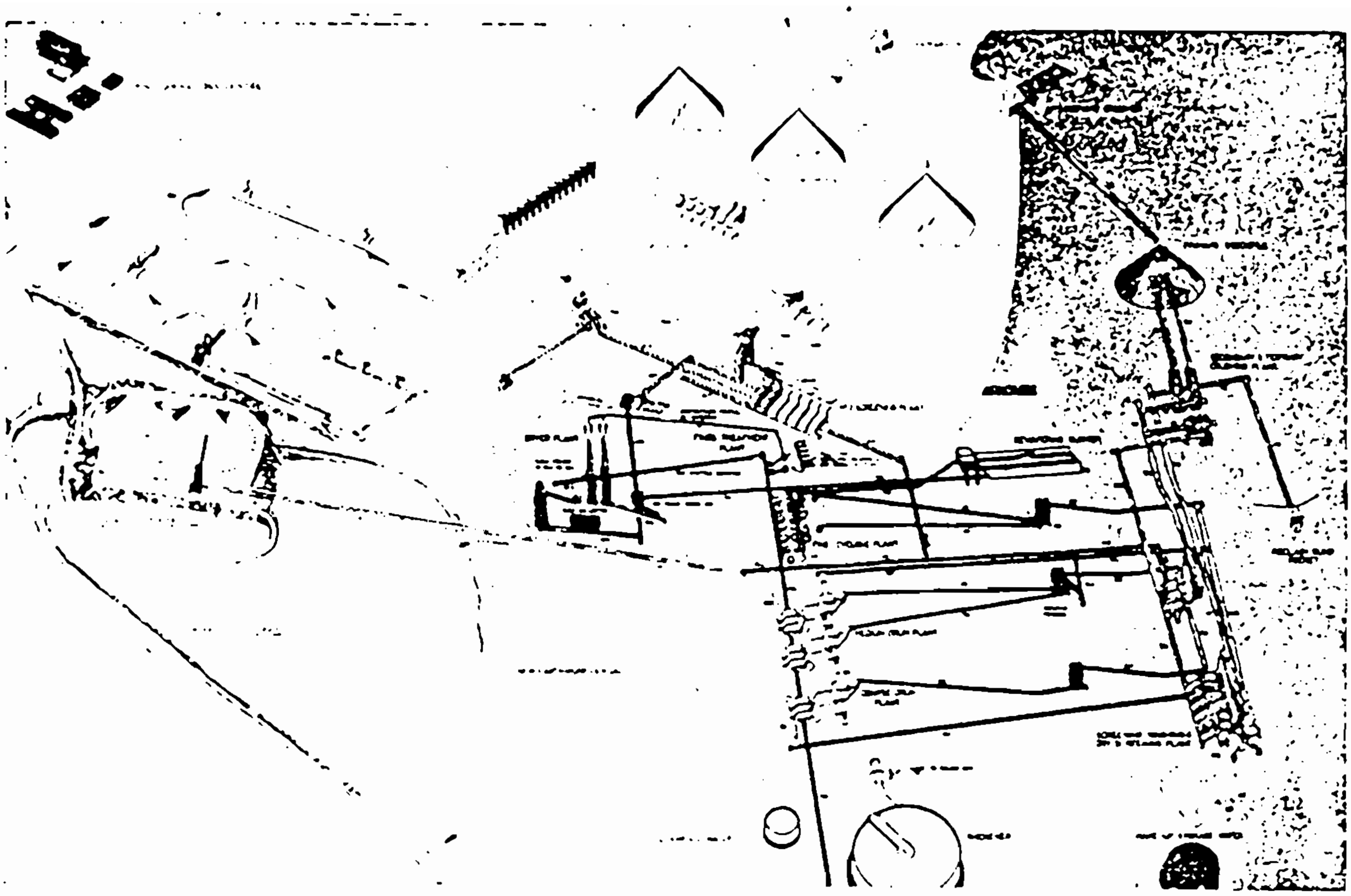

Isometric drawing of low grade iron ore concentrator under construction and existing plant at Mt. Tom Price mine.

coarse size fractions. The coarse ore fractions, therefore, need no beneficiation.

The washability of the remaining ore fractions reflects minimal near gravity material between the high density hematite and the low density shales. The fines are treated more effectively by magnetic separation, and ultrafines, mainly shaley material, are discarded to waste by cyclone classification. By adjusting the separation density in the heavy media separation plants, the product chemical specification, consisting of the iron, alumina, silica and phosphorus contents, can be varied.

The concentrator has been designed to enable Hamersley to produce saleable iron ore from the low grade feed and also to improve the grades and physical properties of Hamersley's total production. In addition, the design enables all concentration sections to be operated to yield concentrate of suitable quality for feeding to direct reduction steelmaking processes.

A total of 13,000,000 metric tons of this low grade ore per year will be available to the concentrator, and this will produce a net increase of 7,700,000 tons of saleable ore per year. The individual plant sections will be fed, as shown in the accompanying table.

The design incorporates plant bypass facilities for the 80 x 30-mm. and the 30 x 6-mm. fractions during periods in which the ore grade as mined is high or during extended shutdown periods resulting from scheduled maintenance requirements. In addition, the wet high intensity magnetic separation circuit can be bypassed under certain conditions.

The heavy medium separation density requirements for normal operation grade production dictates the use of a mixed medium comprising milled ferrosilicon and magnetite. High grade concentrate production requires higher separation densities that necessitate using milled ferrosilicon only for the Wemco drum separators and atomized ferrosilicon in the heavy media cyclone separators. Various grades of correctly sized heavy medium are required to obviate medium instability caused by too coarse a medium and unacceptably high viscosities caused by too fine a medium.

The heavy medium consumption varies considerably from plant to plant and is related to plant operational efficiency, nature of the ore and chemical composition of the plant water. The overall consumption of this commodity should not exceed 500 gms. per ton treated. All of the heavy medium plant modules consist of separate feed preparation screens, medium pumping circuits, densifiers, magnetic separators and sinks and floats product drainage and rinsing screens.

SIZE FRACTION	TYPE OF SEPARATOR	NO. OF MODULES	CAPABILITIES, TON PER HOUR REQUIRED	DESIGN
80 x 30	Wemco drum	1	530	660
30 x 6	Wemco drum	2	600	660
6 x 0.5	Heavy media cyclone	3	420	600
Minus 0.5 x 63	Wet high intensity magnetic separator	2	180	?20

ADDITION OF OTHER PLANT FACILITIES

In addition to the heavy media separation and wet high intensity

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magnetic separation beneficiation plants, the concentrator complex includes additional integrated facilities. Modifications to the existing No. 2 primary gyratory crusher include the provision of a twin dump pocket system comprising 500-ton surge hoppers, vibrating feeders followed by vibrating grizzlies with bar spacing to size effectively at 200 mm. The high grade plus 200-mm. ore fraction delivers to the existing primary crusher with low grade undersize being conveyed to a 95,000-ton live capacity concentrator feed surge stockpile.

High sizing efficiency is required for these scalpers to prevent dilution of the high grade ore stream by fine low grade ore. This requirement necessitates the installation of feeding and sizing equipment virtually unsurpassed worldwide for robustness, capacity, and physical size of the units.

The vibrating feeder and vibrating grizzlies are identical in size being 10 ft. wide by 30 ft. long. System design capacity is 2750 ton per hour per stream. Equipment and size standardization results in optimization of spares holding.

The secondary crushing plant consists of two 7-ft. Standard cone crushers each fed by a scalping screen for sizing at 80 mm. The two feed conveyors each have three vibrating feeders withdrawing ore from the stockpile at a rate of 880 tons per hour per stream.

Scalping screen undersize is conveyed by transfer and tripper conveyor systems to the washing and screening plant feed distribution bin. Secondary crusher product during normal production is conveyed to tertiary sizing screens in closed circuit with tertiary crushers. During high concentrate grade production, the secondary crushed product joins the scalping screen undersize for subsequent beneficiation in the heavy media separation plants.

The tertiary crushing circuit comprises a surge bin, two 7-ft. Short Head cone crushers, each fed by a vibrating feeder. It handles the 80 x 30-mm. sinks product from the heavy media plant and or the 80 x 30-mm. bypass material from the washing and screening plant together with the recirculating load from the tertiary sizing screens. The minus 30-mm tertiary screen undersize product is conveyed to a new product stockpile. The secondary and tertiary crushers are complete with lubrication oil pumping, radiator cooling and dust extraction systems.

TREATMENT BY WASHING AND SCREENING

The washing and screening plant consisting of six screening streams, comprising five operating and one standby, sizes the nominal minus 80-mm. low grade ore into four size fractions composed of 80 x 30 mm., 30 x 6 mm., 6 x 0.5 mm. and minus 0.5 mm.

Each stream is fed by vibrating feeder from the surge bin into a primary double-deck sizing screen. Screen undersize gravitates to a sieve bend followed by a single-deck sizing screen, and minus 0.5-mm. fines gravitate to a transfer pump. The rated capacity per screening stream is 352 ton per hour. The three coarse size fractions are conveyed to separate 1000-ton capacity surge bins to insure a steady feed to the heavy media plants.

The minus 0.5-mm. undersize product after desliming in pump-fed classification cyclones constitutes the feed to the wet high intensity magnetic separation circuit. Cyclone overflow gravitates to a 300-ft. diameter thickener. The thickener underflow is disposed of by an underflow transfer pump prior to a two-stage centrifugal pumping system delivering to a fine tailing dam. Overall water recovery from the tailing that is estimated at 40% is returned to the concentrator water circuit by a transfer pump mounted on a barge at the tailing dam.

The floats fraction from the process plants is transported to a waste dump on a common collecting conveyor transferring onto a portable conveyor-stacker system. The design provides for handling the wet high intensity magnetic separation tailing over dewatering screens onto a waste conveyor.

Product handling is as follows: the 80 x 30-mm. coarse drum product conveyed to tertiary crushers; the 30 x 6-mm. medium drums product conveyed to the lump ore stockpile; the 6 x 0.5-mm. cyclone sinks product conveyed to the dewatering bunker for drainage, reducing moisture content from 12% to 7%. The wet high intensity magnetic separation concentrate and dewatering bunker discharge are conveyed to a rotary kiln dryer. Dryer discharge is conveyed with fine ore from crushing and screening plants to stockpiles.

The rotary drying circuit is complete with surge bins, fuel pumping, two-stage dust scrubbing and feed and product disposal facilities. The design incorporates bypass facilities for periods in which ore drying is unnecessary. For metallurgical accounting, sampling systems are provided as well as belt weigher installations density recording and flow measurement.

CONCENTRATOR WATER SUPPLY PROVISION

The water service provision for the concentrator includes a make up water storage tank, a clarified water storage tank, four 1500-cubic meter per hour clarified water pumps including one standby, one 450-cubic meter per hour dust extraction water services pump, high pressure water filtration facilities on delivery lines, together with the necessary reticulation piping and screen water spray systems in the wet plants.

The provision of electric overhead cranes in all plant buildings varying in capacity from 5 to 25 tons together with monorails on crane inaccessible equipment insures easy handling of mechanical and electrical equipment to the maintenance bays provided in the different plants.

Except for the primary crusher area, which is controlled locally, the concentrator is controlled from a centralized control room situated on level six of a building accommodating transformers, main substation, crib rooms, model rooms, supervisors offices, programmable logic controllers, electrical and mechanical maintenance areas and a mini computer. The building is air-conditioned and pressurized where necessary, and the main control room accommodates the control desk, mimic panel and visual display units.

The control building, which is situated centrally between the drum and cyclone plants, is equipped with a materials and passenger elevator

The heart of the control system is the central programmable logic controller with about 8000 input-outputs. It will be situated two floors below the control room. The control room has a 53-ft. mimic display

EXHIBIT "24"- Reprint from Volume 66 No. 47 Skillings Mining Review entitled "Hamersley's Low Grade Iron Ore Concentration Project" 1977

panel and a central control desk. All on-off field control and protection devices will be connected into the programmable logic controller by means of telephone-type cable.

The analog instrumentation loops associated with items such as the ore dryer and material feeders will bypass the programmable logic controller direct to conventional analog controllers. The mini computer, which is adjacent to the programmable logic controller, will communicate directly with it and the analog controllers to monitor and record data, including about 1500 fault signals, and display information. During initial operations of the plant, the mini computer will function as a data logger and programmable logic controller-visual display unit interface only. Provision is being made for programming at a future date for extended plant control functions.

Some general statistics are as follows: The total connected electrical load will be about 16 mw with an electrical demand of roughly 13 mw. Make up water requirements are 292 cubic meters per hour. The concentrator circulating water requirement is 5000 cubic meters per hour.

In-plant pumping requirements in cubic meters per hour are shown in the accompanying table.

Building and platework steel mass will total about 10,000 tons, and reinforced concrete will amount to about 22,000 cubic meters.

The magnitude of the project necessitated large scale use of established consulting engineers' services throughout Australia. This resulted in a major reduction in the time period required for detailed design and engineering that by Oct. 1, 1977, was more than 90% complete.

About seven or eight main contractors will be engaged at the site for the supply and installation of building steelwork, platework, conveyors, mechanical and electrical equipment. The contract completion date dictated award of all supply and erect contracts by not later than the end of Oct. 1977.

The overall expansion project will provide permanent employment for between 260 and 280 people when completed in mid-1979, with a peak construction workforce of about 875 during construction in 1978.

	HEAVY MEDIUM	DILUTE MEDIUM	MAG. SEP. TAILS	IRON ORE SLURRY	FINE TAILING
Cyclone plant	1800	1350	..	....	....
80 x 30 drum plant	490	450	420	....	....
30 x 6 drum plants	600	900	840	....	....
Washing Plant				1500	
Wet high intensity magnetic separation plant				676	
Thickener					315

EXHIBIT "24"- Reprint from Volume 66 No. 47 Skillings Mining Review entitled "Hamersley's Low Grade Iron Ore Concentration Project" 1977

IN THE SUPREME COURT

OF WESTERN AUSTRALIA

No. 2313 of 1982

EXHIBIT "25" - Affidavit of John Roberts
1.6.1983

IN THE MATTER of an Agreement between LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, WRIGHT PROSPECTING PTY. LTD., HANCOCK PROSPECTING PTY. LTD, two other companies and HAMERSLEY IRON PTY. LIMITED

B E T W E E N:

HAMERSLEY IRON PTY. LIMITED — Plaintiff

AND

LANGLEY GEORGE HANCOCK — First Defendant

ERNEST ARCHIBALD MAYNARD WRIGHT — Second Defendant

HANCOCK PROSPECTING PTY. LTD. — Third Defendant

WRIGHT PROSPECTING PTY. LTD. — Fourth Defendant

L.S.P. PTY. LTD. — Fifth Defendant

THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED — Sixth Defendant

AFFIDAVIT

I, JOHN ROBERTS of 62 Corinthian Road, Shelley in the State of Western Australia, Executive Manager Marketing and Development, make oath and say as follows:

1. I am a Mining Engineer, who from June, 1966 until February, 1969 worked for the Plaintiff at its Mine at Tom Price as Assistant Mine Superintendent, Planning. Except for a period between February, 1969 and January, 1970, I have continued to work for the Plaintiff since that time and have at all relevant times been familiar with the crushing and screening processes used at Tom Price. I am at present Executive Manager Marketing and Development for the Plaintiff. I am duly authorised to make this Affidavit on behalf of the Plaintiff and I do so from my own knowledge.

EXHIBIT "25" - Affidavit of John Roberts
1.6.1983

2. I ask leave to refer to the Affidavits of Colin Roy Langridge sworn on 2nd September, 1982 and 24th May, 1983 and filed herein. Mr. Langridge's description of the crushing and screening processes used at Tom Price in the second, third, fourth and fifth sentences of paragraph 3 of his Affidavit of 24th May, 1983 is true of the processes in use at Tom Price from June, 1966, when crushing and screening of iron ore commenced, to August, 1967.

SWORN by the said JOHN)
ROBERTS at Perth)
in the State of)
Western Australia this)
First day of June, 1983)

Before me:

A Justice of the Peace

Filed on behalf of the Plaintiff.

EXHIBIT "25" - Affidavit of John Roberts
1.6.1983

[Reprinted on the 3rd February, 1976, pursuant to the Acts Republication Act, 1967, as amended.]

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act , 1958

BROKEN HILL PROPRIETARY COMPANY'S STEEL WORKS INDENTURE ACT, 1958

being

Broken Hill Proprietary Company's Steel Works Indenture Act, 1958, No. 28 of 1958 [Assented to 13th November, 1958][1]

An Act to approve and ratify an Indenture made between the State of South Australia of the one part and The Broken Hill Proprietary Company Limited of the other part relating to the establishment of a steel works in South Australia and to provide for carrying the provisions of the Indenture into effect and for other purposes.

BE IT ENACTED by the Lieutenant-Governor of the State of South Australia, with the advice and consent of the Parliament thereof, as follows:

Short title

1. This Act may be cited as the "Broken Hill Proprietary Company's Steel Works Indenture Act, 1958".

Commencement

2. The Act shall come into operation on a date to be fixed by the Governor by proclamation[1].

Interpretation

3. In this Act unless the context otherwise requires:—

"the Indenture" means the Indenture set out in the schedule to this Act;

"the Company" means The Broken Hill Proprietary Company Limited and includes its successors and assigns.

Validation of Indenture

4. (1) The Indenture is hereby ratified and approved and shall notwithstanding any other Act or law be carried out and take effect as though the provisions thereof had been expressly enacted in this Act.

(2) Notwithstanding any other Act or law and without in any way limiting the generality of the effect of subsection (1) of this section—

(*a*) the Minister of Works,

(*b*) the Electricity Trust of South Australia,

(*c*) the South Australian Housing Trust, and

(*d*) the Commissioner of Highways—

are hereby empowered and required to perform the functions and carry out the obligations which are under this Act or the Indenture to be performed or carried out by such body.

Performance of Indenture.

5. The Governor and Ministers for the time being in office shall take all necessary measures to ensure the full performance of the duties and obligations imposed on the State by the Indenture.

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[1] Came into operation 12th December, 1958. *Gaz.* 18th December, 1958, p. 1635

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

Variation of Indenture

6. (1) The parties to the Indenture may by agreement in writing vary the terms of the Indenture so far as may be necessary for the purpose of more effectively carrying out the intention of this Act and of the Indenture but for no other purpose.

(2) The Minister of Works shall cause a copy of every such agreement to be laid before each House of Parliament.

(3) Every such agreement—

(*a*) shall come into operation on the day after the day on which it has lain before both Houses of Parliament for seven sitting days or such later day as is specified in the agreement; and

(*b*) upon coming into operation shall have effect as if the terms thereof had been enacted in an Act of Parliament.

Effluent, smoke and gas

7. The Company and any subsidiary company as defined in the Indenture shall not be liable for discharging, from its works at or near Whyalla, effluent into the sea or smoke dust or gas into the atmosphere or for creating noise, smoke, dust or gas at such works, if such discharge or creation is necessary for the efficient operation of the works of the Company or subsidiary company and is not due to negligence on the part of the Company or subsidiary company as the case may be.

Legal proceedings

8. (1) Notwithstanding anything to the contrary in any other Act or law the State of South Australia may—

(*a*) sue and be sued and be a party to any legal proceedings to enforce any of the provisions of or obligations created by this Act or the Indenture or any agreed variation thereof, or in any way arising out of this Act or the Indenture or any agreed variation thereof or out of any of the rights duties and obligations thereby created;

(*b*) agree with the Company to submit any dispute or difference between the State and the Company arising out of or in connection with the Indenture or any agreed variation thereof or as to the construction of the Indenture or any such variation or as to any rights duties or liabilities thereunder or as to any matter to be agreed between the State and the Company thereunder to the award order and final determination of an arbitrator or arbitrators under the provisions of the laws relating to arbitration for the time being in force in the State; and

(*c*) agree to abide and be bound by such award order and final determination.

(2) In any action or arbitration to which the State of South Australia is a party pursuant to subsection (1) of this section the rights of the parties shall as nearly as possible be the same and judgment may be given or an award may be made and costs awarded on either side as in an action or arbitration between subject and subject and the Treasurer shall satisfy any award or judgment for the payment of money made or given against the State in any such proceedings or arbitration.

Repeal of Private Act, ss 10. 12. 15. 26. 11 (part)

9. (1) Sections 10, 12, 15, 26 and the second paragraph of section 11 of "The Broken Hill Proprietary Company Limited's Hummock Hill to Iron Knob Tramways and Jetties Act, 1900" are hereby repealed.

Amendment of Act No 1821.

(2) In section 8 of the "Hummock Hill to Iron Knob Tramway Extension Act 1927" the figures 10, 12, 15 and 26 shall be deleted and notwithstanding anything therein contained the provisions of the second paragraph of section 11

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

of the Principal Act therein referred to shall not apply to the tramways extension therein defined.

Application of Act No. 309 ss. 6, 23, 26, 32, 34, 44-58, 65 and 20

10. (1) Sections 6, 23, 26, 32, 34, 44 to 58 (inclusive) and 65 of the General Tramways Act 1884-1935 shall not apply to the Company.

(2) In section 20 of the General Tramways Act 1884-1935 the words "with the consent of the Governor" shall not apply to the Company.

Charges on Company's Tramways and jetties

11. Notwithstanding anything in any other Act or law the Company may charge for the carriage of passengers and goods on any of its tramways charges at rates not exceeding those charged from time to time by the South Australian Railways Commissioner for the same distances and, in the case of goods, for goods of a similar class, and may charge for the use of any of its jetties charges not exceeding those charged from time to time by The South Australian Harbors Board[1].

Repeal of Act No. 3 of 1940

12. The Northern Areas and Whyalla Water Supply Act 1940 is hereby repealed.

SCHEDULE

INDENTURE

Section 3

THIS INDENTURE made the fourth day of September 1958 BETWEEN the State of South Australia (hereinafter referred to as "the State") of the one part and THE BROKEN HILL PROPRIETARY COMPANY LIMITED a company incorporated in the State of Victoria and having its registered office in South Australia at Number 28 Franklin Street Adelaide (hereinafter referred to as "the Company" which expression shall include the successors and assigns of The Broken Hill Proprietary Company Limited) of the other part:

WHEREAS the establishment of steel works in South Australia would greatly increase the economic strength of the State and provide opportunities for the employment and advancement of its citizens and be instrumental in influencing other industries which substantially depend on the products of the Company in their processes of manufacture to establish operations at Whyalla:

AND WHEREAS the State has requested the Company to extend its undertaking at Whyalla by the establishment of steel-making plant, rolling mills and other works associated therewith or ancillary or incidental thereto, and the Company is willing to do so upon satisfactory arrangements for that purpose being made:

AND WHEREAS for the proper conduct of its operations it is necessary that the Company should be assured of supplies of raw materials, and security of tenure of certain lands and mineral and other leases, and be granted certain powers and rights:

NOW THIS INDENTURE WITNESSETH that the parties hereto covenant and agree with each other as follows:—

Ratification and operation of Indenture

1. (1) The clauses of this Indenture other than this clause shall not come into operation unless the Parliament of the State passes a Bill to ratify this

[1] See Harbors Act, 1936-1971, s. 52

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

Indenture and unless the Act resulting from the passage of such a Bill comes into operation before the 1st day of January 1959.

(2) If such a Bill is so passed this Indenture shall upon the day when the Bill becomes operative as an Act come into operation and be binding on the parties hereto.

(3) Without in any way derogating from any right or remedy of the Company in respect of a breach of this Indenture if the Parliament of the State should at any time alter or amend the Act passed to ratify this Indenture or should enact legislation which modifies the rights of the Company under such Act or under this Indenture the Company shall have the right to terminate this Indenture.

Interpretation

2. In this Indenture, unless the context otherwise requires—

"the Indenture of 1937" means the Indenture set out in the schedule to the Broken Hill Proprietary Company's Indenture Act, 1937[1]:

"the Middleback Range area" means the area shown on the plan set out in the Appendix A hereto being an area of 242 square miles or thereabouts in the Counties of Hore-Ruthven, Manchester and York, bounded as follows:—

Commencing at a point latitude 32 degrees, 41 minutes south and longitude 137 degrees, 5 minutes east near White Dam in the county of Hore-Ruthven, thence 5 miles, 60 chains east, thence 42 miles south, thence 5 miles, 60 chains west, thence north to the point of commencement; all bearings true:

"steel works" means steel-making plant, rolling mills and other works associated therewith or ancillary or incidental thereto at Whyalla:

"reserved area" means an area which by or pursuant to a proclamation made under the Mining Act, 1930-1955[2], or any subsequent amendment or re-enactment thereof is reserved from the operation of all or any of the provisions of that Act.

"subsidiary company" or "subsidiary" means a company in which the Company holds directly or indirectly at least one half of the issued share capital:

"associated company" means any company carrying on operations at or near Whyalla which substantially depends on the products of the Company for its trading or manufacturing processes:

"the ratification of this Indenture" means the day upon which this Indenture comes into operation.

Construction of works by the Company

3. (1) At a date not later than the 1st day of January 1960 the Company will commence the construction of steel works at Whyalla and subject to sub-clause (5) of this clause will by the 31st day of December 1970 expend on such construction the sum of £30 million[3] in the aggregate.

(2) In computing such expenditure there shall be taken into account all moneys expended by the Company after the 18th day of February 1958 in connection with such construction.

(3) Notwithstanding anything contained in subclause (2) of this clause expenditure by the Company on the construction of a beneficiation and treatment plant for jaspilite and other iron bearing substances shall not be

[1] Now Broken Hill Proprietary Company's Indenture Act, 1937 as amended by Northern Areas and Whyalla Water Supply Act, 1940

[2] The Mining Act, 1930 and its amendments have been repealed and superseded by the Mining Act, 1971 (now Mining Act, 1971-1975)

[3] In this indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

taken into account in computing the expenditure of the Company on steel works.

(4) The Company will, if required by the State, as early as practicable after the end of each financial year until the sum of £30 million[1] has been expended by the Company on the construction of steel works supply to the State a summary audited by the Company's auditors of its expenditure on steel works during such financial year.

(5) If the Company should at any time suffer any delay in the construction of steel works by reason of or arising from any cause beyond the reasonable control of the Company, the date for the completion of the expenditure of £30 million[1] on such construction will be postponed after the said 31st day of December 1970 by a period equal to the period of such delay and any further delay consequential thereon.

(6) Whenever any such delay or further delay consequential thereon occurs the Company will within a reasonable time report it in writing to the State.

Prospecting rights of Company

4 (1) Notwithstanding the Proclamations made on the 15th day of March 1951 and the 17th day of February 1955 under paragraph (*c*) of section 6 of the Mining Act 1930-1951[2], the Company shall for a period of ten years after the ratification of this Indenture and during any period of extension as provided in subclause (2) of this clause, have within the Middleback Range area—

(*a*) the sole and exclusive right to prospect for iron ore and iron bearing substances; and

(*b*) a non-exclusive right to prospect for metal, minerals and natural substances other than iron ore or iron bearing substances.

(2) The Company's rights under this clause will continue for a further period of ten years beyond the period referred to in subclause (1) of this clause unless they cease as provided by subclause (5) of this clause.

(3) For the purpose of any such prospecting the Company may without payment enter and occupy any land within the Middleback Range area and may on any such land erect buildings and structures, drill and dig holes, and carry out such other work as the Company deems necessary but the Company shall not have any such rights over any land—

(*a*) which for the time being is lawfully used as the site of a house, outhouse, shed, building, structure, dam or reservoir, or as a yard, garden, cultivated field, orchard, stockyard or other like enclosure; or

(*b*) which at the date of the ratification of this Indenture is comprised in any claim or lease held under the laws relating to mining by a person other than the Company.

(4) If any such claim or lease as is referred to in paragraph (*b*) of subclause (3) of this clause is terminated on or before the expiration of ten years after the ratification of this Indenture or during any extension under subclause (2) hereof the restriction on the Company's rights under this clause which is contained in the said paragraph (*b*) shall cease to have any operation in respect of the land comprised in such claim or lease.

(5) If the Company at any time before the expiration of twenty years after the ratification of this Indenture ceases to require all or any of the rights

[1] In this indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint.

[2] See now Mining Act, 1971-1975

EXHIBIT "26" - South Australian Brcken Hill Proprietary Company Steel Works Indenture Act, 1958 conferred upon it by subclause (1) of this clause, it shall notify the State of that fact and thereupon the Company's rights under subclause (1) of this clause shall cease to the extent indicated in the notice but not otherwise.

(6) During the period of ten years after the ratification of this Indenture and during any extension under subclause (2) of this clause the State will not register any claim or grant any lease by which any person other than the Company will obtain under the laws relating to mining or otherwise any rights to mine or take natural substances within the Middleback Range area unless the Company's rights under this clause in relation to the area concerned have ceased as provided by subclause (5) of this clause, or unless the Company reports to the State that the area concerned does not contain iron ore or iron bearing substances required by the Company. The Company will, when requested by the State, furnish the State with such information as the Company is then able to furnish, on the question whether any area specified by the State contains iron ore or iron bearing substances required by the Company.

Right to leases in the Middleback Range area

5. (1) Upon application by the Company during any period provided for under clause 4 of this Indenture the State will grant to the Company or will procure the grant to the Company of mineral leases upon the terms provided for in this Indenture conferring upon the Company rights to mine for and obtain iron ore and other iron bearing substances from any land within the Middleback Range area specified by the Company in such application.

(2) Every mineral lease granted pursuant to this clause shall be for a period of 50 years from the date of the grant thereof with rights of renewal from time to time as provided by clause 13 of this Indenture.

(3) Subject to the provisions of this Indenture any such mineral lease shall be in the form or to the effect set out in the Appendix B hereto.

(4) Nothing in this Indenture shall limit any rights of the Company under the Mining laws of the State and upon application by the Company for leases or other rights in respect of metals, minerals and other natural substances (other than iron ore and iron bearing substances) within the Middleback Range area the State will grant to the Company or will procure the grant to the Company of such leases or rights in terms no less favourable than those provided for by the Mining laws of the State.

Iron ore and iron bearing materials discovered in reserved areas

6. (1) If prospecting by the State in a reserved area proves the existence of a worthwhile deposit of iron ore or iron bearing substances the State will as soon as practicable give the Company notice of the discovery of such deposit and any information in the possession of the State as to the deposit.

(2) Without in any way derogating from any other rights of the Company, after receipt of notice under subclause (1) of this clause the Company may apply to the State for such mineral or other leases as will enable the Company to prospect for mine or obtain iron ore or other iron bearing substances on or from such deposit or any part thereof.

(3) Upon any such application being made the State may in its discretion grant to the Company or procure the grant to the Company of mineral or other leases upon such terms as may be agreed upon between the State and the Company as being just and reasonable having regard to the matters set out in the recitals of this Indenture.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

Iron ore and iron bearing materials outside reserved areas

7. (1) Nothing in this Indenture shall in any way restrict any right of the Company under the Mining laws of the State or otherwise—

(*a*) to prospect for iron ore or other iron bearing substances in areas other than reserved areas; or

(*b*) to peg and register claims and be granted mineral and other leases over land in such areas.

(2) The Company may from time to time apply to the Minister of Mines[1] to make a declaration that any specified area not exceeding 50 square miles in which the Company is prospecting or is about to prospect for iron ore or iron bearing substances shall be an approved prospecting area for the purposes of this clause.

(3) The Minister[1] may, in his discretion, grant or refuse an application under subclause (2) but shall not capriciously refuse it.

(4) A declaration under this clause shall be made by written notice to the Company and shall remain in operation for a period fixed by the notice not exceeding four years. The period of operation may be extended by the Minister[1] from time to time for not more than four years at any one extension. The Minister[1] shall not capriciously refuse an application by the Company for an extension under this sub-clause.

(5) No proclamation reserving any land from the operation of all or any provisions of the Mining Act, 1930-1954[2], or of any Act amending or substituted for that Act, shall take away or restrict any right of the Company—

(*a*) to prospect within an approved prospecting area for iron ore and other iron bearing substances; or

(*b*) to peg out and register claims over land situated within an approved prospecting area and containing such ore and substances; or

(*c*) to be granted mineral leases over such land.

(6) Subclauses (2) to (5) of this clause shall not be deemed to derogate from any other rights of the Company under the Mining laws of the State or this Indenture.

(7) Subject to the provisions of this Indenture relating to royalties and labour conditions any mineral lease granted to the Company pursuant to this clause shall be in the form or to the effect set out in the Appendix B hereto.

Rent for mineral leases

8. (1) Notwithstanding the provisions of any mineral lease held by the Company at the time of the ratification of this Indenture or granted to the Company pursuant to this Indenture the Company shall during the period of twenty years after the ratification of this Indenture pay to the State as and by way of rent for all of such leases so held or granted the annual sum of £12,000[3] in addition to the rent fixed by any such lease.

(2) Upon the expiration of such period of twenty years the Company shall pay to the State the rental fixed by any such lease and no more.

Royalties

9. (1) Subject to subclauses (3) and (4) of this clause the Company shall pay to the Treasurer royalties in accordance with this Indenture on all iron ore and other iron bearing substances obtained by the Company from land comprised in mineral leases held by the Company at the time of the ratification of this Indenture or granted to the Company pursuant to this Indenture.

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[1] For interpretation of references in Acts, etc. to The Minister of Mines see s. 11 of Mining Act, 1971-1975

[2] The Mining Act, 1930, and its amendments have been repealed and superseded by the Mining Act, 1971, (now Mining Act, 1971-1975)

[3] In this Indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

(2) The rates of royalty shall be—

(*a*) eighteen pence[1] a ton on—

(i) each ton of high grade iron ore fed directly to furnaces in South Australia or shipped from South Australia without beneficiation; and

(ii) each ton of the dry weight of beneficiated iron bearing substances or iron concentrates fed to furnaces in South Australia or shipped from South Australia;

(*b*) sixpence[1] a ton on the dry weight of all jaspilite and of all other iron bearing substances of similar grade which without beneficiation are fed directly to furnaces in South Australia or shipped from South Australia.

(3) The said rates shall be substituted for the rates of sixpence[1] per ton payable on iron ore and other iron bearing substances under any of the leases of the Company in existence at the time of the ratification of this Indenture.

(4) The rate of royalty fixed by subclause (2) of this clause is related to a basis selling price by the Company of foundry pig iron of £21 7s. 6d.[1] per ton, c.i.f. Port Adelaide. If such basis selling price on the 30th day of June in any year exceeds or is less than £21 7s. 6d.[1] per ton, c.i.f. Port Adelaide the royalty payable under this clause shall be increased or decreased as the case may be by one penny[1] per ton on high grade iron ore and by one-third of one penny[1] per ton on jaspilite and other iron bearing substances of similar grade for each complete £1[1] of the increase or decrease of such basis selling price above or below £21 7s. 6d[1].

(5) In the event of the Company ceasing at any time to sell foundry pig iron at a price calculated with reference to the price per ton c.i.f. Port Adelaide nevertheless there shall be calculated by the Company a notional basis selling price per ton c.i.f. Port Adelaide as if the Company were selling foundry pig iron c.i.f. Port Adelaide and this shall be the basis selling price for the purposes of subclause (4) hereof.

Payment and computation of royalties

10. (1) The royalties payable under clause 9 of this Indenture shall be paid within two months after the end of each half-year ending on the 31st May or 30th November as the case may be.

(2) (*a*) For the purpose of computing the tonnage upon which royalty is payable the Company's weighbridge and weightometer records with any adjustments necessary to compensate for known errors in weighing shall be prima facie evidence of the matters contained therein.

(*b*) For the purpose of determining the moisture content of any beneficiated iron bearing substances or iron concentrates on the dry weight of which royalty is payable under this Indenture, the returns furnished by the Company shall be prima facie evidence of the matters contained therein.

(*c*) The State may at any time check and verify the calculations of the Company.

(3) In the months of December and June of each year the Company will furnish to the Minister of Mines[2] of the State—

(*a*) a return of all substances chargeable with royalty, fed directly to furnaces or shipped as aforesaid during the period of six calendar

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[1] In this indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint.

[2] For interpretation of references in Acts, etc. to The Minister of Mines see s. 11 of Mining Act, 1971-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentu
Act, 1958

months ending on the preceding 30th November or 31st May as the case may be;

(*b*) any other information reasonably required by the Minister of Mines' for the purpose of enabling him to compute the amount of royalty payable by the Company.

(4) The Minister of Mines' and his officers, servants and agents for the purpose of checking and verifying any such return shall during normal office hours have access to and the right of inspection of all books, papers and documents of the Company insofar as they relate to substances chargeable with royalty, and the right to enter and examine the lands comprised in the said leases.

Labour conditions of leases

11. Notwithstanding anything contained in the Indenture of 1937 or in the mining laws of the State the Company shall be deemed to have complied with the labour conditions of all the mineral or other leases held by the Company at the date of the ratification of this Indenture or which may be granted to the Company pursuant to this Indenture if the number of men horsepower and horses employed on any one or more of those leases is not less than the total number of men horsepower and horses required by the Mining laws of the State at the date of the ratification of this Indenture to be employed on all the said leases.

Raw materials other than iron

12. (1) As and when requested by the Company the State will in collaboration with the Company or otherwise carry out or procure the carrying out of prospecting and exploratory work in areas specified by the Company to locate suitable deposits of metals and minerals (other than iron ore and iron bearing substances) required by the Company for its operations generally.

(2) The Company will pay to the State the reasonable costs of any work under subclause (1) of this clause.

(3) On the application of the Company the State will grant to the Company or procure the grant to the Company of mineral or other leases or rights under the Mining laws of the State to enable the Company to mine for and obtain any such metals or minerals.

Renewals of mineral leases

13. (1) Notwithstanding any enactment, the Company shall be entitled to the renewal from time to time of any mineral lease granted to the Company (whether before or after the ratification of this Indenture) and under which the Company obtains materials which it deems essential for any operations of the Company at Whyalla or its steel-making operations generally.

(2) Each renewal shall be for a term of twenty-one years or any shorter term applied for by the Company.

(3) The State upon the application of the Company shall grant to the Company or procure the grant to the Company of any such renewal.

(4) Except as provided in subclause (5) of this clause, the terms, covenants, conditions and other provisions of a lease granted under this clause by way of renewal shall be the same as those of the renewed lease.

(5) By way of the renewal of a mineral lease granted to the Company before the ratification of this Indenture and under which the Company mines for iron ore or other iron bearing substances, a lease for twenty-one years in the form set out in the Appendix B hereto or as near thereto as practicable shall be granted to the Company.

* For interpretation of references in Acts, etc. to The Minister of Mines see s. 11 of Mining Act, 1971-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

(6) This clause shall not restrict the operation of any provision of any lease relating to the forfeiture thereof for breach or non-performance of any term, covenant or condition thereof.

Land for construction and operation of steel works

14. (1) If for the purpose of or in connection with the construction or operation of steel works the Company should require the fee simple of or any lease easement or other rights over any land comprised in any pastoral or other lease granted by the State, and the State or any authority under the State has power to resume such land the State shall at the request of the Company exercise or procure the exercise of such power to the extent necessary and transfer convey or assign to the Company or procure the transfer conveyance or assignment to the Company of the land, lease, easement or rights which the Company requires for the purposes aforesaid; but the Company shall pay to the State or other authority a reasonable price for such land, lease, easement or rights sufficient to cover the expenditure incurred by the State or other authority for or in connection with the resumption.

(2) If for any of the purposes mentioned in subclause (1) of this clause the Company requires the fee simple of or any rights over any Crown lands not subject to any lease or agreement the State will sell to the Company at such reasonable price as may be agreed the fee simple of that land or the other rights required by the Company over that land.

Purchase of Whyalla town water supply

15. The State will, not later than two months after the ratification of this Indenture in accordance with such arrangements as are agreed upon between the parties take over from the Company and operate the mains, pipes, meters, fittings and other works, plant and equipment owned by the Company and used for the reticulation of water within the area of the Whyalla Water District proclaimed under the Northern Areas and Whyalla Water Supply Act 1940.

Water for the company's operations

16. (1) The State will supply to the Company or to any subsidiary or associated company or procure the supply to such company of such amounts of water as such company requires from time to time—

(*a*) for the operations of any such company at Whyalla or within the Middleback Range area; and

(*b*) for local reticulation to the public at Iron Knob or elsewhere within the Middleback Range area if such reticulation is undertaken by any such company.

Provided that the State will not be obliged to supply more than 1,000 million gallons per annum unless the Company notifies the State in writing that it requires a supply from the Morgan-Whyalla pipeline in excess of 1,000 million gallons per annum, in which case the State will procure that within a period of three years from the date of such notice being given to it there will be available to the Company the whole of its requirements in excess of 1,000 million gallons per annum.

(2) Delivery of water to the Company for consumption or use at Iron Knob or elsewhere in the Middleback Range area may at the option of the Company be taken either at a point on the said Morgan-Whyalla pipeline or elsewhere.

(3) The price to be paid for water delivered to the Company or to a subsidiary or associated company at any point on the Morgan-Whyalla pipeline or at Whyalla shall be the basic price set out in subclause (5) of this clause or such lower price as is charged by the Minister of Works pursuant to any law for the time being in force.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

(4) The price to be paid for any water delivered to the Company or to a subsidiary or associated company elsewhere than at a point on the Morgan-Whyalla pipeline shall be the basic price plus the following amounts :—

(*a*) Such proportion of the interest and sinking fund on capital expenditure incurred by the State in constructing a branch pipeline and incidental works to convey water from the Morgan-Whyalla pipeline to the point of delivery, as is attributable to water delivered to the Company or to the subsidiary or associated company as the case may be:

(*b*) Such proportion of the cost of maintenance and repairs of the branch pipeline and incidental works, and of overhead expenses incurred in connection therewith as is attributable to water delivered to the Company or to the subsidiary or associated company as the case may be; and

(*c*) The cost of pumping the water delivered to the Company or to the subsidiary or associated company as the case may be from the Morgan-Whyalla pipeline to the point of delivery.

(5) For the purpose of this clause the basic price of water shall be :—

	Per Thousand Gallons.	
	s.	*d.*[1]
For all water up to the first 300 million gallons per year of supply	2	4
For all water above 300 million gallons and up to 420 million gallons per year of supply	2	3
For all water above 420 million gallons and up to 540 million gallons per year of supply	2	2
For all water above 540 million gallons and up to 600 million gallons per year of supply	2	1
For all water above 600 million gallons per year of supply	2	0

Option of company to construct a main

17. (1) Without in any way derogating from the obligations of the State under this Indenture the Company may—

(*a*) construct a water main from a point on the Morgan-Whyalla pipeline to a point or points in the Middleback Range area; or

(*b*) request the State to construct such a water main on behalf of and at the expense of the Company.

The junction of such water main with the Morgan-Whyalla pipeline shall be at a place convenient to the Company and approved by the Minister of Works, which approval shall not be unreasonably withheld.

(2) At the request of the Company the State will grant to the Company or procure the grant to the Company of such easements or other rights as the Company may reasonably require for the purpose of constructing repairing or maintaining such a water main or doing anything necessary for such purpose.

(3) The Company will if the State so desires sell water to the State from the said water main for reticulation to retail consumers at a price to be agreed between the Company and the State.

[1] In this indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

Quality of water

18. The water to be delivered to the Company under this Indenture shall be potable water in the condition in which it is drawn from the River Murray and without filtering, treatment or change except such change (if any) as necessarily occurs during the transmission of the water from the River Murray to the point of delivery to the Company.

Minimum payment for water

19. (1) Subject to subclause (2) of this clause, the Company shall pay the Minister of Works on the first day of each quarter in each year of supply the sum of £6,000[1] for water supplied or to be supplied during that quarter.

(2) If during any year of supply the sum payable by the Company pursuant to this Indenture for water delivered to the Company exceeds £24,000[1], the Company shall within one month after the end of that year of supply pay to the Minister of Works the amount by which such sum exceeds £24,000[1]. Provided that if in any year of supply during a triennial period the sum payable by the Company pursuant to this Indenture for water delivered to the Company is less than £24,000[1], and in any subsequent year of supply during the same triennial period the sum payable by the Company pursuant to this Indenture for water so delivered is more than £24,000[1], then the amount by which the sum payable by the Company in the earlier year of supply was less than £24,000[1] shall be carried forward to the credit of the Company and set off against any sum or sums in excess of £24,000[1] payable by the Company in any such subsequent year of supply Provided also that in respect of each triennial period the Company shall not be obliged to pay more than £72,000[1], or the price of the water delivered to it during that period whichever is the greater.

(3) In this clause—

"year of supply" means the period of twelve months commencing on the 1st day of May in any year;

"triennial period" means a period of three years commencing on the 1st day of May 1959, or on the corresponding day in any third year thereafter;

"quarter" means the period of three months commencing on the 1st day of May August November and February in any year.

Measurement of water

20. (1) The Minister of Works shall measure all water delivered to the Company under this Indenture by a suitable meter or meters.

(2) The Minister of Works shall, during each month, give the Company a written notice of the amount of water shown by the meter or meters as having been delivered to the Company during the previous month. The notice shall be conclusive evidence of the amount of water delivered in the month to which it relates unless it is disputed as provided in this clause.

(3) The Company may within one month after receipt of any such notice, give the Minister of Works a written notice that it disputes the correctness of the amount of water shown in the notice given by the Minister of Works, and that it requires the meter or meters to be tested.

(4) The Minister of Works shall on the receipt of such notice, test the meter or meters by passing through it or them, into a receptacle of known capacity, sufficient water to fill that receptacle or any part thereof of known capacity. The Company shall if so required by the Minister of Works permit him to use without payment, for the purpose of a test under this subclause,

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EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

any dam or reservoir of the Company which is suitable for that purpose, and can conveniently be so used.

(5) If on such test it appears that any meter is not measuring correctly the water actually delivered, the amount of water shown in the disputed notice and in any subsequent notice given by the Minister of Works prior to the test shall be altered by the Minister of Works so as to show the true amount of water delivered, and the liability of the Company shall be adjusted accordingly. Thereafter, if the meter is not corrected or replaced, due allowance for the error shall be made in each monthly notice showing the amount of water delivered to the Company.

(6) The Company may, at its own expense, install a meter or meters at any convenient point in the pipe from which water is delivered to the Company. The readings of any such meter shall be for the information of the Company, but shall not be binding on the Minister of Works unless he agrees to accept them, with or without adjustments, as correct.

(7) The Minister of Works may, without any request from the Company, at any time test any meter installed by him for the purpose of measuring the water delivered to the Company, and the Company shall if so required by the Minister of Works permit the Minister of Works to use for the purpose of the test any dam or reservoir of the Company which is suitable for that purpose and can conveniently be so used.

Electricity

21. The State will facilitate the making of a just agreement between the Company and the Electricity Trust of South Australia providing for the following matters :—

(*a*) The erection of a high-tension electricity transmission line from the Trust's power stations at Port Augusta to Whyalla;

(*b*) The taking over from the Company by the Trust in accordance with such arrangements as are agreed between the Company and the Trust of the assets of the Company used for the reticulation of electricity at Whyalla;

(*c*) The supply to the Trust at the request of the Trust of electricity generated by the Company and the supply by the Trust to the Company at the request of the Company of the electricity required by the Company; and

(*d*) Securing to the Company the right to generate electricity for its own requirements or for supply to any subsidiary or associated company and to charge for any such supply.

Housing

22. (1) The Company will from time to time during the construction of steel works or of any extensions of the Company's undertaking at Whyalla inform the State of the number of houses which in the Company's opinion will be required for employees (other than the senior staff) of the Company and of any subsidiary or associated company at Whyalla.

(2) The State will build or procure the building of the number of houses required for such employees, and give such employees the opportunity to purchase or become tenants of such houses on reasonable terms and conditions; Provided however that the State will not be obliged to build or procure the building of more than 400 houses in any one year.

(3) The State will arrange consultations between the Company and the South Australian Housing Trust for the purpose of securing the provision of houses under this clause.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

Labour

23. The State will, so far as its powers and administrative arrangements permit, assist the Company to obtain adequate and suitable labour as required for the construction and operation of steel works.

Use of sea water

24. The Company or any subsidiary or associated company may without payment—

(*a*) draw from the sea in the vicinity of Whyalla all sea water which is required for its operations at Whyalla; and

(*b*) construct on any land which such company has the right to use or occupy or on the sea bed, any works which it requires for the purpose of obtaining, pumping and delivering such water.

Use and reclamation of foreshore and sea bed

25. (1) The Company shall have the right to use and occupy the foreshore and sea bed within the area described in subclause (3) of this clause and to deposit substances thereon so as to reclaim the foreshore, sea bed, or any part thereof from the sea.

(2) On the application of the Company, the State will without payment grant or cause to be granted to the Company the fee simple of any land which, whether as a result of reclamation or otherwise, is above high water mark and is within the area described in subclause (3) of this clause.

(3) The area referred to in this clause is the land shown on the plan set out in the Appendix C hereto being the land bounded as follows :—

Commencing at the south-eastern corner of section 27, Hundred of Cultana; thence generally north-easterly along high water mark to its intersection with a straight line drawn from the northernmost corner of section 2 of the said Hundred at a southern angle of 135 degrees with the north-western boundary of said section 2; thence south-easterly along the production of latter line to low water mark; generally south-westerly along said low water mark to its intersection with the north-eastern boundary of the land contained in perpetual licence No. 319A, Register Book Volume 1013 Folio 20; thence southerly by a straight line to the north-eastern corner of the land contained in perpetual licence No. 319, Register Book Volume 512 Folio 105; north-westerly along the north-eastern boundary of latter licence to high water mark aforesaid; thence generally northerly along said high water mark to the point of commencement, together with the coast reserves adjoining part section 19, Hundred of Randell, and section 2, Hundred of Cultana.

Works area to remain outside town

26. The following areas, namely :—

(*a*) the land comprised in Certificates of Title Register Book Volume 1804 Folio 179, Volume 2035 Folio 189, Volume 1093 Folio 115, and Volume 2035 Folio 190;

(*b*) the land comprised in perpetual lease 12974, Register Book Volume 916 Folio 16;

(*c*) any land north or east of the Company's tramway which the Company or any subsidiary or associated company acquires for use or uses as the site of any works; and

(*d*) any land in the Middleback Range area the freehold of which the Company or any subsidiary or associated company acquires for

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act , 1958

use as the site of any works and which at the time of acquisition is outside the area of any municipality or district council district

shall be outside the area of the Whyalla Town Commission[1] and shall not be constituted as or included in a municipality or district council district as defined in the Local Government Act 1934-1954[2] or any re-enactment or amendment thereof and shall not be declared or included in any water district under the Waterworks Act 1932-1936[3] or any re-enactment or amendment thereof. Provided that nothing in this clause shall prevent the Company or any subsidiary or associated company from being liable to pay for water supplied by measure: Provided further that if any of the said land is disposed of by the Company or by the subsidiary or associated company and used for residential purposes this clause shall cease to apply to the land so disposed of and used.

Construction of bridges and crossings

27. (1) The Company may construct bridges, level crossings, tunnels or cuttings by which the Whyalla to Iron Knob tramway may cross the Port Augusta-Whyalla road at a place or places in the vicinity of the Company's works or for other purposes in connection with the operation of steel works or the operations of any subsidiary or associated companies.

(2) The places and nature of such bridges, crossings, tunnels or cuttings and the details of construction thereof shall be approved by the Commissioner of Highways which approval shall not be unreasonably withheld.

Railway to Whyalla

28. If it is decided that the Commonwealth of Australia or any instrumentality thereof or the State should construct a railway line connecting Whyalla with either the South Australian or the Commonwealth railway systems the State will—

(*a*) use its best endeavours to facilitate such construction and will grant all necessary rights and powers for that purpose; and

(*b*) consult with the Company or arrange consultations between the Commonwealth and the Company as to the route of any such railway in the neighbourhood of the Company's land at Whyalla and as to the location of the terminal of any such railway at Whyalla.

Charges in respect of wharves and jetties

29. No charges or imposts other than those payable by the Company at the date of the ratification of this Indenture shall be imposed on the Company or on any subsidiary or associated company in respect of the use or occupation of any wharves or jetties constructed by the Company or by any subsidiary or associated company at or near Whyalla or on the shipment or carriage of goods to over or from the said wharves and jetties or on the ships engaged in the shipment thereof.

Prices

30. The State will not at any time by legislation, regulation, order or administrative action under any legislation of the State as to prices, prevent products produced in South Australia by the Company or by any subsidiary or associated company from being sold at prices which will allow the Company or subsidiary or associated company to provide for such reasonable depreciation, reserves and return on the capital employed in the production of those products as are determined by such company.

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[1] For interpretation of references to the Whyalla Town Commission see Part XIVA of Local Government Act, 1934-1975

[2] Now Local Government Act, 1934-1975

[3] Now Waterworks Act, 1932-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

Assignment

31. (1) With the consent of the State, the Company may assign—

(*a*) any right, power, benefit, or privilege conferred on the Company by this Indenture;

(*b*) any mineral or other lease held by the Company at the date of the ratification of this Indenture or acquired by the Company pursuant to this Indenture.

(2) A person to whom any such right, power, benefit, privilege or lease is assigned may, with the consent of the State, further assign it.

(3) The Company may, with the consent of the State, cause any of its obligations or duties under this Indenture to be performed by any other company, but notwithstanding such consent the Company shall remain liable for any failure to perform such obligations or duties.

(4) The State shall have a discretion to grant or refuse its consent to any assignment of rights, powers, benefits, privileges or leases under this clause or to the performance of any of the Company's obligations or duties by another company but shall not unreasonably withhold such consent.

Subsidiary and associated companies

32. The Company will, whenever requested by the State so to do, furnish the State with a list of subsidiary and associated companies as defined in clause 2 of this Indenture showing the interest of the Company in such subsidiary and associated companies and the State may, for the purposes of this Indenture, rely and act upon any list so furnished by the Company.

Extension of the Indenture of 1937

33. (1) The Indenture of 1937 shall by mutual agreement between the parties hereto be read and construed as if—

(*a*) the expression "the term of this Indenture" and the definition thereof contained in paragraph (*b*) of clause 1 of the Indenture of 1937 were omitted; and

(*b*) the words "upon the expiration of the term of this Indenture" in clause 4 thereof were omitted; and

(*c*) the words "during the term of this Indenture" were omitted from clauses 14, 15 and 16 thereof; and

(*d*) no limitation of time were contained in clause 17 thereof.

(2) No limitation of time shall be implied in clauses 7, 8, 9, 10, 11, 12 and 13 of the Indenture of 1937.

Notices

34. (1) Any notice consent or application authorized or required by this Indenture to be given or made shall be given or made in writing.

(2) Any notice consent application or other writing authorized or required by this Indenture to be given or made by the State shall be deemed to have been duly given or made if signed by a Minister and forwarded by prepaid post to the registered office of the Company in South Australia or its office at Whyalla.

(3) Any notice consent or application or other writing authorized or required by this Indenture to be given or made by the Minister of Mines[1] the Minister of Works, the Commissioner of Highways, the South Australian Housing Trust or the Electricity Trust of South Australia shall be deemed to have been duly given or made if signed by such Minister or Commissioner, or by the Chairman of the South Australian Housing Trust or of the Electricity Trust of South Australia, as the case may be, and forwarded by prepaid post

[1] For interpretation of references in Acts, etc. to the Minister of Mines see s. 11 of Mining Act, 1971-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act , 1958.

to the registered office of the Company in South Australia or its office at Whyalla.

(4) Any notice consent application or other writing authorized or required by this Indenture to be given or made by the Company shall be deemed to have been duly given or made if signed on behalf of the Company by the Managing Director General Manager Secretary or Attorney of the Company and forwarded by prepaid post—

(*a*) in the case of any notice consent application or other writing concerning the prospecting or mineral rights of the Company under this Indenture to the Minister of Mines[1] of the State;

(*b*) in the case of any notice consent application or other writing concerning the supply of water under this Indenture to the Minister of Works;

(*c*) in the case of any notice consent application or other writing under this Indenture not otherwise provided for in this indenture or in this clause to the Treasurer of the State.

(5) Any notice consent application or other writing forwarded by prepaid post as provided for in this clause shall be deemed to have been duly given on the day on which it would be delivered in the ordinary course of post.

Preservation of rights

35 (1) Subject to the due observance by the Company of its obligations under this Indenture the State shall at all times take all necessary steps to secure to the Company and to each subsidiary and associated company the rights powers and privileges provided for in this Indenture or the Indenture of 1937 and to prevent them from being impaired disturbed or prejudicially affected in any way whatsoever. Provided that no tax payable by the Company or by any subsidiary or associated company or in respect of the property of any such company under any public general Act of the Parliament of the State at rates not exceeding those applicable generally throughout the State shall be deemed to impair disturb or prejudicially affect any right of the Company or of the subsidiary or associated company.

(2) No person other than the Company or a subsidiary or associated company shall acquire any right under the Mining laws of the State over any land occupied by the Company or by any subsidiary or associated company for the operations of such company, save with the consent of such company.

Labour at Whyalla

36. (1) This Indenture is made on the assumption that subject to the provision of adequate housing at Whyalla sufficient labour will be obtainable by the Company under conditions prescribed by the relevant industrial orders or awards to enable the Company both to carry on effectively the activities which it carries on at Whyalla at the time of the execution of this Indenture and to construct and operate steel works.

(2) Without in any way altering the effect of the foregoing provisions of this Indenture if at any time sufficient labour is not available for the purpose and under the conditions mentioned in subclause (1) of this clause the State will, at the request of the Company confer with the Company as to the obligations of the parties under this Indenture with a view to agreeing upon such variations thereof as are necessary or appropriate under the circumstances.

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[1] For interpretation of references in Acts etc. to The Minister of Mines see s. 11 of Mining Act 1971-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act , 1958

IN WITNESS whereof this Indenture has been executed by His Excellency the Lieutenant-Governor of the State and by the Company.

His Excellency the Lieutenant-Governor of South Australia caused the public seal of the State to be hereto affixed, and signed this Indenture on the fourth day of September, 1958, in the presence of:
M. A. F. PEARCE

J. M. NAPIER
Lieutenant-Governor

Public Seal of the State.

THE COMMON SEAL OF THE BROKEN HILL PROPRIETARY COMPANY LIMITED was hereunto affixed on the twenty-second day of August, 1958, in the presence of:

C. Y. SYME
Director.

E. LEWIS
Director.

R. G. NEWTON
General Manager
Commercial.

Seal of Company.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

BROKEN HILL PROPRIETARY COMPANY'S STEEL WORKS
INDENTURE ACT 1958

APPENDIX 'A' TO THE INDENTURE

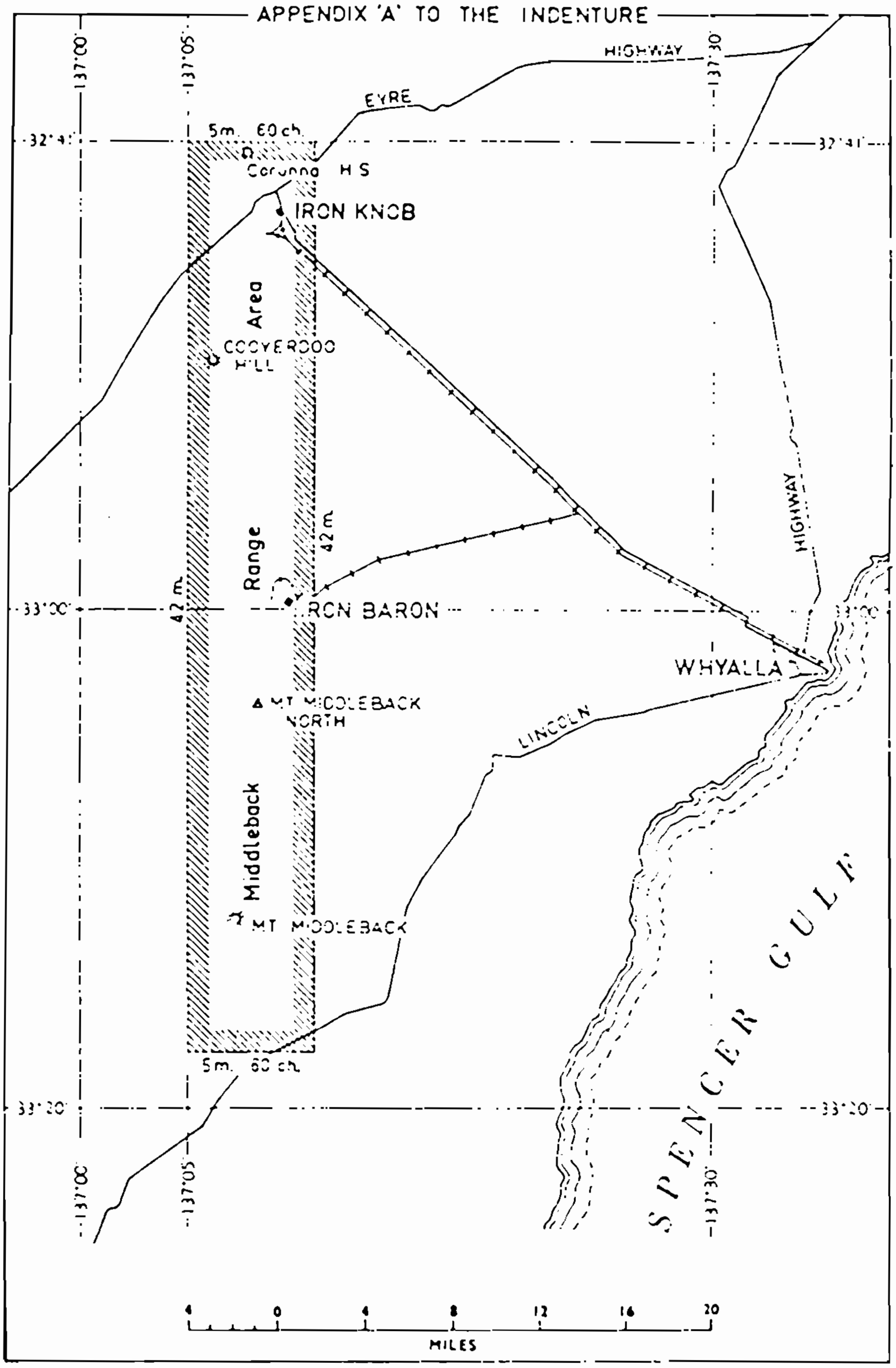

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

APPENDIX B TO THE INDENTURE

South Australia

Crown Lease

(Mineral No.)

HIS EXCELLENCY THE GOVERNOR in and over the State of South Australia in the Commonwealth of Australia in conformity with and in exercise of the powers and authorities conferred upon him by the Mining Act 1930-1955[1] and the "Broken Hill Proprietary Company's Steel Works Indenture Act 1958" (hereinafter referred to as "the Indenture Act") and of all other powers enabling him in that behalf doth hereby lease to THE BROKEN HILL PROPRIETARY COMPANY LIMITED of Melbourne in the State of Victoria (hereinafter referred to as "the lessee" which expression shall include its successors and assigns) all that piece of land containing acres or thereabouts and situate and being in the said State as the same is delineated in the public maps deposited in the office of the Department of Mines in the City of Adelaide and in the plan in the margin hereof and therein coloured together with all ways waters water courses privileges and appurtenances to the same now belonging or therewith occupied or enjoyed.

Including in such lease during its continuance the following rights and liberties for the lessee and the lessee's agents servants and workmen in and upon the said land:—

(1) To search work mine for win obtain and treat for the lessee's own use and benefit all metals and minerals except gold in or upon the said land; and

(2) For or incidental to the purposes aforesaid in or upon the said land:—

(*a*) To cut and construct races drains dams reservoirs roads and tramways; and

(*b*) To erect offices buildings works and machinery; and

(*c*) To erect dwellings for use by the lessee and the lessee's agents servants and workmen for the purpose of residence,

and all other necessary or convenient powers authorities privileges and advantages for all or any of the purposes aforesaid

subject to the provisions of the Mining Acts 1930-1955[1] and regulations made thereunder and of the Mines and Works Inspection Act 1920-1957[2] and all regulations made thereunder save insofar as any such provisions are modified or affected by the Indenture Act and subject to such rights interests and authorities as may be lawfully subsisting in the said land at the date of this lease: *Except and always Reserved* out of this lease all gold and other substances not being metals or minerals in or upon the said land and all persons authorized by the said Acts and regulations shall have full and free liberty of access ingress egress and regress with or without horses cattle carts drays carriages motor cars engines and machinery and all other necessary implements and things into upon and from the said land or any part or parts thereof for all reasonable purposes and to search work mine for win and obtain gold and other substances not being metals or minerals in or upon the said land

[1] The Mining Act, 1930, and its amendments have been repealed and superseded by the Mining Act, 1971 (now Mining Act, 1971-1975)
[2] Now Mines and Works Inspection Act, 1920-1974

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

and for or incidental to those purposes the rights and liberties mentioned in the preceding paragraph (2): *And also Excepting and Reserving* to all pastoral lessees (if any) of the said land a right of access and user for domestic purposes and for the purposes of watering stock to and of any surface water on the said land which shall not have been provided or stored by artificial means by the lessee.

To hold the said land with the appurtenances (except and reserved and subject as aforesaid) unto the lessee from the day of 19 for and during the term of fifty (50) years from thence next ensuing for the purpose of mining therein and thereon for all metals and minerals except gold together with the rights and liberties hereinbefore granted but for no other purpose and with the right to the lessee to the renewal from time to time for periods of 21 years on the same terms and conditions as those contained in this lease including this right of renewal.

Yielding and paying therefor unto the Governor the following rent and other sums:—

(1) A rent of £[1] payable yearly and every year in advance on the first day of in each year during the said term and any renewal thereof.

(2) A further sum amounting to—

(*a*) eighteen pence[1] a ton on—

(i) each ton of high grade iron ore fed directly to furnaces in South Australia or shipped from South Australia without beneficiation; and

(ii) each ton of the dry weight of beneficiated iron bearing substances or iron concentrates fed to furnaces in South Australia or shipped from South Australia;

(*b*) sixpence[1] a ton of the dry weight of all jaspilite and of all other iron bearing substances of similar grade which without beneficiation are fed directly to furnaces in South Australia or shipped from South Australia.

The sums payable under this paragraph (2) are related to a basis selling price by the lessee of foundry pig iron of £21 7s 6d.[1] per ton c.i.f. Port Adelaide. If such basis selling price on the thirtieth day of June in any year exceeds or is less than £21 7s. 6d.[1] per ton c.i.f. Port Adelaide the payments under this paragraph (2) shall be increased or decreased as the case may be by one penny[1] per ton on high grade iron ore and by one third of one penny[1] per ton on jaspilite and other iron bearing substances of similar grade for each complete one pound[1] of the increase or decrease of such basis selling price above or below £21 7s. 6d[1]. In the event of the lessee ceasing at any time to sell foundry pig iron at a price calculated with reference to the price per ton c.i.f. Port Adelaide nevertheless there shall be calculated by the lessee a notional basis selling price per ton c.i.f. Port Adelaide as if the lessee were selling foundry pig iron c.i.f. Port Adelaide and this shall be the basis selling price for the purposes of this paragraph (2).

For the purpose of computing the tonnage upon which such further sums are payable the weighbridge and weightometer records of the lessee with any adjustments necessary to compensate for known errors

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[1] In this indenture the amounts of money expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act, 1958 in weighing shall be prima facie evidence of the matters contained therein.

For the purpose of determining the moisture content of any beneficiated iron bearing substances or iron concentrates on the dry weight of which such further sums or part thereof are payable the returns furnished by the lessee shall be prima facie evidence of the matters contained therein.

(3) A further sum amounting to two and one half per centum of the gross amounts realised from the sale of all metals and minerals other than iron ore or iron bearing substances which shall be obtained from the said land, or such other sum as may be agreed upon between the Minister of Mines[1] (hereinafter referred to as "the Minister") and the lessee.

The further sums mentioned above in paragraphs (2) and (3) shall be paid within two months after the end of each half year ending on the 31st day of May or the 30th day of November as the case may be.

And the lessee doth hereby covenant with the Governor in manner following that is to say:—

1. That the lessee will during the said term pay or cause to be paid to the Minister[1] at the office of the Department of Mines in the City of Adelaide on behalf of the Governor the rent and further sums hereby reserved at the times and in the manner hereinbefore appointed for payment thereof free and clear of all rates, taxes impositions outgoings and deductions whatsoever:

2. That the lessee will pay and discharge all rates taxes assessments impositions and outgoings which during the said term shall become payable in respect of the said land:

3. That the lessee will maintain in position during the said term the posts and trenches or piles of stone required by the said regulations to be erected or cut on the said land when the same was pegged out as a claim and in addition thereto will paint legibly on such posts the number of this lease:

4. That the lessee will during the said term make construct and work all mines and do and perform all things authorized by this lease in a fair orderly skilful and workmanlike manner:

5. That the lessee will during the said term employ and keep constantly employed not less than one man for every 10 acres in mining or prospecting for all metals and minerals except gold in or upon the said land and will whenever thereunto required by the Minister[1] furnish him with satisfactory evidence that such number of men have been and are so employed due allowance being made by the Minister[1] for machinery or horses employed at the rate of two men for each horse or horsepower of machinery and provided that if the number of men horsepower and horses employed by the lessee on any one or more of the mineral leases held by the lessee is not less than the total number of men horsepower and horses required to be employed by the lessee on all the mineral leases held by the lessee the lessee shall be deemed to have complied with this covenant:

6. That the lessee will make such provision for the disposal of the silt sludge dirt waste or refuse which may be brought out of the said mines and premises so that the same will not flow or find its way into any stream brook

[1] For interpretation of references in Acts, etc. to The Minister of Mines see s. 11 of Mining Act, 1971-1975

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

river or water channel or so as to injure or interfere with any land set apart for water supply purposes:

7. That the lessee will build and keep in proper repair a sufficient and substantial stone wall or other fence around all the pits and shafts which may at any time during the said term be open in any part of the said land for the purpose of this lease so as effectually to prevent all access thereto by all kinds of stock:

8. That the lessee will whenever lawfully required so to do at the lessee's own cost and in manner required by any regulations for the time being in force in that behalf cause to be made a survey of the said land and cause to be forwarded to the said Department of Mines a map or plan of such survey:

9. That the lessee will at all times during the said term keep and preserve the said mines in good order repair and condition and in such good order repair and condition at the end or other sooner determination of the said term deliver peaceable possession thereof and of the land hereby leased unto the Governor or the Minister[1] or to some officer authorized by him or them to receive possession thereof:

10. That the lessee will permit the pastoral lessee (if any) of the said land at all times to have free access and user for domestic purposes and for the purposes of watering stock to and of any surface water on the said land which shall not have been provided or stored by artificial means by the lessee:

11. That the lessee will report to a warden when gold precious stones coal shale oil salt gypsum or other minerals other than iron ore or iron bearing substances are found in payable quantities in or upon the said land:

12. That the lessee will not during the continuance of the said term without the written consent of the Minister[1] first had and obtained use or occupy or permit to be used or occupied the said land except for the purpose of exercising the rights and liberties hereinbefore granted:

13. That the lessee will not prevent any person who holds a right privilege or authority under the said Acts and regulations or any amendment thereof from exercising the same:

Provided always and it is hereby agreed and declared in manner following:—

14. That it shall be lawful for the Governor or the Minister[1] or any person authorized by him or them at all proper and reasonable times during the said term without any interruption from the lessee or the lessee's agents servants or workmen to enter into and upon the said land and into and upon any mines or works that may be found therein to view and examine the condition thereof and whether the same be worked in a proper skilful and workmanlike manner and for such purpose to make use of any of the railroads or other roads or ways machinery and works belonging to the said mines and to examine and take extracts from all books accounts vouchers and documents relating thereto:

15. That if the said rent be not paid on or before the day hereinbefore appointed for payment thereof a penalty of five pounds per centum[2] shall be

[1] For interpretation of references in Acts, etc. to The Minister of Mines see s. 11 of Mining Act, 1971-1975.

[2] In this indenture the amounts of money and the percentage expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indenture Act, 1958

added to the said rent and if the said rent and penalty be not paid within one calendar month after the said day a further penalty of ten pounds per centum[1] shall be added and if the said rent and penalties be not paid within one calendar month after the said first month the same shall be recoverable by the Minister[2] by action in any court of competent jurisdiction:

16. That if the lessee shall during the said term commit any breach of or shall fail to comply with any covenant condition or proviso herein contained this lease shall be liable to forfeiture in manner hereinafter provided:

17. That if the Minister[2] has reason to believe that there has been a breach of or non-compliance with any of the covenants conditions or provisos herein contained the Minister[2] shall give written notice to the lessee specifying the covenants conditions or provisos which he has reason to believe are not being complied with and notifying the lessee that this lease will be liable to forfeiture at the expiration of one month from the date of such notice unless in the meantime such covenants conditions or provisos are duly complied with and if at the expiration of such notice such covenants conditions or provisos are still not being complied with by the lessee the Governor may cancel this lease notwithstanding that the rent payable under this lease for the period during which such breach is committed may have been paid and notwithstanding any implied waiver of such breach by the Governor and the Minister[2] shall thereupon insert a notice in the *Government Gazette* declaring this lease to be forfeited:

18. That a notice of forfeiture so published in the *Government Gazette* shall be taken to be conclusive evidence that this lease has been legally cancelled and forfeited:

19. That in case this lease shall become liable to forfeiture the Minister[2] may extend the period during which the lessee may perform the covenants conditions and provisos of this lease for such time and subject during such period of extension to such terms and conditions as the Minister[2] may think fit:

20. That the lessee shall be at liberty to surrender this lease by giving to the Minister[2] three calendar months' notice in writing of the lessee's desire or intention so to do and upon payment of all arrears of rent up to the date of surrender:

21. And lastly that the lessee shall be at liberty to remove from the said land at any time within—

(*a*) three months after the date of forfeiture or surrender of this lease any improvements plant machinery engines or tools;

(*b*) six months after the date of forfeiture or surrender of this lease any metals and minerals except gold won by the lessee stacked upon the said land but shall not remove or interfere with any timber in any mine upon the said land.

[1] In this indenture the amounts of money and the percentage expressed in the old currency have not been converted to decimal currency as some of those amounts have no exact equivalents in decimal currency and it would be inappropriate to alter them in this reprint.

[2] For interpretation of references in Acts etc. to The Minister of Mines see s. [illegible] of Mining Act, 1971-1975.

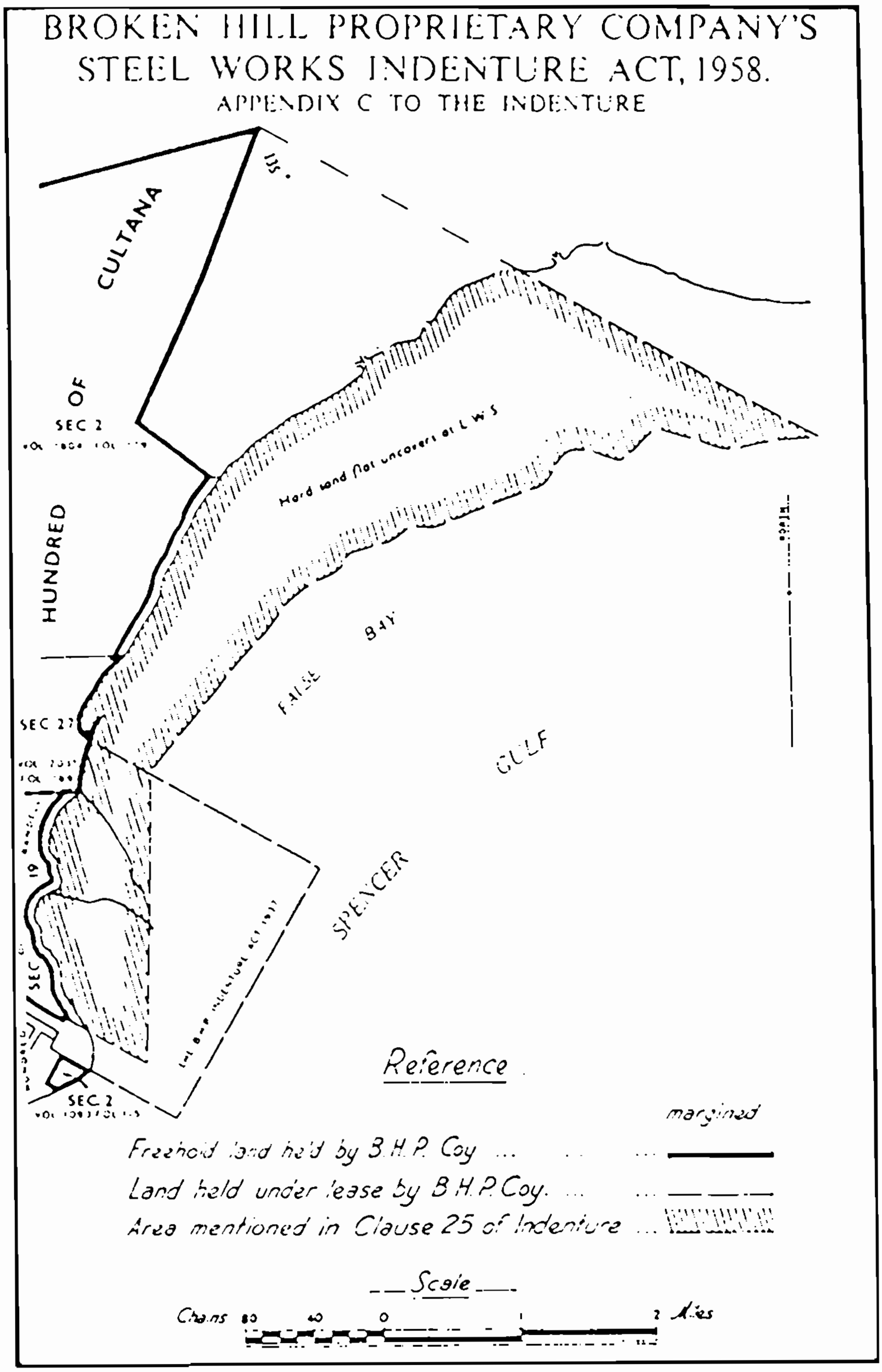
<u>EXHIBIT "26"</u> - South Australian Broken Hill Proprietary Company Steel Works Indenture Act , 1958

1661

IN WITNESS WHEREOF this lease has been executed by His Excellency the Governor of the State and by the Company.

His Excellency the Governor of South Australia caused the public seal of the State to be hereto affixed on the day of 19 .	.... Governor.
THE COMMON SEAL OF THE BROKEN HILL PROPRIETARY COMPANY LIMITED was hereunto affixed on the day of 19 in the presence of:	.... Director. .... Director. .... Secretary.

EXHIBIT "26" - South Australian Broken Hill Proprietary Company Steel Works Indentur Act , 1958



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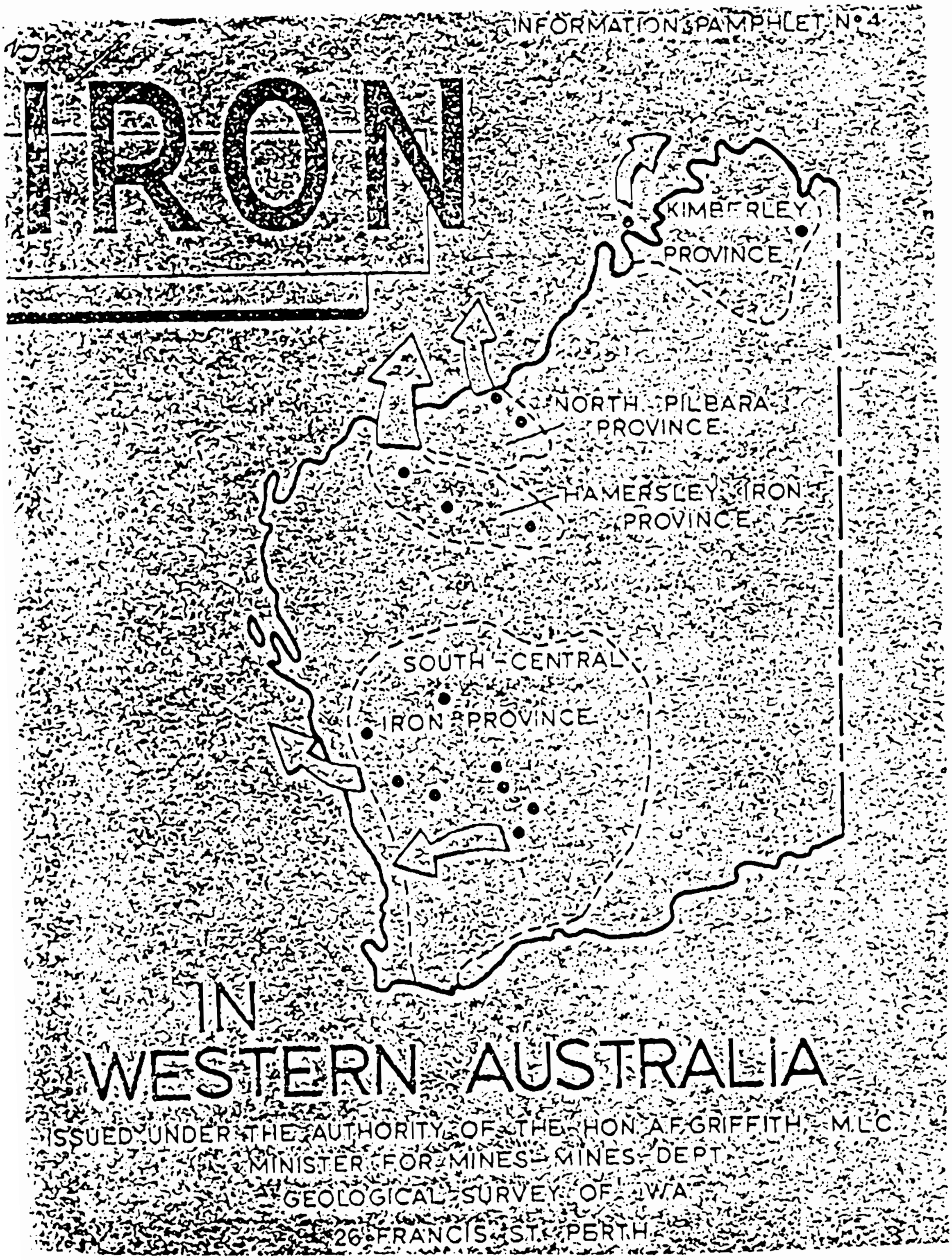

EXHIBIT "27" - Two Pamphlets entitled "Iron Ore" published by the Geological Survey of Western Australia, 1966 (copy) and 1983

FOREWORD

This series of Information Pamphlets is issued at irregular intervals by the Geological Survey of Western Australia, to meet a popular demand for information on topical geological subjects.

The pamphlets are available from this office free of charge. For further information the reader should call or write to the Geological Survey Branch of the Mines Department.

26 Francis Street,
PERTH.

J. H. LORD
Director.

15th October, 1966

INFORMATION PAMPHLETS

(1) How and where to look for Copper.

(3) How and where to look for Tin.

(4) Iron in Western Australia.

1

EXHIBIT "27" - Two pamphlets entitled "Iron Ore" published by the Geological Survey of Western Australia, 1966 (copy) and 1983

IRON ORE IN WESTERN AUSTRALIA

Iron, in its various forms of steel, pig iron, cast-iron, wrought iron, and various alloys is the most extensively utilized metallic element, in the earth's crust. In the more developed countries, such as those of Western Europe, North America and Australasia, approximately half a ton of steel is produced annually per head of population. This figure is rising with each year that passes despite the substitution of other metals and plastics for iron in some fields.

Next to aluminium, iron is the most abundant metallic element in the earth's crust. Practically all rocks contain iron to some degree, but in only a few types is the iron sufficiently concentrated and in such a state of chemical combination for the material to serve as an iron ore.

Iron ore is a low value mineral product; valued at the mine between 8 and 10 $A. per ton, and can only be produced economically in large quantities. The development of an iron ore field is primarily dependent upon the existence of a large tonnage of suitable ore, but there are numerous other important factors which must be

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considered. Firstly, suitable markets must exist either for the ore or the iron and steel products. Mining and transport costs from the deposits to the seaport or industrial area are crucial, as are the geographical relationships of the iron ore to deposits of limestone and coal which are used in the smelting of the ore. In the past many low-grade ore deposits have been worked because the above conditions have been satisfactorily fulfilled, whilst many high-grade deposits of large tonnage have lain idle because of lack of markets or unfavourable location.

Between 1951 and 1964, annual iron ore production throughout the world increased from 140 million tons to over 500 million tons, a fourfold increase in 15 years. This trend seems certain to continue with increasing demand for iron and steel in both the developed and under-developed countries. By 1975 it is anticipated that the total annual world requirement of iron ore will be of the order of 1,000 million tons.

This tremendous increase in the utilization of iron has completely changed the position of iron ore as a world trade commodity. Up to 1950 most iron ore was produced in the countries that had their own iron and steel industries. The increased exploitation of the favourably situated deposits has threatened their rapid depletion and short term exhaustion. Consumers have been obliged to seek and develop deposits of iron ore in other countries, which themselves have become major exporters of iron ore with a production far in excess of the requirements of their own local industries. Countries which have become major iron ore producers and exporters are Brazil, Venezuela, Peru, Chile, Liberia, and Mauretania. These countries produce iron ore solely for export. Other major exporting countries which have their own iron and steel industries but which export more than they consume are Sweden, Canada and India. Australia will shortly be entering this category in the iron ore trade. Up to the present Australia has produced iron ore only for her own industry, but by 1970 will be exporting about 75 per cent of the total iron ore produced within the Commonwealth.

ECONOMIC IRON ORE MINERALS

Despite the wide distribution of iron in

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	Chemical composition	Percent iron
Magnetite	Fe_3O_4	72.4
Hematite	Fe_2O_3	69.9
Goethite	$Fe_2O_3 \cdot H_2O$	62
Limonite	Mixture of hydrated iron oxides	Variable (50 - 60)
Siderite	$FeCO_3$	48.2

In natural deposits, the percentages shown in the above table are rarely attained, due to the presence of impurities such as silica (quartz), alumina, sulphur, phosphorus and manganese. Hematite ores are the most widely utilized and many of the major hematite deposits of the world can be mined at a grade of better than 60 per cent iron. Magnetite ores are extensively mined in Sweden, where the magnetite occurs as large high grade deposits. In Canada, magnetite-quartz rocks, known as taconites, are mined on a large scale as beneficiable ore. Magnetite can be separated cheaply from the quartz impurity by magnetic separation after crushing.

The iron and steel industry of Western

Europe was founded on the utilization of low-grade carbonate ores averaging about 35 per cent iron. The close association of these ores with deposits of limestone and coking coals permitted the large scale development of such deposits.

The Lake Superior Region of the United States is characterized by hematite ores averaging about 50 per cent iron. This has been the most productive iron ore region in the world and has yielded over 3,000 million tons of ore during the past century.

The Australian iron and steel industry is based on the high-grade hematite ores of the Middleback Ranges in South Australia and the hematite ores of Yampi Sound in Western Australia. These two areas currently produce over 5 million tons of iron ore per annum and large reserves remain in these deposits to satisfy local requirements for many years to come.

Western Australia possesses tremendous reserves of high-grade hematite ores. The distribution and nature of these deposits are outlined in the succeeding sections.

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PROCESSING AND SMELTING OF IRON ORE

Many of the high-grade hematite ores can be used directly for pig iron production after crushing to appropriate size specifications. Other ores, although of satisfactorily high grade for direct smelting, must be altered in physical properties before reduction. Many hematite ores are friable, such as those of Yampi Sound, and the ore must be sintered or agglomerated into coherent lumps of the correct size before being fed into the furnace.

The nature and proportion of the impurities in the ore is also of great importance. For easy fluxing in the furnace, the proportion of silica should exceed that of alumina. Phosphorus and sulphur are two impurities with which the steelmaker is most concerned and most iron ore contracts have rigid specification limits on these two components. Most iron ore used throughout the world, and certainly all used in Australia, contains less than 0.1 per cent of sulphur and phosphorus.

Many ores are up-graded or beneficiated before reduction. Low-grade magnetite ores can be

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up-graded by magnetic separation, and some ores by gravity concentration of the heavier iron oxide particles. Pelletizing of iron ore is becoming increasingly common. In this process the ore is finely ground, dehydrated and mixed with bentonite or some similar balling agent, to form small pellets which after sintering are of uniform size and physical properties. This process is applied to fines obtained during the crushing of lump ores or in dealing with ores that contain a high content of hydrated iron oxides. In North America it is now common practice to crush and beneficiate low-grade siliceous magnetite ores and then pelletize the iron rich magnetitic fraction to give a furnace feed comparable in grade to a natural high-grade lump ore.

In the blast furnace a mixture of iron ore, coke and limestone flux in the approximate ratio of 100 parts iron ore (60% Fe), 50 parts coke and 15 parts limestone, is heated by a stream of hot air which causes the coke to burn and liberate carbon monoxide which reduces the iron oxides of the ore to metallic iron. The molten iron is tapped at regular intervals from the base of the furnace, and additional charge of ore, coke and limestone fed in at the top. Blast furnaces often operate continuously for years. The average furnace capacity is about 2000 tons of raw feed of the composition described above and such a furnace would be capable of producing 1,800 tons of pig iron in an operating day of 24 hours.

Pig iron from the blast furnace contains about 4 per cent of carbon and is high in sulphur, phosphorus and manganese. These impurities must be removed from the pig iron to make steel. This is normally done in an open hearth furnace in which the pig iron is re-melted and heated to high temperatures. The excess carbon is oxidized from the steel and the other impurities are absorbed in the floor of the furnace, which is suitably lined with materials which will react with and retain the undesired constituents. Limestone is added to the charge to flux the metal and form a slag which also absorbs much of the unwanted impurities of the steel. The open hearth furnaces are also used to make alloy steels. Additional elements such as nickel, chromium, molybdenum and many others can be added to produce an alloy steel of specified composition.

DISTRIBUTION OF IRON ORES IN WESTERN AUSTRALIA

The highest grade iron ore deposits in the world occur in association with, and are derived from, a particular group of sedimentary rocks. In different countries these rocks are known variously as banded iron formation, jaspilites, hematite quartzites, taconites or itabirites but all are essentially the same rock type.

The iron formations are characterized by an initial high iron content of between 20 and 40 per cent iron in the form of magnetite or hematite, finely interbanded with quartz and carbonate minerals. These rocks occur only in the ancient Precambrian zones of the earth's crust and are not found in later geological epochs.

The banded iron formations are prone to enrichment. When favourable geological conditions occur, the silica and carbonate content of the rocks can be selectively removed either by groundwaters or by fluids derived from granite intrusions, to leave a residue sufficiently rich in iron to constitute an economic iron ore deposit. Iron formations serve as the hosts of practically all the major hematite deposits in the world.

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In Western Australia the banded iron formations are widespread and abundant in the extensive Precambrian areas of the State. They fall into two age groups. Firstly, there are the older Archaean iron formations which are most abundant in the south-central area of the State and in the Pilbara Archaean nucleus. These have been dated at between 2,400 million and 2,300 million years old. Secondly, there are the younger iron formations associated with rocks of lower Proterozoic age in the Hamersley Range Area. These are between 2,000 million and 2,200 million years old.

The Archaean iron formations have been strongly folded and intruded by granites and other igneous rocks. High temperatures and pressures and the influence of fluids derived from the near-by granites, have served to metamorphose the iron formations. In many zones, high-grade hematite lenses have been formed due to solution and mobilization of the iron in the original iron formation and subsequent redeposition of this iron as massive high-grade ore bodies.

Although essentially similar in original composition to the Archaean iron formations, the

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Proterozoic iron formations have not been metamorphosed by heat and pressure. Nevertheless, large iron deposits have been developed through the agency of groundwaters operating over a long period of geological time. These waters are capable of slowly leaching silica and carbonate minerals from the iron formations, and leaving a residue rich in hematite and goethite or other hydrated oxides of iron.

The Proterozoic iron formations in the Hamersley Range are the site of the principal iron deposits in Western Australia. Total reserves of high-grade ore in this region are measurable in thousands of millions of tons.

The hematite deposits in the islands of Yampi Sound, Kimberley Division, are also of Proterozoic age but are associated with a different and virtually unique type of iron formation. The Yampi ores appear to be the product of direct sedimentary deposition of iron oxides, and are not due to later processes of enrichment such as have produced the hematite ores of the central and southern parts of the State.

Four distinct iron ore provinces can be recognized in Western Australia. These are listed

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hereunder and their extent is shown on the accompanying map (inside rear cover):

1. South-central Iron Province
2. Hamersley Iron Province
3. North Pilbara Iron Province
4. Kimberley Iron Province

The principal deposits of each of these provinces, are briefly described in the following sections.

[illegible]

In this section of the State banded iron formations occur within narrow elongated belts of sedimentary and volcanic rocks surrounded by granite. The iron formations are resistant to erosion and normally form prominent sinuous ridges that can be followed for many miles.

The densest concentration of iron ore deposits is found in the sedimentary belt lying east and north of Southern Cross in the Yilgarn Goldfield. The important deposits of Koolyanobbing are situated in a range of hills about 35 miles northeast of Southern Cross. These iron ores are currently mined to supply ore for the charcoal

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iron and steel industry at Wundowie. They have been accurately assessed by The B. H. P. Co. and are ultimately scheduled for use in the iron and steel industry to be constructed at Kwinana in 1968. Proven reserves exceed 50 million tons of hematite-limonite ore averaging slightly over 60 per cent iron.

At Mt. Bungalbin, thirty miles north of Koolyanobbing, there are several large hematite-limonite ore bodies which are also leased to The B. H. P. Co. Pty. Ltd. Reserves in these deposits are comparable to those of Koolyanobbing.

Forty miles west of Mt. Bungalbin, in the same sedimentary belt, there are the important hematite deposits of Mt. Jackson, which have been tested by Western Mining Corporation. Reserves of ore in these lenses probably amount to at least 30 million tons.

A further group of hematite lenses, containing a high proportion of massive high-grade hematite with more than 65 per cent iron, occurs at North Windarling, about 20 miles north of Mt. Jackson.

Many smaller occurrences of hematite ore are scattered throughout the Yilgarn. The total

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reserves of ore in the area are of the order of 200 million tons, an ample quantity to supply the requirements of the projected local steel industry for many years to come. The Yilgarn deposits, although far from the coast, are conveniently close to the new standard gauge railway, which has been routed to pass the Koolyanobbing ore deposits.

Smaller hematite deposits occur near the western side of the Archaean zone at Tallering Range, Koolanooka, and Mt. Gibson. The Tallering and Koolanooka deposits are under development for export to Japan commencing in 1966 with a contract for the sale of over 5 million tons of ore. Although small, the deposits are comparatively close to existing railways and the port of Geraldton.

Many other iron ore occurrences in the Archaean area are known, but most of these are too far from the coast to be of any immediate economic interest. The hematite deposits of the Weld Range (30 million tons) and Mt. Gould (15 million tons), must be included in this category.

All the abovementioned deposits occur in association with banded iron formations, and are the products of enrichment by various processes.

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In the extreme southwestern corner of the State at Scott River, near Augusta, another type of iron ore deposit occurs which is the result of lateritization. Iron has been dissolved from ferruginous sandstones and has been re-deposited close to the surface as thin but extensive cappings of low-grade lateritic iron ore containing between 30 and 40 per cent iron. This material is unusable in its present form but could be upgraded to a sponge iron. These deposits are only a few miles from the coast and may be utilized in the future.

THE HAMERSLEY IRON PROVINCE 10

The Hamersley Iron Province is situated in the North-West Division of the State and includes a thick succession of gently to moderately folded sediments and volcanic rocks. From the point of view of iron deposits, the most important members of this sedimentary succession are three thick and remarkably persistent banded iron formations which extend over an area of about 30,000 square miles.

All three iron formations have been locally enriched to form zones of high-grade hema-

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tite ore. The total reserves of hematite have been estimated at 8,000 million tons. In addition there is a comparable tonnage of lower-grade limonite ore derived by enrichment of scree and detrital material from the iron formations. The Hamersley Province is one of the great iron ore provinces in the world and in the future will supply the bulk of Australian iron ore exports. Contracts have been negotiated for the sale of over 200 million tons of ore from this area alone. Production is scheduled to commence in 1966.

The most important known hematite deposits of the Hamersley Province are those of Mt. Tom Price, with reserves of 300 million tons and Mt. Whaleback, with reserves of 330 million tons. In these deposits there is a high proportion of high-grade lump hematite ore containing up to 68 per cent iron. This is direct shipping ore which after crushing can be used as furnace feed without further processing. These deposits, and many others, contain hundreds of millions of tons of hematite-goethite ore containing between 50 and 65 per cent iron, which is readily amenable to beneficiation.

The limonite ores have a lower iron con-

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tent, (about 55 per cent) than the hematite deposits, but the principal impurity is combined water. Tests have shown that this material is particularly suitable for beneficiation. A large scale pelletizing project is planned to treat this ore in the Robe River area of the Hamersley Province where this type of ore is abundant.

The resources of the Hamersley Iron Province are virtually unlimited as far as direct shipping and beneficiable iron ores are concerned, and it seems destined to become one of the principal iron ore producing regions in the world.

The Hamersley ores are considered to have originated as a result of groundwaters progressively leaching impurities from the iron formation and upgrading it to nearly pure iron oxides. A feature of the province is the large extent of some of the deposits. The Mt. Tom Price ore body is 4 miles long, up to 4,000 feet wide and, in places nearly 400 feet thick. Many other ore zones of comparable dimensions have been recognized.

NORTH PILBARA IRON PROVINCE

The Archaean rocks of the Pilbara nucleus

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contain similar types of iron ore deposits to those in the South-Central Iron Province. Banded iron formations occur interbedded with metamorphosed sediments and volcanic rocks, and this assemblage has been intruded by granite.

The most important iron deposits in this region are those of Mt. Goldsworthy where reserves approaching 30 million tons of hematite ore have been proven. The main ore lens at Mt. Goldsworthy extends to at least 300 feet below plain level and the deposit is located along the plane of a major fault. This fault has apparently served to channel the movements of iron-bearing solutions and the rocks on either side of the fault plane have been replaced by hematite. Adjoining the main ore lens at Mt. Goldsworthy are zones of lower grade hematite-goethite ore which have resulted from surface enrichment of the banded iron formation.

Other important hematite deposits in the Pilbara are those of Mimingarra, Shay Gap, Yarrie, Strelley Gorge, and the Ord Range. The Mt. Goldsworthy deposits are being developed for export and the ore will be shipped from Port Hedland.

Total ore reserves in the North Pilbara province amount to at least 150 million tons of hematite ore.

THE PROTEROZOIC KIMBERLEY IRON PROVINCE

The most important iron deposits in the northern area of the State are those of Cockatoo Island and Koolan Island at Yampi Sound. The iron ores in these deposits appear to be the product of direct sedimentation, rather than enrichment of pre-existing sediments. The ore bed forms a distinct sedimentary unit in a surrounding succession of quartzite, shale, and conglomerate, and attains a very high grade of over 65 per cent iron. Hematite is the principal ore mineral.

Production of iron ore commenced at Cockatoo Island in 1951 and annual production is of the order of 1½ million tons. The large deposit on the neighbouring Koolan Island was brought into production in 1965. Reserves of ore in both islands exceed 70 million tons.

Few iron ore deposits in the world are more favourably located for mining and shipment as those of Yampi Sound. At Cockatoo Island the ore bed, which is about 60 feet thick, forms a steep cliff along the side of the island and large

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vessels can be berthed almost against the actual ore body in deep water on the protected side of the island. At Koolan Island the ore body is only a few hundred yards from the deep water of the sound. Yampi ores, although hard at the surface, are friable at depth and require sintering before reduction.

Hematite deposits of similar character and geological environment to those of Yampi Sound have been investigated in other areas of the Kimberley Division. The largest of these occurs 10 near Pompey's Pillar, about 30 miles south of Wyndham. The hematite rich ore bed is preserved as an erosion remnant along the summit of a high range for about 8 miles. The ore bed is between 15 and 40 feet thick over the greater part of this distance. The ore is more variable and generally lower in grade than that of Yampi. A similar bed of hematite occurs in the Bandicoot Range near Kununurra.

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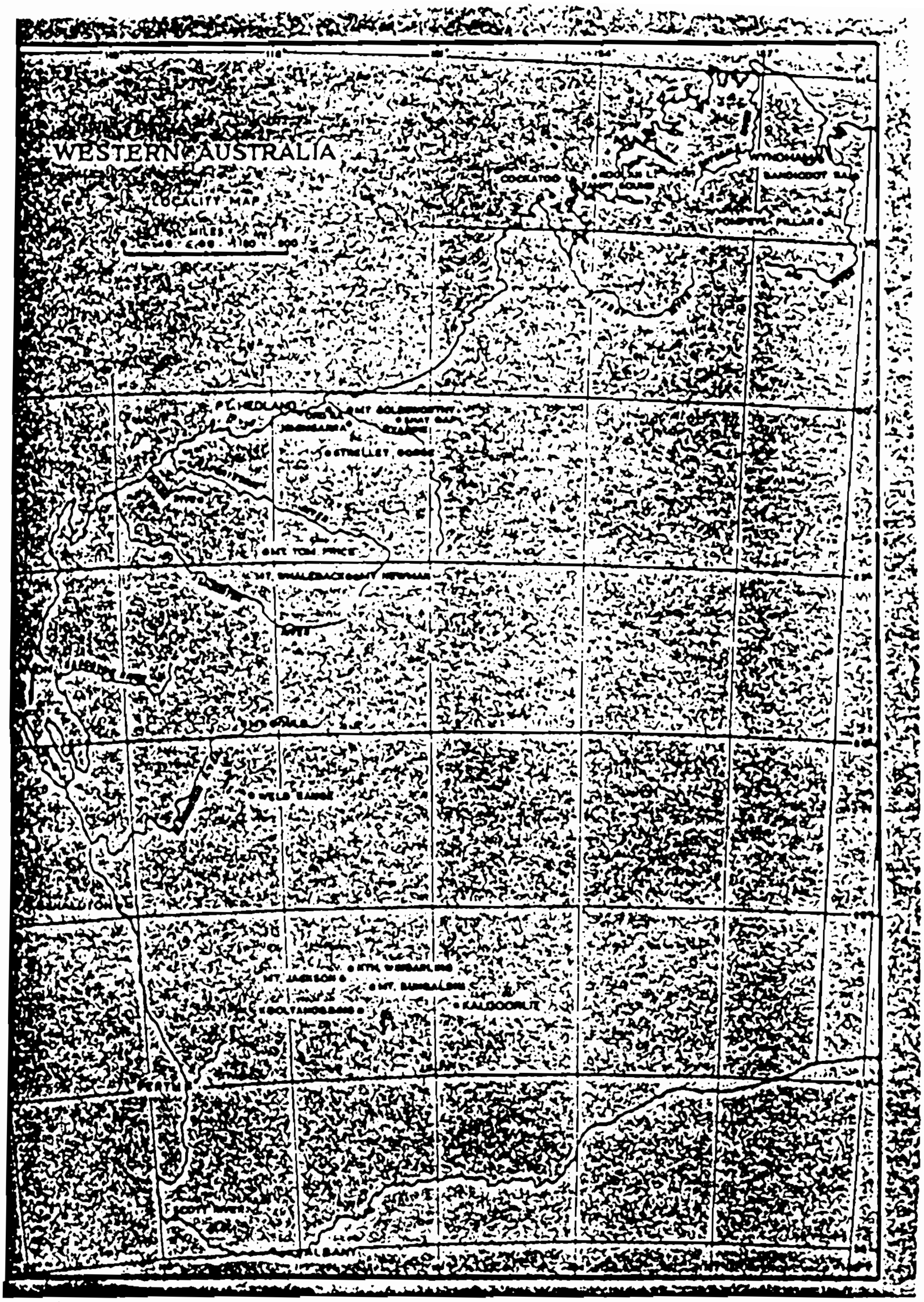

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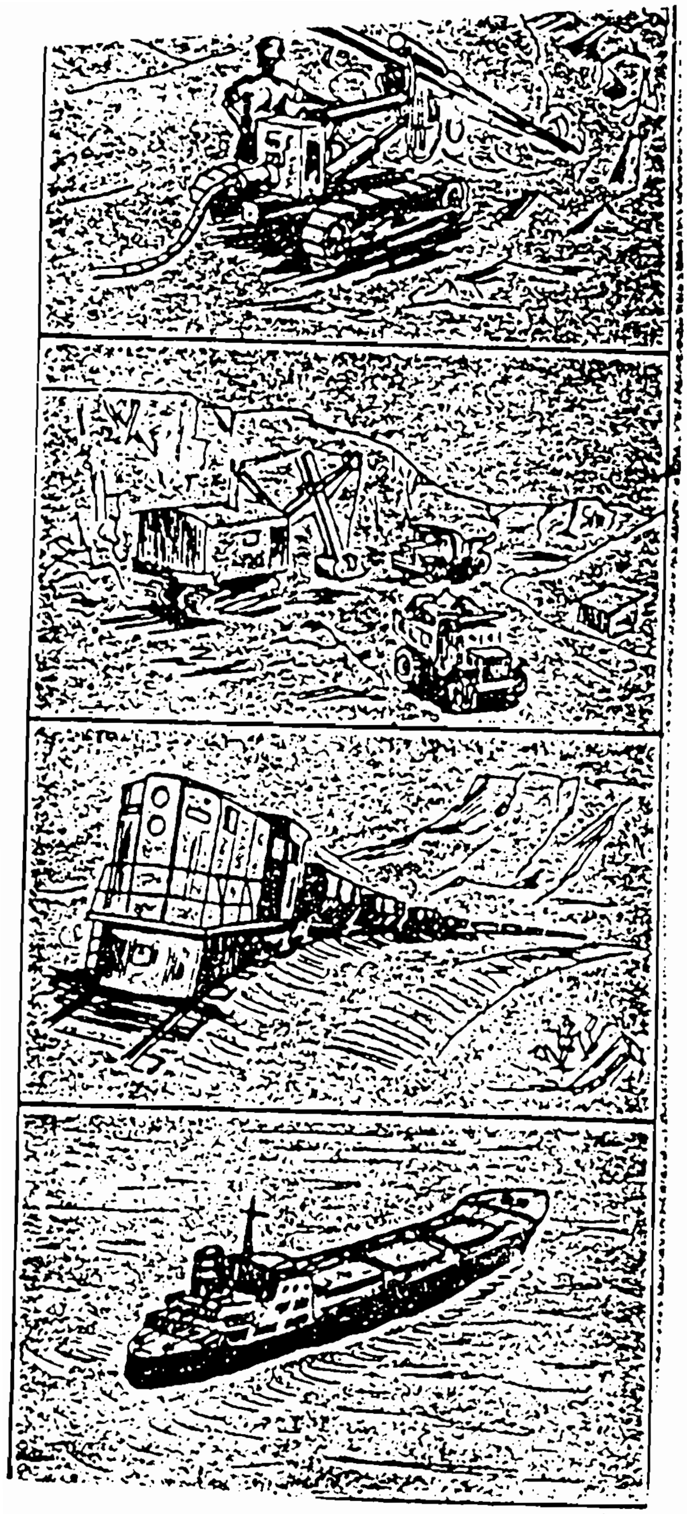

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IRON ORE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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IRON ORE

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FOREWORD

Information Pamphlets are issued at irregular intervals by the Geological Survey to meet popular demand for general information on topical subjects. Copies of the pamphlets and further information are available from this office.

A F Trendall
DIRECTOR

Mineral House
66 Adelaide Terrace
Perth W.A. 6000

INTRODUCTION

Iron is used in greater quantities than any other metal. In Japan and in the developed countries of western Europe, North America, and Australasia, approximately 0.7 tonnes of steel is produced annually per head of population. This figure is rising with each year that passes despite the substitution of other metals and plastics in some applications. Such is the importance of iron to society that historians and archaeologists have named the period beginning about 1000 BC – when the technique of smelting iron ore first made its appearance – the 'Iron Age'.

To be sure, some artefacts, dating from around 2000 BC, have been found in Egypt. As iron was then a rarity, it was used for jewellery and, occasionally, for special weapons. Chemical analyses indicate that this iron was obtained from meteorites, some of which are composed of an iron-nickel alloy. Apparently the Egyptians, while able to forge the metal, had not mastered the art of smelting iron ores. By 400 BC, iron ores were being smelted at a number of centres around the Mediterranean, and by the Middle Ages, iron was in widespread, if not common, use throughout Europe, Asia, and Africa.

During the 16th Century primitive forms of the modern blast furnace began to appear in northern Europe, these produced, as blast furnaces still do, a material called pig iron, which is a mixture of iron, carbon, and slag. Pig iron itself is of little use, it may be melted to form cast iron or treated in special furnaces that remove the impurities to produce steel, which in its simplest form is an iron-carbon alloy.

The large-scale manufacture of steel is, however, a fairly recent development. Until the middle of the 19th Century, when the Bessemer Converter was developed, most pig iron was converted to wrought-iron by the simple process of hammering red-hot billets to squeeze out impurities. The wrought iron produced in this way has approximately the same overall composition as mild steel, but because of the manufacturing process, it has a laminated or fibrous structure and a non-homogenous composition. Although used extensively until the end of the 19th Century, wrought-iron has now been superseded by mild steel in most applications.

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The first serious attempt to establish an iron industry in Australia appears to have been made at the Fitzroy Works near Mittagong NSW between 1848 and 1855. Although technically successful, the project failed for economic reasons, as did the several attempts to reactivate the Fitzroy Works or to establish another smelter near Lithgow NSW. It was not until 1915 that a successful large-scale iron works was established at Newcastle NSW by the Broken Hill Proprietary Company Ltd. Coking coal was obtained near Newcastle, but the iron ore was shipped from Iron Knob in South Australia.

The Iron Age did not reach Western Australia until 1948, when a small state-owned plant was established at Wundowie. This plant obtained ore from Koolyanobbing and used charcoal, which was made on site, as a fuel and reducing agent. The plant was probably never more than marginally profitable and has recently been sold to private interests for conversion to other purposes. Western Australia entered a new phase of the iron industry in 1951, when the first ore was shipped from Cockatoo Island. This marked the beginning of an ore-exporting industry, further details of which are given below.

After aluminium, iron is the most abundant metallic element in the earth's crust. Most rocks contain iron to some degree, but in only a few is the iron sufficiently concentrated and in a suitable state of chemical combination for the material to serve as an iron ore. Native iron, that is, naturally occurring metallic iron, is virtually unknown except in meteorites.

Iron ore is a low-value mineral product; it realizes (1981) about $ 18 a tonne and can only be produced economically on a large scale. Thus, the development of an iron-ore field is primarily dependent upon the existence of a large tonnage of suitable ore, but there are numerous other important factors which must be considered. First, markets must exist, either for the ore, or the iron and steel products that may be produced. The cost of mining and transport from deposit to seaport or industrial area is crucial to the development of a deposit, as is the geographical relationship of the iron ore to deposits of limestone and coal, which are used in the smelting of iron ore. In the past, many low-grade ore deposits have been worked because the above conditions have been satisfactorily fulfilled; on the other hand, many high-grade deposits of large tonnage have lain idle because of lack of markets or unfavourable location.

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Between 1960 and 1970 the iron-ore production of the world increased by about 30%, however, this increase has slowed, and in the 10 years between 1970 and 1980, world production rose from about 740 million tonnes to about 870 million tonnes, an increase of only about 15%. By 1990 it is anticipated that the total annual world requirement of iron ore will be of the order of 980 million tonnes.

This jump in the consumption of iron has completely changed the position of iron ore as a commodity. Up to 1950, most iron ore was produced in countries that had their own iron and steel industries. The rapid exploitation of these favourably situated deposits threatened their ultimate depletion.

Consumers were obliged to seek and develope deposits in other countries, countries which have since become major exporters and produce much in excess of their own requirements. These major iron-ore producers and exporters are: Australia, Brazil, Venezuela, Peru, Chile, Liberia, and Mauretania. Most of them produced iron ore initially for export, but, in the case of Brazil and Venezuela, iron ore has also recently formed the basis of a rapidly expanding steel industry.

Other major exporting countries, which have their own iron and steel industries but which export more than they consume, are Sweden, Canada, South Africa, and India. Australia became a major exporter in 1966, when exports began from Koolanooka, Mount Goldsworthy and Mount Tom Price. Before that, Australia had produced iron ore mainly for domestic consumption. In 1980, it exported about 15% of the total iron ore produced in the western world and became, along with Brazil, the largest supplier to western world markets.

ORE MINERALS

Despite the wide distribution of iron in nature, comparatively few minerals are used as ores. The principal ore minerals are as follows.

	Chemical composition	*Contained iron (%)*
Magnetite	Fe_3O_4	72.4
Hematite	Fe_2O_4	69.9
Goethite	$Fe_2O_3.H_2O$	62
Limonite	Mixture of hydrated iron oxides	Variable (50–60)
Siderite	$FeCO_3$	48.2

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In natural deposits, the percentages shown in the above table are rarely attained because of the presence of impurities such as silica, alumina, sulphur, phosphorus, and manganese. Hematite ores are the most widely used, and many of the major hematite deposits of the world can be mined at a grade of better than 60% iron. Magnetite ores are extensively mined in Sweden, where magnetite occurs in large high-grade deposits. In the U.S.A., magnetite-quartz rocks, known as taconites, are mined on a large scale as beneficiable ore. Magnetite can be separated cheaply from the quartz impurity by magnetic separation. In Canada, low-grade, free-milling hematite-quartz deposits are mined and upgraded to salable concentrates by a simple gravity separation.

The iron and steel industry of Western Europe was founded on low-grade carbonate - hydrated oxide ores which contained about 30% iron. The close association of these ores with deposits of limestone and coking coal permitted large-scale development of such low-grade deposits.

Hematite ores in the Lake Superior region of the United States averaged about 50% contained iron. This region has been the most productive in the world and has yielded over 3 000 million tonnes of ore during the past century. The deposits have been largely worked out, and over 90% of the production of the region now comes from the upgrading of taconites.

The Australian iron and steel industry is based on the high-grade hematite ores of the Middleback Ranges in South Australia and the hematite ores of Yampi Sound, Koolyanobbing, and Mount Whaleback in Western Australia. However, part of the Yampi Sound production and most of the Mount Whaleback production is exported as ore. There are ample reserves of iron ore in Australia to satisfy local requirements for many decades to come.

PROCESSING AND SMELTING

Many high-grade hematite ores can be used directly for the production of pig iron after crushing to an appropriate size. Other ores, although of a satisfactory grade, must be altered in physical properties before smelting. Many hematite ores, such as those of Yampi Sound, are friable and the ore must be sintered or agglomerated into coherent lumps of a suitable size before being fed into a blast furnace.

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The nature and proportion of the impurities in the ore are also of great importance. For easy fluxing in the furnace, the proportion of silica should exceed that of alumina. Phosphorus and sulphur are the two impurities with which the steelmaker is most concerned, and most iron-ore contracts have rigid specification limits on these two components. Most iron ore used throughout the world, and certainly all used in Australia, contains less than 0.1% of combined sulphur and phosphorus.

Many ores are upgraded or beneficiated before reduction. Low-grade magnetite ores can be upgraded by magnetic separation; some others can be upgraded by gravity concentration of the heavier iron oxide particles. Pelletizing of fine iron ore is common, but the increasing cost of fuel in recent years has restricted the use of this technique. In this process, the ore is finely ground, dehydrated, and mixed with bentonite or some similar balling agent, to form small pellets which, after being hardened, are of uniform size and of suitable physical properties. This process is applied to fines obtained during the crushing of lump ores, or in dealing with ores that require fine grinding to liberate the particles of iron mineral, as in North America, where it is now common practice to pelletized the beneficiated low-grade siliceous magnetite ores mentioned previously.

In a blast furnace, a mixture of iron ore, coke, and limestone flux, in the approximate ratio of 100 parts iron ore (60% Fe), 50 parts coke, and 15 parts limestone, is heated by a stream of hot air. This causes the coke to burn and liberate carbon monoxide, which, in turn, takes up oxygen from the ore minerals thus reducing the ore to impure metallic iron. This molten pig iron is tapped from the base of the furnace at regular intervals, and additional charges of ore, coke, and limestone, are fed in at the top. Blast furnaces often operate continuously for years. The average furnace capacity is about 7 000 tonnes of raw feed of the composition described above, and such a furnace is capable of producing about 6 000 tonnes of pig iron in an operating day of 24 hours, although more efficient, large, modern blast furnaces have a capacity of 10 000 tonnes a day.

Pig iron from a blast furnace contains about 4% carbon and is rich in sulphur, phosphorus and manganese. These impurities must be removed from the pig iron to make steel. This is commonly done in a basic

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oxygen furnace, where the pig iron is heated to high temperatures and re-melted. The excess carbon is oxidized from the pig iron, and the other impurities are absorbed at the bottom of the furnace. Limestone is added to the charge to flux the metal, which has now become steel, and to form a slag, which absorbs much of the unwanted impurities.

Alloy steels of specified compositions are usually produced in electric-arc furnaces by the addition of various elements such as nickel, chromium or molybdenum, to a batch of molten steel.

DISTRIBUTION OF IRON ORES IN WESTERN AUSTRALIA

The highest grade iron-ore deposits in the world occur in association with, and are derived from, a particular group of sedimentary rocks. In different countries these rocks are known variously as banded iron-formation, jaspilite, hematite quartzite, taconite or itabirite, but all are essentially the same rock type.

Iron-formations initially contain 20-40% of iron in the form of magnetite or hematite that is finely interbanded with quartz and carbonate minerals. Such iron-formations occur only in Precambrian rocks.

Banded iron-formations are subject to natural enrichment. When favourable geological conditions occur, the silica and carbonate content of the rocks can be selectively removed either by groundwater or by hot fluids that emanate from granite-like intrusions. This leaves a residue sufficiently rich in iron to constitute an economic iron-ore deposit. Iron-formations are the hosts for practically all major hematite deposits in the world.

In Western Australia, banded iron-formations are common. They fall into two age groups: Archaean iron-formations are most abundant in the south-central area of the State and in the Archaean Pilbara Block, and have been dated at between 2 700 million and 3 500 million years old, and younger iron-formations, of Early Proterozoic age, which occur in the Hamersley Range area and which are about 2 500 million years old.

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The Archaean iron-formations have been strongly folded and intruded by granites and other igneous rocks. High temperatures and pressures, and the chemical action of hot fluids from nearby granites, have altered these iron formations. High-grade hematite lenses have been formed by the dissolution and mobilization of the iron in the iron-formation, and its subsequent redeposition as massive high grade iron oxide.

Although similar in original composition to the Archaean iron-formations, the Proterozoic iron-formations have not been metamorphosed by heat and pressure. Nevertheless, large iron-ore deposits have been developed through the agency of groundwater operating over a geologically long period. Groundwater is capable of slowly leaching silica and carbonate minerals from the iron-formation and leaving a residue rich in hematite and goethite or other hydrated oxides or iron.

The Proterozoic iron-formations in the Hamersley Range are the site of the principal iron-ore deposits in Western Australia. Total reserves of high-grade ore in this region are over 30 000 million tonnes.

The hematite deposits in the islands of Yampi Sound in the Kimberley Province are also of Proterozoic age, but are associated with a different and virtually unique type of iron-formation. The Yampi ores appear to be the product of direct sedimentary deposition of iron oxides and are not due to later processes of enrichment such as have produced the hematite ores of the central and southern parts of the State.

Four distinct iron provinces can be recognized in Western Australia. These are listed hereunder and their extent is shown on Figure 1.

(1) South-central
(2) Hamersley
(3) North Pilbara
(4) Kimberley

The principal deposits (Fig. 2) of each of these provinces are briefly described in the following sections. Western Australia has iron-ore resources of over 35 000 million tonnes (1981), of which over 95% is located in the Hamersley Iron Province.

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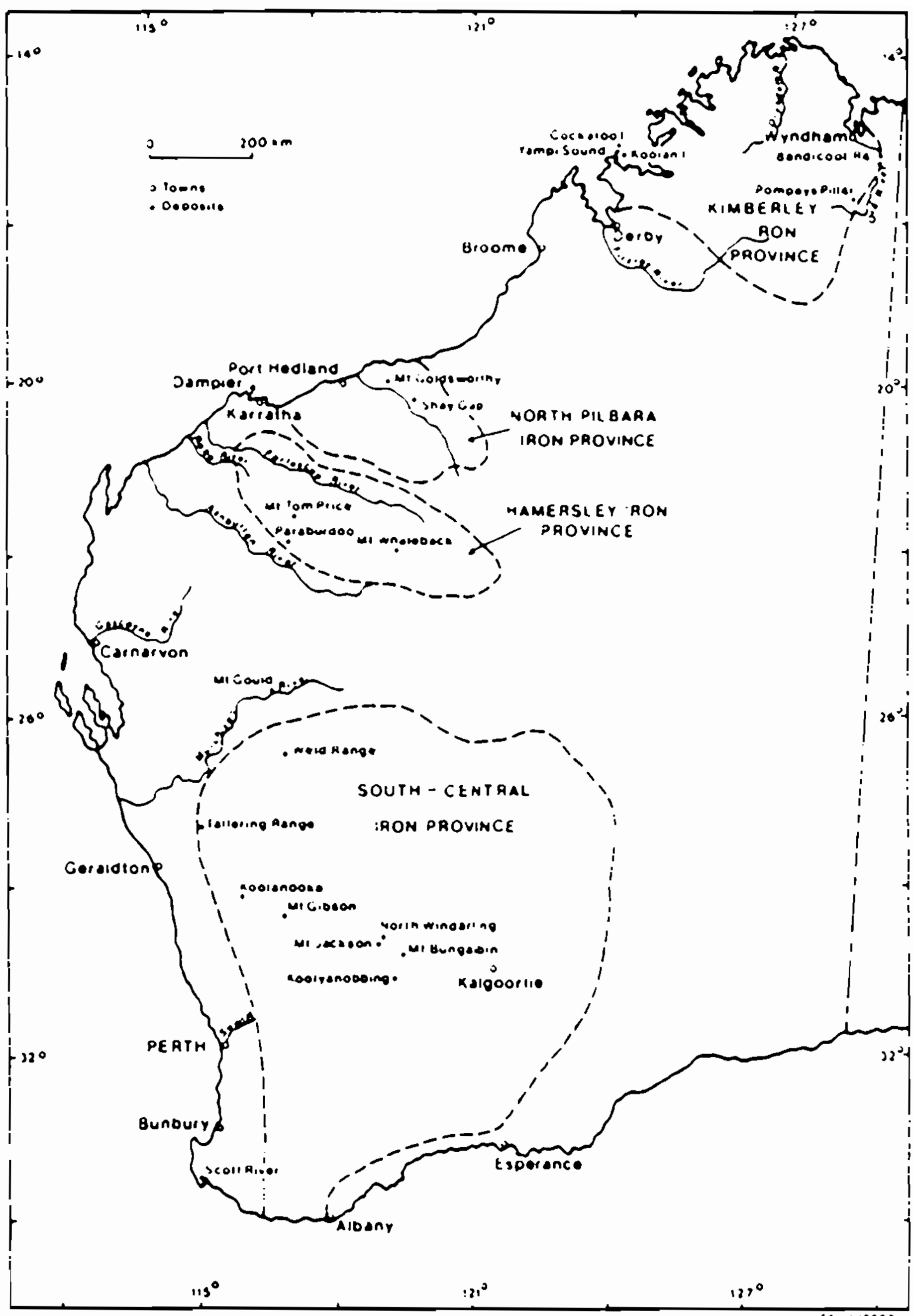

Figure 1 Iron provinces of Western Australia

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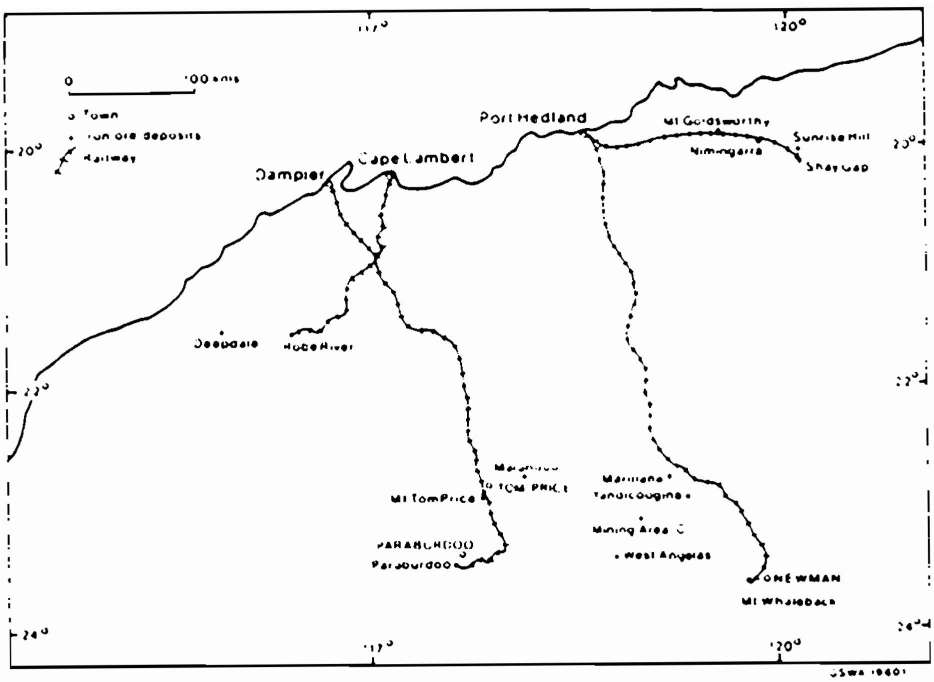

Figure 2 Major iron deposits of the Pilbara and Hamersley areas

SOUTH-CENTRAL IRON PROVINCE

In this part of the State, banded iron-formations occur within narrow elongated belts of Archaean sedimentary and volcanic rocks that are surrounded by granite. The iron-formations are resistant to erosion and normally form sinuous ridges that can be followed for many kilometres.

The greatest concentration is found in the Yilgarn Goldfield, in a sedimentary belt lying east and north of Southern Cross. The important deposits at Koolyanobbing are situated in a range of hills about 50 kilometres northeast of Southern Cross. These iron ores have been mined for many years to supply ore for the former charcoal iron and steel industry at Wundowie. More recently they were assessed by the Broken Hill Proprietary Company Ltd and are now used in the iron and steel industry at Kwinana, an industry whose future is (1982) in some doubt. Proven reserves are 60 million tonnes of hematite-limonite ore which average slightly over 60% iron content.

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At Mount Bungalbin, 50 kilometres north of Koolyanobbing, there are several large hematite-limonite ore bodies which are also held for the Broken Hill Proprietary Company Ltd. Reserves in these deposits are comparable to those of Koolyanobbing.

Forty miles west of Mount Bungalbin, in the same sedimentary belt, there are hematite deposits at Mount Jackson, which have been tested by Western Mining Corporation. Reserves of ore in these lenses probably amount to at least 30 million tonnes.

A further group of hematite lenses, containing a high proportion of massive high-grade hematite grading more than 65% iron, occurs at North Windarling, about 30 kilometres north of Mount Jackson.

Many smaller occurrences of hematite ore are scattered throughout the Yilgarn. The total reserves of ore in the area are of the order of 200 million tonnes. The Yilgarn deposits, although far from the coast, are conveniently close to the standard-gauge railway, which passes the Koolyanobbing ore deposits.

Smaller hematite deposits occur near the western side of the South-central Province, at Tallering Range, Koolanooka, and Mount Gibson. The Koolanooka deposits were developed in 1966, and over 5 million tonnes of ore exported to Japan. Although small, the deposits were comparatively close to existing railways and the port of Geraldton.

Many other iron-ore occurrences are known in the South-central Province but most of these are too far from the coast to be of any immediate economic interest. The hematite deposits of the Weld Range (110 million tonnes) and Mount Gould (15 million tonnes) must be included in this category.

All the above-mentioned deposits occur in association with banded iron-formations and are the products of enrichment by various processes. In the extreme southwestern corner of the State, at Scott River, near Augusta, another type of iron-ore deposit, which is the result of lateritization, occurs. Iron has been dissolved from ferruginous sandstones and has been re-deposited close to the surface as thin but extensive cappings of low-grade laterite containing between 30 and 40% iron. Although this deposit is close to the coast it is unlikely to be mined in the future.

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HAMERSLEY IRON PROVINCE

The Hamersley Iron Province is situated in the North-West Division of the State and includes a thick succession of gently to moderately folded sedimentary and volcanic rocks. From the point of view of iron-ore deposits, the most important members of this sedimentary succession are three, thick and remarkably persistent banded iron-formations which extend over an area of about 80 000 square kilometres.

All three iron formations have been locally enriched to form zones of high grade hematite ore. The total reserves of hematite have been estimated at 28 000 million tonnes. In addition, there is available over 8 000 million tonnes of low-grade limonite ore that has been derived by enrichment of scree and detrital material from the iron-formation and deposited in former river valleys. The Hamersley Iron Province is one of the great iron provinces of the world and will continue to supply the bulk of Australian iron-ore exports for the foreseeable future. Production from this region commenced in 1966, and to 1982, over 786 million tonnes of ore worth $ 7 933 million have been exported.

Hematite deposits of the Hamersley Iron Province currently being mined are, Mount Whaleback, Mount Tom Price, and Paraburdoo, which between them have reserves of over 2 000 million tonnes. Ore from Mount Whaleback is shipped through Port Hedland, Mount Tom Price and Paraburdoo ore is shipped from Dampier. Other promising deposits of hematite iron ore likely to come into production in the future are West Angelas, Marandoo, and Mining Area C (MAC). In the deposits being mined at present there is a high proportion of high-grade lump hematite ore containing up to 68% iron. This is direct shipping ore, which, after crushing, can be used as furnace feed without further processing. These deposits, together with many similar ones, contain thousands of million tonnes of hematite-goethite ore grading between 50 and 65% iron and are readily amenable to beneficiation.

The limonite ores have a lower iron content (about 55%) than the hematite deposits, but the principal impurity is combined water and this is easily removed by heating. The main deposits of this type are at Robe

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River, Deepdale, and Yandicoogina. Currently only the Robe River deposit is being mined, formerly the ore was pellitized at Cape Lambert prior to shipment, but increased energy costs resulted in the closure of the pelletizing plant, and the ore is now directly shipped as fines.

The resources of the Hamersley Iron Province are virtually unlimited as far as direct shipping and beneficiable iron ores are concerned, and it has become one of the principal iron-ore producing regions in the world. Japan is the main market for the Hamersley ores, which make up about 45% of Japans imports and 70% of Australias exports.

The Hamersley ores are considered to have originated as a result of the leaching by groundwater of impurities from the iron-formation to produce nearly pure iron oxide. A feature of the province is the large extent of some of the deposits. The Mount Tom Price ore body is 6 kilometres long, up to 1 300 metres wide and, in places nearly 130 metres thick. Many other ore zones of comparable dimensions have been recognized.

NORTH PILBARA IRON PROVINCE

The Archaean rocks of the north Pilbara contain iron-ore deposits similar to those in the South-central Iron Province. Banded iron-formation, interbedded with metamorphosed sedimentary and volcanic rocks, occur, and this assemblage has been intruded by granite.

The most important iron-ore deposits in this region are those of Mount Goldsworthy Mining Ltd, where over 92 million tonnes of hematite ore have been extracted. The main ore lens at Mount Goldsworthy extends to at least 270 metres below the ground level. The deposit is located along a major fault, which has apparently served as a channel for iron-bearing solutions, with the result that rocks on either side of the fault plane have been replaced by hematite. Adjoining the main ore lens at Mount Goldsworthy are zones of low-grade hematite-goethite ore which have resulted from surface enrichment of the banded iron-formation.

Other important hematite deposits are at Shay Gap, Sunrise Hill, and Nimingarra. Mount Goldsworthy, Shay Gap, and Sunrise Hill ores are shipped from Port Hedland; however, the remaining exploitable reserves are now almost entirely limited to Sunrise Hill, where approximately 30 million tonnes of ore remains to be mined.

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KIMBERLEY IRON PROVINCE

The most important iron-ore deposits in the northern area of the State are those of Cockatoo Island and Koolan Island in Yampi Sound. The iron ores in these deposits appear to be the product of direct sedimentation rather than enrichment of pre-existing sediments. The ore bed forms a distinct sedimentary unit in a surrounding succession of quartzite, shale, and conglomerate, and attains a very high grade of over 65%. Hematite is the principal ore mineral.

Production of iron ore commenced at Cockatoo Island in 1951 and the large deposit on the neighbouring Koolan Island was brought into production in 1965. Total production now exceeds 3 million tonnes a year. Reserves of ore in both island exceed 140 million tonnes.

Few iron-ore deposits in the world are more favourably located for mining and shipment as those of Yampi Sound. At Cockatoo Island, the ore bed, which is about 20 metres thick, forms a steep cliff along the side of the island, and large vessels can be berthed in deep water on the protected side of the island, almost against the ore body. At Koolan Island the ore body is only a few hundred metres from the deep water of the sound. Yampi ores, although hard at the surface, are friable at depth and require sintering before being fed to a blast furnace.

Hematite deposits of similar character and geological environment to those of Yampi Sound have been investigated in other areas of the Kimberley Division. The largest of these occurs near Pompey's Pillar, about 100 kilometres south of Wyndham. The hematite-rich ore bed is preserved as an erosion remnant along the summit of a high range for about 13 kilometres. The ore bed is between 5 and 13 metres thick over the greater part of this distance. The ore is more variable and generally lower in grade than that of Yampi. A similar bed of hematite occurs in the Bandicoot Range near Kununurra.

A number of iron-ore mining projects are ready for future development, the go-ahead for these deposits is chiefly awaiting the arrangements of suitable contracts.

(1) Deepdale : a pisolitic ore deposit; situated near the Robe River deposit owned by the Broken Hill Proprietary Company Ltd.

(2) Yandicoogina – also a pisolitic ore deposit about 80 kilometres northwest of Newman owned by the Colonial Sugar Refinery Ltd.

(3) Marandoo – a hematite-goethite deposit situated 40 kilometres northeast of Tom Price, owned equally by Conzinc Rio Tinto Australia Ltd and Hancock & Wright.

(4) MAC (Mining Area C) – another hematite-goethite deposit about 100 kilometres northwest of Newman; owned by the partners operating the Mount Goldsworthy deposits

(5) West Angelas – a hematite-goethite deposit 100 kilometres west of Newman, owned by Cliffs Robe River Iron Associates.

CURRENT STATE OF THE INDUSTRY

The table below shows the current iron-ore mines in Western Australia, their ownership and production in 1981

Mine	Major Ownership	Production in 1981 (tonnes)
Koolyanobbing	Broken Hill Proprietary Co Ltd	2 501 418
Cockatoo Island Koolan Island	Broken Hill Proprietary Co Ltd	3 380 352
Mount Tom Price Paraburdoo	Conzinc Rio Tinto Australia Ltd (through its subsidiary Hamersley Iron Ltd)	58 539 480

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Mine	Major Ownership		Production in 1981 (tonnes)
Mount Whaleback (Mount Newman)	Amax Iron Ore Corp	(25%)	46 883 262
	Broken Hill Proprietary Co Ltd	(30%)	
	Colonial Sugar Refinery Ltd	(30%)	
	Seltrust Mining Corp Ltd	(05%)	
	Mitsui - C Itoh Iron Pty Ltd (through the operating company Mount Newman Mining Co Ltd)	(10%)	
Robe River	Robe River Ltd	(35%)	25 125 208
	Cliffs Western Australian Mining Co. Pty Ltd	(30%)	
	Mitsui Iron Ore Development Pty Ltd	(30%)	
	Cape Lambert Iron Associates (through the operators Cliffs Robe River Iron Associates)	(05%)	
Mount Goldsworthy	Consolidated Gold Field Ltd	(46 2/3%)	10 947 568
Shay Gap	Utah Development Co.	(33 1/3%)	
Sunrise Hill	Mount Isa Mines Holdings Ltd (through the operating company Goldsworthy Mining Ltd)	(20%)	

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EXHIBIT "28" - Copy pages 7-01, 7-06, 7-36 ar 7-37 of Taggart's "Handbook of Mineral Dressing" 1976

SECTION 7

SCREEN SIZING

1. INTRODUCTION

Definitions. SIZING is the process of dividing a mixture of grains of different sizes into groups or GRADES whose characteristic is that the particles therein are more or less nearly of the same size that all have passed an aperture of certain dimensions and failed to pass through some smaller aperture. The screen through which the particles have passed is called the LIMITING SCREEN, that which has retained them is sometimes called the RETAINING SCREEN. CLOSE SIZING is practiced when the apertures of limiting and retaining screens are nearly the same. The sized product is SHORT-RANGE. A mass of particles is said to be a NATURAL OR LONG-RANGE PRODUCT when it has all passed a given limiting screen but has been subjected to no further treatment. Material that stays on a given screen is the OVERSIZE or PLUS (>) of that screen, that passing is the UNDERSIZE or MINUS (<). A SIEVE SCALE is the list of apertures of successively smaller screens in a step-sizing operation. The SIEVE RATIO is the ratio of the aperture of a given screen in a given sieve scale to the aperture of the next finer screen. PERCENTAGE OF OPENING is the ratio of the combined area of the openings to the total area of the screening surface. CLASSIFICATION is a process of approximate sizing; it is discussed in Sections 8 and 9.

Purposes of screen sizing: (*a*) to SCALP off the coarse end of a long-range product, usually for further reduction; (*b*) to cut off the fine end from crusher feeds and thus save power and prevent over-grinding; (*c*) to grade broken rock products into commercial sizes, as for road metal, ballast, concrete aggregate, sands, and the like; (*d*) to perform a step in a concentration process, *e.g.*, to size before jigging (see Sec. 11, Art. 2).

Principles. The fundamental function of screening is to pass undersize particles through the apertures and reject oversize particles. The particles must therefore be brought to the openings and be presented thereto at such a velocity and in such direction that passage of undersize will not be hindered or prevented by rebound from the edges or walls of the opening. If every particle of undersize could be brought to an opening individually, at substantially zero velocity, in a direction perpendicular to the plane of the opening, and with the center of its least projected cross-section in line with the center of the aperture, and if the screening surface had no thickness, every such particle would immediately pass. But tonnage requirements forbid individual and low-velocity presentation, while mechanical considerations prevent perpendicular presentation and the use of screening surfaces of gossamer thickness. Practically, particles are crowded and continually interfering at the apertures, they are presented at considerable velocity, in a direction nearly parallel to the plane of the screen surface, with their maximum rather than their minimum projected surfaces generally parallel to the plane of the screen, and the screen opening has a depth frequently greater than the greatest dimension of the particle of undersize. Many undersize particles are thus excluded for a considerable time from access to an opening; others come to the opening from such a direction or with such orientation or at such velocity that they fail to enter; others, entering, are delayed in passage or stopped by friction against the walls of the opening or, if on a vibrating screen, may actually be ejected.

Chance rules the approach of a particle to hole or imperforate surface and the probability that the lowermost point of the approaching particle will strike hole rather than screen fabric is proportional to the percentage of opening in the fabric. Chance coupled with the

EXHIBIT "28" - Copy pages 7-01, 7-06, 7-36 ar 7-37 of Taggart's "Handbook of Mineral Dressing" 1976

1706

If the original material tested were bone dry and another test were made with somewhat over 3 or 4% of water added, the slope of the early part of curve *a* would fall, and the height and sharpness of the maximum of curve *b* would decrease. Within a range of moisture content, varying with the mineralogical character of the material, its maximum size, and size distribution, but with a top around 15 to 20% water, the presence of water decreases the rate of passage of undersize greatly. Further increase of water content first restores the passing rate quickly to that of bone-dry material, and thereafter the screening rate rises above that for dry material to an extent dependent upon the size of aperture.

Thus the true capacity of a screen is measured by its ability to pass difficult grains. It is simply a conveyor for EXCESS OVERSIZE (>1.5 times aperture), while EXCESS FINES (<0.7 times aperture) are as so much water.

For capacity ratings of different types of screens see the particular screens.

3. SCREENING SURFACES

The three general types of screening surface are: (*a*) woven wire or silk; (*b*) punched plate or sheet metal; (*c*) parallel bars, rods, or wires.

Screen-size designation. The minimum clear space between the edges of the opening in a screening surface is called the APERTURE OR SCREEN SIZE. Aperture is expressed in several ways; the most accurate, undoubtedly, is to give the dimension in inches or millimeters; the commonest, particularly with woven screens, is to express it as so many MESH, meaning the number of openings in the screen per linear inch. This latter method is definite only when coupled with a statement of the size of wire, or when referred to one of the testing-sieve scales (Sec. 19, Art. 12). When size of wire is given it should be expressed in ordinary units of measure, i.e., inches or millimeters. If gage numbers are used the gage must be named, on account of the differences in dimensions corresponding to the same gage number in different gage scales. See Table 3. Given two of the quantities a = aperture, d = diameter of wire, and m = mesh, the percentage of opening, P, and the other quantity can be determined from the following relations (applying only to square-mesh screen):

$$P = a^2m^2 = \frac{a^2}{(a+d)^2} = (1 - md)^2;\ m = \frac{1}{a+d};\ a = \frac{1}{m} - d;\ d = \frac{1}{m} - a$$

The mesh of punched-plate screens does not mean the number of openings per linear inch but that the aperture has a dimension near that of some woven-wire screen of the stated mesh and usually of medium weight. If the largest and smallest apertures corresponding to a given mesh in Table 4 are averaged, the result will be close to the punched-plate aperture called by that mesh number. Certain districts, notably South Africa, express aperture as SQUARE MESH, i.e., the number of apertures per square inch. Europeans, describing fine screens, commonly state the number of openings per square centimeter. NEEDLE MESH is a number used to designate an aperture and corresponds to that of a needle of the same or nearly the same diameter as the dimension of the opening. See Table 11.

Materials for screening surfaces include cast iron and steel, plain high- and low-carbon steels, manganese steel, chrome-nickel ("stainless") steel, brass, phosphor bronze, Monel metal, nickel, and occasionally other metals and alloys for special purposes; rubber-plated wire screens are available. Silk bolting cloth is used mainly in the preparation of graphite and abrasives, and for the finest sizes of testing screens. The screening surface must be strong enough to carry its load (a fine-wire screen is often reinforced by laying it on top of a coarser and stronger screen) and, so far as possible, it should resist abrasion and corrosion. At the same time it should be cheap. When corrosion is not a factor, screens are normally made of high-carbon steel and in certain cases of special alloy steels. Steel is stronger and resists abrasion better than any other material equally available. Cloth is advertised of wire with 450 Brinell and 225,000 lb. per sq. in. tensile strength. When corrosion must be resisted, iron, copper, bronze, Monel metal, and other alloys are used. Such materials cost more than steel initially and are not so highly resistant to abrasion. Their use is justified only when the final cost, by reason of their greater resistance to corrosion, is less than that of steel screens. Stainless steel is particularly suitable for wet screens since it is resistant to both corrosion and abrasion, and consequently blinds less readily.

Woven-wire screens are made with either square or rectangular openings, and in several different manners intended to prolong their life or prevent displacement of the wires in service. They are regularly obtainable in any length and in widths up to 5 ft.; greater widths are woven to order. Table 3 gives diameters of wires as gaged under various stand-

1707 EXHIBIT "28" - Copy pages 7-01, 7-06, 7-36 an 7-37 of Taggart's "Handbook of Mineral Dressing" 1976

Table 27. Performance of Symons horizontal shaking screens (Q)

	Climax, Colo	San Francisco de Mex.
Screen: Width × length, ft	5 × 9	3 1/2 × 10
Material	Steel rods	Ty-Rod
Diam. of rod or wire, in.	1/4	0.177
Aperture, in.	5/16	5/8 × 4
Life, days		14
Replacement, 2 men, hr		1/2
Blinding		b
Speed, r p m	825	790
Amplitude, in.	3/4	3/4
Power, hp	7 1/2 f	5 1/3 c
Drive	V-belt	Tex-rope
Feed: Size	< 2 in	Cone prod. a
Per cent. moisture	2-3	2
Tons per hr.: New	42	100
Total	105	150
Effect of moisture on capacity	Serious	None
Feeding method	48-in belt	Conveyor

a > 3/4 in., 7.7%, 3/4~1/4, 67%, 1/4-in ~10-m., 8.6%, < 10-mesh, 16.7%.
b Screen cleaned once in 8 hr.
c Power consumed.
f Power installed.

exactly the same manner on the screen box: the other ends of these bars carry a feed box. Vibration induced by the eccentric rotation is thus divided between the screen box and the outside bars and is practically neutralised. Single- and double-deck screens are 36, 42, and 48 in. wide by 6, 8, 10, 12, 14, 16, 18, and 20 ft long; triple-deck (same widths), 8, 10, and 12 ft long; a single-deck 24 in. × 6 or 8 ft is also available. Over-all length (incl. motor) is about 53 in. plus screen length; over-all width, 23 to 26 in. plus screen width; height of feed box above floor, 40 to 43 in. for single- and double-, and 52 in. for triple-deck screens. For performance see Table 27.

Cole screen has a slightly sloping deck supported on four inclined legs (Ferraris principle) and oscillated by two pitmans driven from eccentrics, thus producing an upward movement on the forward stroke. Legs and pitmans are all attached to the screen frame through flexible rubber wrists. Such a screen at CANANEA (IC 6651), with 44 × 49 in. of double-crimped cloth (1/4-in. wire, 1-in. opening) received 2,500 tons per day of product from a gyratory crusher set at 3 1/2-in. max., speed, 430 r p m. Table 28 gives sizing analyses of feed and products, showing 25% of undersize remaining in oversize.

Table 28. Feed and products of Cole screen at Cananea

Mesh	Feed	Oversize	Undersize
3-in.	14.2	29.4	
2	15.6	25.3	
1	22.9	20.2	
1/2	10.8	11.9	21.6
3-m.	9.9	3.4	16.2
4	3.1	1.4	9.1
8	5.2	1.8	13.0
14	4.0	1.3	10.1
48	5.2	1.9	11.9
100	2.0	0.8	4.0
200	1.2	0.6	2.3
< 200	5.9	2.0	11.8
	100.0	100.0	100.0

VIBRATING SCREENS

In recent years, vibrating screens have largely displaced trommels and shaking screens, owing chiefly to their larger capacity per unit of screen area and floor space and lower cost of operation and upkeep per ton screened. Their field ranges from 10-in. to 100-m. aperture, wet or dry; in the finer sizes they have been substituted at several mills for mechanical classifiers, and in coarse sizes for grizzlies. In industrial screening they have been used down to 200-m. wet and 325-m. dry, but even the manufacturer concedes that air classifiers (Sec. 9) are superior in the latter field. As substitutes for grizzlies they save headroom and floor space, make a cleaner cut, blind less, and serve also to equalize rushes of feed to a certain extent. The modern eccentric-drive machines, with rubber-floated bearings to cushion the shocks caused by unbalancing from heavy fluctuating live loads, can handle feed lumps of several hundred pounds by using protective grids (see p. 31). See the different types for their special size fields.

Vibrating screen consists essentially of a substantially plane screening surface, usually stretched taut, more or less inclined, and caused to vibrate with small amplitude and comparatively high frequency. The screening surfaces, single up to 4-deck, are set as diaphragms in a rectangular frame having suitable side walls to confine flow (screen box). Sizes, which are stated as deck dimensions, range from 1 1/2 × 3 ft. to 6 × 16 ft.

EXHIBIT "28" - Copy pages 7-01, 7-06, 7-36 an
7-37 of Taggart's "Handbook of Mineral
Dressing" 1976

Types. Vibrating screens are available under a bewildering variety of trade names. Fundamentally, however, there are only two types, (a) those in which points in the screening surface reciprocate over substantially rectilinear paths, and (b) those in which the paths are closed, either nearly circular or pronouncedly elliptical in general outline. In both types the path lies in a plane or substantially plane surface parallel to the side walls of the screen box. Motion along the paths is nonuniform in most cases; in the impact types reversal is sudden.

Vibrating mechanisms are electrical or mechanical; their impulses are applied directly to the screening surface, or, in most cases, to the screen box. Electrical mechanisms are all a.-c. electromagnets, with or without mechanical expedients such as stops or interposed resilient elements to amplify and/or intensify the vibrational effects. Mechanical methods comprise hammers, cams, eccentrics, gyrators, and various combinations of these mechanisms. More detailed descriptions follow in connection with specific machines.

Impulse and restraint. The force applied to the particles on a vibrating screen is a resultant of the impulse of the mechanism on the screening surface or the frame, the restraints opposed to this impulse by the screen structure, and the further restraints imposed by gravity acting on the screen structure and on the material on the screening surface. The magnitude of the initial impulses depends upon the power supplied and the way in which it is converted to force at the points of application. The impulse on the screening surface depends upon the type and strength of the constraints to motion brought into play between the point of application of the applied force and the screening surface.

Intensity of vibration is a function of length of path and rapidity of reversal. Ordinarily it is expressed simply as the product of the length of projected path at right angles to the screen frame and the frequency, which is to say, the cumulative linear travel in one direction at right angles to the screen surface per unit of time. Thus a screen surface making 1,000 v.p.m. along a circular path $^1/_{16}$ in. diam. would be said to have an intensity of 62.5 (in. per min.). But the actual intensity of such vibration, assuming uniform motion along the path, would be greater if the path were elliptical, with $^1/_{16}$ in. the major axis, and at right angles to the screen surface, and the relative increase would be greater the larger the ratio of major to minor axis of the ellipse. The intensity would be much greater with a linear path of the same projected length if there were any substantial approach to uniform motion along the path, and it becomes a maximum when a linear path is stopped by a sudden impact. No method has been devised for numerical quantification of the intensification due to rapid reversal.

Particle movement on and over the screening surface is the resultant of gravity and the force exerted on the particles by the surface. With most screens gravity is the primary force and the screen surface is inclined to such an extent (20 to 40°) that a very slight impulse from the surface is sufficient to make the particle progress down slope. The ideals in particle movement are rapid translation, which makes for high capacity; continuous contact with the surface, which insures repeated presentation to openings; turnover, which causes ever changing orientation of the presented particles; and ejection, or outthrowing of particles incapable of passage through an aperture, in order to give other particles access to that aperture and to give the ejected particle opportunity to present itself differently to another aperture.

Rapid translation is obtained by steep slope and/or high intensity of vibration. Speed should not, however, be so high as to cause the load to bound across the surface, since such progression defeats the other purposes of particle movement by preventing access to apertures.

Continuous contact is attained by decreasing the slope and by increasing the load passing over the surface. The decreased slope of itself decreases the length of screen surface passed over in one bound caused by an impulse of a given intensity, and the increase in load reduces the freedom of particles to respond to impulses by leaving the surface.

Turnover is effected to a certain extent by opposition of the rough surface of the screen fabric to the forward flow of particles in contact with it. It is accentuated, however, with closed-path motion, by having the upper portion of the vibratory path directed toward the feed end of the screen (COUNTERFLOW).

Ejection is best effected by impact at the end of the upward stroke. Failing this, it is probably next-best attained by an acutely elliptical path with as nearly as possible uniform motion along the path.

7. OPEN-PATH (RECIPROCATING) VIBRATORS

These were the earliest type, representing the first departure from trommels. The pioneer forms comprised mechanical hammers applied to fixed inclined screens. An a.-c.

EXHIBIT "28" - Copy pages 7-01, 7-06, 7-36 an[d] 7-37 of Taggart's "Handbook of Mineral Dressing" 1976

IN THE SUPREME COURT

OF WESTERN AUSTRALIA

No. 2313 of 1982

IN THE MATTER of an Agreement between LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, WRIGHT PROSPECTING PTY. LTD., HANCOCK PROSPECTING PTY. LTD., two other companies and HAMERSLEY IRON PTY. LIMITED

BETWEEN:

HAMERSLEY IRON PTY. LIMITED	Plaintiff

AND

LANGLEY GEORGE HANCOCK	First Defendant
ERNEST ARCHIBALD MAYNARD WRIGHT	Second Defendant
HANCOCK PROSPECTING PTY. LTD.	Third Defendant
WRIGHT PROSPECTING PTY. LTD.	Fourth Defendant
L.S.P. PTY. LTD.	Fifth Defendant
THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED	Sixth Defendant

AFFIDAVIT

I, NILES EARL GROSVENOR of 5200 Aspen Drive, Littleton, Colorado in the United States of America, Consulting Engineer, MAKE OATH AND SAY as follows:-

1.(a) I hold the degrees of Engineer of Mines (1950) and Master of Science in Mining Engineering (1952) from the Colorado School of Mines. I am a Registered Professional Engineer in 11 States of the United States of America.

EXHIBIT "29" - Affidavit of Niles Earl Grosvenor dated 27.10.1982

W BERGE PHILLIPS NILES E GROSVENOR

(b) I am a Senior Vice President of Gates Engineering Company ("Gates"). Gates is a professional consulting engineering firm specialising in mining engineering in all fields of mining. It was established in 1905 and now has offices in Beckley in West Virginia, Pittsburgh in Pennsylvania and Denver in Colorado. It has a staff of over 60 professionally qualified engineers. Gates carries out consulting work throughout the world. Its clients include the Rand Corporation (South Africa), Bank of America, Continental Illinois Bank, Chase Manhattan Bank, W.R. Grace Company, Amoco Oil Company, Republic Steel Company, Peabody Coal Company, the governments of the United States, France, Puerto Rico and the Electricity Trust of South Australia. For the last four years I have been a Senior Vice President of Gates and I rank equal third in its corporate structure. Since 1972 I have been a Vice President of Gates and responsible for its operations in the Western States of the United States.

(c) Prior to 1972 I taught for 20 years at the Colorado School of Mines. The school is completely devoted to mineral engineering. It was established in 1874 and has 3000 students. It is one of the leading mineral engineering schools in the United States. At the time of my retirement I was a full Professor. I taught at both undergraduate and graduate level in the areas of rock mechanics, mine development,

W. BERGE PHILLIPS   NILES E. GROSVENOR

underground and open pit mining and coal preparation which includes heavy media separation, jigs, screening and drying.

(d) Since joining Gates I have been in charge of more than 175 mining engineering projects including the evaluation of preparation plants and studies to improve the efficiency of preparation plants as well as mine design, reserve estimates and rock mechanics. I have visited and have done consulting work for mining companies in most of the mainland United States, in South Africa, Greenland, Alaska, Canada and Mexico.

(e) While teaching at the Colorado School of Mines I inspected very many mines including iron ore mines in the Mesabi Range in Minnesota, the Sunrise Iron Mine in Wyoming, the US Steel Iron Mine at South Pass, Wyoming and the Kaiser Steel Eagle Mountain Iron Mine at Fontana, California. The purpose of these inspections was to study the plant and processes used and to instruct students on the practical application of principles of mining engineering.

(f) I have been retained or given evidence as an expert witness in more than 15 cases or inquiries and have acted as an arbitrator.

2. I have been retained by solicitors acting on behalf of the first to fourth Defendants ("H&W") to advise in

EXHIBIT "29" - Affidavit of Niles Earl Grosvenor dated 27.10.1982

W BERGE PHILLIPS NILES E. GROSVENOR

relation to disputes between H&W and the Plaintiff ("HI") concerning royalties payable under an agreement made in 1962 under which H&W sold to HI the right to mine iron ore in certain areas in Western Australia.

3. On 16th August 1982 I inspected the mine operated by HI at Tom Price and the associated concentration plant. I have read a copy of the affidavit of Colin Roy Langridge sworn 2nd September 1982 and the exhibits thereto.

I have also read a letter dated 21st October 1982 from CRA Services Limited to H & W's solicitors and inspected the general arrangement drawings nos. P-004-5041 and P-004-5033 referred to therein.

Now produced and shown to me marked respectively as follows are:

"NEG 1" - Letter dated 21st October 1982

"NEG 2" - Drawing P-004-5041

"NEG 3" - Drawing P-004-5033

4. The expressions "beneficiation", "treatment", "crushing" and "screening" as used in Clause 9 of Exhibit "CLR 1" ("the Agreement") have been for very many years, and since long before 1962, terms used in a technical sense in the mining industry in those countries where English is the working language.

5. Beneficiation

The term "beneficiation" is used in its broadest sense to comprehend treating ore to improve its physical or chemical characteristics. This may include the use of

W BERGE PHILLIPS NILES E. GROSVENOR

physical, chemical, thermal or magnetic processes, so as to upgrade the ore and make it a more commercially usable product. Sometimes the term is used in a narrower sense which involves only mechanical or physical processes whereby higher grade ore materials are separated from lower grade materials and "gangue" (the earth or stony matter in which the ore is found).

6. <u>Treatment</u>

"Treatment" may be used in a very broad sense as meaning the subjecting of ore to physical or chemical action with the object of achieving some definable result. Used in that broad sense treatment includes beneficiation. Treatment may also be used in a more narrow sense relative to some particular form of treatment, such as pelletising, refining or smelting.

7. <u>Crushing</u>

"Crushing" means the mechanical reduction in size of a material.

8. <u>Screening</u>

"Screening" is a means of separation of particles by size. The basic concept of screening involves presenting the material onto a surface which contains apertures of a given size which exclude particles larger than that size ("oversize") and allow particles of a smaller size ("undersize") to pass through.

9. Very frequently crushing and/or screening is carried out as part of a beneficiation process. However, I

W. BERGE PHILLIPS NILES E GROSVENOR

note that Clause 9 of the Agreement specifically excludes crushing or screening from beneficiation.

10. Often water is added in the course of the screening process to increase the capacity of the screen and improve its sizing efficiency. The water may be introduced either by adding it to the feed or by spraying it over the material on the screen deck or by a combination of both methods. The process of screening with the addition of water is known as "wet screening". For material of certain sizes wet screening increases the amount which can be made to pass through a given area of screen surface when ample water is mixed with the material to make a slurry. It is usually better to make the slurry prior to the material reaching the screen itself rather than to attempt to do all of the wetting on the screening surface. Is is essential for effective wet screening that the material be very wet. As Professor Gaudin has noted (Principles of Mineral Dressing (1939) pages 151-152), bone-dry or very wet material is relatively easy to screen but a small percentage of water in a dry feed increases the difficulty of screening out of all proportion to the amount of water.

11. Wet screening installations must be carefully designed having regard to the nature of the material to be screened. Now produced and shown to me marked "NEG4" is a copy of "Vibrating Screen Theory and Selection" a publication by Allis-Chalmers of Milwaukee, Wisconsin,

which is a leading manufacturer of screens for mining operations in the United States. I have noted that the screens referred to in paragraph 9 of Mr. Langridge's affidavit are Allis-Chalmers screens. The views expressed and the design factors recommended at page 17 of the publication are in accordance with my experience and opinion.

12. The application of water can have the effect of washing the material being screened. In this context "washing" means the separation on a size basis between particles differing so widely in size that the smaller are readily carried away in a fluid current. Washing may also be referred to as cleaning. Screens are a common form of apparatus used for washing. A washing screen is an ordinary screen provided with more or less powerful water jets spraying on the oversize material, suitably housed to lead away slurry undersize and confine splash. Wetting the ore before it reaches the screen makes washing on the screen more efficient. To the extent that washing occurs, it comes about as an integral part of wet screening. Depending on the particular application, washing may be the primary purpose of a wet screening installation or may be merely incidental. But whatever is the case the process is still termed wet screening. I again refer to the Allis-Chalmers publication marked "NEG4", especially at page 3. The commentary therein is in accordance with my experience and opinion.

13. Wet screening, whether for sizing purposes or washing

W. BERGE PHILLIPS NILES E. GROSVENOR

or both, was well known in the processing of iron ore in 1962, as was pre-wetting the ore before it reached the screens.

14. Wet screening in the screenhouse at Tom Price includes the use of double deck vibrating screens. The ore is first wetted in a chute immediately before it goes onto the first deck, then it is wetted again on each deck. There is nothing unusual about the wetting of the ore either in the chute or on the screens to make the process anything other than normal wet screening.

15. In my opinion no beneficiation or other treatment (except screening) takes place in the chute or at the wet screens in the screenhouse.

16. In my opinion no beneficiation or other treatment takes place in the surge bins after the screening in the screenhouse.

17. In my opinion no beneficiation or other treatment (except screening) takes place at the preparation screens, where fines are removed by sizing prior to the heavy media drums and cyclones. Similarly, only screening takes place in the sieve bends and screens for the feed to the hydrocyclones and wet high intensity magnetic separators ("WHIMS").

18. The process used in the heavy media drums and cyclones in the concentrator plant involves feeding the ore into a mixture of water and a medium, i.e. ferrosilicon. The

W. BERGE PHILLIPS NILES E GROSVENOR

addition of the medium raises the specific gravity of the mixture to more than that of water with the result that some material which would sink in water floats in the mixture. For example, in the drums the lower grade (and therefore lighter) ore and gangue floats and is separated while the higher grade (and heavier) ore sinks. Hydrocyclones are used to separate the fines fraction into two products. The larger fraction goes to the WHIMS and the very fine material is discarded to tailings. The larger fraction that is sent to the WHIMS is separated into a magnetic iron concentrate and a non-magnetic tailing which is discarded.

19. In my opinion the processes described in paragraph 18 comprise beneficiation other than crushing or screening.

20. The basic concepts described in paragraph 18 (other than the WHIMS plant) were well known within the iron ore industry long before 1962, and would have been described as concentration or beneficiation. Of necessity the application of such concepts involves crushing and screening (wet or dry). However both in 1962 and now the terms "crushing" and "screening" would be equally applicable to crushing and screening when used for sizing the feed for a media separation process like the one at Tom Price as they would be to a crushing and screening operation carried out for any other purpose.

EXHIBIT "29" - Affidavit of Niles Earl Grosvenor dated 27.10.1982

W. BERGE PHILLIPS NILES E GROSVENOR

SWORN at Sydney in)
the State of New South)
Wales this 27th)
day of October 1982.)

NILES E GROSVENOR

Before me:

W. BERGE PHILLIPS
....

A Commissioner of the Supreme Court
of Western Australia for taking
Affidavits in New South Wales.

This Affidavit is filed on behalf of the first to fourth Defendants.

EXHIBIT "29" - Affidavit of Niles Earl
Grosvenor dated 27.10.1982

COPY

C R A SERVICES LIMITED
INCORPORATED IN VICTORIA
HAMERSLEY HOUSE
191 ST. GEORGE'S TERRACE, PERTH,
WESTERN AUSTRALIA, 6000

TELEPHONE 322 2327
BOX A42, G.P.O.
PERTH
WESTERN AUSTRALIA 6001
TELEX No. AA92315

EXHIBIT "29NEG1" - Copy letter from Plaintiff's Solicitor to C.R. Fieldhouse dated 21.10.82

21st October, 1982.

BY HANCOCK & WRIGHT
AIR BAG

Mr. C.R. Fieldhouse,
Solicitor,
45 Macquarie Street,
SYDNEY. N.S.W. 2000

Dear Sir,

Re: HAMERSLEY v. HANCOCK & ORS.

With reference to Item 1.A of your telex of 15th October, please find attached the following design drawings:-

P-004-5041 - Washing and Screening Plant General Arrangement

P-004-5033 - Washing and Screening Plant Wet Feeder General Arrangement

Regarding Item 1.B, the design pressures and feed rates for water admitted to the pulping box are:

Pressure: 450KPa through Clayton pressure sustaining valves

Feed Rate: 91m^3/hour for pulping box
(48m^3/hour for Primary Screen Top Deck
66m^3/hour for Primary Screen Bottom Deck
45m^3/hour for Secondary Screen)

We advise that washing module No. 4 was modified earlier this year on a trial basis by the addition of a 6/4 FHH pump which feeds at the following rates:-

400m^3/hour for pulping box
(48m^3/hour for Primary Screen Top Deck
100m^3/hour for Primary Screen Bottom Deck
45m^3/hour for Secondary Screen)

The pressure remains uniform at 450KPa. The effect of this trial is still being studied by Hamersley.

Yours faithfully,

A.W. PATTERSON
CRA Legal Department, Perth

EXHIBIT "29NEG1" - Copy letter from Plaintiff's Solicitor to C.R. Fieldhouse dated 21.10.82

Enc.

EXHIBIT "29NEG2" - Drawing P-004-5041 General
Arrangement of Tom Price Concentrator Washing
and Screening Plain Wet Feeder dated 7.12.76

EXHIBIT "29NEG2" - Drawing P-004-5041 General
Arrangement of Tom Price Concentrator Washing
and Screening Plant Wet Feeder dated 7.12.76

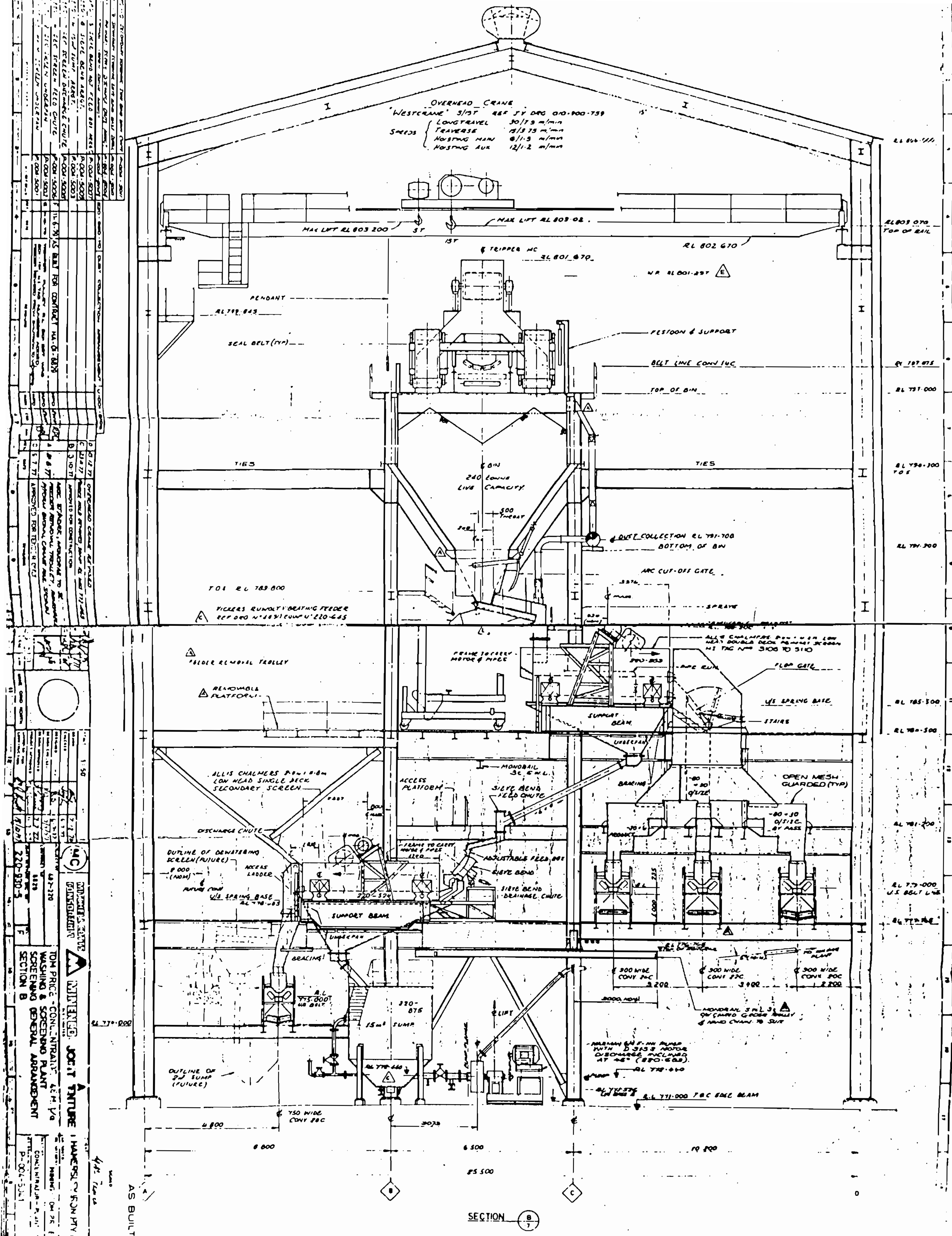
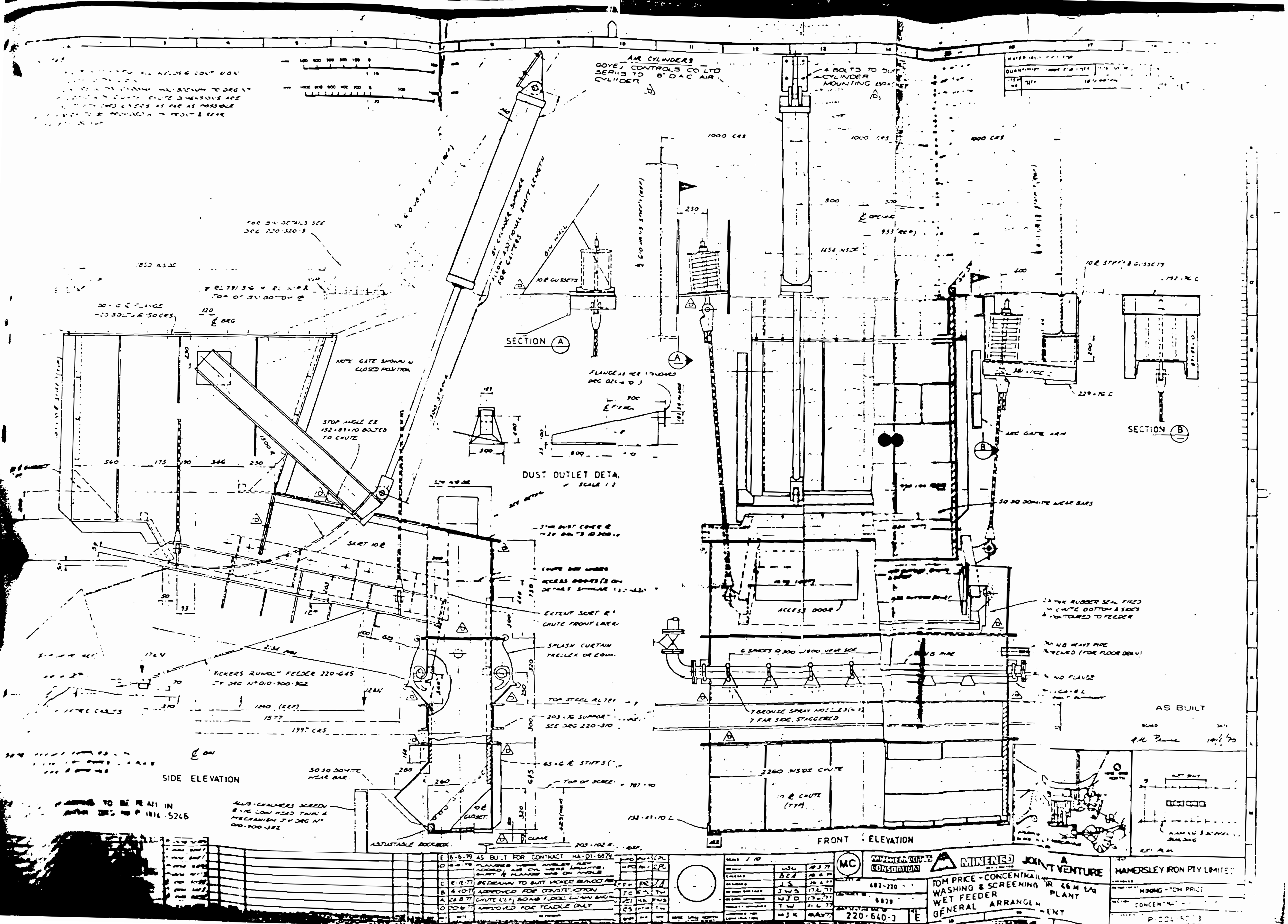

OVERHEAD CRANE
'WESTCRANE' 5/15T
SPEEDS
LONGTRAVEL 30/7.5 m/min
TRAVERSE 15/3.75 m/min
HOISTING MAIN 6/1.5 m/min
HOISTING AUX 12/1.2 m/min
MAX LIFT RL 803 200
MAX LIFT RL 803 02
RL 802 670
RL 803 070 TOP OF RAIL
TRIPPER HC
RL 801 670
PENDANT
SEAL BELT (TYP)
FESTOON & SUPPORT
BELT LINE CONV
TOP OF BIN
TIES
BIN 240 TONNE LIVE CAPACITY
DUST COLLECTION
BOTTOM OF BIN
ARC CUT-OFF GATE
SPRAYS
VICKERS RUHOLT VIBRATING FEEDER
FEEDER REMOVAL TROLLEY
REMOVABLE PLATFORM
FLAP GATE
STAIRS
SUPPORT BEAM
UNDERPAN
OPEN MESH GUARDED (TYP)
MONORAIL
ACCESS PLATFORM
SIEVE BEND FEED CHUTE
ALLIS CHALMERS
LOW HEAD SINGLE DECK SECONDARY SCREEN
DISCHARGE CHUTE
OUTLINE OF DEWATERING SCREEN (FUTURE)
ACCESS LADDER
ADJUSTABLE FEED BOX
SIEVE BEND
SIEVE BEND DRAINAGE CHUTE
U/S SPRING BASE
U.S. BELT
BRACING
15m³ SUMP
OUTLINE OF 2ND SUMP (FUTURE)
750 WIDE CONV
900 WIDE CONV
T.O.C. EDGE BEAM
4 800
6 800
6 500
10 200
25 500
SECTION B
AS BUILT
HAMERSLEY IRON PTY. LTD.
TOM PRICE CONCENTRATOR
WASHING & SCREENING PLANT
SCREENING GENERAL ARRANGEMENT
SECTION B
220-930-5
P-004-5001

EXHIBIT "29NEG3"-Drawing P-004-5044 General Arrangement of Tom Price Concentrator Washing and Screening Plant Wet Feeder dated 18.5.77

1722 EXHIBIT "29NEG3"-Drawing P-004-5033 General Arrangement of Tom Price Concentrator Washin and Screening Plant Wet Feeder dated 18.5.77


AIR CYLINDERS
COYEJ CONTROLS CO LTD
SERIES 10 8" D.A.C. AIR CYLINDER
4 BOLTS TO SUIT CYLINDER MOUNTING BRACKET
1000 CRS
500
1454 INSIDE
FOR BIN DETAILS SEE DRG 220-320-3
NOTE GATE SHOWN IN CLOSED POSITION
STOP ANGLE EX 152×89×10 BOLTED TO CHUTE
SECTION A
FLANGE AS PER STANDARD
DUST OUTLET DETAIL
SCALE 1:2
SKIRT 10 R
CHUTE SIDE LINERS
ACCESS DOORS
EXTENT SKIRT
CHUTE FRONT LINER
SPLASH CURTAIN
VICKERS RUHOLT FEEDER 220-G45
TOP STEEL RL 781
203×76 SUPPORT
SEE DRG 220-310
65×6 R STIFF'S
TOP OF SCREEN
1240 (REF)
1577
1997 CRS
SIDE ELEVATION
50×50 DOMITE WEAR BAR
ALLIS-CHALMERS SCREEN
ADJUSTABLE BOCKBOX
GUSSET
ACCESS DOOR
7 BRONZE SPRAY NOZZLES
7 FAR SIDE, STAGGERED
2260 INSIDE CHUTE
FRONT ELEVATION
ARC GATE ARM
50 50 DOMITE WEAR BARS
SECTION B
10 R STIFF'S & GUSSETS
AS BUILT
E 6-6-79 AS BUILT FOR CONTRACT HA-01-687
D ADDED AIR CYL WEAR DOMITE
C REDRAWN TO SUIT VICKERS RUHOLT
B APPROVED FOR CONSTRUCTION
A CHUTE LLK, BOMB FLOOR LINER
0 APPROVED FOR TENDER ONLY
SCALE 1/10
MC
MITCHELL COTTS CONSORTIUM
MINENCO
JOINT VENTURE
TOM PRICE - CONCENTRATION
WASHING & SCREENING PLANT
WET FEEDER
GENERAL ARRANGEMENT
220-640-3
E
HAMERSLEY IRON PTY LIMITED
MINING - TOM PRICE
CONCENTRATION

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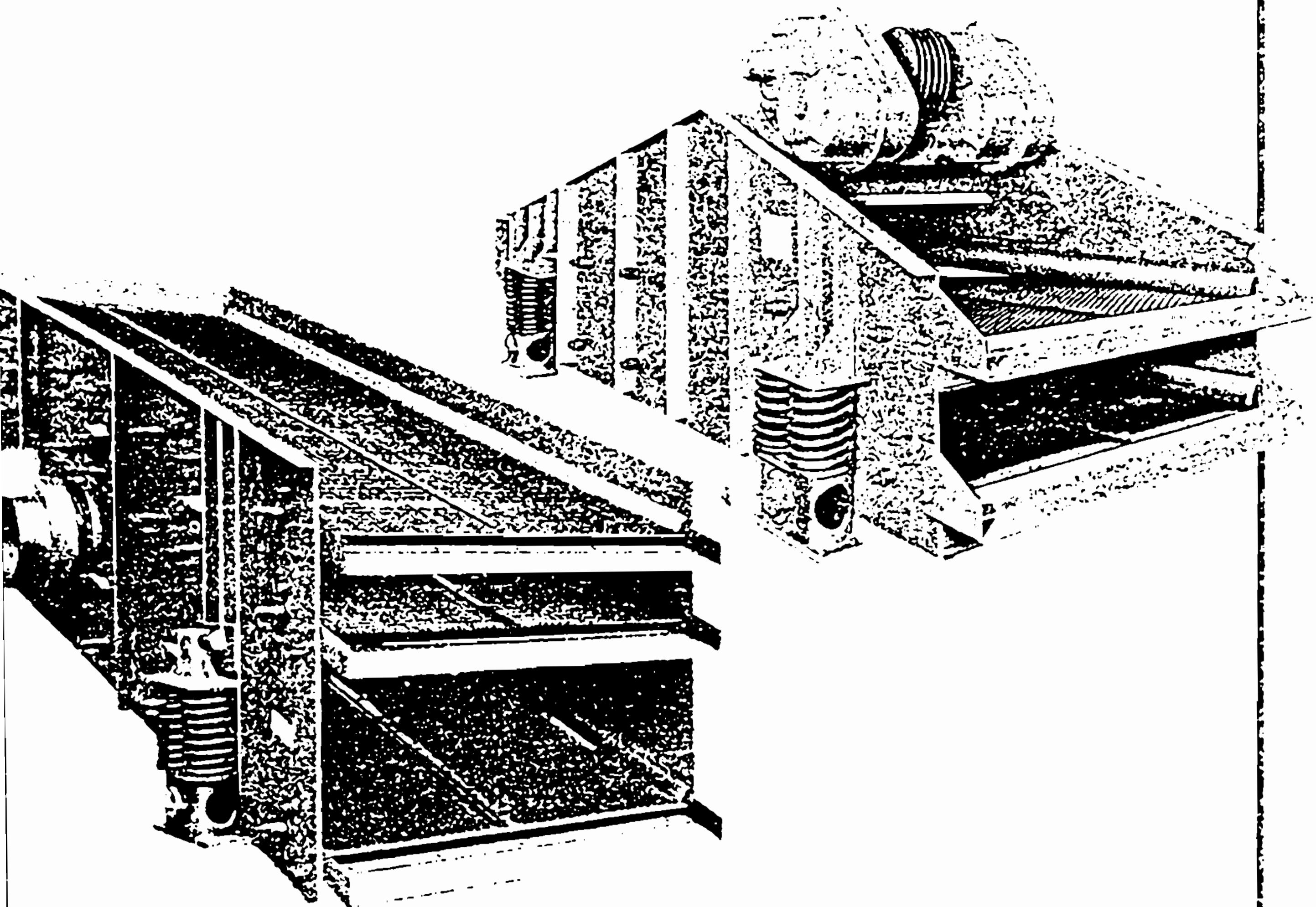
ALLIS-CHALMERS

VIBRATING SCREEN | *Theory and Selection*



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INTRODUCTION

Billions of tons of raw material are torn from the earth every year and processed in various ways to make them useful to man. It is safe to say that at one point or another most of this vast bulk passes over screening surfaces.

Screening is the separation of material particles on the basis of size. Particles are presented to apertures in a screening surface and rejected if larger than the opening or passed through if smaller.

Many screen types are in use today, each with special advantages for specific functions. Most common, however, is the vibrating screen — a highly efficient, large volume machine. Depending on the application, it can handle lump sizes as big as two feet or more in the largest dimension, or particles of less than .01 inch cross section.

Classification of materials is done through the medium of specialized screen surfaces, which contain the apertures through which undersize can pass. Surface specialization makes possible a variety of uses for screens.

Screen Uses

Size separation: Material separation by size, including:
- Scalping — removal of small amount of oversize.
- Coarse — greater than 4 mesh separation.
- Fine — between 4 and 48 mesh separation.
- Ultra-fine — less than 48 mesh separation.

Dewatering: Removal of free water from solids.

Deslime: Fine, wet separation of material at 28 mesh or less.

Media recovery: Reclaiming media (FE_3O_4 and water) in float-sink process.

Trash removal: Separating foreign material from product, e.g., wood from coal.

Washing: Washing or rinsing material with water, e.g., wet dust removal.

Dedusting: Dry dust removal.

Conveying: Material transfer from one point to another.

Concentration: Blending or adding material to specific concentration, e.g., pulp dewatering.

THEORY OF SCREENING

The principles of screening for any of these uses are basically the same. Material to be screened is delivered to the screen surface at a continuous rate. Dropped onto the surface or feed box, it loses its vertical component of velocity and undergoes a change in direction of travel. By vibration, the bed of material tends to develop a fluid state.

The large particles remain on top of the bed while the smaller particles sift through the voids and find their way to the bottom. This characteristic of particle orientation in the bed is called stratification. Material stratification presents the smaller particles to the screening surface to be passed through or over the surface. Without stratification there would be no opportunity for separation to take place.

Once the particle has sifted its way through the bed of material, the principle of probability becomes significant. As it is conveyed from feed to discharge end of the screen surface the particle is subjected to the probability of either passing through the opening or striking the wires of the screening surface.

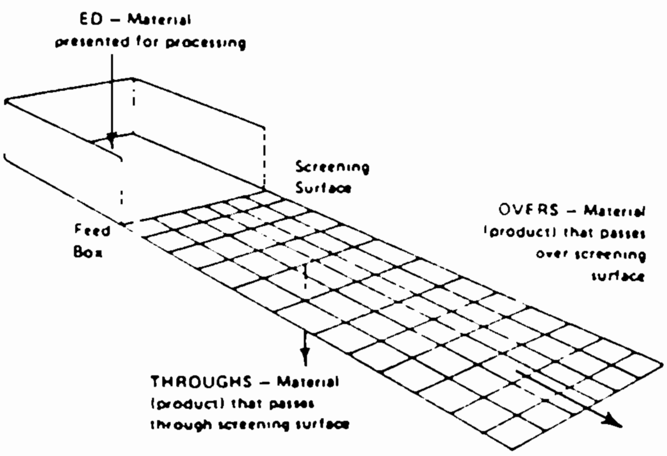

Fig. 1 – The screening process

In commercial sizing or screening, two basic processes take place:

1. **Stratification:** The process whereby the large size particles rise to the top of the vibrating material bed while the smaller size particles sift through the voids and find their way to the bottom of the bed.
2. **Probability of separation:** The process of particles presenting themselves to apertures and being rejected if larger than the opening or passed through if smaller.

Stratification is an obvious necessity without which separation could not take place. To take maximum advantage of this phenomenon, the depth of bed of material at the feed and discharge ends (for a continuous feed, as opposed to a batch condition) must be reasonable for the size separation to be made. Thus, for a given rate of feed, the width of screen is selected to control this depth of bed and achieve optimum stratification.

A general rule of thumb for good screening is:

"The bed depth of material at the discharge end of screen should never be over four times the size opening in the screen surface for material weighing 100 pounds per cubic foot or three times for material weighing 50 pounds per cubic foot. The feed-end bed depth can be greater, particularly if the feed contains a large percentage of fines."

Other interrelated factors which affect stratification are:

1. material travel rate – a function of the material specifications, screening media specifications, depth of bed, stroke characteristics, and slope of screen.
2. stroke characteristics – amplitude, direction of rotation, type of motion, and frequency.
3. surface moisture – high surface moisture hinders stratification.

Under some conditions it is possible to have too little bed on a vibrating screen. Figure 2 is the typical plot of separation efficiency at various feed rates for a given size screen and material gradation. Efficiency, as used here, refers to the ability of equal screening areas to remove undersize material from a given feed.

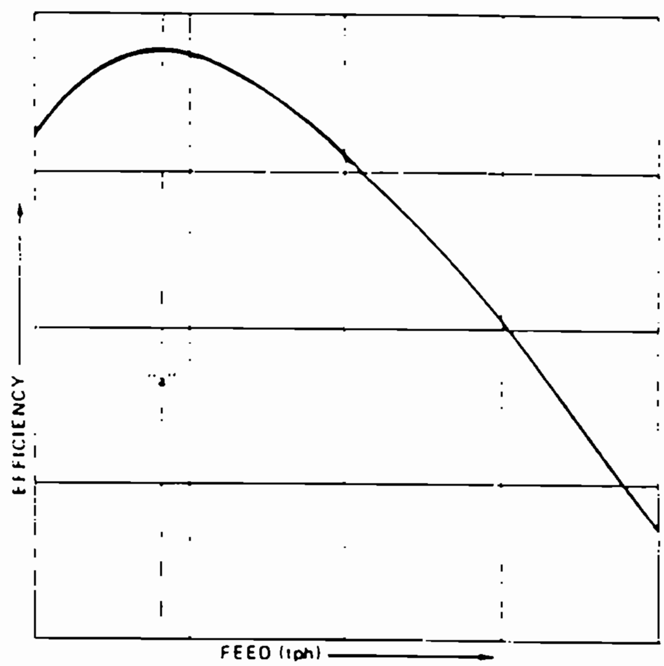

Fig. 2 – Screen efficiency vs. feed rate

For very small feed rates, up to point "a", efficiency actually increases with increased tonnage. The bed of oversize material on top of the marginal particles prevents them from bouncing excessively, increases their number of attempts to get through the screening medium, and helps push them through. Beyond optimum point "a," efficiency rapidly drops off with increased tonnage. The screen is not large enough to pass all the undersize material.

Although the separation process is well recognized and considered synonymous with screening, the fact that stratification must also take place is often overlooked. This oversight frequently leads to aggravation rather than relief of poor screening efficiency. Operators may reduce the slope of a screen in an effort to slow down the rate of material travel and retain it longer on the deck, attempting to give the undersize material more of an opportunity to pass through the screening medium. Instead, an excessive

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bed of material results with inadequate stratification and poorer screening efficiencies.

Another practical corollary is that stratification is generally difficult to attain when screening damp materials, or fine materials of lighter density such as coal, and a relatively thin depth of bed from feed to discharge end of the screen is required.

In the separation process, near size particles must have the opportunity to present themselves to an opening in many different positions. Commercially, particles are of an infinite number of shapes. Particles which have all dimensions considerably smaller than the deck openings will fall through readily.

Probability of the particle hitting the screen surface or passing through the opening is directly affected by particle size to screen surface opening relationship:

1. The larger the opening, compared to the particle size, the higher the degree of probability that the particle will pass through the opening.
2. The smaller the opening, compared to the particle size, the lower the degree of probability that the particle will pass through the opening.

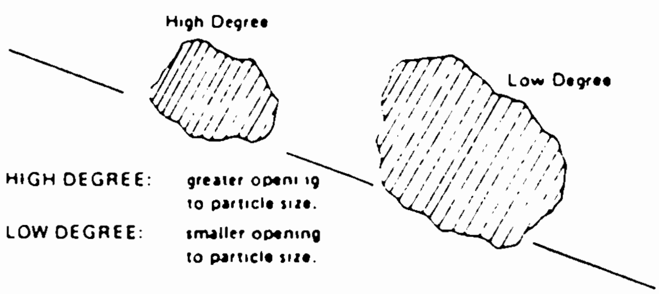

Fig. 3 – Degree of probability.

The principle of stratification and probability is accomplished by vibrating the screen. Vibration is produced on inclined screens by circular motion in a vertical plane of one-eighth to one-half inch amplitude at 700 to 1000 cycles per minute. The vibration lifts the material, producing stratification. With the screen on an incline, the material will cascade down the slope, introducing the probability that the particle will either pass through the opening or over the screen surface.

Since horizontal screens are not installed on a slope, the motion must be capable of conveying the material without the assistance of gravity. Straight line motion at an angle of approximately 45 degrees to the horizontal produces a lifting component for stratification and a conveying component for probability of separation as the material passes across the screen surface.

The rate of material flow through the screen surface openings will vary, depending on the degree of stratification and probability. See Figure 5.

When material is introduced to the feed end of the screening surface, the vibration causes the material to stratify (smaller particles working their way to bottom of the bed). This is from point "a" to "b," with maximum stratification at "b." Maximum particle removal occurs from "b" to "c" (saturation screening), the point of highest degree of probability, because of the high percentage of fine particles – much less in size relative to the opening of the screen surface.

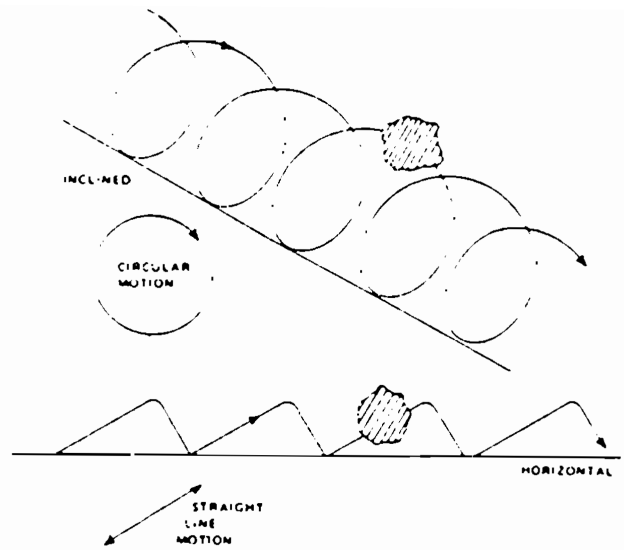

Fig. 4 – Inclined and horizontal screen motion

Following saturation screening is the area of low degree probability screening, points "c" to "d." In this area the relation of particle size to opening is closer, and probability of the particle passing through the opening is less.

With a typical simple screen separation, as shown in Figure 5, perfect separation (100% efficiency) is not commercially practical because from point "d" on, capacity through the deck is extremely low. Theoretically, for an absolutely perfect separation, the screen would have to be infinitely long because the curve of Figure 5 becomes asymptotic to the screen length axis. Perfect screening is an impossibility. "Commercially perfect" screening is normally regarded as in the order of 90 to 95% efficiency.

In actual practice, however, a "perfect separation" is defined by the standard of a sieve analysis, where a sample is retained on a sieve and the near size particles are given an opportunity to fit and try themselves for periods normally ranging between one and one-half to three minutes. Commercially, this is equivalent to having the material travel down the length of a 90- to 180-foot long screen. A 24-foot length is the largest single screen presently being manufactured.

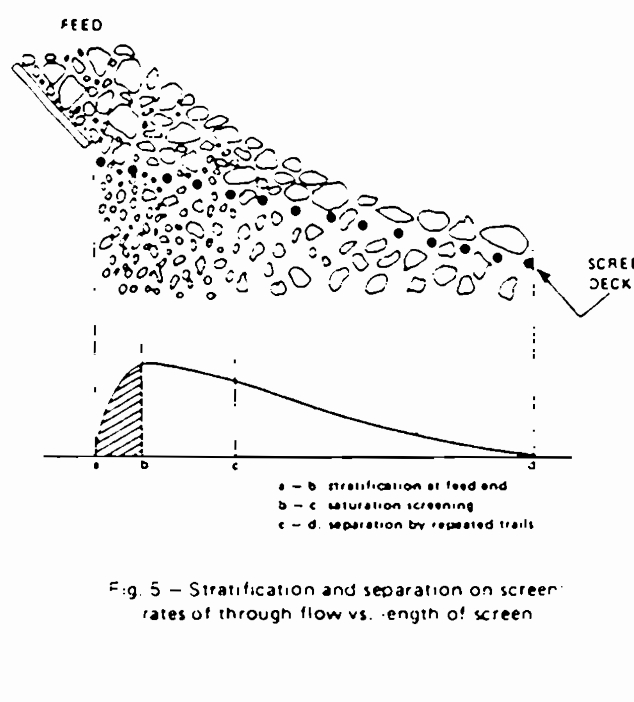

Fig. 5 – Stratification and separation on screen: rates of through flow vs. length of screen

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SCREENING EFFICIENCY

The major concern of screen operators is that the screened product meets specifications. They look at efficiency of the screening operation in terms of how much undersize remains in the oversize product. Conversely, if the undersize is considered to be a product, how much oversize remains in the undersize. This is what screening efficiency is all about.

There are two common methods of calculating screen efficiency, depending on whether the desired product is the "overs" or "throughs" from the screening deck. If the oversize is considered to be the product, the screen operator wants to remove as much as possible of the undersize material. In that instance, we express screen performance as "efficiency of undersize removal." When the throughs are considered to be a product, the operator wants to recover as much of the undersize as possible. We look at this case in terms of the "efficiency of undersize recovery."

"Efficiency of undersize removal" is determined by taking a sample of the oversize off a screening deck and ma[illegible] a sieve test to determine the screen analysis (gra[illegible]ion). The analysis will show some of the overs product to be of the desired size, and a portion to be misplaced undersize particles. No screen is commercially capable of removing all the undersize.

The percentage of undersize particles in the overs product is then expressed as a percent of the overs product, and this value is subtracted from 100%. The resulting value represents the efficiency of the tested deck. The "efficiency of undersize removal" may be determined for any deck of a screen by obtaining a sample of overs from that deck and making the calculations.

For example, a sample of oversize material from a screen deck is found by sieve analysis to contain 9% by weight of undersize (calculated as a percent of overs), or material that should have gone through the deck but did not. Subtracting from 100%, we have 91% efficiency for that deck. The definition can be reduced to formula, as follows.

Formula 1

Efficiency of undersize removal = 100 −b

Wh[illegible] "b" = % of undersize in overs product, as a % of overs.

Expressed in another way:

Formula 2

Efficiency of undersize removal

$$= \frac{\text{\% (or tph) of feed which is oversize}^{①}}{\text{\% (or tph) of feed which passes over}^{②}} \times 100$$

① From analysis of feed to the screen deck;

② From analysis of material over the deck.

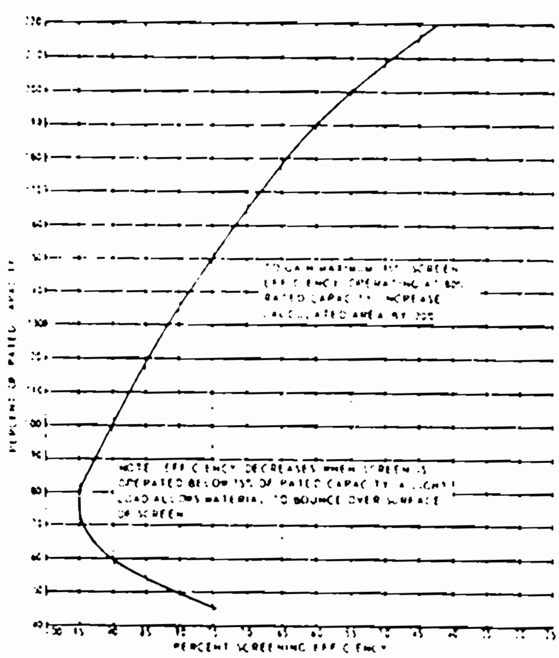
Formulas 1 and 2 relate to "efficiency of undersize removal." They cover those applications where undesired fines are to be removed from the overs product. Both formulas will yield the same result.

Caution: When expressing screen efficiency by this method, if there is relatively little oversize product as compared to undersize (30% or less oversize) even a small amount of carryover of marginal undersize pieces will make screening efficiency low.

To improve efficiency, either the screening area must be increased or the amount of feed decreased. That is because a screen operates at peak efficiency with a material load of approximately 80% of that at which the screen area was calculated. This is shown graphically in Table 1, below. The formula for calculating screen area is discussed in "Screen Area And Bed Depth," p. 22. It is based on screen operation with 100% of the material load on the screen (100% of rated capacity).

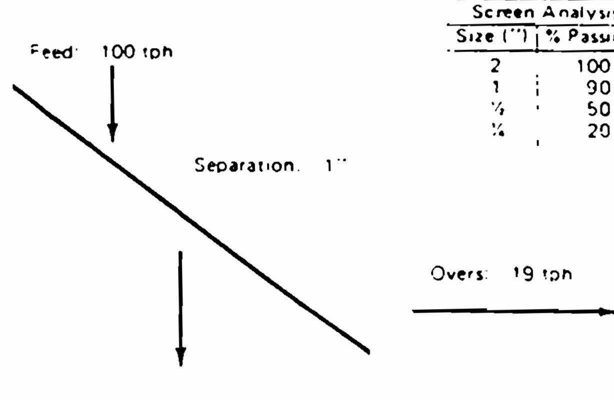
When sizing a new screen we can assume that the customer does not want to reduce capacity — or feed. This leaves only the option of increasing screening area as a means of improving screen efficiency. Therefore, when oversize material in the feed is 30% or less, or when maximum screen efficiency is required, regardless of the amount of oversize material in the feed, increase calculated area by 20%. This will result in improved efficiency.

Table 1 — Screen Efficiency as Affected by Load



By way of illustration, consider the two cases which follow. Both are for a 1" separation at 100 tph.

Case 1



Feed	
Screen Analysis	
Size (")	% Passing
2	100
1	90
½	50
¼	20

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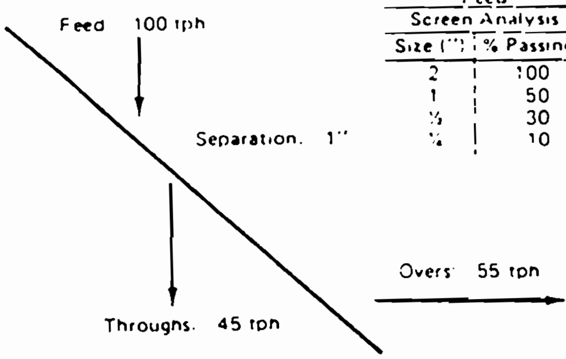
By analysis of the feed to the screen deck, 90% (or 90 tph) is minus 1", but only 81 tph goes through the screening medium. 9 tph of minus 1" material carries over with the oversize.

(a) By Formula 1:
Efficiency of undersize removal = 100% − 47% = 53%
9 ÷ 19 = .47 and (9 ÷ 19) 100 = 47%

(b) By Formula 2:
Efficiency of undersize removal = (10 ÷ 19) 100 = 53%
Where: 10 is the % of feed which is oversize (see analysis of feed to the screen deck) and 19 is the % of feed which passes over, or (19 ÷ 100) 100 = 19%.

Case 2



Feed Screen Analysis

Size (")	% Passing
2	100
1	50
½	30
¼	10

By analysis of the feed to the screen deck, 50% (or 50 tph) is minus 1", but only 45 tph goes through the screening medium. 5 tph of minus 1" material carries over with oversize.

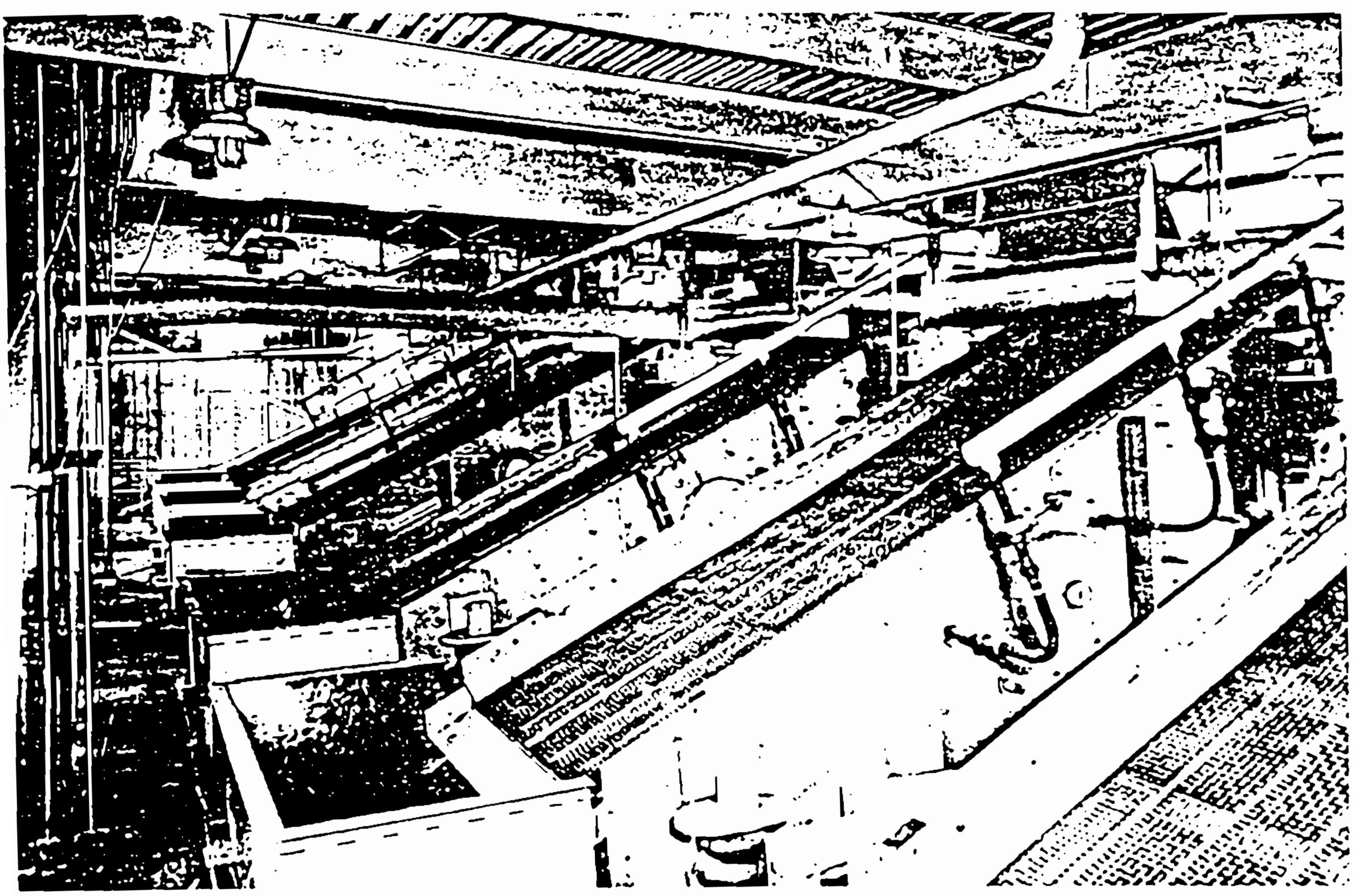
(a) By Formula 1:
Efficiency of undersize removal = 100% − 9% = 91%
5 ÷ 55 = .09 and (5 ÷ 55) 100 = 9%

(b) By Formula 2:
Efficiency of undersize removal = (50 ÷ 55) 100 = 91%
Where: 50 is the % of feed which is oversize (see analysis of feed to the screen deck) and 55 is the % of feed which passes over, or (55 ÷ 100) 100 = 55%.

When the amount of oversize is small, the resulting efficiency appears to be low (Case 1: efficiency of undersize removal = 53%). Where there is a large amount of overs product, the resulting efficiency of undersize removal appears to be high (Case 2: 91%). In both cases, the actual amount of undersize is relatively small (9 tph and 5 tph). The apparent low efficiency in Case 1 can be improved, as previously discussed, by increasing the screening area by 20%.

"Efficiency of undersize recovery"

To this point we have discussed "efficiency of undersize removal," for conditions where oversize is considered to be the product. Let's examine the situation where the



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undersize is considered to be the product, and discuss "efficiency of undersize recovery." In this instance, we measure the percentage of undersize material actually removed (determined by analysis of material over the deck) versus the percentage of feed which is undersize (determined from analysis of the feed to the screen).

We define "efficiency of undersize recovery" by formula as follows:

Formula 3

Efficiency of undersize recovery

$$= \frac{\%\text{ (or tph) of feed which passes through}^{①}}{\%\text{ (or tph) of undersize feed}^{②}\text{ which should pass thru}} \times 100$$

Or Formula 4

Efficiency of undersize recovery

$$= \frac{100\,(a \text{ minus } b)}{a\,(100 \text{ minus } b)} \times 100$$

Where: a = % of undersize in feed ① as a % of feed.
b = % undersize in overs product ② as a % of overs.

① From analysis of feed to screen deck;
② From analysis of material over the deck.

As example: look at cases 3 and 4, considering the undersize as the product.

Case 3

(a) By Formula 3:
Efficiency of undersize recovery = (81 ÷ 90) 100 = 90%

Where: 81 tph actually passes through the screening medium, and 90 tph represents the undersize which should have passed through (from screen analysis of feed).

(b) By Formula 4:
Efficiency of undersize recovery

$$= \frac{100\,(90-47)}{90\,(100-47)} \times 100 = 90\%$$

Where: a = 90%, per screen analysis of feed
b = (9 ÷ 19) 100 = 47%

Case 4

(a) By Formula 3:
Efficiency of undersize recovery
= (45 ÷ 50) 100 = 90%

Where: 45 tph actually passes through the screening medium, and 50 tph represents the undersize which should have passed through (from screen analysis of feed).

(b) By Formula 4:
Efficiency of undersize recovery

$$= \frac{100\,(50-9)}{50\,(100-9)} \times 100 = 90\%$$

Where: a = 50%, per screen analysis of feed
b = (5 ÷ 50 + 5) 100 = 9%

In some instances, the customer may consider both the oversize and undersize (throughs) from the same screen to be products. In these cases, check both the "efficiency of undersize removal" and "efficiency of undersize recovery." Again, if there is a small amount of oversize, and efficiency of undersize removal looks poor, increase the area by 20%.

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SCREEN SELECTION

Most screen applications are for size separation of like materials – separating smaller from larger particles. This section on "Screen Selection" treats exclusively with this type of duty. For other applications, such as dewatering, media recovery, etc., refer to Factory.

Considering separation on a vibrating screen as a continuous flow process, the unit selected must be capable of handling the required capacity and making the separation before the material reaches the end of the screen. Proper vibrating screen selection is of key importance to assure operating plant efficiency. All too often the screening portion of a plant is not taken seriously, and problems such as poor efficiency, low tonnage, etc., develop after installation.

There are two primary considerations. One is to select between an inclined or a horizontal type, and the other is to determine area requirements (screen size).

Size selection formulas apply to both inclined or horizontal screens. As a rule, we recommend inclined screens for all sizing applications, except where low headroom is a factor (horizontal types require considerably less headroom than inclined screens) or where water contamination of the oversize product is undesirable.

Table 2 is a compilation of limitations guides for good screening application, which states maximum lump size, 1
maximum and minimum size separations, material drop and temperatures for the standard Allis-Chalmers screen lines.

Screen selection requires that you analyze your flow sheet, determine capacity requirements for each screening station, know the characteristics of the material, and what efficiency is acceptable. Once this has been done, you can select the screen size on the basis of required screening area. 2

Table 2 – Limitations Guide (Good Practice)

Screen Type	Inclined			Horizontal	
Model	XH Ripl-Flo	SH Ripl-Flo	ST Ripl-Flo	Levl-Flo	LowHead
Maximum lump size (inches)					
50 #/ft^3	24	10	10	10	10
100 #/ft^3	16	8	8	8	8
140 #/ft^3	12	6	6	6	6
Minimum opening (inches)	1/8	1/8	1/8	1/8	1/8
Maximum opening (inches)					
Single deck	10	5 1/2	4	3	2 1/8
Double and triple deck	10	3 1/2	4	3	2 1/8
Maximum material drop (inches)	30	30	30	30	30
Maximum material temperature (°F)	150	150	150	150	150

Maximum and minimum openings are based on standard design.
Any application requiring a deviation from standard values must be referred to the Factory.

INFORMATION NECESSARY TO SELECT VIBRATING SCREENS

Certain variables must be known to determine screening area. Failure to first determine them will surely lead to improper screen sizing.

- Maximum tons per hour
- Material size consist
- Type and weight of material
- Desired separations
- Material surface moisture
- Special operating requirements

1. **Maximum tons per hour** (short tons) to be screened. Include any circulating load (Table 3, page 11) or surges in feed rate.

Circulating load is a factor in sizing of screens to be used as part of crushing circuits where the product must be 100% minus a given product top size. A problem exists because crushing machines do not reduce all their feed to a size equal to or smaller than the crusher setting. In normal practice, the crusher is set at a smaller setting (opening) than the screen deck opening, to obtain a good balance between net finished product (100% minus product top size) and circulating load.

The amount of crusher throughput that is oversize and must be recrushed is expressed as the % of oversize in the crusher product. It continues to be recirculated through the crusher until it is reduced to a size that will pass the screen opening. This is called "closed circuiting."

With each pass through the crusher an additional amount of oversize will be reduced to undersize. The number of passes for any given batch of material, with no addition of new feed, before 100% reduction is achieved, is infinite. The percent of oversize remaining after each pass through the crusher and over the screen deck diminishes in a geometric progression.

By definition, circulating load = total feed to the crusher minus original crusher feed. It is expressed in % of original feed to the crusher.

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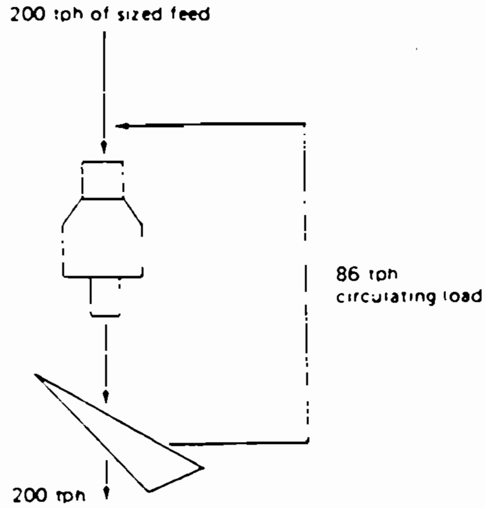
The formula for % circulating load is:

Formula 5

$$R = \frac{100}{e/r - 1}$$

Where: R = % circulating load to crusher
e = % screen efficiency
r = % oversize in crusher product

The following example will help to explain circulating load and the effect of screening efficiency. This example assumes 100% screen efficiency, and 30% oversize in the crusher product.



For this example the geometric progression of crusher oversize would be:

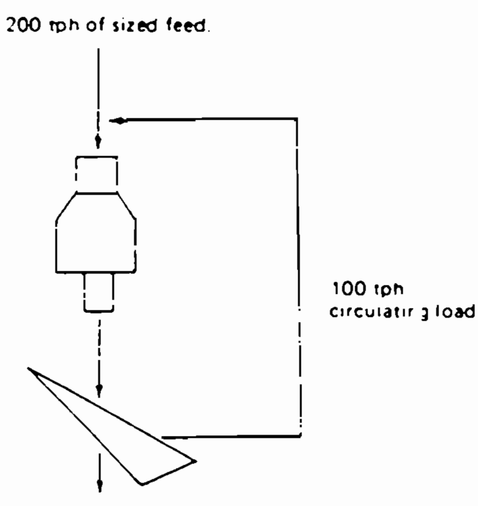
Pass thru crusher **TPH**

1	200x.30	=	60.00
2	200x.30x.30	=	18.00
3	200x.30x.30x.30	=	5.40
4	200x.30x.30x.30x.30	=	1.62
5	200x.30x.30x.30x.30x.30	=	.49
6	200x.30x.30x.30x.30x.30x.30	=	.15
	etc.		
			85.66
			or 86 tph

By formula: $R = \frac{100}{e/r - 1} = \frac{100}{100/30 - 1} = \frac{100}{2.33} = 42.9\%$

∴ Circulating load = new feed to crusher x R
200 x .429 = 85.8 or 86 tph

Look at the same example, with a change of screen efficiency. Assume 90% screen efficiency — other factors the same.



With 90% screen efficiency, the geometric progression of crusher oversize would be

Pass thru crusher **TPH**

1	$200(.30 \times \frac{1}{.90})$	= 66.67
2	$200(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})$	= 22.22
3	$200(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})$	= 7.41
4	$200(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})$	= 2.47
5	$200(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})$	= .82
6	$200(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})(.30 \times \frac{1}{.90})$	= .27
		99.86
		or 100 tph

By formula: $R = \frac{100}{e/r - 1} = \frac{100}{90/30 - 1} = \frac{100}{2} = 50\%$

Circulating load = 200 x .50 = 100 tph

To simplify circulating load calculations, Table 3 has been established for various percentages of crusher oversize product and screen efficiency, based on formula $R = \frac{100}{e/r - 1}$

These tables are based on theoretical values and should by no means be used as a basis for direct guarantees as the actual circulating loads will undoubtedly vary somewhat from the theoretical calculations contained herein.

Additional percentages for intermediate oversize percentages may be calculated from the formulae. Do not interpolate from tables as this is not a straight line variation between points.

For simple explanation of screen efficiency, the previous example assumed that the original feed to the crusher was sized. It contained no fines or materials of lesser size than the desired crusher product. To do this in actual practice would mean that feed would have to be screened before going to the crusher, as in the example:

Assumptions:

90% screen efficiency
30% oversize in crusher product
20% oversize in new feed

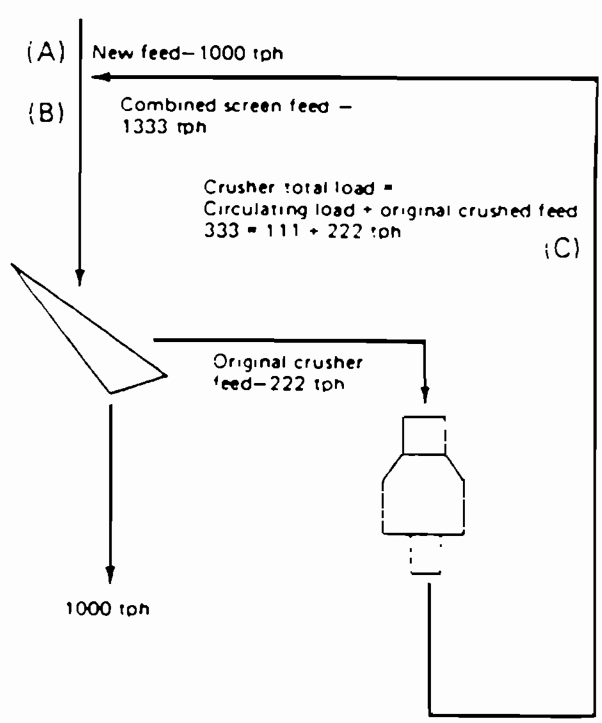


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Table 3 – Circulating Loads $R) \frac{100}{e\ r - 1}$

Percent Undersize in Crusher Product	(r) Percent Oversize in Crusher Product	Screen Efficiency (e) Percent 100	Percent 95	Percent 90	Percent 85	Percent 80	Percent 75	Percent 70
95	5	5.3	5.7	5.9	6.3	6.7	7.1	7.7
90	10	11.2	11.8	12.6	13.3	14.2	15.4	16.8
85	15	17.7	18.8	20.0	21.5	23.1	25.0	27.3
80	20	25.0	26.7	28.6	30.7	33.4	38.3	40.0
75	25	33.4	35.8	38.7	42.0	45.4	50.0	55.5
70	30	42.9	46.3	50.3	54.7	60.0	66.7	74.5
65	35	53.9	58.5	63.8	70.0	77.8	87.7	100.0
60	40	66.7	73.0	80.0	89.0	100.0	114.3	133.5
55	45	81.8	90.5	100.0	112.5	128.5	150.0	181.0
50	50	100.0	111.4	125.0	143.0	166.7	203.0	250.0
45	55	122.2	137.5	158.0	183.5	219.5	276.0	365.0
40	60	150.0	172.0	200.0	240.0	300.0	400.0	600.0
35	65	186.0	216.0	261.0	326.0	435.0	652.0	1290.0
30	70	233.0	280.0	351.0	568.0	700.0	1416.0	.....
27.5	72.5	.....	.....		..	963.0	....	.....
25	75	300.0	374.0	498.0	747.0			
20	80	400.0	537.0	802.0				
15	85	567.0	852.0					

Original crusher feed = 1000(A) x 20/90 = 222 tph

Circulating load = original crusher feed x % circulating load (R). (Refer to Table 3 for 30% oversize in crusher product and 90% screen efficiency.)

R = 50.3.

Circulating load = 222 x .503 = 111 tph

Total load to crusher = original feed to crusher plus circulating load
= 222 + 111 = 333 tph(C)

Combined feed to screen
= new feed + crusher total load
= 1000 + 333 = 1333 tph(B)

2. **Size consist or sieve analysis** of the material. If this is not available, an estimated analysis is required.

Many operators are doubtful of the screen analysis of the feed to a screen. Tables 4 to 9, pages 11, 12, 13, 14, and 15, have been included as a guide in making an assumed screen analysis of the feed. If these tables are used in computing a screen size, you must state in your customer proposal that the screen recommendation is based on an assumed feed and on our knowledge of numerous other applications.

Estimating crusher product analysis. Product screen analysis from any crusher will vary widely depending upon the material, quarry conditions and the amount of fines or product size in the initial feed at the time the sample is taken. These factors must be considered when estimating crusher product screen analysis – but only as approximations. The product gradation curves, tables 6-9, can be used for estimating.

The discharge opening on the open side will govern primary crusher product gradation, if corrected to consider quarry or mine conditions, especially the amount of fines in the crusher feed. Table 4, at right, gives the approximate percentage of product equal to the open side setting, based on many screen analyses. In actual use, values should be corrected to include known feed conditions, particularly the percentage of fines or product size in the feed.

Table 4 – Percent of Product Passing Square Opening Equal to Crusher Open Side Setting

Type of Crusher	FEED: Run of Quarry	Scalped Percent	Scalped and Recombined with Fines
LIMESTONE			
Jaw	90	85	88
Gyratory	90	85	88
GRANITE			
Jaw	75	75	75
Gyratory	82	75	80
TRAP ROCK			
Jaw	70	70	70
Gyratory	75	70	75
ORES			
Jaw	90	85	85
Gyratory	90	85	85

Tables 5 through 8 have been prepared giving the approximate screen analysis of product for impactors and primary crushers and for quarry-run material. Use these tables in conjunction with Table 4.

Table 5 – Typical Impactor Product. Feed – Minus 4' Limestone.

Openings	Percent Passing
1"	90
[illegible]	80
[illegible]	70
[illegible]	58
[illegible]	48
4 mesh	4[illegible]
8 mesh	28
14 mesh	[illegible]

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Table 6

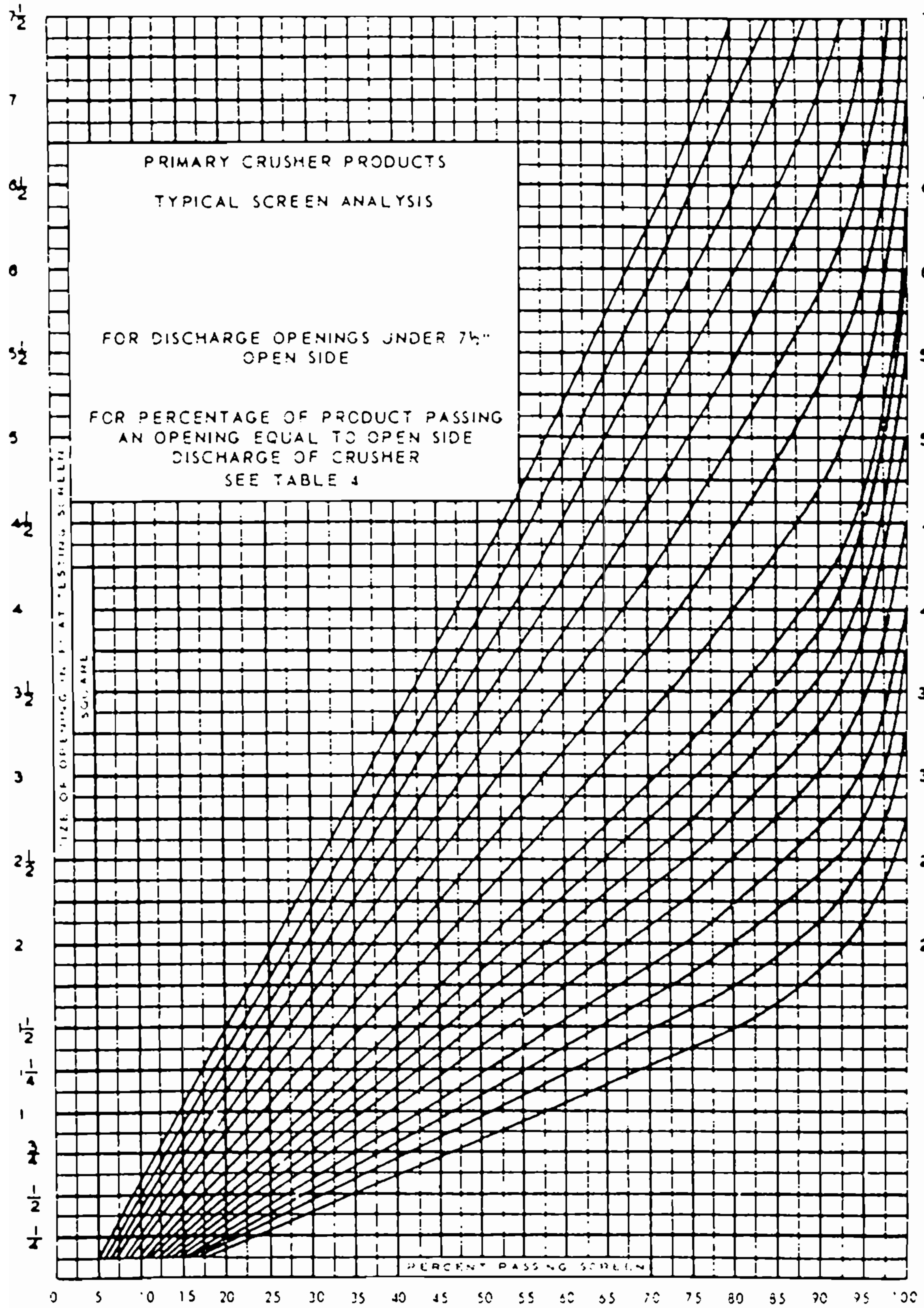

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Table 7

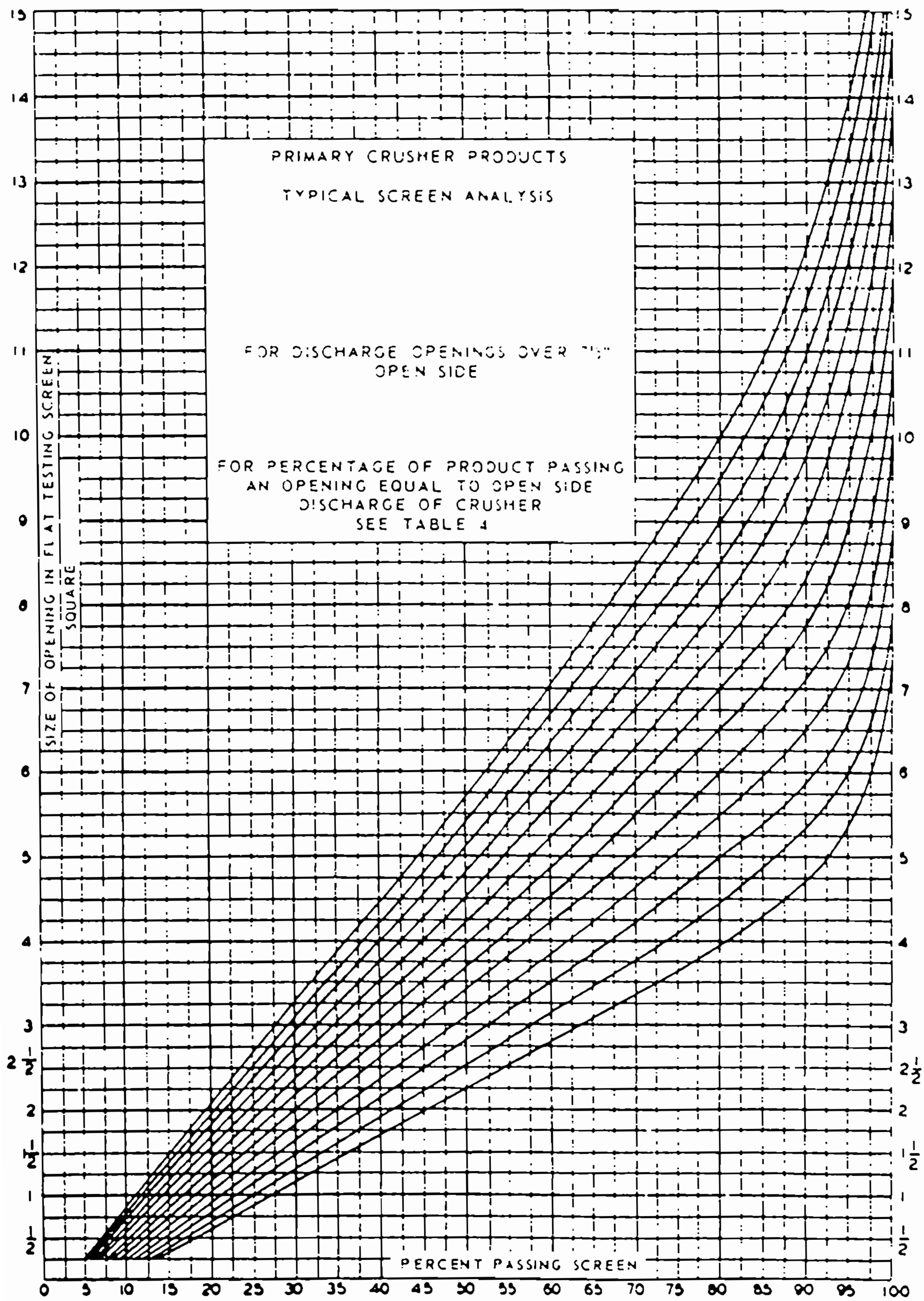

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Table 8 – Screen Analysis of Quarry Run Material

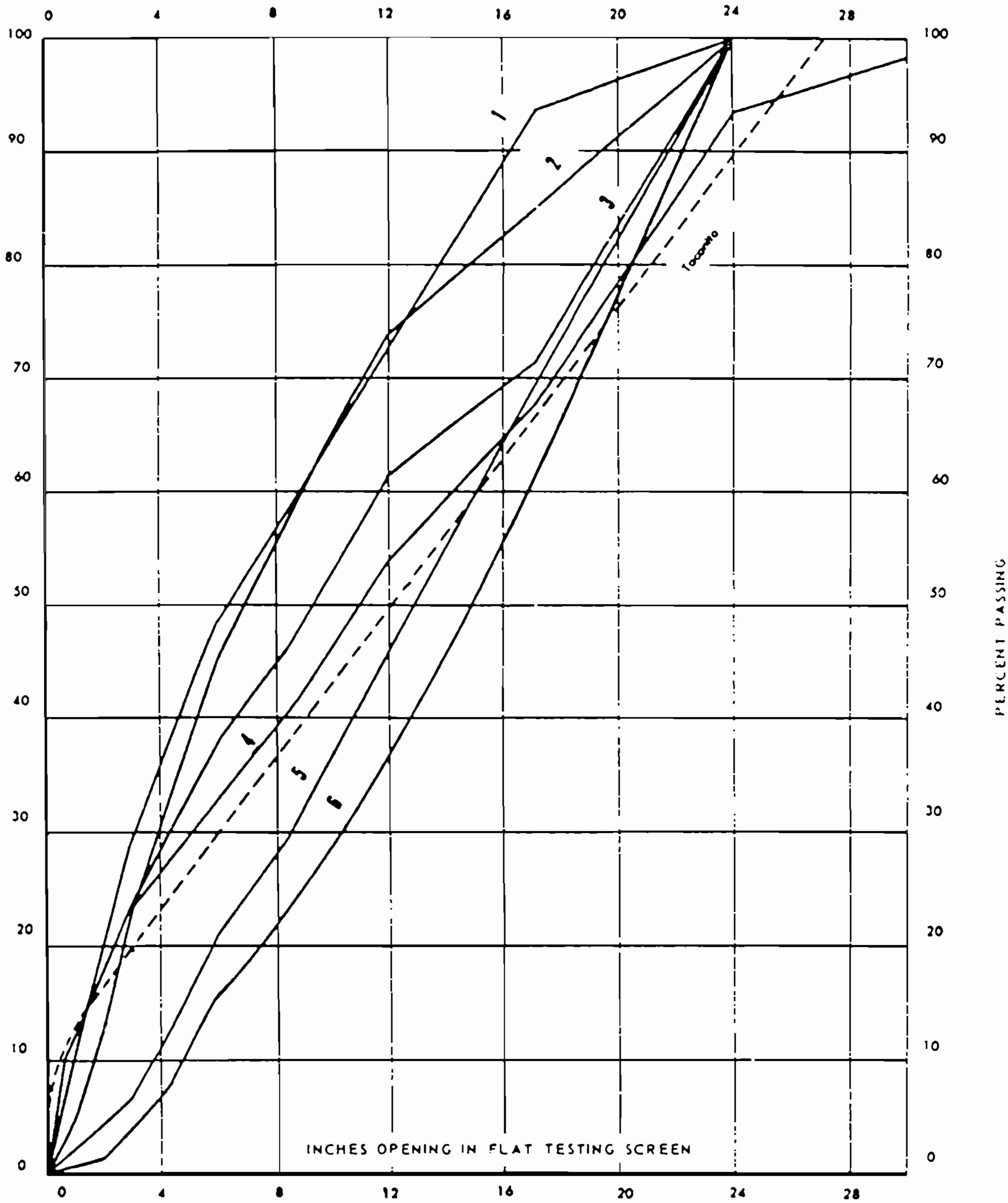

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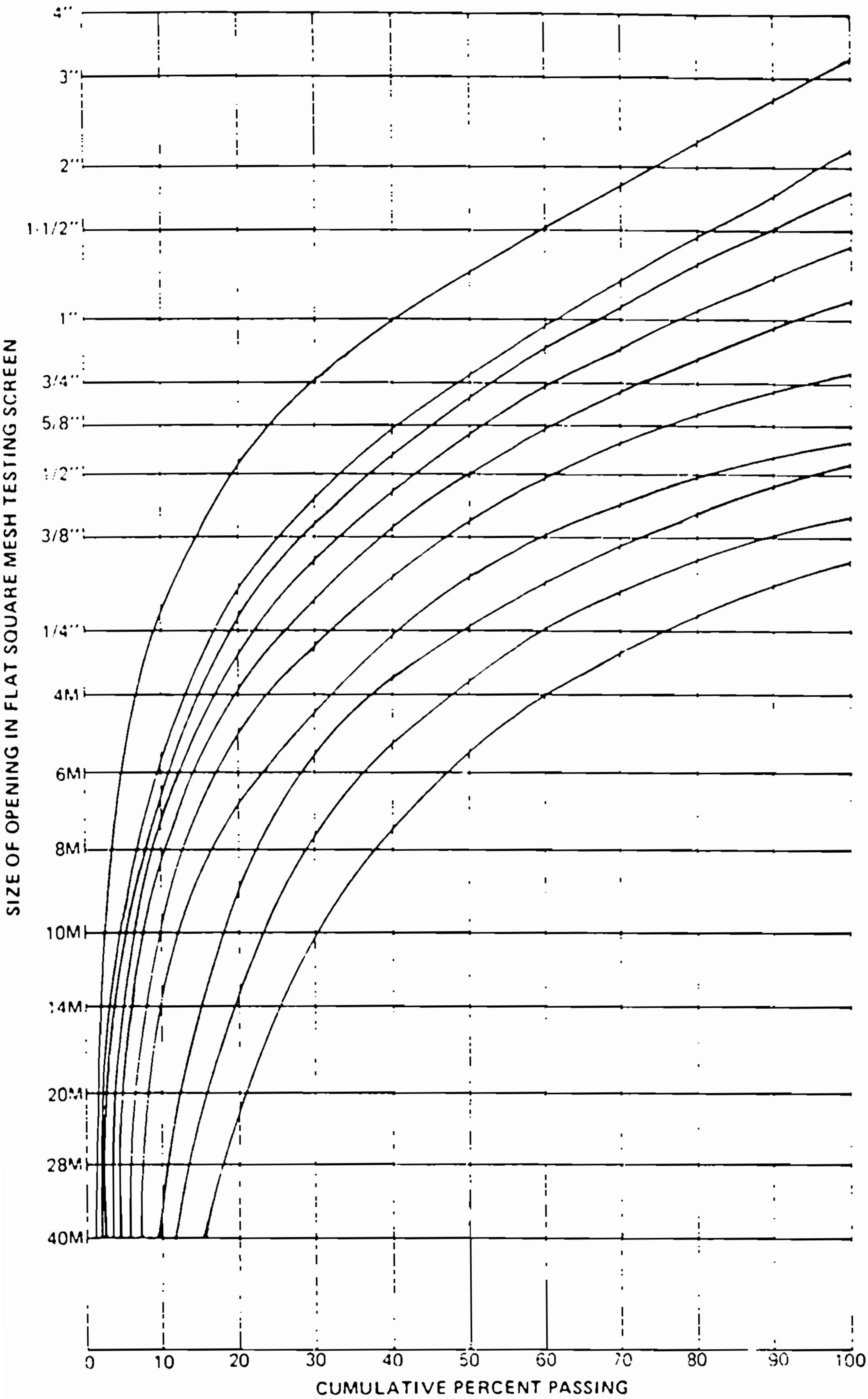
Table 9 – Typical Hydrocone Crusher Products



These curves are intended for use in calculating flow sheets only and are not to serve as the basis for any performance warranty

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Table 10 – Weight Per Cubic Foot of Materials Loosely Piled

Material	Lbs.
Alum	33
Ashes, Cinders	40-45
Barley	37
Basalt	96
Bauxite	85
Caliche	90
Cement, Portland	90
Cement, Clinker	95
Charcoal	10-14
Chips, Wood	18
Clay & Gravel, Dry	100
Coal, Anthracite	47-58
Coal, Bituminous	40-54
Coke	23-32
Cork	15
Corn	37
Cullet	80-100
Dolomite	109
Feldspar	100
Fullers Earth	42
Gneiss	96
Granite	96
Greenstone, Hornblende	107
Gypsum	75
Ilmenite	120
Iron Ore, Hematite	130-160
Iron Pyrites Ore	165
Lime, Gypsum	65-75
Limestone	95-100
Marble	95
Mica	100
Oats	26
Phosphate Rock	75
Porphyry	103
Quartz	95
Rock Salt	94
Rye	48
Sand & Gravel, Dry	90-105
Sandstone	82
Shale	92
Slag	98-117
Sulphur Ore	87
Taconite	150-200
Talc	109
Trap Rock	109

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Table 3 gives the approximate screen analysis of HYDROCONE crusher products. Experience gained in recent years indicates that 60% passing the closed side setting is a good estimating value for coarse and medium chambers. For fine chambered crushers, particularly those in closed circuit operation, use 65% passing the c.s.s. When the material is soft and friable, more will pass the setting; conversely, with hard material or that which tends to pack, less passes the setting than these figures indicate. Use your knowledge of how a particular material breaks and past experience with similar materials in deciding the percent passing the c.s.s. to be used.

3. Type of material and the weight per cubic foot of the material in the crushed or loose state. Refer to table 10, page 16, for weights of commonly processed materials.

4. Separation desired on each deck.

5. Surface moisture carried by the material if screening is to be done dry, or the amount of water with the feed if screening is to be done wet.

Wet Screening With Sprays. The number and size of water sprays and water pressure on a vibrating screen depends on the application and the physical dimensions of the screen. Different materials require varying amounts of water for efficient screening. There is a vast difference between wet screening a feed containing clay or other sticky materials and rinsing a material.

The first step in determining the number of sprays required is to establish the total water necessary for good screening. For raw coal containing a large amount of insoluble clay as much as 5 gallons per minute per ton of material handled may be needed. For rinsing presized gravel 3 gallons will suffice. When the total water required is determined, the next step is to distribute it over the screen surface so that the screen is covered by a curtain of water from side to side.

The final step is to locate the rows of sprays along the length of the screen. For ordinary sizing the sprays can be located at or near the center but if dewatering is required, they should be grouped near the feed end. If the feed contains a large quantity of clay, the sizing may be improved by presoaking or adding water to the feed in a flume ahead of the screen.

The sprays should be adjusted so that the water strikes the material at an angle of 45 degrees uphill and staggered so that adjacent sprays will not strike each other. The sprays furnished by Allis-Chalmers when operated at pressures of 30-40 psi will cover an area approximately equal to the height of the orifice above the bed of material.

The amount of spray water required is given in Table 11, below. In general, more water is required for double deck screens than for single deck screens. More of the water should be used on the bottom deck, usually the smaller sizes are more difficult to size, wash or rinse because they contain more clay and the bed of material is more impervious to water sprays. By using the information on capacity of spray nozzles, given in Table 12, below, the number of nozzles and pipes can be determined.

Table 11 – Spray Water Requirement for Wet Screening.

Material	Application	GPM per Ton of Feed	Spacing of Sprays (Inches)		PSI
			Top Deck	Bottom Deck	
Stone	Washing	2-4	10-12	7-10	30
Stone	Rinsing	1½-2	10-12	7-10	40
Stone	Rinsing and Rewashing	2-3	10-12	7-10	40
Stone	Sizing	3-5	10-12	7-10	30
Stone and Clay	Washing	5-10	10-12	7-10	40
Sand and Gravel	Washing	3-5	10-12	7-10	30
Sand and Gravel	Sizing	3-5	10-12	7-10	30
Sand and Gravel	Rinsing and Rewashing	2-3	10-12	7-10	40
Sand and Gravel	Media Recovery	2½-3½	10-12	7-10	30
Iron Ore	Sizing	5-10	10-12	7-10	40
Iron Ore	Media Recovery	2½-3½	10-12	7-10	30
Coal	Sizing	3-6	10-12	7-10	30
Coal	Media Recovery	1½-3	10-12	7-10	30
Coal	Prewet	1-3	10-12	7-10	30

Table 12 – Spray Nozzle Capacity.

Pressure (Lbs./Sq. In.)	Gallons per Minute — Diameter of Orifice (Inches)					
	3/16	1/4	5/16	3/8	7/16	1/2
20	3.0	5.2	8.1	11.7	15.8	20.1
30	3.6	6.4	10.0	14.4	19.5	25.4
40	4.1	7.4	11.5	16.5	22.4	29.4
50	4.6	8.2	12.8	18.5	25.0	32.9
60	5.1	9.0	14.0	20.2	27.5	36.0

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6. **Special operating requirements or conditions**, including temperature, abrasiveness, corrosiveness or other physical characteristics of the feed, efficiency or product requirements which determine the selection of screening surface or installation problems which affect the screen size selection or capacity.

Screening surfaces must be carefully selected for the specific application. Various types of surfaces are available, and the selection depends on operating conditions and anticipated results. Size of feed, analysis, separations required, feeding method and required efficiency all affect selection.

Most common is woven wire cloth of regular, spring or stainless steel. Its advantages include relative low cost, variety of openings and wire diameters, and light weight. Disadvantages include short life under certain conditions, a tendency to blind in certain types of weaves and high maintenance.

Woven wire cloth is usually mounted on a crowned support frame with longitudinal bars for support.

The cloth is tensioned by means of clamping bars to prevent secondary vibration which will cause failure by fatigue. Satisfactory cloth life can be obtained by proper selection for the operating conditions, maintaining proper tension and providing adequate support under the cloth.

Woven wire cloth is available in three basic types of weaves — re, short rectangular and long rectangular. Short rectangular ...) is similar to square cloth except with a rectangular opening two to three times as long as it is wide. Long rectangular cloth is made with three cross wires at the ends of the slots instead of single wires as with square or short rectangular openings. The opening in long rectangular cloth is about ten times as long as it is wide.

A variation of the long rectangular opening cloth is a type with an oval bar in place of one of the three shoot wires. This oval bar permits the installation of the wire cloth with the long openings down the screen when used on a side tensioned screen. If a standard long rectangular opening cloth is installed on a screen with the long openings down the screen, it is impossible to maintain proper tension because of the few wires in tension, and the cloth will fail prematurely.

Perforated plate is extensively used for openings one inch and larger. Openings smaller than one inch do not have enough open area for practical use. Perforated plate can be made of a wide variety of abrasion-resistant alloys and in stainless steel. It can be made with round or square openings and fitted with skid bars for handling large size feed. Perforated plate has less tendency to blind because of its smooth surface. Perforated plates with smaller openings can also be used for dewatering a presized feed or screening paper pulp.

Other types of screening surfaces using specially shaped parallel bars are used on vibrating screens. Bixby-Zimmer and UOP-Johnson screen surfaces consist of round or triangular rods welded to heavy cross rods. Wedge Wire consists of formed wires riveted together at intervals. Wedge Bar screen surface consists of wedge shaped bars spaced by U-shaped holders at intervals.

These screen surfaces are usually used for dewatering since they are available with fine openings, yet are heavy enough to carry large loads of material and water.

Table 13 – Gauge and Thickness of Perforated Plate.

U.S. Standard Gauge	Thickness: Regular Steel	Thickness: Stainless Steel
0		.3125
1		.28125
2		.265625
3	.2391	.2500
4	.2242	.234375
5	.2092	.21875
6	.1943	.203125
7	.1793	.1875
8	.1644	.171875
9	.1495	.15625
10	.1345	.140625
11	.1196	.1250
12	.1046	.109375
13	.0897	.09375
14	.0747	.078125
15	.0673	.0703125
16	.0598	.0625
17	.0538	.05625
18	.0478	.0500
19	.0418	.04375
20	.0359	.0375
21	.0329	.034375
22	.0299	.03125
23	.0269	.028125
24	.0239	.0250
25	.0209	.021875
26	.0179	.01875
27	.0164	.0171875
28	.0149	.015625
29	.0135	.0140625
30	.0120	.0125
31	.0105	–
32	.0097	–

Table 14 – Standard Screen Scale for Wire Cloth.

Screen Openings: Inches	Screen Openings: Millimeters	Mesh: Tyler	Mesh: U.S. Series	Diameter of Wire: Inches	Diameter of Wire: Millimeters
3.000	76.2	...	...	.207	5.26
2.000	50.8	...	...	.192	4.87
1.500	38.1	...	...	.162	4.11
1.050	26.67	...	...	.148	3.76
.883	22.43	...	...	.135	3.42
.742	18.85	...	...	.135	3.42
.624	15.85	...	...	.120	3.05
.525	13.33	...	...	.105	2.67
.441	11.20	...	...	.105	2.67
.371	9.423	...	...	.092	2.34
.312	7.925	2½	...	.088	2.24
.263	6.680	3	...	.070	1.78
.221	5.613	3½	...	.065	1.65
.185	4.699	4	4	.065	1.65
.156	3.962	5	5	.044	1.12
.131	3.327	6	6	.036	.915
.110	2.794	7	7	.0328	.833
.093	2.362	8	8	.032	.813
.078	1.981	9	10	.033	.838
.065	1.651	10	12	.035	.890
.055	1.397	12	14	.028	.712
.046	1.168	14	16	.025	.635
.0390	.991	16	18	.0235	.597
.0328	.833	20	20	.0172	.437
.0276	.701	24	25	.0141	.358
.0232	.589	28	30	.0125	.318
.0195	.495	32	35	.0118	.300
.0164	.417	35	40	.0122	.310
.0138	.351	42	45	.0100	.254
.0116	.295	48	50	.0092	.234
.0097	.246	60	60	.0070	.178
.0082	.208	65	70	.0072	.183
.0069	.175	80	80	.0056	.142
.0058	.147	100	100	.0042	.107
.0049	.124	115	120	.0038	.096
.0041	.104	150	140	.0026	.066
.0035	.089	170	170	.0024	.061
.0029	.074	200	200	.0021	.053
.0024	.061	250	230	.0016	.041
.0021	.053	270	270	.0016	.041
.0017	.043	325	325	.0014	.036
.0015	.038	400	400	.001	.025

Note: This screen scale table gives the openings and wire sizes of the standard testing sieves used for obtaining screen analysis. It should be referred to only for the purpose of determining the relationship between standard sieve Mesh Sizes and the equivalent square openings in screen cloth. The actual screen cloth used on a vibrating screen and the size of wire suited to the job will depend entirely upon the particular conditions encountered. See table of standard wire and perforated plate sizes for ¼" openings and greater.

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A screen surface made of rods held in position by rubber or steel holders can be used where high capacity is desired but screening efficiency is not important, such as for scalping the feed ahead of a crusher. They can also be used in screening difficult material which cannot be screened on conventional screening surfaces, such as wet or sticky materials.

Grizzly bar screen surface consisting of heavy bars welded to cross ties can be used for heavy-duty scalping service where abrasive materials must be screened. Usually, the bars are arranged so that the openings between bars are tapered to permit free discharge of material. Refer to Tables 13-17, pages 18-21, for screen surface details.

Table 15 – Wire Cloth Standards – Square Openings.

Dry Screening Only.

(For wet screening, select next larger wire diameter.)

A – Light, 50-75 lb. cubic feet – Coal – Non-abrasive.
B – Standard, 75-100 lb. cubic feet – Limestone, Sand and Gravel.
C – Medium Heavy, 100-120 lb. cubic feet – Average Ores – Moderate Abrasives.
D – Heavy, 120-140 lb. cubic feet – Heavy Ores – High Abrasives.

Clear Square Opening	A		B		C		D		Feed Size		
	Dia.	Open Area	Dia.	Open Area	Dia.	Open Area	Dia.	Open Area	I	II	III
1/8	.041	57	.054	48	.072	40	.080	37	1/2	3/4	1
3/16	.047	64	.080	49	.092	45	.105	41	3/4	1	1 1/4
1/4	.063	64	.105	49	.120	46	.135	42	1	1 1/2	2
5/16	.072	66	.120	52	.135	49	.148	46	1 1/2	2	2 1/2
3/8	.080	68	.135	54	.148	51	.162	49	1 1/2	2	2 1/2
7/16	.092	71	.148	56	.162	53	.177	51	2	2 1/2	3
1/2	.105	68	.162	57	.177	55	.192	52	2	2 1/2	3
9/16	.105	70	.177	58	.192	56	.207	54	2 1/2	3 1/4	3 3/4
5/8	.120	70	.177	61	.192	58	.225	54	2 1/2	3 1/4	3 3/4
3/4	.135	72	.192	63	.207	61	.250	56	3	3 1/2	4 1/2
7/8	.148	73	.207	65	.225	63	.250	61	3	3 3/4	4 1/2
1	.162	74	.225	67	.250	64	5/16	58	3 1/2	4 1/2	5 1/2
1 1/8	.177	75	.225	69	.250	67	5/16	61	3 1/2	4 1/2	5 1/2
1 1/4	.192	75	.250	69	5/16	64	3/8	59	4	5	6
1 3/8	.207	76	.250	72	5/16	66	3/8	62	4	5	6
1 1/2	.225	76	.250	73	5/16	69	3/8	64	4	5	6
1 5/8	1/4	75	5/16	70	3/8	66	7/16	62	4 1/2	5 1/2	7
1 3/4	1/4	77	5/16	72	3/8	68	7/16	64	4 1/2	5 1/2	7
1 7/8	1/4	78	5/16	73	3/8	69	7/16	66	4 1/2	5 1/2	7
2	5/16	75	3/8	71	7/16	67	1/2	64	5	6 1/2	8
2 1/4	5/16	77	3/8	73	7/16	70	1/2	67	5	6 1/2	8
2 1/2	5/16	79	3/8	76	7/16	72	1/2	69	5	6 1/2	8
2 3/4	5/16	81	3/8	77	7/16	74	5/8	72	5	6 1/2	8
3	3/8	79	7/16	76	1/2	74	5/8	69	6	7 1/2	9
3 1/2	3/8	82	7/16	79	1/2	77	5/8	72	6	7 1/2	9
4	7/16	81	1/2	79	5/8	75	5/8	71	7	8 1/2	10

Wire diameters listed above are suitable for feed size not exceeding that listed in Column I. When feed size exceeds Column I but not Column II use next larger wire diameter. When it exceeds Column II but not Column III increase wire diameter two sizes. When it exceeds Column III relief deck is recommended to increase life of wire.

(1) Rectangular openings are preferred to obtain heavier wire or more open area.

Selections below heavy line require wedge type clamping bars.

Perforated plate is recommended for openings below dotted line.

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Table 16 – Wire Cloth Standards – Rectangular Openings

For Vibrating Screens

Dry and Wet Screening as indicated

A – Light, 50-75 lb. cubic feet – Coal – Non-abrasive.
B – Standard, 75-100 lb. cubic feet – Limestone, Sand and Gravel.
C – Medium Heavy – 100-120 lb. cubic feet – Average Ores – Moderate Abrasives.
D – Heavy – 120-140 lb. cubic feet – Heavy Ores – High Abrasives.

Sieve Opening	A Opening	A Dia.	A Open Area	B Opening	B Dia.	B Open Area	C Opening	C Dia.	C Open Area	D Opening	D Dia.	D Open Area	Feed Size I	Feed Size II	Feed Size III
DRY SCREENING															
10 M	.065 x 1¼	.035	60	.064 x 2	.054	50	.062 x 2	.063	45	.063 x 2	.080	42	¾	1	1¼
8 M	.084 x 1	.041	64	.080 x 2	.063	51	.082 x 3	.072	50	.080 x 3	.080	46	¾	1	1¼
¼	.100 x 2	.054	57	.104 x 2	.063	57	.102 x 3	.080	52	.108 x 3	.092	49	1	1½	2
5/16	.125 x 2	.054	64	.125 x 2	.072	57	.125 x 3	.092	53	.125 x 3	.105	49	1	1½	2
⅜	3/16 x 2	.063	65	3/16 x 3	.092	61	3/16 x 3	.120	55	3/16 x 4	.135	53	1½	2	2½
7/16	¼ x 2	.072	70	¼ x 3	.120	60	¼ x 4	.135	59	¼ x 4	.148	57	2	2½	3
½	5/16 x 4	.105	72	5/16 x 4	.162	65	5/16 x 4	.177	63	5/16 x 5	.192	62	2½	3½	4
WET SCREENING															
½ mm	.0197 x .156	.028	34	.0197 x .159	.032	28	.0197 x .239	.041	26	.020 x .328	.063	19	¼	⅜	½
20 M	.028 x .250	.035	37	.029 x .337	.054	29	.030 x .343	.063	22	.028 x 2	.072	25	⅜	½	¾
10 M	.064 x 2	.044	50	.062 x 2	.063	45	.063 x 2	.072	42	.063 x 2	.080	39	¾	1	1¼
8 M	.079 x 2	.054	51	.082 x 3	.072	50	.080 x 3	.080	46	.082 x 3	.092	42	¾	1	1¼
¼	.104 x 2	.063	53	.102 x 3	.080	52	.108 x 3	.092	49	.102 x 3	.120	42	1	1½	2
5/16	.125 x 2	.072	55	.125 x 3	.092	53	.125 x 3	.105	49	.125 x 4	.148	41	1	1½	2
⅜	3/16 x 3	.080	61	3/16 x 3	.120	55	3/16 x 4	.135	53	3/16 x 4	.162	48	1½	2	2½
7/16	¼ x 3	.092	60	¼ x 4	.135	59	¼ x 4	.148	57	¼ x 5	.192	51	2	2½	3
½	5/16 x 4	.120	65	5/16 x 4	.177	63	5/16 x 4	.192	62	5/16 x 5	.207	60	2½	3½	4

Wire diameters listed are suitable for feed size not exceeding that listed in Column I.

When feed size exceeds Column I but not Column II use next larger wire diameter. When feed size exceeds Column II but not Column III use increase wire diameter two sizes. When feed size exceeds Column III, relief deck is recommended to increase life of the wire.

Long openings should be at right angle to the hook strip in order to obtain the greatest number of wires in tension.

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Table 17 – Perforated Plate Standards – Square Opening

A – Light, 50–75 lb. cubic feet – Coal – Non-Abrasive.
B – Standard, 75–100 lb. cubic feet – Limestone, Sand and Gravel – Average Ores.
C – Heavy 100–140 lb. cubic feet – Heavy Ores – High Abrasives.

Clear Square Openings (Inches)	A Thickness	A Bar (Inches)	A Open Area	B Thickness	B Bar (Inches)	B Open Area	C Thickness	C Bar (Inches)	C Open Area	Maximum Feed Size A	Maximum Feed Size B	Maximum Feed Size C
3/16	14 ga.	3/32	44	12 ga.	1/8	36	12 ga.	1/8	36	2	1½	1
1/4	12 ga.	1/8	45	10 ga.	1/8	45	10 ga.	3/16	33	3	2	1½
5/16	11 ga.	5/32	45	10 ga.	5/32	45	10 ga.	3/16	39	3	2	1½
3/8	11 ga.	1/8	56	10 ga.	3/16	44	3/16	1/4	36	4	3	2
7/16	10 ga.	1/8	61	10 ga.	5/32	54	3/16	1/4	40	4	3	2
1/2	10 ga.	5/32	58	8 ga.	3/16	53	3/16	1/4	45	4	3	2
9/16	3/16	3/16	56	3/16	1/4	48	1/4	1/4	48	5	4	3
5/8	3/16	3/16	59	3/16	1/4	51	1/4	3/8	39	5	4	3
3/4	3/16	1/4	56	3/16	3/8	45	1/4	1/2	36	5	4	3
7/8	3/16	1/4	61	3/16	3/8	49	1/4	1/2	41	5	4	3
1	3/16	3/8	53	3/16	1/2	44	1/4	5/8	38	5	4	3
1 1/8	3/16	3/8	56	1/4	3/8	56	1/4	1/2	48	6	5	4
1 1/4	3/16	3/8	53	1/4	7/16	48	5/16	3/8	45	6	5	4
1 3/8	1/4	3/8	62	1/4	7/16	58	5/16	9/16	50	6	5	4
1 1/2	1/4	3/8	64	1/4	1/2	56	5/16	3/4	44	6	5	4
1 5/8	1/4	3/8	66	5/16	1/2	58	5/16	1/2	58	7	6	5
1 3/4	1/4	1/2	61	5/16	1/2	61	3/8	5/8	54	7	6	5
1 7/8	5/16	1/2	63	5/16	1/2	60	3/8	3/4	54	7	6	5
2	5/16	1/2	64	5/16	1/2	60	3/8	3/4	60	7	6	5
2 1/4	5/16	1/2	68	3/8	1/2	63	3/8	3/4	63	7	6	5
2 1/2	5/16	1/2	69	3/8	3/4	64	1/2	3/4	64	8	7	6
2 3/4	5/16	1/2	70	3/8	3/4	66	1/2	3/4	66	8	7	6
3	5/16	5/8	72	3/8	3/4	68	–	–	–	8	7	6
4	3/8	3/4	70	–	–	–	–	–	–	10	8	6

Feed Size: When feed exceeds the sizes listed for respective openings, a relief deck is recommended to increase life of plate. When feed exceeds 10 in. for coal and 8 in. for other material, an extra heavy duty, flat surface deck is recommended.

Selections below heavy line require wedge type clamping bars, with plate rolled to camber of the deck.

Flat surface, heavy duty decks are recommended for plate thickness larger than 5/16 in.

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SCREEN AREA AND BED DEPTH

The formula for selecting screen size determines the number of square feet of screening surface needed to remove the undersize material from the feed before it is discharged off the end of the screen surface. Once this is known, you are able to select a screen width and length that will provide an area equal to or greater than the required square footage of screening surface calculated.

Calculated area is the net screening area, equal to the width times length of screen, less the deck parts that reduce the available opening for screening such as clamp bar, center holddown bars, etc., and less the loss of available screening area due to particles passing from one deck to another on a double or triple deck screen. Refer to Table 18, below, which lists the net screening areas for different sizes of screen.

Several combinations of widths and lengths can provide the area needed. For good application and design practice, the minimum length to width ratio for sizing screens should be 2 to 1. For example, 4 feet by 8 feet.

First determine the width that will maintain the proper bed depth for efficient screening; then determine the length to get the area required. Remember the "rule of thumb" for good screening: the bed depth of material at the discharge end of the screen should never be over four times the size opening in the screen surface for material weighing 100 pounds per cubic foot or three times for material weighing 50 pounds per cubic foot. The feed end bed depth can be greater, particularly if the feed contains a large percentage of fines.

If the largest screen available does not provide the required area, select multiple units to provide equivalent area. The length of screen should be at least two times the width for good practical design.

Formula 6

Screen area: $A = \frac{T}{CN}$

Where: A = area of screen surface required
T = short tons per hour of feed to the screening deck
Cn = short tons per hour one square foot of screen surface can be fed while effectively removing the undersize particles
Cn = C x M x K x Q (See explanations below)

"C" Factor (Reference, Capacity Curves, Table 19, page 25). "C" factor in our formula is an empirical value of the amount of feed in tons per hour one square foot of screen surface can handle for different size open separations. It is based on a feed containing 25% oversize and 40% passing holes half the size of the opening in the screen surface.

"C" factor is also based on:

1. estimated efficiency of 90%
2. handling material having a bulk density of 100 pounds per cubic foot
3. using square opening or equivalent round opening in the screen surface
4. having 50% open area in screen surface for 100 lbs./ft.^{3} material and 60% for 50 lbs./ft.^{3} material

"M" Factor (Reference, Oversize Curve, Table 20, page 26). Expressed as a percent of feed to the screening deck that is larger than the opening in the deck, "M" factor compensates for the difference in the percent oversize at which the "C" factor was established (25%) and the actual application.

It compensates for how easy or difficult it will be for the fines to sift through the bed of material. The principle of screening is to agitate the feed so the fine particles will sift their way through the bed (stratification) and present themselves to the opening in the screen surface either to pass through or over the screen.

Not all applications have the same gradation of material. Material coarseness or fineness determines how the fines sift through the bed of material.

"K" Factor (Reference, Halfsize Curve, Table 21, page 26). Expressed as the percent of feed to the screening deck that is one-half the size of opening in the screen surface, "K" factor compensates for the difference in the percent half size at which the "C" factor was established (40%) and what your application is.

Material gradation will determine whether this will be a high or a low degree of probability of separation. Depending on how coarse or fine the material is, it may be easy or difficult for the undersize to pass through the screen surface openings. The smaller the particle is compared to opening size (high percentage of half-size), the greater the degree of probability. Conversely, the larger the particle is compared to opening size (low percentage of half-size), the smaller the degree of probability.

Table 18 – Net Effective Screening Area (sq. ft.)

Screen Size	Top Deck	2nd Deck	3rd Deck	Screen Size	Top Deck	2nd Deck	3rd Deck	Screen Size	Top Deck	2nd Deck	3rd Deck	Screen Size	Top Deck	2nd Deck	3rd Deck
12" x 30"	1.9	1.7		3' x 14'	35.0	31.5	28.4	5' x 10'	45.0	40.5	36.5	6' x 16'	88.0	79.2	71.3
12" x 48"	3.0	2.7		3' x 16'	40.0	36.0	32.4	5' x 12'	54.0	48.6	43.7	6' x 20'	110.0	99.0	89.1
18" x 36"	4.0	3.6	3.3	4' x 6'	21.0	18.9	17.0	5' x 14'	63.0	56.7	51.0	7' x 12'	78.0	70.2	63.2
18" x 48"	5.3	4.8	4.5	4' x 8'	28.0	25.2	22.7	5' x 16'	72.0	64.8	58.3	7' x 14'	91.0	81.9	73.7
2' x 4'	6.0	5.4	4.9	4' x 10'	35.0	31.5	28.4	5' x 20'	90.0	81.0	72.9	7' x 16'	104.0	93.6	84.2
2' x 6'	9.0	8.1	7.3	4' x 12'	42.0	37.8	34.0	6' x 6'	33.0	29.7	26.7	7' x 20'	130.0	117.0	105.3
3' x 4'	10.0	9.0	8.1	4' x 14'	49.0	44.1	39.7	6' x 8'	44.0	39.6	35.6	8' x 12'	90.0	81.0	72.9
3' x 6'	15.0	13.5	12.1	4' x 16'	56.0	50.4	45.4	6' x 10'	55.0	49.5	44.6	8' x 14'	115.0	103.5	93.2
3' x 8'	20.0	18.0	16.2	5' x 6'	27.0	24.3	21.9	6' x 12'	66.0	59.4	53.5	8' x 16'	120.0	108.0	97.2
3' x 10'	25.0	22.5	20.0	5' x 8'	36.0	32.4	29.2	6' x 14'	77.0	69.3	62.4	8' x 20'	150.0	135.0	121.5
3' x 12'	30.0	27.0	24.3												

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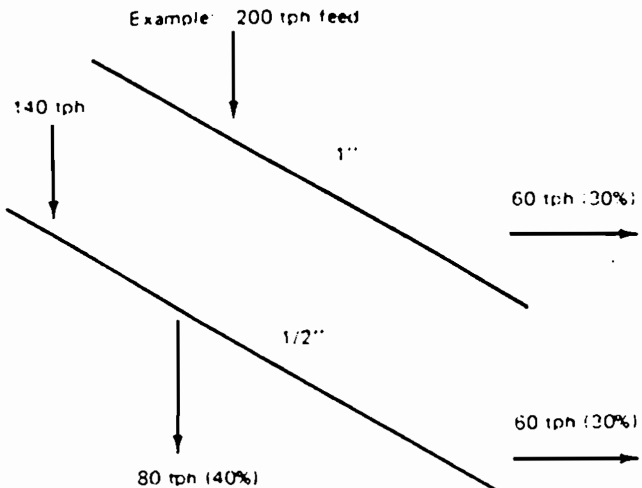
Note: Each deck of a multiple deck screen is considered as a separate screening problem. Factors M and K must be corrected to percentage of feed to the deck in question before obtaining values of M and K in Tables 20 and 21, page 26. Here is a typical example.

Analysis	
Size (")	% Passing
2	85
1	70
3/4	50
1/2	40
1/4	20



From top deck,

% oversize = 30, % half-size = 40 } taken from screen analysis

For second deck,

$$\% \text{ oversize} = \frac{60 \text{ tph}}{140 \text{ tph}} \times 100 = 42.8\%$$

$$\% \text{ half-size} = \frac{200 \times .20}{140} \times 100 = 28.6\%$$

"Q" Factor (additional factors affecting "C" capacity). "Q" factor corrects for the difference in the value of "C" due to any variance between the conditions under which our "C" factor was established and the specific application. It is the product or two or more of the following "Qn" factors...

$$\text{"Q"} = Q_1 \times Q_2 \times Q_3 \text{ etc.}$$

"Q" variances and their corrections are as follows:

1. **Bulk Density** – defined as the weight of a volume of one cubic foot of material in its "loose state." Refer to Table 10, page 16.

Bulk Density	"Q_1"
100 lbs./ft.^{3}	1.00
130 lbs./ft.^{3}	1.30
50 lbs./ft.^{3}	.50
25 lbs./ft.^{3}	.25
Etc.	

2. **Screening Surface Opening** – "C" factor was based on square opening screen surface and must be corrected for round or slotted openings.

Type Opening	"Q_2"
Square	1.00
Round	.80
Slotted:	
2:1 Slot	1.15
3:1 Slot	1.20
4:1 Slot	1.25

3. **Particle Shape** – "C" factor was based on dry, free flowing particles such as sand and gravel with uniform cubical shape. A correction must be made for slabby elongated particle shapes.

Particle Shape	"Q_3"
Dry Cubical	1.00
Slabby Elongated	.90

4. **Screening Surface Open Area** – "C" factor was established for 50% open area in the screening surface for 51 to 100 lbs./ft.^{3} material and 60% open area for 50 and less lbs./ft.^{3} material. Any variance may be compensated for by the ratio of percent area available to these base values.

Example:

$$Q_4 = \frac{\% \text{ surface area available}}{\% \text{ surface area base}}$$

$$Q_4 = \frac{45}{50} = .90$$

5. **Wet Or Dry Screening** – "C" capacity was based on dry screening. In many applications increased screenability is obtained by adding water to the feed through a series of high pressure sprays above the deck surface. The value of increased screenability depends upon the opening, type of screen surface and amount of water used. Refer to Tables 11 and 12, page 17, for recommended spray water requirements and capacities of spray nozzles at different pressures.

Note: The increase in value when using spray water will decrease as the screen surface opening approaches 1" and a correction for using water at opening 1" or more is considered negligible. On openings smaller than 3/16", its effect is reduced due to open area and water surface tension.

When dry screening (no spray), $Q_5 = 1$. Following factors apply for wet screening with spray water.

Size Opening	"Q_5"
1/32 to 1/8"	1.25
3/16 to 1/4"	1.40 max.
5/16 to 1/2"	1.20
9/16 to 1"	1.10

6. **Surface Moisture** – The film of moisture adhering to the exposed surface of a particle affects the ease or difficulty with which material can be screened. Surface moisture is expressed in percent by weight. "C" capacity was established for dry material with no more than 3% surface moisture.

Note: Only the surface moisture will have any effect on screenability of material. Total moisture is made up of the inherent and surface moisture. Inherent moisture is

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contained inside the material or particle and has no effect on screenability. Dense material such as trap rock or iron ore could have a total moisture of 8% with only 3% surface, while lignite (lowest form of coal) could have a total moisture of 18 to 25% with 3% surface moisture.

Surface Moisture	"Q_6"
Up to 3%.	1.00
Damp quarried or stock piled material with 3 to 6% surface moisture.	.85
Damp quarried, sand & gravel, coal, iron ore, etc., with greater than 6% surface moisture but not greater than 9%.	.75
When wet screening	1.00

Note: Greater than 6% surface moisture, depending on how sticky or the clay content, may dictate using wet screening. Depending on clay content, consideration should be given to use of heated decks, if surface moisture is between 3 and 6%. It may be wise to consider a Sta-Kleen deck to free particles in opening, depending on opening and dampness of material. Consult Factory on these applications.

Once all the factors have been determined, the area required can be calculated by the formula A = T/Cn. This area is based on 90% screening efficiency, with not over 10% undersize material in the oversize. Greater capacities can be obtained, but only at a sacrifice in efficiency. Refer to Table 1, page 6, to determine the efficiency for increased capacities. Note from Table 1 that maximum screening efficiency (95%) is obtained when operating at 80% of rated capacity. In those applications where a customer specifically requests maximum efficiency, 20% more area should be added to the calculated area.

The area required for each deck of a multiple deck screen must be calculated and the selection of the width and length of the screen must have an area equal to or greater than the deck area calculated. Calculated deck area is net effective area, taking into consideration area loss due to cl[illegible] bars, center hold bars, and longitudinal support bars, plus area loss where particles pass from one deck to another. Refer to Table 18, page 22, for size of screen and available net effective area. With multiple decks, the deck with the greatest screening area requirement will govern selected width and length.

Screen Size Selection – Several combinations of widths and lengths could give you the area needed. Make the proper choice by selecting the width that will maintain proper bed depth for efficient screening and then determining the length to get the area required.

Note: If required area is greater than net effective area available from Table 18, multiple screens must be used in parallel. If installation limitations restrict multiple screens in parallel and it is desired to put units in series (in line), enough area could be available, but the bed depth may be more than is acceptable for efficient screening, reducing efficiency of separation. (In cases of series installation, consult Factory.)

Formula 7

Bed depth: $D = \frac{T \times K}{5 \times S \times W}$ or . . .

Net width: $W = \frac{T \times K}{5 \times S \times D}$

Where: D = bed depth (inches) at discharge end

Note: In good screen application practice, when solving for "W", limit "D" to 4 times the screen opening at the discharge end for material weighing 100 lbs./ft.^{3}, or 3 times for material weighing 50 lbs./ft.^{3}.

T = tons per hour material at discharge end

K = cubic feet per ton of material (determined by dividing 2000 lbs. by bulk density)

Example: K for 100#/ft.^{3} = $\frac{2000}{100}$ = 20

S = material travel rate in feet per minute, which is dependent on screen and material characteristics. Refer to Tables 22 and 23, page 27, travel rate of screens.

W = net width of screen in feet = nominal width minus 6 inches.

Example: 6' wide screen (nominal width) has net effective width of 5.5'.

Bed depth calculation is done by trial, choosing different widths that will give a bed depth at the screen discharge end not over four times the screen surface opening for 100 lbs./ft.^{3} material or three times for 50 lbs./ft.^{3} material. Feed end bed depth can be greater, particularly if feed contains a large percentage of fines.

The slope on inclined screens will affect travel rate and capacities, as well as the resultant opening, compared to a testing sieve (refer to Table 24, page 27). Our standard slope is 20° (refer to Tables 22 and 23, page 27). For reduced slopes, capacities must also be reduced if screening efficiency is to be maintained.

Slope Reduction	% Of Rated Capacity
2-1/2 degrees less	90 - 92-1/2
5 degrees less	80 - 85
7-1/2 degrees less	70 - 75
10 degrees less	60 - 65

By following these guidelines, you can make a calculated estimate of the size and number of screens to recommend. Calculated capacities are conservative; however, due to the inconsistencies in the screenability of material or materials, even under similar conditions they should be considered as approximate only. Use them as a guide and not as a guarantee or representation that they will apply to any particular case.

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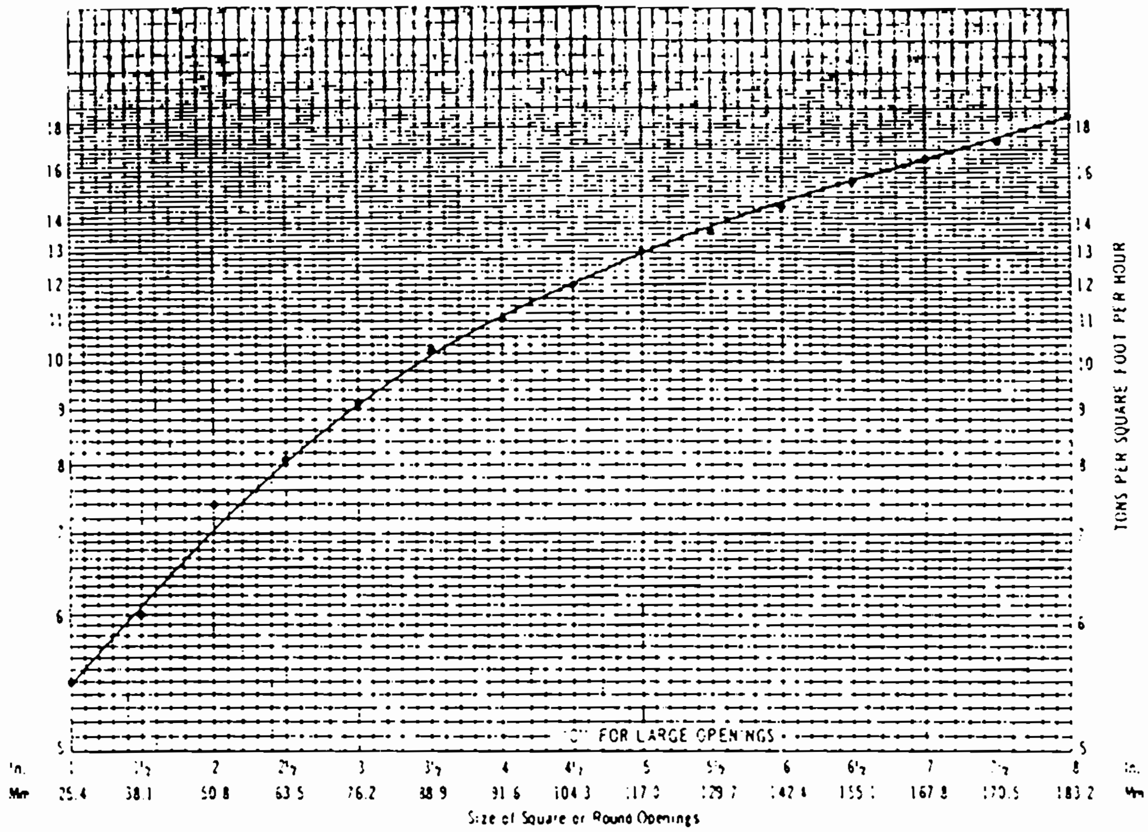
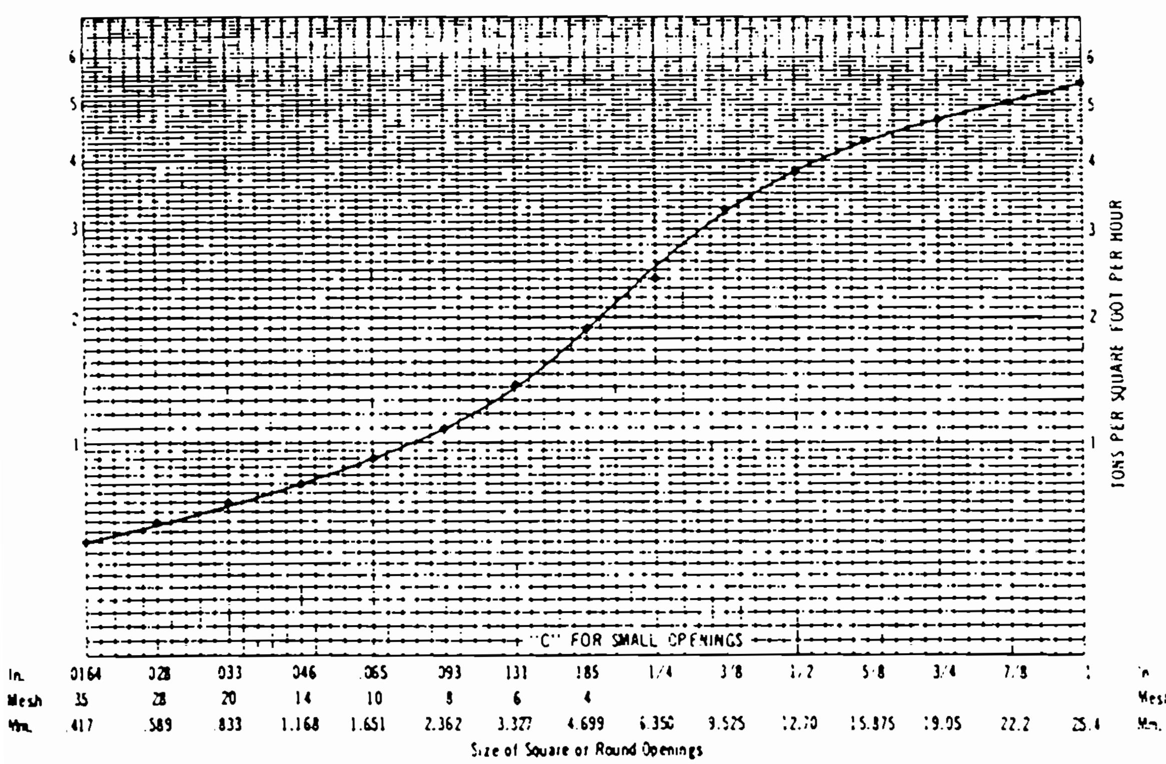
Table 19 – Factor "C" in Screen Capacity Formula





NOTE: Dry screening at openings smaller than 35 mesh is not considered economical on vibrating screens. Air separators, while not efficient may be more economical. Confer with factory.

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Table 22 – Travel Rate of Inclined Screens

Screen Model	Travel Rate (fpm)	Screen Surface	Screen Opening (Inches)	Mechanical Rotation	Speed (rpm)	Throw (Inches)
ST	100	wire	≤ 1	flow	800	3/8
ST	125	wire	> 1	flow	800	3/8
SH	100	wire	≤ 1	flow	890	5/16
SH	125	wire	> 1	flow	890	5/16
XH	125	plate	> 1	flow	755	7/16

Based on dry, free-flowing material with 3% or less surface moisture and 20° slope.

NOTE: For counter-rotation, reduce travel rate by 10%.

Table 23 – Travel Rate of Horizontal Screens

Screen Model	Travel Rate (fpm)	Screen Surface	Screen Opening (Inches)	Speed (rpm)	Throw (Inches)
Levl-Flo	45	wire	≤ 1	845	1/2 to 5/8
Levl-Flo	40	wire	> 1	845	1/2 to 5/8
LowHead	45	wire	≤ 1	900	7/16 to 1/2
LowHead	40	wire	> 1	900	7/16 to 1/2

Based on dry, free-flowing material with 3% or less surface moisture and units installed horizontally (no slope).

Table 24 – Relation Between Opening on Vibrating Screens and in Testing Sieves

Product Size Through Flat Test Sieve		Square Aperture on Vibrating Screen (Inches)		
		Horizontal Screens	Inclined Screens	
Round	Square		20° Slope	25° Slope
...	20 mesh	...	0.036	0.039
...	14 mesh	...	0.060	0.065
...	10 mesh	0.079	0.085	0.093
1/8"	3/32"	3/32	1/8	3/32
3/16"	5/32"	5/32	5/32	3/16
1/4"	3/16"	3/16	7/32	1/4
5/16"	1/4"	1/4	3/8	5/16
3/8"	5/16"	5/16	7/16	[illegible]
1/2"	3/8"	3/8	1/2	[illegible]
5/8"	1/2"	1/2	5/8	11/16
3/4"	5/8"	5/8	3/4	13/16
7/8"	3/4"	3/4	7/8	15/16
1"	7/8"	7/8	1	1 1/8
1 1/4"	1"	1	1 1/8	1 1/4
1 3/8"	1 1/8"	1 1/8	1 1/4	1 3/8
1 1/2"	1 1/4"	1 1/4	1 3/8	1 1/2
1 3/4"	1 1/2"	1 3/8	1 5/8 (1)	1 3/4
2"	1 3/4"	1 3/4	1 7/8 (1)	2
2 1/4"	1 7/8"	1 7/8 (1)	2 1/8 (1)	2 1/4
2 3/8"	2"	2	2 3/8 (1)	2 1/2
2 1/2"	2 1/8"	2 1/8 (1)	2 1/2	2 5/8 (1)
2 3/4"	2 1/4"	2 1/4	2 5/8 (1)	2 3/4
3"	2 1/2"	2 1/2	3	3 1/8 (1)
3 1/4"	2 3/4"	2 3/4	3 1/4	3 3/8 (1)
3 1/2"	3"	3	3 1/2	3 5/8 (1)
3 3/4"	3 1/8"	3 1/8 (1)	3 5/8 (1)	3 3/4
3 7/8"	3 1/4"	3 1/4	3 3/4	3 7/8 (1)
4"	3 5/16"	3 5/16 (1)	3 13/16 (1)	4
4 1/4"	3 1/2"	3 1/2	4	4 1/4
4 1/2"	3 3/4"	3 3/4	4 1/4	4 1/2
4 3/4"	4"	4	4 1/2	4 3/4

(1) This opening is not a wire cloth manufacturer's standard specification.

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Washing Mesabi Iron Ores

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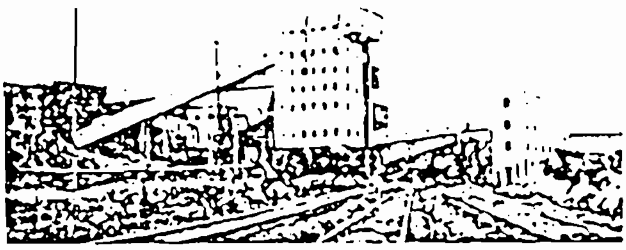

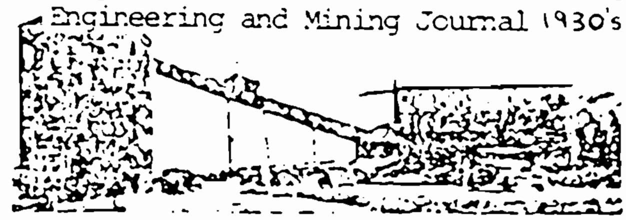

Left, Butler Bros. Patrick Unit No. 1, May, 1930, Cooley, Minn. Right, Holman-Cliffs washing plant

BENEFICIATION of iron ore on the Mesabi range by the method of washing began when the Trout Lake plant of the Oliver Iron Mining Company was put into operation in 1910. The development and design of this was the result of experiments carried on by the company during 1905-09 after preliminary work by other individuals on iron ores from the Arcturus and Holman properties had demonstrated the commercial possibilities of washing Mesabi ores. In this plant was initiated what came to be known as the standard Mesabi flow sheet, consisting of a revolving trommel, two 25-ft log washers, four 18-ft logs, or turbos as locally termed, and ten to twenty concentrating tables. A flow sheet is shown herewith.

[illegible] during the past six years have [illegible] noteworthy deviations from the standard flow sheet been made. The departures have been a consequence of the [illegible] nature of the ores and a tendency toward simplification. On the upper wash ores and on the better grades of the lower wash seam, the standard plant was successful, but in many instances it was found to be less efficient with lean lower wash ore. The lower wash seam often contains coarser sands and finely crystalline quartz adhering to the ore particles. Chunks of ore will contain segregations of silica now disintegrated to fine sand, which can be liberated only by crushing.

Many operators realized that the silica content in the product was gradually increasing. The trommel oversize which washed under a heavy spray of water, was formerly a satisfactory concentrate, began to analyze too high in silica, owing to the presence of too much material not yet decomposed into ore and sand, and to lumps coated with "frozen silica." The [illegible] in the log washer was probably greater than ever, but [illegible] remained in the washed [illegible]. With the leaner wash ores a [illegible] amount of somewhat coarser silica was found in the [illegible] of the turbos. This, coupled with the smaller percentage of fine [illegible] made a less satisfactory [illegible]. The necessity for improving these conditions has resulted in departures from the old system.

Changes found to be necessary comprise principally (1) the replacement of the turbos and tables with bowl classifiers; (2) the introduction of secondary crushing for further liberation of silica from the coarser sizes, and (3) the tendency toward the use of abrasive screening on much of the material formerly treated in the 25-ft log washers. The two first mentioned changes have been incorporated in all the new plants as built. The last has several different methods of application and is finding favor among many operators.

Of major importance, the first change to be made in the original Mesabi flow sheet was the introduction of the bowl classifier, to take the entire log-washer overflow, replacing the turbos, chip screens, settling tanks, tables, and concentrate pumps. This classifier had already been developed and widely adopted in Western metallurgical practice, and three of these machines were in use at the [illegible] plant of the Mesabi Iron Company.

The first application to the sandy wash ores of the range was made in 1924. An average of sixteen tests conducted throughout the season showed that the bowl classifier would recover 8.92 per cent more weight and 15.33 per cent more iron from the log-washer tailing than was possible with the turbos and tables. With the use of the bowl classifier an increased recovery of 3.92 per cent of the weight and 4.35 per cent of the iron units in the crude ore was obtained. The concentrate produced by the bowl classifier was [illegible] both in [illegible] natural iron and lower in silica than the combined concentrate of turbos and tables. The iron assay of the total plant tailing was lowered 4 per cent in consequence. In addition to better metallurgical work accomplished by the bowl classifier, as shown in further detail in Table I, the operation and maintenance costs of one bowl classifier were lower than parallel costs for turbos, tables and auxiliary equipment.

The first season's demonstration of the merits of the bowl classifier resulted in the adoption of the machine throughout the district. At present nearly all the plants on the Mesabi range are equipped with bowls. They have completely replaced the turbos and tables wherever used, with the exception of the Hawkins plant, where turbos are still used to [illegible] the feed to the bowl classifiers.

Tests made in one plant show that, in terms of crude ore, the amount recovered from high-grade wash ore as classifier product is 11.8 per cent and on low-grade ore 9.1 per cent. At another plant the classifier product is segregated from the rest of the plant concentrate, and shipped separately to the furnaces, where it is sintered. An accurate record of the amount is thus easily kept. In this plant it is found to be about 18 per cent of the total plant product, about 12½ per cent of the crude.

Secondary crushing of trommel oversize is employed to improve the structure of the ore, and further to eliminate

Table I—Comparative Results

	Turbo	Tables	Turbo Plus Tables	Bowl Washer
Recovery from log-washer tailing				
Weight recovery	23.22	1.59	24.81	33.73
Iron unit recovery	42.54	2.89	45.43	[illegible]
Recovery from crude ore				
Weight recovery	10.39	0.71	[illegible]	[illegible]
Iron unit recovery	11.79	0.80	12.59	16.94
Analysis of concentrate				
Dry iron	[illegible]	[illegible]	[illegible]	[illegible]
Natural iron	48.14	4[illegible]	[illegible]	[illegible]
Silica	[illegible]	[illegible]	[illegible]	[illegible]
Moisture	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]				
W[illegible]				
I[illegible]				

[illegible]

[illegible] and Mining Journal

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. .e Co. built a new washing . . its St. Paul Mine and is ex- . .e its operation to include the .. the Wentworth Mine.

. S. Moore Co. moved its con- . ntrator from the old Prindle Mine to the Mariska property. A similar move of existing facilities to a new location was made by M. A. Hanna Co., who moved equipment formerly used at the Buckeye Mine to the Douglas property near Chisholm.

Oliver Iron Mining Co. is installing a large addition to its Trout Lake property near Coleraine, Minn. This plant, which has washed millions of tons of ore since the early 1900's, will now be provided with two float-sink and cyclone sections. Float and sink separatory apparatus will consist of two 10x10-ft drums. These drums will have about double the capacity of the conventional 8x8-ft drum normally used on the Mesabi.

Another example of the change in the trend is the installation by Pickands Mather & Co. of a new concentrator at its Mahoning Mine. This well-known mine has shipped nothing but direct shi g ore for almost 70 years. The new plant will consist of washing equipment, float and sink units, cyclones and spirals. Feed to the spirals will be made up of deslimed washing plant tailings and the minus 20 mesh portion of the cyclone tailings.

The first commercial flotation plant ever installed on the Mesabi Range will be in operation for the 1957 season. This is Jones & Laughlin's plant, which is nearing completion at its Hill Annex Mine near Calumet, Minn. At this property, washing plant tailings that have accumulated over a number of years will be recovered by means of a floating dredge and this material will be sized by cyclones. The coarser fraction will be treated by Humphrey spirals which will produce a concentrate and a tailing. Middling from these spirals together with the deslimed portion of the cyclone overflow will constitute the flotation plant feed.

Flotation will be practiced in an acid circuit, using petroleum sulphanates as the collector. Hematite will be floated away from the siliceous gangue. If this plan proves successful, it will probably be the first of many built, as tonnages of such tailings have . . .ated over many years on the Mesabi Range.

In addition to the installation and alteration of mills to improve quality, much is being done to improve the structure of ores in the Lake Superior District. A few mills have shipped fine concentrates separately for a number of years, but this trend is being accentuated. There are several advantages to the steel mill of having the separation between coarse and fine concentrates made at the concentrator.

At most mills, treating either wash or retreat ores, the concentrates, at some phase of the operation, are wet screened at about ¼ in. It has been the practice to combine all these concentrates into one product for shipment. By some rearrangement of mill equipment, it is possible to keep separate the course plus ¼-in. fraction not requiring sintering, and to segregate the minus ¼-in. material which requires sintering. An almost perfect separation at this size can be made with the wet screening commonly employed at the concentrator.

If the concentrates are shipped together, and as often happens, mixed with direct shipping ore, this mixture must be screened dry at the steel mills. Usually the finest screen that can then be used is about ¾-in. If the screening is done at the concentrator, and the plus and minus ¼-in. product shipped separately, a much smaller percentage of the ore requires sintering, and because of the more uniform size, a better sinter is produced.

As an example of this trend, two of the mills managed by Pickands Mather made this conversion for the 1956 season and all mills of this company will be converted to practice this sizing for the 1957 season.

A similar transition is taking place in the preparation of direct shipping ores. This is in line with recommendations of blast furnace technicians, who have determined that sized ore charges with the agglomeration of all fines, yields superior results.

Crushing of ores to a maximum of 4 in. has been practiced at most Lake Superior Mines for years. This practice is being elaborated on at some properties to include not only crushing of such ores, but the screening of the ore into two coarse size increments and a fine size increment. Fines will be of such a size that no further sizing will be required at the steel plant for use as sinter feed. Products usually shipped are a minus 4-in. plus 1½-in., a minus 1½-in. plus ½-in., and a minus ½-in. product.

Leader in this field has been Oliver Iron Mining with two large plants under construction on the Mesabi Range. Plants are under construction at both the Rouchleau and at the Sherman properties for sizing ores from the Virginia and Chisholm areas.

M. A. Hanna Co. will open up the long known iron or property at Moose Mountain, 35 miles north of Sudbury, Ontario. Ore at this property consists of a disseminated magnetite. It will be concentrated magnetically and shipped to U.S furnaces for mixture with lower grade Lake Superior ores for sintering.

A number of mining companies have been actively engaged for several years in exploring the Butternut District, south of Ashland, Wis. This district, which is a western continuation of the Gogebic Range, contains taconite-like material requiring fine grinding for concentration. The Ashland Mining Co. has drilled out a rather large deposit in this area and experimental work is presently being done at the Pickands Mather Laboratory in Hibbing to determine the most feasible flowsheet. 2

One of the major fields of endeavor for iron ore concentration engineers in the coming years will be the working out of means for treating ores in the Labrador and Ungava areas. With the exception of the large amount of direct shipping ores held by the Iron Ore Co. of Canada in the Ruth Lake area, it is becoming more apparent, as exploration work continues, that the bulk of the ores in the other areas must be concentrated and probably agglomerated before they are marketable. 3

From what scanty information is now available, it seems certain that there are wide variations in the type of minerals present within individual deposits, as well as major variations from one deposit to another. Such varied concentration methods as flotation, gravity separation, high and low density magnetic processes, as well as magnetic roasting may well find a place in this large area. 5

Now that a good many major Canadian, American and European steel and mining interests have properties in this area, and with the seemingly unending demand for increasing amounts of iron ore, it requires no crystal ball to predict that this area will be one of great activity in the next few years.• 6

4" = 102 mm
1½" = 38 mm
½" = 13 mm

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1750

THIS ELLIPTICAL-ROLL FEEDER, also known as the "wobbly" feeder, has recently been introduced. It is intended to replace both the conventional feeder and the scalper that follows it.

Minnesota's Lean Ores

...any instances this unit is located near the bottom of the open pit to minimize truck haulage. A belt conveyor or a series of conveyors brings the ore out of the pit to the concentration section.

Treatment After Crushing

The character of the ore now determines which of the following treatments will be applied:

1. Direct shipment of merchantable ore.
2. Dry screening before direct shipment.
3. Washing.
4. Scrubbing.
5. Jigging.
6. Heavy density separation.
7. Humphreys spirals.
8. Sintering.
9. Drying.

"Direct shipment" and "dry screening before direct shipment" are self-explanatory. Dry screening is done to separate the fines from the coarse material to permit them to be sintered before being fed to the blast furnace. To handle these ores dry requires very steep chute slopes because of their sticky nature, particularly where they are high in alumina.

Of the remaining processes, washing, jigging, heavy-density separation and concentration on spirals require wet screening and crushing to 1½ in. or finer.

Wash ores are ores having the contaminating silica in a fine state where it can be easily freed. Such ores are first wet-screened on a vibrating screen. The oversize is crushed in a reduction crusher, usually a cone-type. The crusher product is either rescreened or else washed in a log washer and then screened. The minus ¼-in. screen undersize and the log washer overflow (which contains the free silica washed from the ore) are fed to a rake or spiral classifier. The bulk of the silica is then discharged in the classifier overflow. The classifier rake (or spiral) product and the screen oversize are combined to make the wash ore concentrate.

Working on Jig Ores

This same circuit is used to prepare feed for other methods of concentration on the so-called "jig" ores, in which the silica is coarse or locked with the iron minerals. The screen oversize (plus ¼ in. or plus 3/16 in.) may be fed to either jigs or heavy-density equipment. The classifier rake product (minus 3/16 in. plus 65-mesh, approximately) can be fed either to jigs or to heavy-density cyclones. The classifier overflow (minus 65-mesh) may be deslimed and fed to spirals.

A scrubber is being installed at one plant this summer for the purpose of freeing the alumina from "painty" ore. The minus 3-in. crude ore will be fed with water to the Hardinge scrubber. The scrubber product will be screened. The undersize will be fed to screw classifiers, the rake product of which will be combined with the screen oversize as concentrate. Besides removing the alumina in the ore, this treatment will have the effect of lowering the moisture content.

If the ore is to be treated further by jigs alone, the screen oversize and the classifier rake product are combined for jig feed. At present, the Remco jig and the Conset jig are the only such machines in this service. Each type produces a tailing, a coarse bed concentrate, and a hutch concentrate. In one plant, four stages of Remco jigs are used. The first, or rougher, jig produces a finished tailing and a rough concentrate. The three jigs following clean up the concentrate and produce a middling which is ground in open circuit in a rod mill and fed back to the roughers. The concentrates are dewatered in classifiers before shipment.

High-Density Separation

The majority of plants now treating "jig" ores use high-density separation to treat the plus ¼-in. fraction. In most of the plants, the screen oversize from the crushing and washing section is given a final screening and washing on a horizontal screen before being fed to the high-density process. In plants of sufficient capacity to warrant the use of two high-density circuits, this preparation screen also serves to separate the ore at about 5/8 in. into a coarse and a fine feed.

A slurry of ferrosilicon and water is used as the medium for concentrating the plus ¼-in. (plus 3/16-in.) fraction. The medium is circulated at a gravity somewhere between 2.70 and 3.20, depending on the ore being treated. The two-circuit plant has the advantage of being able to operate with the circuit handling the finer feed at a lower gravity than the coarse circuit, thereby increasing recovery with no sacrifice in grade.

The cone-type Heavy-Media separator has been almost entirely

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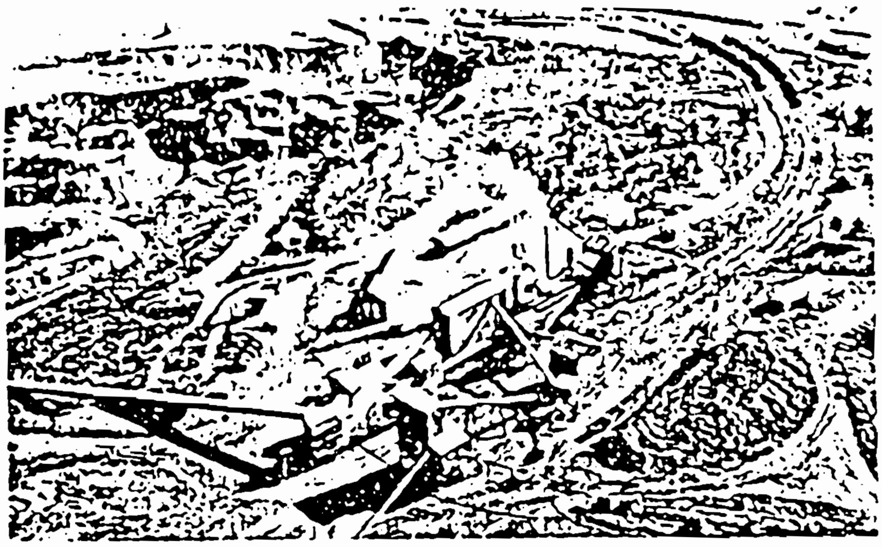

AGGLOMERATION is the final step in preparing fine ores and concentrates for the furnace. Here is one of the two Dwight-Lloyd sintering plants at present installed in Minnesota.

superseded by the newer types of separator. The Hardinge drum separator, the Akins screw separator, and the Wemco drum separator are the three types in general use. Each has its ardent supporters. A Roller separator is also being installed at one plant this summer.

High-density wash and drain screens are exclusively horizontal, single or double-deck, with either punched plate or wire cloth, Hendricks, Bixby-Zimmer, or wedge-wire decks, depending on the operator's preference. The latest trend is to combine the drain and washing functions on a single screen 20 ft. in length, and in widths up to 6 ft. A good many plants, however, still have separate wash and drain screens.

The Wilfley-type pump is standard for medium circulation, inasmuch as it requires no seal water and hence does not cause medium dilution. Several manufacturers have developed different types of pumps which require little or no sealing water. Several of these new types have been installed.

Magnetic Separators for Cleaning Medium

The belt type of magnetic separator is the most common in medium-cleaning circuits. Many drum-type magnetic separators have been installed in the past two or three years, often as secondary separators following belt-type primaries.

The coarse-size Heavy-Media plant produces three products: concentrate, which is ready for loading and shipping; coarse tailing, which is either stacked by conveyor or trucked away; and magnetic separator tailing, which is either returned to fines treatment or sent out with the fine tailings, depending on its grade.

Cyclones Enter Picture

Five plants are using Heavy-Media cyclones for treating the minus 3/16-in. plus 65-mesh fraction of the ore, with more installations of the same process in the planning stage. In general, the classifier product from the crushing and washing section described is further de-watered, then fed with circulating magnetite medium through a mixing chute into a pump sump. The ore-medium mixture is then pumped into a cyclone, or into two cyclones operating in parallel. The spigot product of the cyclone is sink or concentrate, while the effluent is float or tail. The two cyclone products are screened, a portion of the screen undersize is recirculated, and the remainder of the screen undersize is run through the cleaning circuit, which is a much modified version of the coarse Heavy-Media cleaning circuit. The concentrate and tails from the process are recovered as non-magnetic product from the magnetic separators.

More drum-type than belt-type magnetic separators are used in this application. An interesting development along this line is a proposed installation in which the secondary magnet drums will be mounted as an integral part of the product-dewatering classifiers.

Several plants are using jigs to treat the classifier product from the crushing and washing section, with either two or four cells in series. Remco, Pan American and Denver jigs are the machines being used in this application.

Spirals and Abrasion Milling

Humphreys spirals are used to treat the minus 20-mesh plus-200 mesh fraction. Hydroseparators, classifiers, or sizers are used to deslime the feed ahead of the spirals. The spirals are often used in conjunction with jigs or Heavy-Media cyclones to cover the range from ¼ in. to 200-mesh, in which case the top size to the spirals would be approximately 65-mesh. When used without other fines treatment, a screen is necessary to limit the top size of the feed to the spirals to about 20-mesh.

Abrasion milling, as practiced at several plants, is a useful auxiliary to these various methods of treating fines. Either the feed that goes to fines treatment, or else the middling from the fines treatment, is given a light pass through a ball mill charged with small balls. Silica adhering to the ore particles is abraded off, and coarse, friable pieces of silica are reduced to a size easily removed by fines treatment.

Two sintering plants are in operation. One plant uses Dwight-Lloyd equipment. The other plant uses both Dwight-Lloyd sintering and nodulizing.

One drying plant is in operation. It is on the Cuyuna range.

Provision for surge capacity ahead of the various processes has not been mentioned. Almost all plants have some type of surge capacity or storage ahead of high-density jigging, and fines treatment.

The majority of the new plants, and many of the older plants, have incorporated the most modern of electrical equipment, for safety and reliability. In most instances, all critical equipment is interlocked. Where possible, all machines in each section are controlled from one strategic location.

The management of these plants stresses safety in equipment and in operation, as is evidenced by the excellent safety record of the Minnesota ranges.

No two of these plants are exactly the same. Each has been built to fill a particular need. The research and operating personnel of each company are constantly on the alert and are ready to make any change which will increase the efficiency of their operations.

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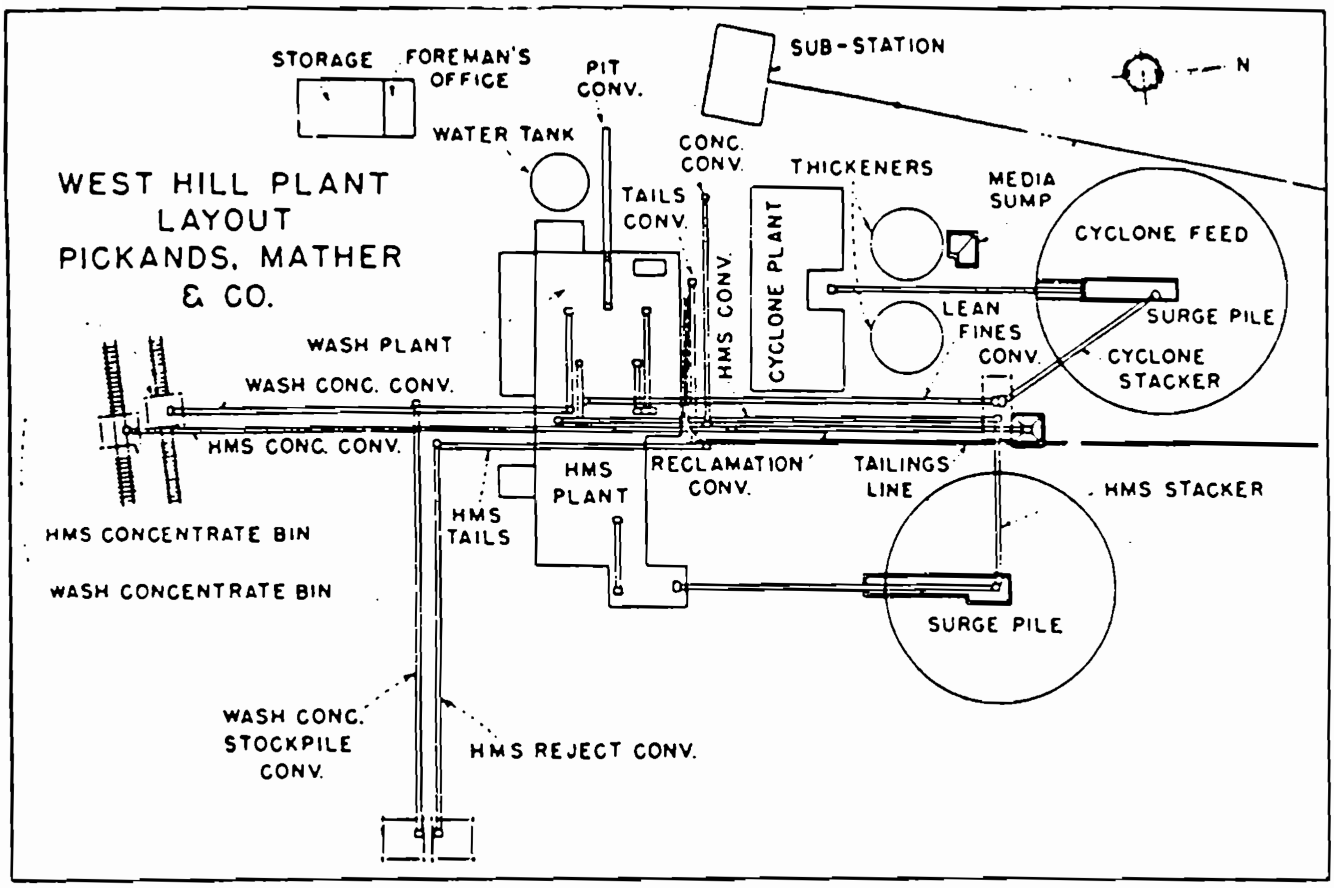

FIG. 1. Completed in July 1953, the West Hill plant is designed to handle both straight wash and heavy density or jig ores, separately or in any combination. Designed for 700 long tons per hour, it has treated over 1,000 tph.

Modern Plant Will Treat Mesabi Lean Ores

E. C. HERKENHOFF
Pickands, Mather & Co.,
Hibbing, Minn.

THE WEST HILL PLANT of the Western Mining Co., operated by Pickands, Mather & Co., is the newest and most modern of the growing number of beneficiation plants that treat Mesabi lean iron ores. After being placed in operation early in July 1953, plant performance has met expectations and promises to exceed them in the future.

The West Hill mine is located about two miles west of Coleraine and is the westernmost producing mine on the Mesabi. It is adjoined on the west by the Lind-Greenway mine of Jones & Laughlin Steel Corp., which at present is under development. The West Hill's eastern neighbor is the Buckeye mine of the M. A. Hanna Co., where, it is interesting to note, the first commercial cyclone separation plant was placed in operation in 1951.

The ores of the West Hill mine are of two types: straight wash and heavy density or jig ores. Both types require processing and the plant is designed to handle either type or combinations of either type.

Development of the open pit mine began in December 1951 and proceeded at a steady pace until July 1953. Plant construction began in September 1952 and met the completion date of July 1953. The mine and plant are under the supervision of L. M. Becker, mine superintendent, and E. J. Fearing, general superintendent of the Western Mesabi District for Pickands, Mather & Co. George Paul is plant foreman.

The plant engineering design and erection were by the North Central District office of Western-Knapp Engineering Co. to the flowsheet specifications of Western Mining Co. J. J. Sheppard is chief engineer for Western-Knapp's North Central office.

Plant Flow Scheme

The plant flow scheme may be divided into four sections as follows:

(1) Pit screening and crushing section.
(2) Washing section
(3) Heavy-Media section
(4) Cyclone concentrator section (to be completed in 1954)

The processes used may be considered conventional, but the plant design incorporated several new features which will be described in detail.

Fig. 1 is a plan view showing the general arrangement of the entire plant. Fig. 2 shows the layout of the wash and Heavy-Media sections. The flexible flowsheets (pp 80 and 81) permit the treatment of various fractions

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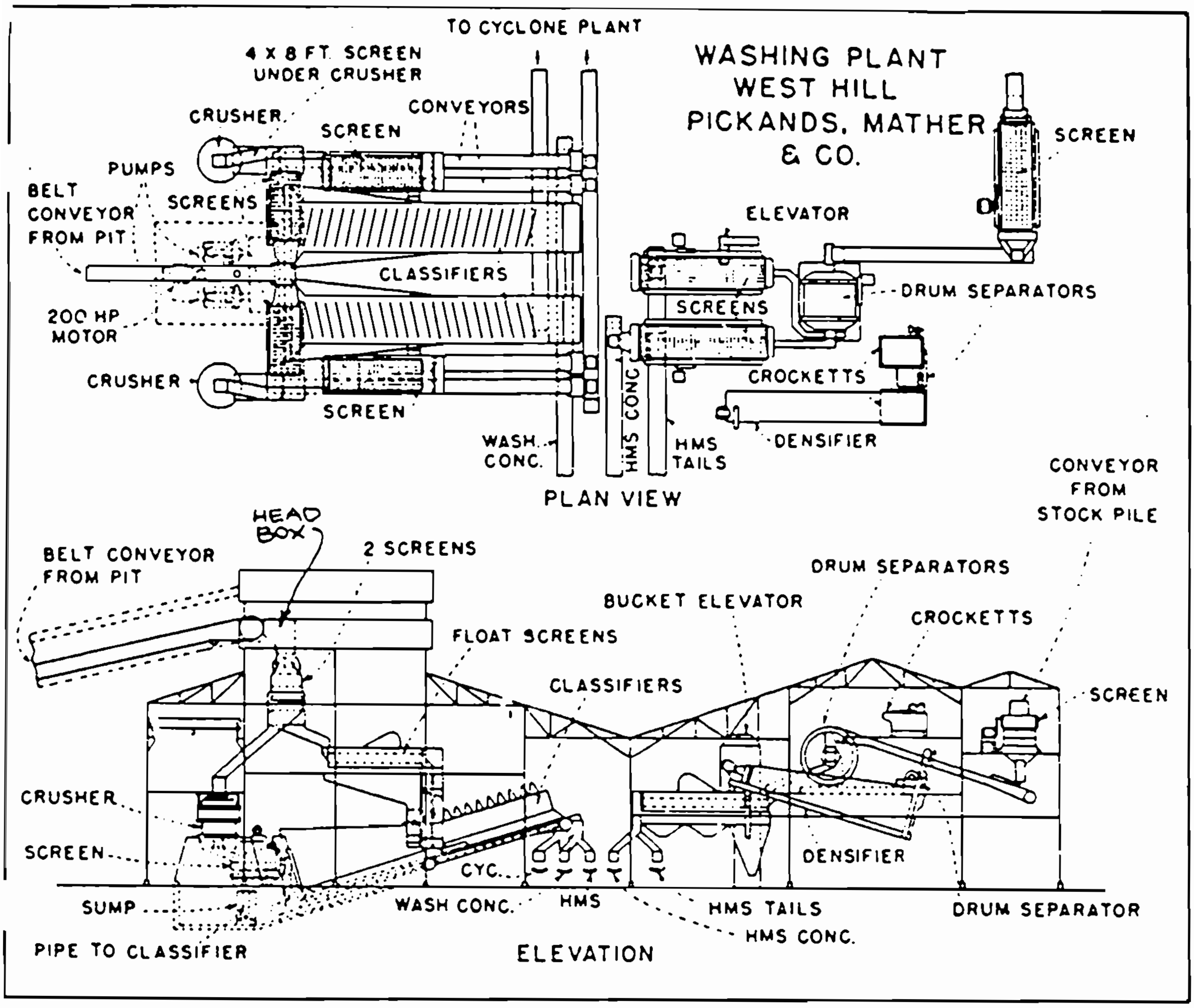

FIG. 2. Throughout plant economy of structure and better interior visibility simplify operations. Use of floor gratings throughout also contributes to better housekeeping. Medium consumption here was below 1.0 lb per ton in 19..

of the ore by either straight washing, Heavy-Media, or cyclone separation. Fig. 3 shows an elevation of the cyclone section which is now under construction.

This plant was designed for a capacity of 700 long tons of ore per hour and easily attained this figure. In fact, feed rates of over 1,000 tph were attained. The designed capacities of the various sections of the plant are as follows: Crude ore, 700 tph; Heavy-Media feed, 220 tph; cyclone concentrator feed, 160 tph.

Ore Treatment

Crude ore, dumped by 20-ton trucks into the pit plant hopper, is fed to a 6x12-ft Tyrock F-900 scalping screen by a 5x17-ft pan feeder. The plus 4½-in. material passes through a 42 x 48-in. jaw crusher and, optionally, may join the scalping screen undersize or be diverted to the rock reject bin when lean or retractory. The screen undersize is delivered to the main slope belt by a 36-in x 10-ft speedup belt.

This speedup belt takes the place of a conventional pan feeder. Traveling at the same speed as the main belt, it takes the brunt of the wear resulting from accelerating the load, thus minimizing wear on the long, expensive slope blet.

The 42x48-in. Pioneer jaw crusher, with welded steel frame, is the largest overhead eccentric type crusher on the Range. It is driven by a 150-hp slip ring motor.

Referring to Fig. 2, the screened and crushed ore is delivered dry to the head box of the plant. Water is added and the pulp stream is split to two identical sections, each section providing the following treatment:

The pulp passes over the primary wash screen having 1¼-in top deck openings and a troughed lower deck with ⅜-in openings. The plus 1¼-in fraction is chuted to a 4-ft Symons crusher and the crusher product is washed and dewatered on a 4x8-ft double deck screen. Screen undersize (minus 10 mesh) is pumped to the 84-in. classifier. Oversize is conveyed to join the other coarse fractions.

In many cases, the plus 1¼-in. fraction of Mesabi wash ores is lean and requires gravity concentration, whereas the minus 1¼-in. fraction may wash up to a satisfactory product. The West Hill flowsheet allows the operators to check the quality of the cone crusher product visually and divert it to Heavy-Media treatment if required.

The minus 1¼-in. fraction of the ore, after passing either over or through the bottom deck of the primary wash screen (for scrubbing only), goes to a horizontal double deck secondary wash screen. The plus ⅜-in. fraction optionally joins the minus ⅜-in., plus ⅛-in. fraction and may be sent to Heavy-Media or conveyed to the loading pocket. The mi-

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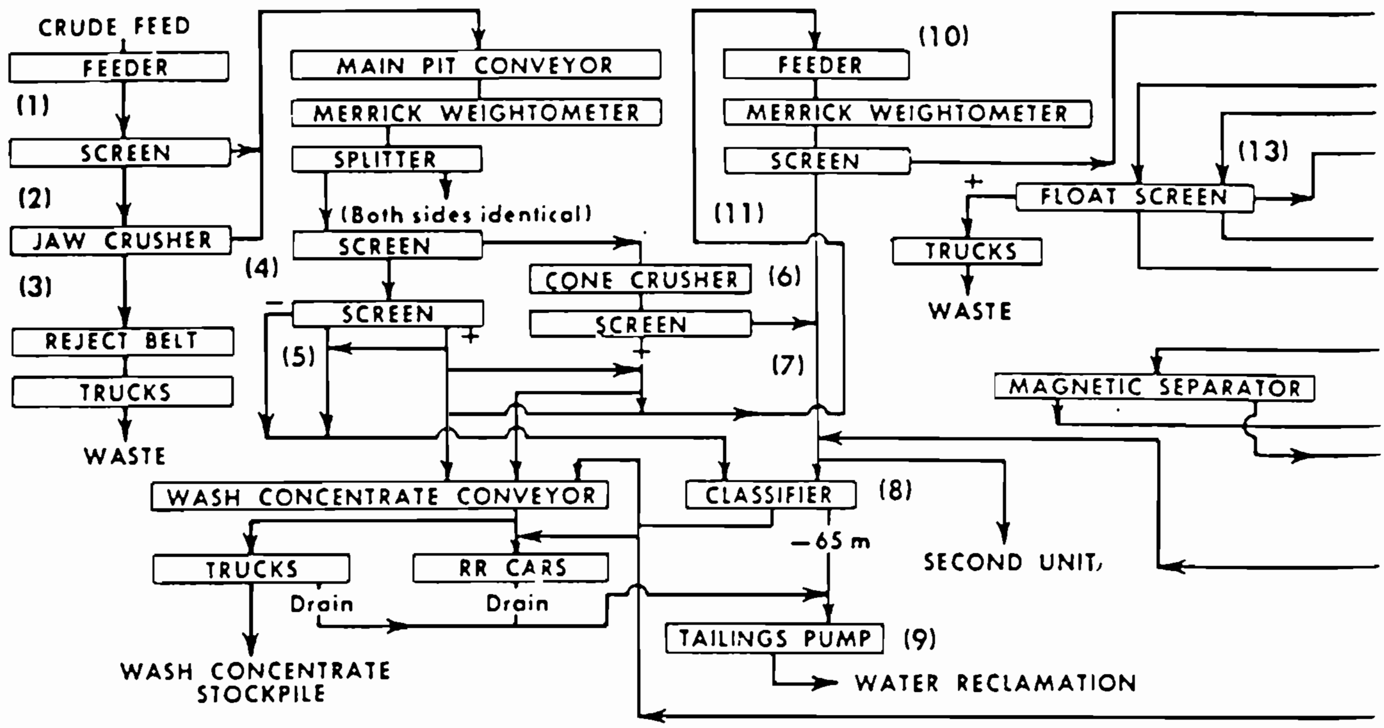
MAIN FLOWSHEET — WEST HILL PLANT

Pickands, Mather & Co.



LEGEND

1. Bathke Pan Feeder (5x17-ft)
2. Tyler Scalping Screen (4½-in.) (6x12-ft)
3. Pioneer Jaw Crusher (42x48-in.)
4. Allis-Chalmers Primary Wash Screen (5x12-ft DD)
5. Simplicity Secondary Screen (5x14-ft DD)
6. 4-ft Symons Cone Crusher (1½-in.)
7. Allis-Chalmers Lo Head Screen (4x8-ft DD)
8. Wemco Classifier (84-in.)
9. Pettibone-Mulliken Tailings Pump
10. Link-Belt Pan Feeder
11. Simplicity Feed Preparation Screen (5x16-ft DD)
12. Wemco HMS Drum (8x8-ft)
13. Simplicity Sink Screen (5x20-ft DD)
14. Simplicity Float Screen (5x20-ft DD)
15. 6x6-in. SRL Sand Pump

nus 3/16-in. fraction is fed to the 84-in. classifier which makes a separation at about 65 mesh. The classifier overflow is a tailing and is pumped to the sludge basin. The classifier sand joins other coarse fractions and, if high grade, goes to cyclone plant.

In contrast with many of the large Range plants, the West Hill wash plant height is quite low. From ground elevation to the centerline of the head pulley is only 42 ft, 9 in. as shown in Fig. 2. This resulted in economy of structure and better interior visibility which simplifies operation. The reduction in plant height was achieved principally by separate screening of the cone crusher product and installation of the tailings pumps below the main floor grade. The cone crushers are mounted near floor level on concrete foundations, eliminating expensive steel supports and attendant vibration troubles.

The use of floor grating throughout the plant provides the operators with clear visibility, and contributes to better plant housekeeping.

The 84 in. x 42 ft Wemco spiral classifiers are the largest ever built for such purposes. The drive is 20-hp and speed is 5 rpm. The flights are equipped with longitudinal lifter bars and wash boxes are built into the dry-deck section of the tank.

Double deck horizontal screens, with specially designed washing and pumping troughs, are used extensively throughout the plant. All screen surfaces are woven wire, providing maximum open area. Screen openings for 1953 were as shown in Table I.

At present, the Heavy-Media section consists of one unit, treating feed having a size range of minus 1¼, plus 3/16-in.

Novel features of the Heavy-Media unit are the wash and drain screens and medium cleaning system. A sec-

Table I. Screen Sizes — West Hill Plant

Section	Screen	Top	Bottom
WASHING	5x12-ft Prim. Wash	1¼ in.	⅛ in.
	5x14-ft Sec. Wash	⅛ in.	3/16 in.
	4x 8-ft Crusher Product	3/16 in.	.090 in
HMS	5x16-ft Preparation	⅛ in.	.206 in.
	5x20-ft Drain and wash* (Fig. 4)	.40 in.	.104 in.
CYCLONE	6x16-ft Dewaterizer	.0098 in.	(S.D.)
(FUTURE)	5x10-ft Drain screens	.025 in.	(S.D.)
	5x10-ft Tramp screen	.025 in.	(S.D.)

(*) First 5 ft is single deck covered with 2¼ mm Wedge-Bar cloth

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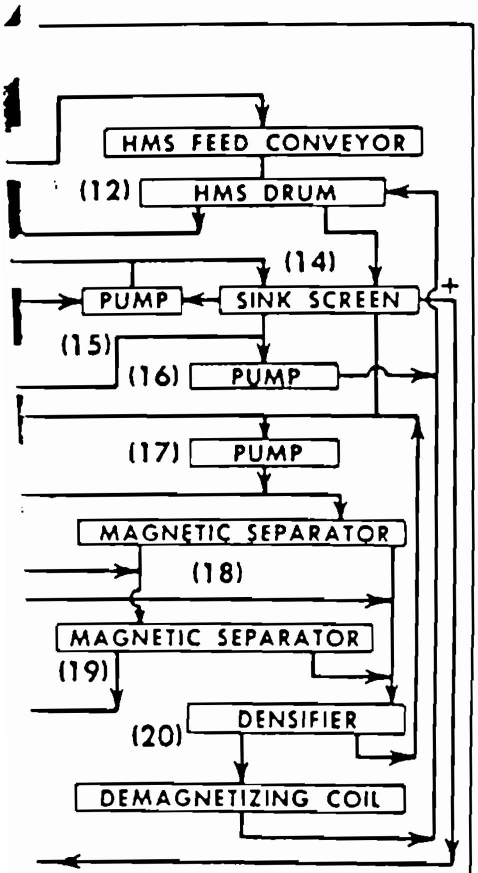


16. 5-in. Sand Pump
17. 6x6-in. SRL Sand Pump
18. Dings Magnetic Separator, Crockett Type (48-in.)
19. Dings Magnetic Separator, Drum Type (72-in.)
20. Wemco Densifier (48-in.)

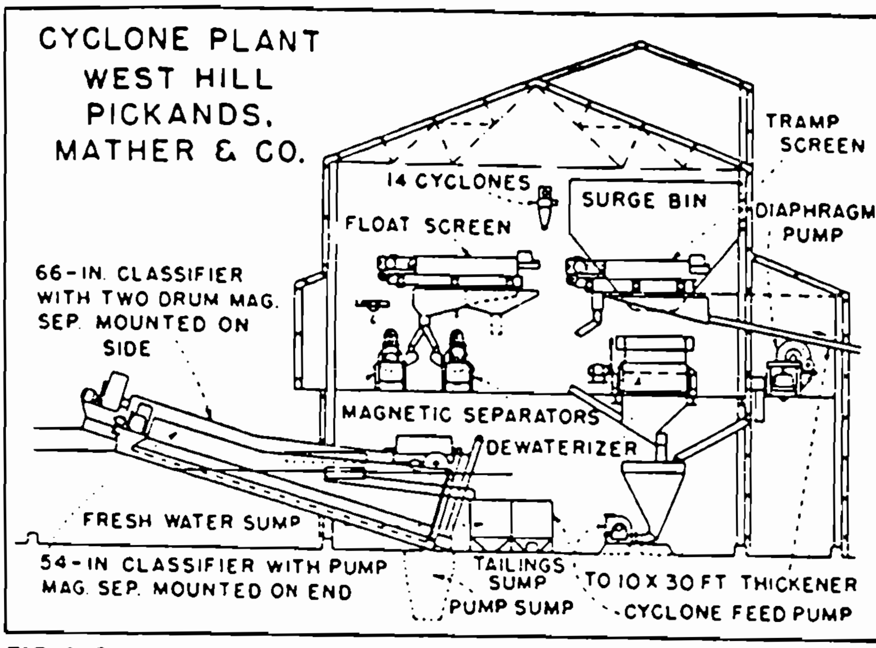
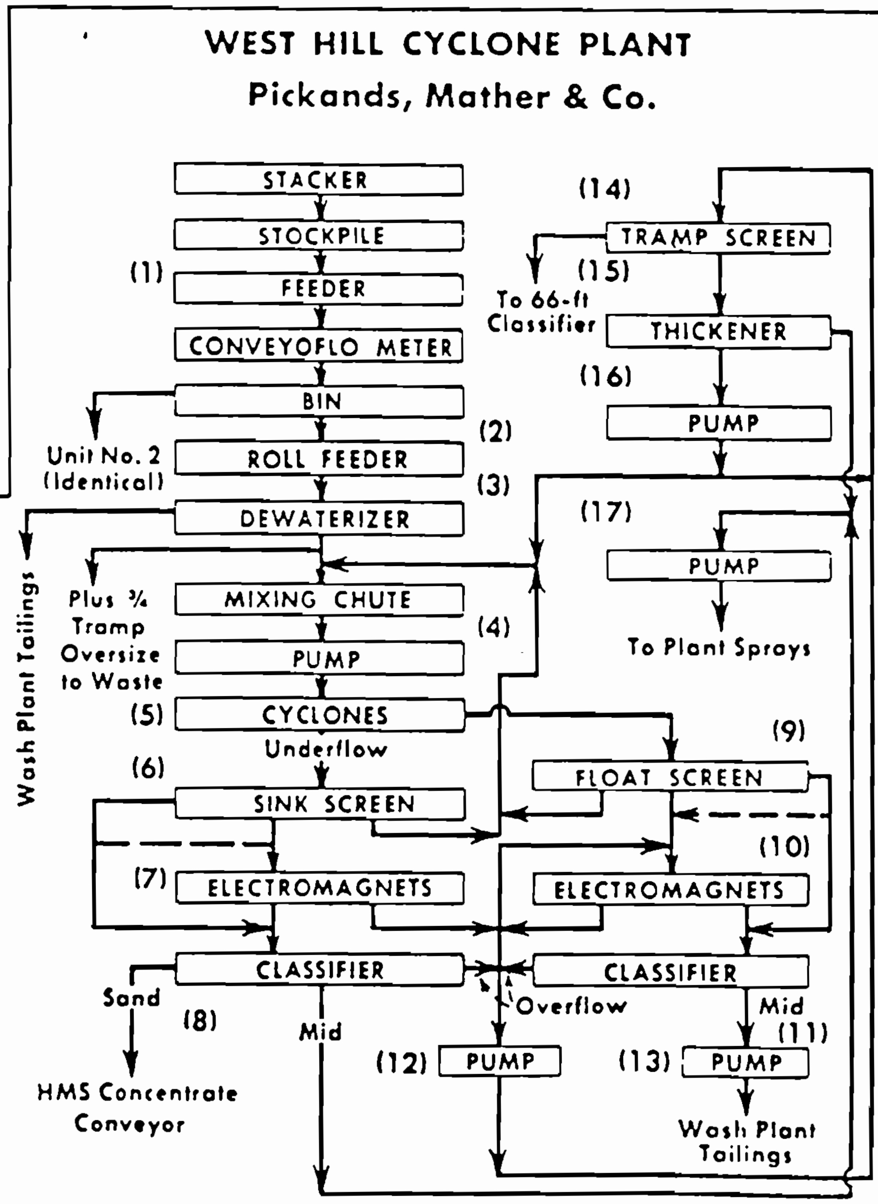


FIG. 3. Cyclone section, now under construction, will be in operation early in 1954. Cyclones will be built of cast Ni-Hard by the Staver Foundry.



LEGEND

1. Simplicity Vibrating Feeder
2. 16-in. Wemco Roll-Feeders
3. Hewitt-Robins 6x16-ft Dewaterizer
4. Wemco 6-in. Sand Pump
5. Two Erie 14-in. Cyclones
6. Symons Sink Screen (5x10-ft SD)
7. Electromagnet (30x72-in.)
8. Wemco Classifier (54-in.) containing 30x60-in. Alnico Magnet
9. Symons Float Screen (5x12-ft SD)
0. Electromagnets (30x60-in.)
1. Wemco Classifier (66-in.) containing 30x60-in. Alnico Magnet
2. 5-in. Hazleton Pump (Vertical)
3. Allis-Chalmers 4-in. CW Pump
4. Symons Tramp Screen (5x8-ft SD)
5. Hardinge Thickener (10x30-ft)
6. 6-in. Dorr Triflex Diaphragm Pump
7. Allis-Chalmers 5-in. CW Pump

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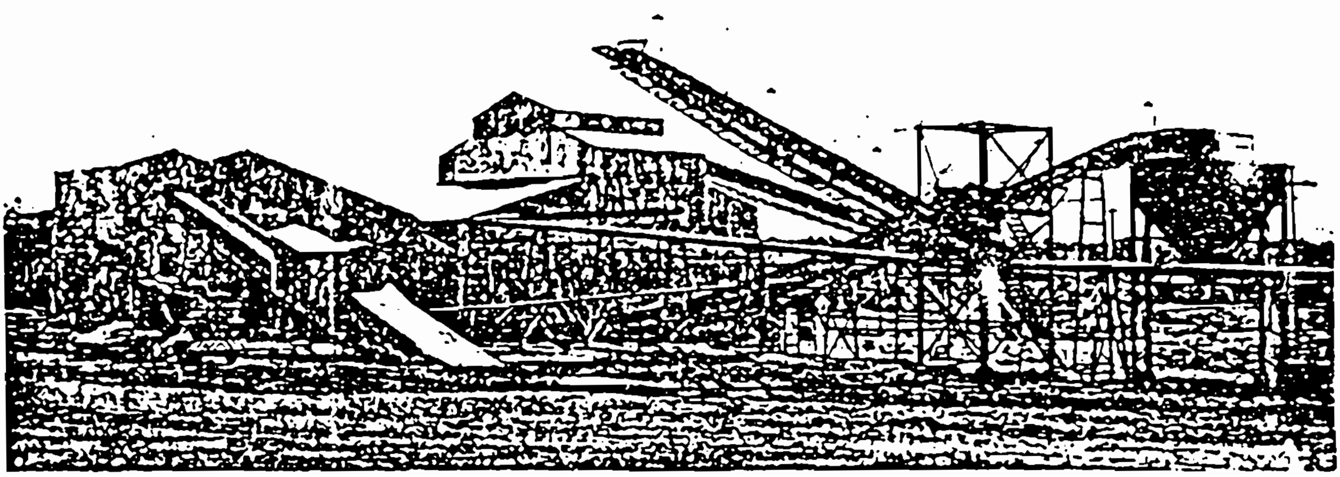


Low building, only 42 ft. 9 in. from ground to centerline of head pulley, departs from Range practice. Crushers mounted near ground level on concrete foundations, don't require extensive steel supports with attendant vibration.

tion through one of the 5x20-ft wash and drain screens is shown in Fig. 4. Here it will be noted that the long wearing features of Wedge-Bar are utilized in the first 5 ft of the screen where wear is at a maximum and ample drainage of medium can readily be obtained even with a minimum of open area.

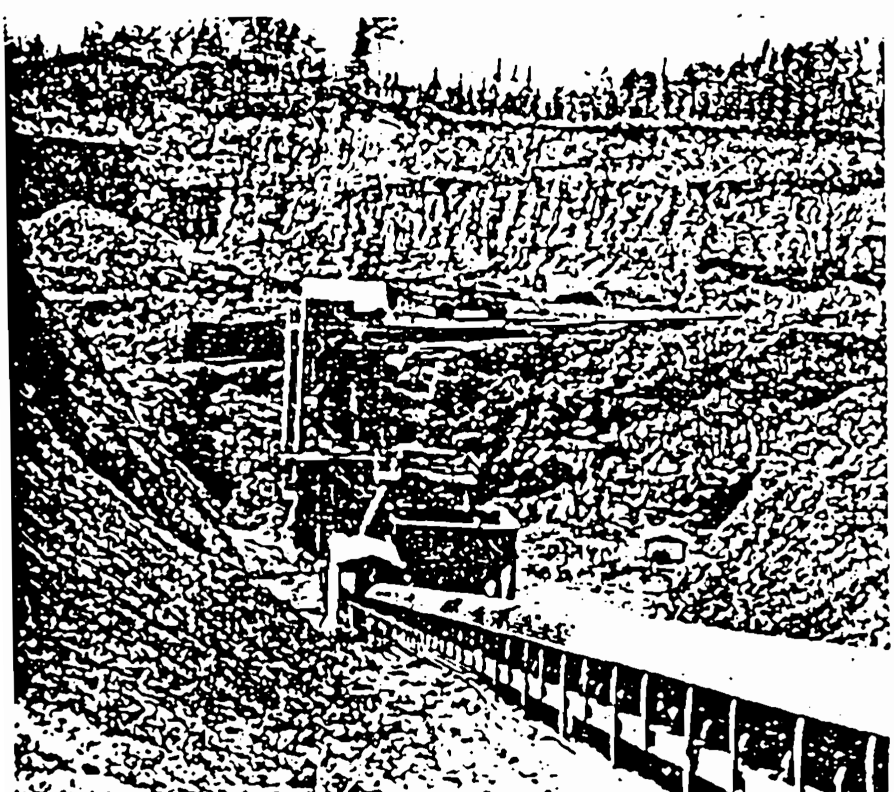
The remainder of the screen is divided into alternating troughs and screen panels, utilizing two decks. Here the medium is thoroughly scrubbed and washed from the products by applying the wash water in counterflow principle.

Fresh water added near the discharge end of the screen is collected in a separate sump and is pumped back to the head end of the washing section of the screen and is applied at the troughs of both decks through 3-in dia pipe distributor headers having ½-in. round openings (ordinary sprays cannot be used because of the solids content) spaced on 6-in. centers. Thus, the wash water provides double washing and lowers the attachment loss of medium. So far as is known, this plant is the first on the Range to employ counterflow washing although the practice is common in coal separations.

All present Range Heavy-Media plants use single deck wash and drain screens. The use of double deck screens minimizes the depth of ore on the screen surface and greatly reduces the attachment losses of medium. Wire cloth provides high percentages of open area and the division of load protects the bottom deck cloth from undue wear.

It will be noted that the wash water is not thickened before going to the magnetic separators. However, ample magnetic separator capacity was provided in the form of two 48-in. Dings HM electro machines. The combined tailings go to a 24x72-in. Dings permanent magnet secondary separator. This type of separator has been in common use in Europe for ferrosilicon recovery but the West Hill and Biwabik plants on the Mesabi are the first to use a permanent magnet for such service.

Evidence of the effectiveness of the above designed features is offered by the medium consumption for the 1953 season, which fell substantially below 1.0 lb per ton of feed to the section. Inasmuch as medium costs make up a substantial portion of total Heavy-Media treatment costs, the problem of reducing the consumption has received special attention in the West Hill Plant design.



Pit screening and crushing section feeds ore to the modern plant. Mine development was begun in December 1951 by Pickands, Mather & Co.

Cyclone Separation Section

During the 1953 season, the lean fines from Heavy-Media or jig ores were stockpiled for future treatment in a 2-unit cyclone separator section. This cyclone section is now under con-

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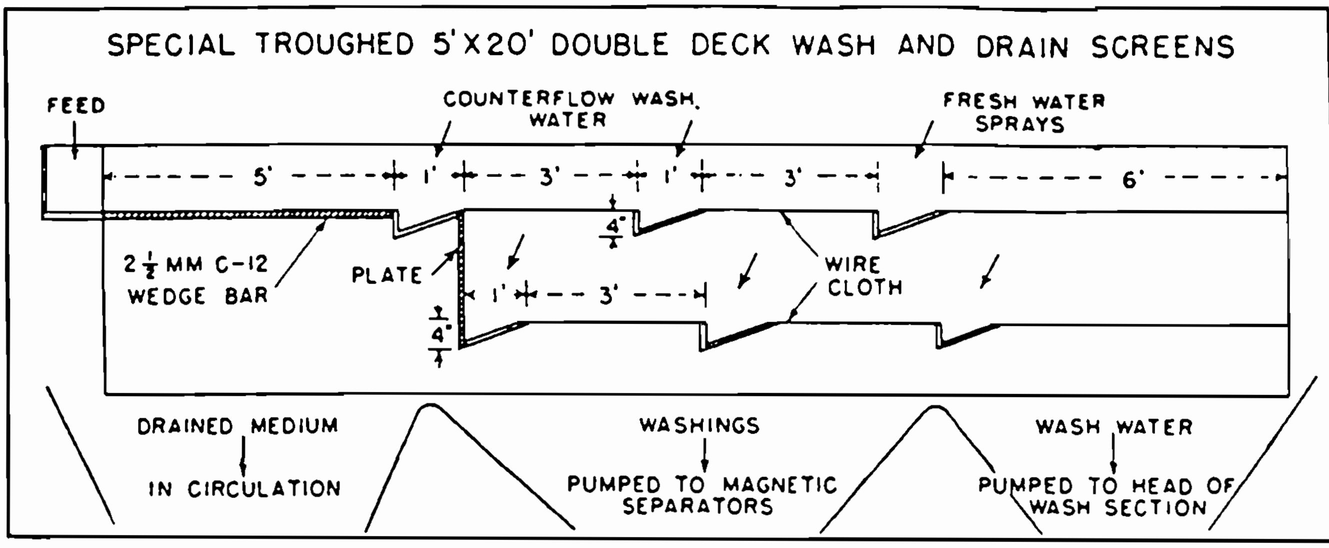

FIG. 4 Counterflow washing, an innovation on the Range, is one of the features of the West Hill plant. Use of double deck screens reduces attachment losses of medium cuts down wear on screen cloths.

struction and will be in operation early in 1954. A description of the flow scheme to be used is as follows:

If the 84-in. classifier sand product is lean and requires treatment, it is diverted to the cyclone concentrator section. Feed is conveyed to a surge pile by a boom stacker, and is reclaimed by means of a vibrating feeder under the surge pile. This feed is conveyed to a 100-ton bin at the head of the cyclone plant. From this bin the feed will be split to two identical sections, each having a capacity of 80 tons per hour.

Feed rate to each section is controlled by a 16-in. diameter roll feeder. The feeder discharge is dewatered over a 6x16-ft Hewitt-Robins Dewaterizer, this being done to minimize dilution of the medium by free water.

Tramp oversize, plus ⅝-in., is rejected at the Dewaterizer. The dewatered product falls to the cyclone feed pump sump and is mixed with circulating and fresh medium therein. A 6-in. sand pump delivers the pulp to two 14-in. dia cyclone separators which make the split into underflow or concentrate, and overflow or tailing. These cyclones are to be constructed of cast Ni-Hard, according to design, by the Stuver Foundry.

Nordberg Type F screens are to be used for drain screens. The drained medium is recirculated. Some washing will be done on the screens, but initially no attempt will be made to produce a washed final product from the screen oversize. The screen undersize and washings are laundered to 60-in. and 72-in. primary electromagnet separators which produce a magnetic concentrate and a tailing. The tailing will be combined with the screen oversize product and be fed to 60-in. long secondary permanent magnet separators.

Inasmuch as one of the major problems in cyclone separation plants is the recovery of the fine medium from the relatively coarse non-magnetic iron concentrate and siliceous tailing products, much attention has been given to this problem. Where the ore products from the separation are passed through the magnetic separators and discharged as spigot products, maintenance of drum submergence is highly important to medium recovery.

When the spigot load varies widely due to ore grade fluctuations, as is the case with most Mesabi ores, the operator is faced with a continually fluctuating pulp level in the magnetic separators. To combat this problem at the West Hill plant, the secondary magnetic separators will be mounted in the tanks of the dewatering classifiers, thus insuring a constant water level. Head room is saved also.

The dewatering classifier sand products represent the concentrate and coarse tailings from the ore. The classifier overflow, sink side, will be recirculated as dilution water to the magnetic separators. The classifier overflow on the float side (common to both sections) will be discarded as tailing.

Magnetic concentrates from both primary and secondary separators join and are to be pumped to a 5x8-ft tramp screen (to remove entrapped coarse material) and then pass to a 10x30-ft Hardinge thickener. Thickened concentrate is pumped by a 6-in. Triplex Deco diaphragm pump and is split, either to the cyclone feed pump or returned to the thickener via the vertical pump and tramp screen.

New medium will be charged to the thickeners by means of a 3-in. vertical Hazleton pump.

General

Wash concentrates and Heavy-Media plus cyclone concentrates are conveyed to separate 200-ton railroad loading bins. Coarse rejects are conveyed to a bin and trucked away. Fine tailings are pumped to the sludge basin about 3500 ft away. When no railroad cars are available, the concentrates are diverted to a bin and are trucked to stockpile. During the 1953 season the lean fines were stockpiled, and are to be reclaimed in 1954.

Water for the plant is pumped from the mine into a 50,000 gal storage tank adjacent the plant. Two Fairbanks-Morse 10-in. centrifugal pumps provide 4500 gpm of pressure water to required points in the plant.

All electrical low-voltage transformers, breakers, switch gear, and meters are located in a separate bay adjacent the washing section. Current at 440v is distributed to each section of the plant where starters and controls for the various units of equipment are located in panel boards and stop-start stations. Extensive interlocking of controls assures a minimum of trouble from power outages or possible machine failures.

During the 1953 season the grade of crude ore averaged between 40 to 45% Fe and satisfactory grades of merchantable concentrates were produced. The utilization of lean ores such as those occurring at the West Hill and other mines promises to extend the life of the Mesabi Range and benefit the country as a whole.

Metallurgical control and coordination of metallurgical and production problems are under the supervision of the Metallurgical Department of Pickands, Mather & Co., Fred D. DeVaney is chief metallurgist, and H. C. Gerber, general plant foreman.

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... Co. built a new washing ... its St. Paul Mine and is ex... its operation to include the ... the Wentworth Mine.

... S. Moore Co. moved its con...trator from the old Prindle Mine to the Mariska property. A similar move of existing facilities to a new location was made by M. A. Hanna Co., who moved equipment formerly used at the Buckeye Mine to the Douglas property near Chisholm.

Oliver Iron Mining Co. is installing a large addition to its Trout Lake property near Coleraine, Minn. This plant, which has washed millions of tons of ore since the early 1900's, will now be provided with two float-sink and cyclone sections. Float and sink separatory apparatus will consist of two 10x10-ft drums. These drums will have about double the capacity of the conventional 8x8-ft drum normally used on the Mesabi.

Another example of the change in the trend is the installation by Pickands Mather & Co. of a new concentrator at ... Mahoning Mine. This well-known ...e has shipped nothing but direct shipping ore for almost 70 years. The new plant will consist of washing equipment, float and sink units, cyclones and spirals. Feed to the spirals will be made up of deslimed washing plant tailings and the minus 20 mesh portion of the cyclone tailings.

The first commercial flotation plant ever installed on the Mesabi Range will be in operation for the 1957 season. This is Jones & Laughlin's plant, which is nearing completion at its Hill Annex Mine near Calumet, Minn. At this property, washing plant tailings that have accumulated over a number of years will be recovered by means of a floating dredge and this material will be sized by cyclones. The coarser fraction will be treated by Humphrey spirals which will produce a concentrate and a tailing. Middling from these spirals together with the deslimed portion of the cyclone overflow will constitute the flotation plant feed.

Flotation will be practiced in an acid circuit, using petroleum sulphanates as the collector. Hematite will be floated away from the siliceous gangue. If this plan proves successful, it will ...obably be the first of many built. ...large tonnages of such tailings have ...cumulated over many years on the Mesabi Range.

In addition to the installation and alteration of mills to improve quality, much is being done to improve the structure of ores in the Lake Superior District. A few mills have shipped fine concentrates separately for a number of years, but this trend is being accentuated. There are several advantages to the steel mill of having the separation between coarse and fine concentrates made at the concentrator.

At most mills, treating either wash or retreat ores, the concentrates, at some phase of the operation, are wet screened at about ¼ in. It has been the practice to combine all these concentrates into one product for shipment. By some rearrangement of mill equipment, it is possible to keep separate the course plus ¼-in. fraction not requiring sintering, and to segregate the minus ¼-in. material which requires sintering. An almost perfect separation at this size can be made with the wet screening commonly employed at the concentrator.

If the concentrates are shipped together, and as often happens, mixed with direct shipping ore, this mixture must be screened dry at the steel mills. Usually the finest screen that can then be used is about ⅝-in. If the screening is done at the concentrator, and the plus and minus ¼-in. product shipped separately, a much smaller percentage of the ore requires sintering, and because of the more uniform size, a better sinter is produced.

As an example of this trend, two of the mills managed by Pickands Mather made this conversion for the 1956 season and all mills of this company will be converted to practice this sizing for the 1957 season.

A similar transition is taking place in the preparation of direct shipping ores. This is in line with recommendations of blast furnace technicians, who have determined that sized ore charges with the agglomeration of all fines, yields superior results.

Crushing of ores to a maximum of 4 in. has been practiced at most Lake Superior Mines for years. This practice is being elaborated on at some properties to include not only crushing of such ores, but the screening of the ore into two coarse size increments and a fine size increment. Fines will be of such a size that no further sizing will be required at the steel plant for use as sinter feed. Products usually shipped are a minus 4-in. plus 1½-in., a minus 1½-in. plus ½-in., and a minus ½-in. product.

Leader in this field has been Oliver Iron Mining with two large plants under construction on the Mesabi Range. Plants are under construction at both the Rouchleau and at the Sherman properties for sizing ores from the Virginia and Chisholm areas.

M. A. Hanna Co. will open up the long known iron or property at Moose Mountain, 35 miles north of Sudbury, Ontario. Ore at this property consists of a disseminated magnetite. It will be concentrated magnetically and shipped to U.S. furnaces for mixture with lower grade Lake Superior ores for sintering.

A number of mining companies have been actively engaged for several years in exploring the Butternut District, south of Ashland, Wis. This district, which is a western continuation of the Gogebic Range, contains taconite-like material requiring fine grinding for concentration. The Ashland Mining Co. has drilled out a rather large deposit in this area and experimental work is presently being done at the Pickands Mather Laboratory in Hibbing to determine the most feasible flowsheet.

One of the major fields of endeavor for iron ore concentration engineers in the coming years will be the working out of means for treating ores in the Labrador and Ungava areas. With the exception of the large amount of direct shipping ores held by the Iron Ore Co. of Canada in the Ruth Lake area, it is becoming more apparent, as exploration work continues, that the bulk of the ores in the other areas must be concentrated and probably agglomerated before they are marketable.

From what scanty information is now available, it seems certain that there are wide variations in the type of minerals present within individual deposits, as well as major variations from one deposit to another. Such varied concentration methods as flotation, gravity separation, high and low density magnetic processes, as well as magnetic roasting may well find a place in this large area.

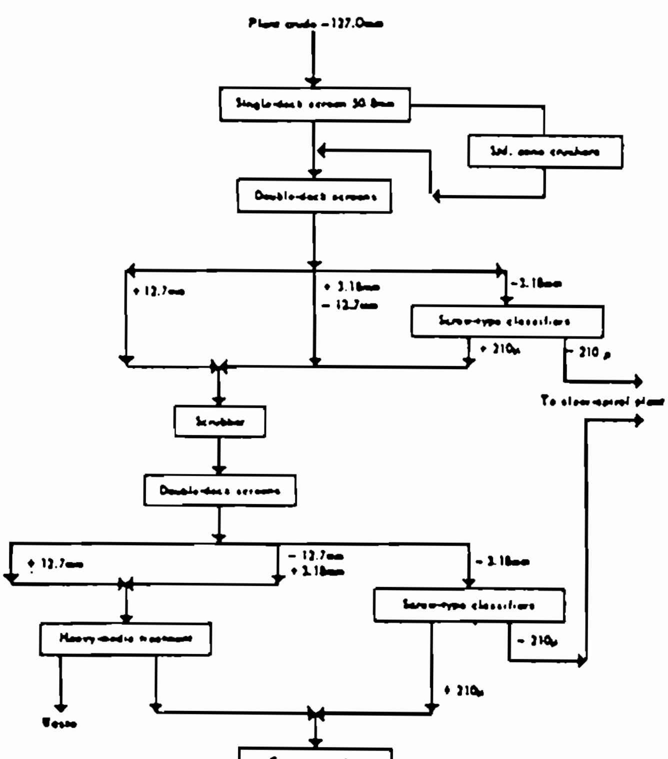
Now that a good many major Canadian, American and European steel and mining interests have properties in this area, and with the seemingly unending demand for increasing amounts of iron ore, it requires no crystal ball to predict that this area will be one of great activity in the next few years.●

EXHIBIT "30" - Copies pages 108,115,119-120, 127-132 and 149 of a compilation of extracts from the American Engineering and Mining Journal 1930's - 1950's

Table 184 — Selected list of beneficiation plants on the Mesabi Range, 1963

Name of plant	Company	Type of plant
Jessie	Jessie H. Mining Co.	Washing.
Morton	Morton Ore Co.	Washing.
South Agnew	South Agnew Mining Co.	Washing.
Webb	Snyder Mining Co.	Washing.
Weggum	Philbin Mining Co.	Washing.
Scranton	W. S. Moore Co.	Crushing and washing.
Longyear	Jones & Laughlin Steel Corp.	Crushing, screening, washing.
Meadow	Pittsburgh Pacific Co.	Crushing, screening, washing.
Arcturus	Oliver Iron Mining Div.	Washing, high-density, spirals, cyclones.
Canisteo	The Cleveland-Cliffs Iron Co.	Washing and high-density.
Duncan	Douglas Mining Co.	Washing, high-density, cyclone.
Harrison	Butler Bros.	Washing, high-density, cyclone, spirals.
Hill-Trumbull	The Mesaba-Cliffs Mining Co.	Washing and high-density.
Holman-Cliffs	The Mesaba-Cliffs Mining Co.	Washing and high-density.
Hunner	Hanna Iron Ore Div.	Washing, high-density, spirals, cyclones.
Julia	Pittsburgh Pacific Co.	Washing and high-density.
Mary Ellen	Pittsburgh Pacific Co.	Washing and high-density.
Mesabi Chief	Hanna Ore Mining Co.	Washing, high-density, hydrosizer.
Patrick A	Butler Bros.	Washing, high-density, spirals.
Pierce	Hanna Ore Mining Co.	Washing, high-density, spirals, cyclones.
Plummer	Oliver Iron Mining Div.	Washing, spirals, cyclones.
Troy	Rhude and Fryberger, Inc.	Washing, jigging, high-density.
Bennett	Pickands Mather & Co.	Crushing, washing, high-density.
Coons-Pacific	Coons-Pacific.	Crushing, washing, jigging, high-density.
Danube	Pickands Mather & Co.	Crushing, washing, jigging, high-density.
Mahoning	Pickands Mather & Co.	Crushing, washing, high-density.
Mariska	W. S. Moore Co.	Crushing, washing, jigging, high-density, spirals.
St. Paul	Pacific Isle Mining Co.	Crushing, washing, hydrosizer, spirals.
West Hill	Pickands Mather & Co.	Crushing, washing, high-density.
Hill Annex	Jones & Laughlin Steel Corp.	Crushing, screening, washing, high-density, spirals.
Lind-Greenway	Jones & Laughlin Steel Corp.	Crushing, screening, washing, jigging, high-density.
Schley	Jones & Laughlin Steel Corp.	Crushing, screening, washing, spirals.
Sherman	Oliver Iron Mining Div.	Crushing, screening, washing, high-density, spirals.
Harrison B	Butler Bros.	Fines treatment (spirals).
Hill Annex	Jones & Laughlin Steel Corp.	Fines treatment (spirals, flotation).

Fig. 20—Generalized flow diagram of the Canisteo scrubber (27)



As would be expected, the crushing and grinding departments are an important part of a taconite beneficiation plant. All the taconite plants have multi-identical circuits operating in parallel. The ore is crushed in three or four stages, and the crushing departments have interchangeable standby units.

In all plants but one, the ore is ground in the first stages in rod mills and in the finishing stages in ball mills. Closed-circuits in the plants actually result in multi-stage grinding. It has been determined that the control of the cyclone-feed density is critical in maintaining constant sizing from the closed-circuit grinding system (29). All plants use wet magnetic, electromagnetic, or permanent magnet separators and reject a large part of the gangue in rougher separation stages. The deslimer shown in figure 21 is a suite of magnetizing coils to flocculate the magnetite which then settles very rapidly in the hydraulic separator, while nonmagnetic gangue is rejected to overflow. The grain size of the final concentrate ranges from 85% —325 mesh to 95% —500 mesh.

The Empire plant is the newest of the magnetite processing plants in the United States and the first in the iron-ore industry to employ fully autogenous grinding. The crude ore grinds itself in 7.3 m × 2.4 m cascade mills and is ground to the final stages in

EXHIBIT "31" - Page 270 of the United Nations' Publication,"Economic Aspects of Iron Ore Preparation' 1966

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EXHIBIT "32"-Hamersley Iron "Resources Technology Operations" Booklet, page 16, Plant layout, Mt Tom Price January 1981

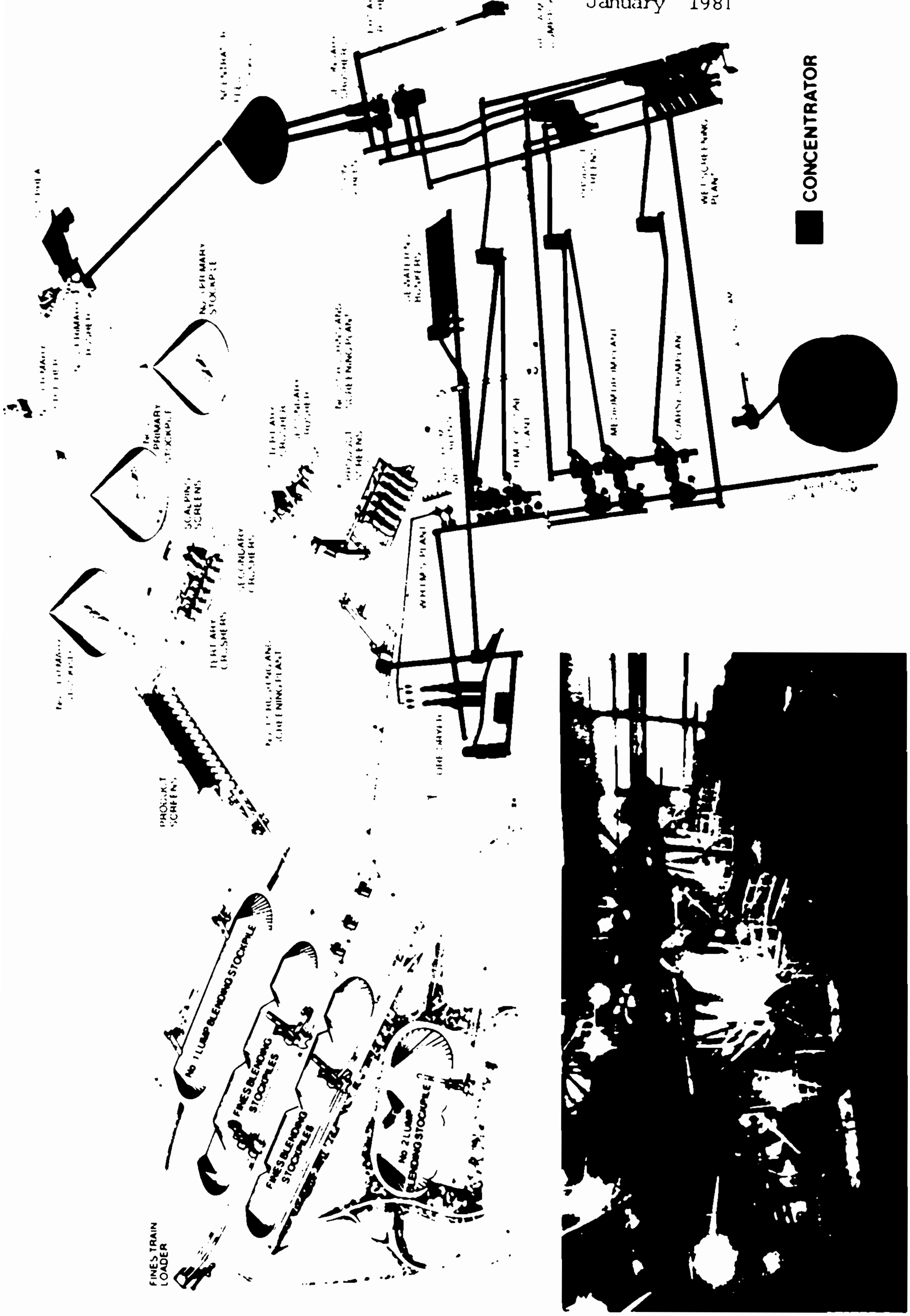


EXHIBIT "32"-Hamersley Iron "Resources Technology Operations" Booklet, page 16, Plant layout, Mt Tom Price January 1981

IN THE SUPREME COURT

OF WESTERN AUSTRALIA

EXHIBIT "33" - Affidavit of Peter Forbes Booth (with exception of paragraph 4) dated 27.10.82

No.2313 of 1982

IN THE MATTER of an Agreement between LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, WRIGHT PROSPECTING PTY LIMITED., HANCOCK PROSPECTING PTY LIMITED., two other companies and HAMERSLEY IRON PTY LIMITED

BETWEEN:

HAMERSLEY IRON PTY LIMITED	Plaintiff
AND	
LANGLEY GEORGE HANCOCK	First Defendant
ERNEST ARCHIBALD MAYNARD WRIGHT	Second Defendant
HANCOCK PROSPECTING PTY LIMITED	Third Defendant
WRIGHT PROSPECTING PTY LIMITED	Fourth Defendant
L.S.P. PTY LIMITED	Fifth Defendant
THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALIA LIMITED	Sixth Defendant

AFFIDAVIT

I PETER FORBES BOOTH of 72 Viking Road, Dalkeith in the State of Western Australia, Consulting Engineer, MAKE OATH AND SAY as follows:-

1. (a) I graduated Bachelor of Engineering (Mechanical) from the University of Western Australia in 1960. I am a Fellow of the Institution of Mechanical Engineers (London) and a Fellow of the Institution of Engineers, Australia.

   (b) Since 1979 I have been a consulting engineer in private practice. In that capacity I have carried on practice as a consulting engineer specialised in mining, industrial and manufacturing engineering.

EXHIBIT "33" - Affidavit of Peter Forbes Booth (with exception of paragraph 4) dated 27.10.82

P. J. Booth W. Berse Phillips

(c) From 1969 to 1979 I was employed by Mt Newman Mining Company Pty Limited in engineering design, construction and technical support to the operations of that company. In 1971 I was appointed Project Manager for the Mt Newman project which is located in the Pilbara region of Western Australia. I was directly responsible for the design and construction of the Mt Newman project including the mine and associated plant, township, railway system and port facilities. Mt Newman is reputed to be the biggest single open pit iron ore mining operation in the world. The project involved an expenditure of about $1 billion. The plant at Mt Newman includes two complete primary and secondary crushing and train loading systems. There is a third primary and secondary crushing system associated with a beneficiation plant. That plant was commissioned in 1979.

(d) While employed by Mt Newman Mining Company Pty Limited I made a number of overseas visits to investigate operating practice and technology. In particular, in 1974 I travelled around the world to study the secondary processing of iron ore including beneficiation and concentration plants and visited research, design, contracting and operating establishments in Brazil, Mexico, the United States, Canada, West Germany, Holland, Belgium and South Africa.

(e) I have given a number of addresses and published a number of papers and addresses including one on the Mt Newman beneficiation plant.

(f) Since entering private practice my work has included the design engineering of extentions and modifications in the Mt.Newman beneficiation plant and the design and construction administration of beneficiation facilities in connection with gold and mineral sands. Investigation or feasibility engineering of proposed beneficiation or upgrading facilities in relation to manganese, mica and feldspar have also been completed.

2. I have been retained by solicitors acting on behalf of the first to fourth Defendants ("H&W") to advise in relation to disputes between H&W and the plaintiff ("HI") concerning royalties payable under an agreement made in 1962 under which H&W sold to HI the right to mine iron ore in certain areas in Western Australia.

3. Shortly prior to its commissioning I inspected the concentrator plant and associated facilities then being constructed by HI at Tom Price. I have read copies of the affidavits of Colin Roy Langridge sworn 2nd September 1982 and Niles Earl Grosvenor sworn 27th October 1982 and the exhibits thereto, and in particular I have inspected the drawings which are exhibited to Mr.Grosvenor's affidavit.

EXHIBIT "33" - Affidavit of Peter Forbes Booth (with exception of paragraph 4) dated 27.10.82

P. F. BOOTH

W. BERGE PHILLIPS

5. <u>Beneficiation</u>

The term "beneficiation" has both wide and narrow meanings. A wide meaning is the treating of ore to improve its physical or chemical characteristics. Narrow meanings which may be used in particular contexts include for example the removal of unwanted constituents and the concentration of the valuable ores. "Concentration" may be defined as the process of ore treatment whereby the valuable minerals are collected as an enriched product.

6. <u>Treatment</u>

The term "treatment" in relation to ore means - to subject to chemical or physical action with the object of achieving some definable result.

7. <u>Crushing</u>

"Crushing" means the physical reduction in size of lump or granular materials.

8. <u>Screening</u>

"Screening" is a means of separating material into two or more size fractions. The screen device may take many forms including stationary, vibrating and rotary. Screens may be operated dry or wet. Dry screening is often used where water is of limited availability or where dry products are required. Wet screening is often used where sufficient water is available and where more efficient screening performance is required or where the separation of finer particles is required and where wet processes follow or where a wet product is acceptable.

9. With the Pilbara iron ores crushing and screening can be used to upgrade ore either separately or as part of a beneficiation

process. Dry screening is used in primary ore handling but if water were more readily available wet screening could be used to improve the efficiency of separation.

10. When water is added to a screen it is usually added in two stages. Firstly it is added to the ore ahead of the screen entry to wet and fluidise the feed to enhance the efficiency of screen separation. Secondly it is added above the screen surfaces for a similar reason. The water may be added as a flood or as a high pressure jet. Where feed material contains ores or contaminants prone to break down in size, the high pressure jets are used to accelerate the break down process. Pilbara iron ores in general are not easily wetted and water needs to be added as early as possible in a wet process.

11. A wet screening operation generally requires a wet feeder or wet chute ahead of the screen entry as an integral part of the arrangement so as to precondition the feed. The water provided on the screen surface continues the wetting process and is usually so arranged as to liberate and separate the bulk of the material into the two or more size ranges required. Water also washes or cleans the material being screened. In the overall effect the wet screen provides a similar result to a dry screen in breaking down and separating a feed material but achieves a more complete result and is therefore more efficient. More of the undersize particles are removed as undersize and a cleaner oversize material leaves the screen surface.

12. As in the case of a dry screening facility, a wet screening plant may be part of an overall treatment plant or may be a separate feed preparation and feed sizing facility.

13. In the screening of the feed material the result is to obtain required size ranges of material as separate streams. These streams contain both valuable ore and the contaminants together. Particularly in wet screening there may be an accelerated breaking down of both the ore and contaminants with the softer material incurring the greater size reduction. Lumps comprising ore combined with contaminants may separate partly or wholly into their separate constituents.

14. Where the contaminant material is softer than the ore and will reduce in size with handling or when wetted, the breakdown in size may continue or even accelerate in operations subsequent to screening. Retention in storage bins can contribute significantly to this breakdown. Where a following operation involves a heavy media concentration it is vital that a final wet screening operation immediately precedes the concentration equipment. An efficient screening stage is required at that point.

15. As a result of the natural breakdown of ore and its contaminants during wet screening and handling operations there is an increasing amount of screen undersize material. There is usually an economic size cut point below which concentration and recovery of valuable fine ore particles is not justified.

16. Wet screening in the screenhouse at Tom Price is described

EXHIBIT "33" - Affidavit of Peter Forbes Booth (with exception of paragraph 4) dated 27.10.82

P. F. Booth W/ Reece Phillips

in paragraph 9 of Mr Langridge's affidavit, and the plant is shown and further described in exhibits "NEG 1", "NEG 2" and "NEG 3" of Mr. Grosvenor's affidavit. Wet screening in the screenhouse at Tom Price includes the use of double deck wet screens together with associated wet feed chutes. The arrangement appears to be a quite standard one with the feed chute providing simple water injection with provision to reduce ore induced wear and provide an even feed distribution of material to the screen surface.

17. In my opinion the operation referred to in paragraph 16 is screening, and no other beneficiation or treatment takes place.

18. In my opinion the operation taking place at the preparation screens is screening and no other beneficiation or treatment takes place. An appropriate sized clean feed material is then available for the subsequent heavy media drums and cyclones.

19. In my opinion the operation taking place at the sieve bends and screens for feed to the hydrocyclones and WHIMS is screening, and no other beneficiation or treatment takes place.

20. In my opinion it is important to provide a competent, clean, carefully sized, feed material to each of the concentration units. This is achieved by wet screening.

21. In my opinion beneficiation (other than screening) takes place in the heavy media drums and cyclones, and in the hydrocyclones and WHIMS, in each of which the more valuable ore is separated from the contaminants or low grade ore.

SWORN at Sydney in)
the State of New South)
Wales this 27th)
day of October 1982)

P. F. BOOTH.

Before me:

W. BERGE PHILLIPS

A Commissioner of the Supreme Court
of Western Australia for Taking
Affidavits in New South Wales.

This Affidavit is filed on behalf of the first to fourth Defendants.

EXHIBIT "33" - Affidavit of Peter Forbes Booth
(with exception of paragraph 4) dated 27.10.82

AFFIDAVIT

I, PETER FORBES BOOTH of 72 Viking Road, Dalkeith in the State of Western Australia, Consulting Engineer, being duly sworn make oath and say as follows:

1. I have read copies of the affidavits of Colin Roy Langridge sworn 24th May 1983, Alban Jude Lynch sworn 22nd May 1983, Arthur Noel Pritchard sworn 24th May 1983, Robin John Batterham sworn 25th May 1983, Desmond Evered Wright sworn 20th May 1983, Douglas Frederick Tompsitt sworn 24th May 1983 and John Roberts sworn 1st June 1983 and copies of the exhibits to all those affidavits. Other than to say I adhere to the opinions expressed in my first affidavit I do not propose to deal in any detail in this affidavit with the matters raised in the affidavits filed on behalf of the Plaintiff.

2. I have read the affidavit of Christian Frederick Beukema sworn 22nd June 1983 and the exhibits thereto. The statements in paragraph 6 accord with my experience. I agree with the opinions expressed in paragraphs 13, 14, 15, 16, 17, and 18. [Although I do not have Mr Beukema's vast personal experience of the Mesabi Range iron ore mines and processing plants,] I can accept and agree with his statements that the beneficiation of iron ore simply by the washing and size separation which is achieved by wet screening was an operative practice based on technology available in 1962. I also agree with his statement that screening is screening whether wet or dry. The recently issued Australian Standard 2418 Part 1 1980 entitled Glossary of Terms Relating to Solid Mineral Fuels Part 1 - Terms Relating to Coal Preparation

EXHIBIT "34" - Affidavit of Peter Forbes Booth dated 30.6.83

P.F. Booth T. Loudon J.P.

covers this as follows:- Screening - the separation of solid particles of different sizes (with or without the use of water) by causing one component to remain on a surface provided with apertures through which the other component passes.

3. I refer to paragraph 9 of Dr Lynch's affidavit. I say that if it was desired to maximise a scrubbing effect in the chutes, good engineering practice would have dictated quite a different design. I have caused alternative conceptual designs to be prepared that would fit into the Tom Price wet feeder chute location. Now produced and shown to me marked "PFB 1" is a conceptual drawing of these designs.

4. In the H.I. affidavits reference is made to "scrubbing" and it is said, in substance, that the chutes immediately preceding the wet screens at Tom Price carry out a scrubbing function. I agree with Mr Beukema's opinion that these chutes would not normally be described as "scrubbers" or considered as being involved in a "scrubbing" rather than "wetting" process. This point may be illustrated by considering the wet screen feed chutes installed in a similar location in the Newman wet screening plant for which I was responsible. Now produced and shown to me marked "PFB 2" is a drawing showing in simplified form the Tom Price chute and also the Newman chute. The latter is almost double the height of the former. In the Newman chute the ore stream is split, tumbled, exposed to more sprays and spends longer in the chute than is the case at Tom Price. All the design features mentioned were chosen with the object of maximising the wetting of the ore. Insofar as the concept of

 EXHIBIT "34" - Affidavit of Peter Forbes Booth dated 30.6.83

P. F. Booth T. Loudon J.P.

"scrubbing" involves wetting and tumbling of ore with the ore lumps being rubbed against each other (Taggart, "Handbook of Mineral Dressing", 10-01), the chutes at Newman carry out much more of a scrubbing treatment than those at Tom Price. The chutes at Newman have never to my knowledge been described or referred to or considered as providing a scrubbing effect. To the best of my recollection there was no process, design or operating requirement for a scrubbing function or effect in the Newman wet screening plant.

SWORN by the Deponent at)
Perth in the State of)
Western Australia the 30th)
day of June 1983)
before me:)

P. J. BOOTH

T. LOUDON J.P.
JUSTICE of the PEACE
WESTERN AUSTRALIA.

This AFFIDAVIT was filed on behalf of the First to Fifthnamed Defendants by Keall, Brinsden & Co., of 9th Floor, 150 St George's Terrace, Perth, W.A. 6000. Tel. 321 8531
Ref. NH:28641
SC.T200-HIJ

EXHIBIT "34" - Affidavit of Peter Forbes Booth dated 30.6.83

EXHIBIT "34PFB1" - Copy Conceptual Drawings of Wet Feeder Designs

IN THE SUPREME COURT)
OF WESTERN AUSTRALIA) No. 2313 of 1982

IN THE MATTER of an Agreement between LANGLEY GEORGE HANCOCK, ERNEST ARCHIBALD MAYNARD WRIGHT, WRIGHT PROSPECTING PTY LIMITED, HANCOCK PROSPECTING PTY LIMITED, two other companies and HAMERSLEY IRON PTY LTD

B E T W E E N HAMERSLEY IRON PTY LTD

Plaintiff

- and -

LANGLEY GEORGE HANCOCK

First Defendant

ERNEST ARCHIBALD MAYNARD WRIGHT

Second Defendant

HANCOCK PROSPECTING PTY LIMITED

Third Defendant

WRIGHT PROSPECTING PTY LIMITED

Fourth Defendant

L.S.P. PTY LIMITED

Fifth Defendant

THE NATIONAL MUTUAL LIFE ASSOCIATION OF AUSTRALASIA LIMITED

Sixth Defendant

EXHIBIT "PFB 1"

This is exhibit "PFB 1" referred to in the Affidavit of PETER FORBES BOOTH sworn the 5th day of June 1983 before me:

EXHIBIT "34PFB1" - Copy Conceptual Drawings of Wet Feeder Designs

SUPREME COURT WESTERN AUSTRALIA

T. LOUDON

JUSTICE OF THE PEACE.

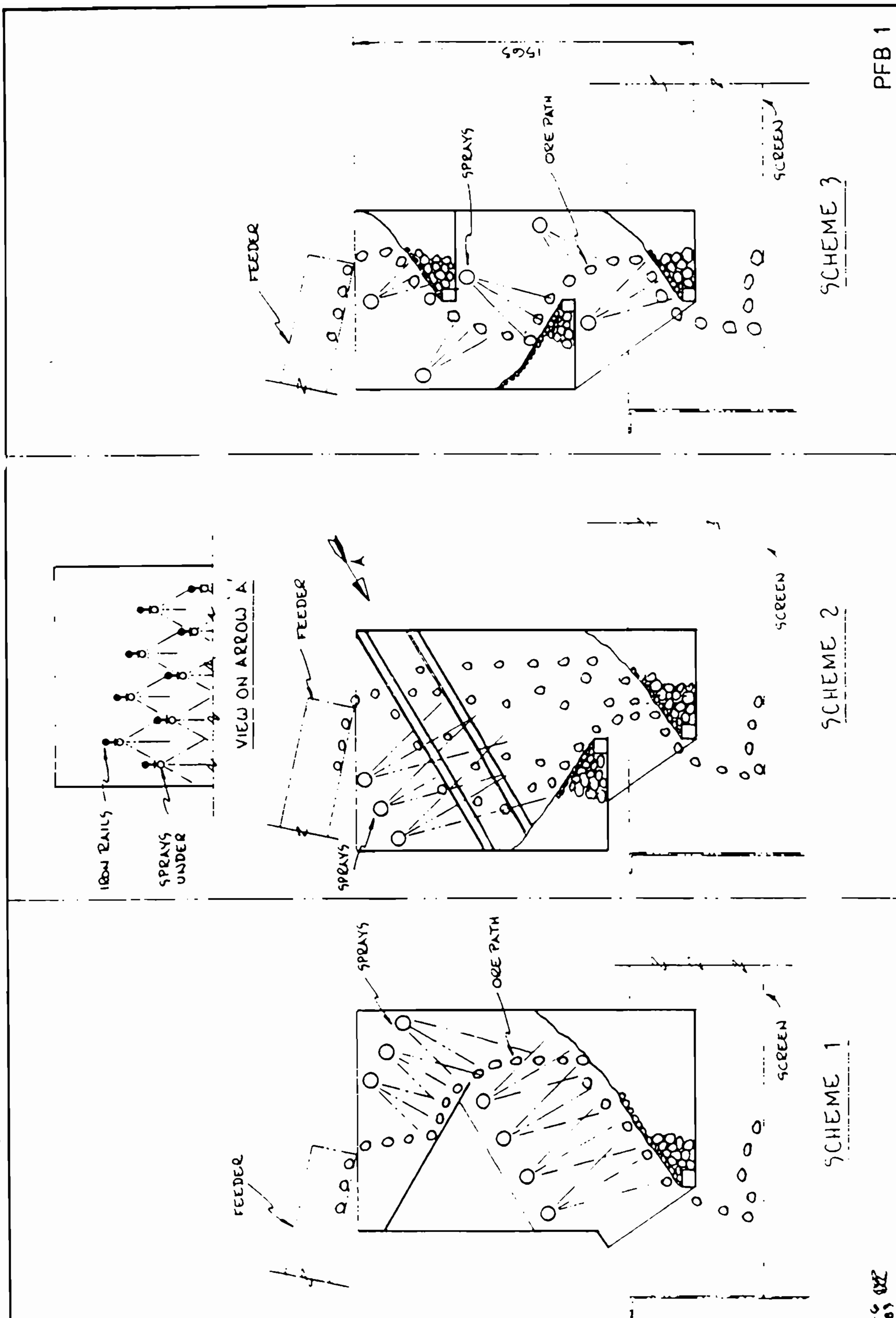
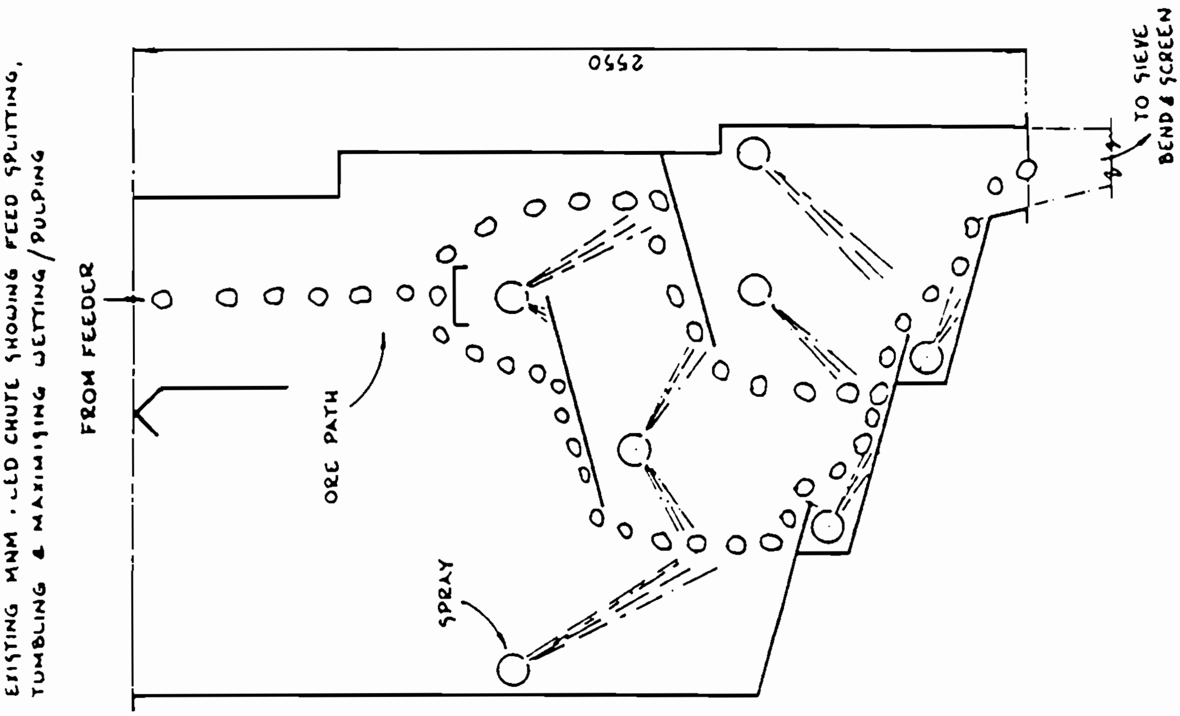


EXHIBIT "34PFB1" - Copy Conceptual Drawings of Wet Feeder Designs

EXHIBIT "34PFB2" - Copy Conceptual Drawings of Feeder Chutes at Tom Price and Mt Newman

PFB 2



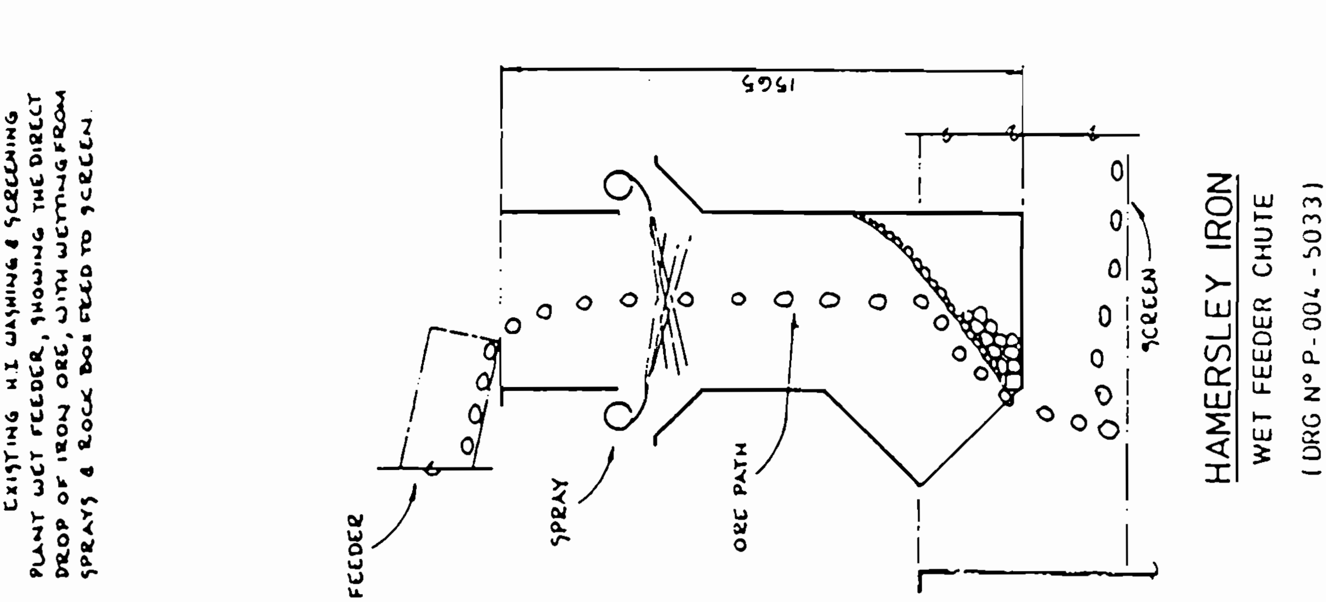


EXHIBIT "34PFB2" - Copy Conceptual Drawings of Feeder Chutes at Tom Price and Mt Newman

AFFIDAVIT

I, GEOFFREY SAMUEL BAKER of 31 Mitchell Street, Ardross in the State of Western Australia, Business Manager, having been duly sworn make oath and say as follows:

1. I am now and have for the last 17 years been the Manager of Mineral By-Products Pty Ltd. Prior to that, and with the exception of a brief period of employment as Works Manager for Universal Milling Company, I worked solely in the far north of Western Australia in the tin and lead mining industries. I spent several years working for companies owned by Messrs Hancock & Wright, the First and Second Defendants herein. I have been involved with screening operations (wet and dry) in the mining industry all my working life.

2. In 1953 Hancock & Wright acquired the Ragged Hills Lead Mines situated 150 kilometres east of Marble Bar. At that stage I was Surface Foreman of the Mine, which had underground workings. I managed the mine for Hancock & Wright for two years until its closure. I then worked at the Nunyerry asbestos mine for six weeks before joining Pilbara Explorations Pty Ltd as manager of a tin mine situated at Shaw River 50 kilometres south west of Marble Bar. Pilbara Explorations was also owned by Hancock & Wright. In 1959 I left Hancock & Wright to manage the nearby Cooglegong Tin Mine, owned by Cooglegong Tin Pty Ltd, a company unrelated to Hancock & Wright. I worked for Cooglegong Tin until Christmas 1962.

EXHIBIT "35" - Affidavit of Geoffrey Samuel Baker dated 17.10.83

3. Wet screening was used at every mine I worked at or visited in my time in the north west, with the exception of the Nunyerry asbestos mine.

4. The operation at Ragged Hills involved a separation process designed to produce lead concentrate. The ore was removed from the mine, crushed and wet screened to size and then the sized material was gravity separated on concentrating tables. Water was an essential component in the separation process. The feed to the tables consisted of two sizes, being fines and middle size, produced on sizing screens immediately before the tables. As a result of screening a third size, known as oversize, was produced. This was re-cycled for further crushing and screening prior to separation.

5. The water required for the separation (i.e. concentration) process was introduced in the feed chutes to the screens and utilised during sizing. The water assisted sizing of the ore and was useful in dust control. Nevertheless, it was possible to employ dry screening, with water being added after sizing. However, since the downstream processes were wet and water assisted screening, the water was added before the screening stage. The purpose of the screens was purely to size the ore for separation.

6. The operations at Cooglegong and Shaw River were similar to that at Ragged Hills. The tin bearing ore was removed from river beds and placed on sizing screens in slurry form. After being sized the ore was fed into jigs for separation (i.e. concentration) of the ore. Water was essential to the separation process. As at Ragged Hills, the water was in

EXHIBIT "35" - Affidavit of Geoffrey Samuel Baker dated 17.10.83

fact added to the screens so as to assist sizing. Once again the purpose of screening was to prepare the ore into appropriately sized feed for the separation process.

SWORN by the deponent at Perth)
in the State of Western)
Australia this 17th day of)
October 1983 before me:)

T. LOUDON
JUSTICE OF THE PEACE
WESTERN AUSTRALIA

This AFFIDAVIT was filed by Keall, Brinsden & Co., Solicitors for the Plaintiff of 9th Floor, 150 St George's Terrace, Perth W.A. 6000 Tel: 321 8531 Ref: NH:SW:28641
MAC.T-180-ABC

EXHIBIT "35" - Affidavit of Geoffrey Samuel Baker dated 17.10.83

AFFIDAVIT

I, CHRISTIAN FREDERICK BEUKEMA of 4502-2A Windjammer Lane, Fort Myers Florida, United States of America MAKE OATH AND SAY as follows:-

1. (a) I hold the degree of Bachelor of Science in Civil Engineering (1940) from Michigan State College. I have held the following positions in relevant industry and professional organisations:

   Member, American Institute Mining & Metallurgical Engineers; Member, American Iron & Steel Institute; Member, Eastern States Blast Furnace & Coke Oven Association; Vice-President and Director, American Iron Ore Association; Vice-Chairman and Director, American Mining Congress.

   (b) Apart from war service with the US Army between 1941 and 1944, I was employed by Unites States Steel Corporation ("U.S. Steel") from 1940 until 1979. My earliest duties concerned design, construction and operations engineering leading to assignment in 1953 as General Manager (Operations) Michigan Limestone Division. Later I became President of the Michigan Limestone Division Detroit (1955), President of the Oliver Iron Mining Division, Duluth (1960), Vice-President, Ore & Limestone Operations, Pittsburgh (1964), Vice-President Ore, Limestone & Lake Shipping Pittsburgh (1968), Vice-President and General Manager, Raw Materials and Shipping, Pittsburgh (1974), Vice-President and Assistant to the President, Pittsburgh (1979). U.S. Steel is the largest steel maker and integrated iron miner in the Western World.

   (c) I have had overall responsibility for U.S. Steel's iron ore operation in Michigan, Wisconsin, Minnesota,

EXHIBIT "36" - Affidavit of Christian Frederick Beukema dated 22.6.83

C. F. Beukema

J.P

Utah and Wyoming as well as co-ordination with U.S. Steel iron ore subsidiaries in Venezuela and Canada. Because of the insistence on quality requirements by blast furnace customers, I have been very much concerned with mine planning, ore beneficiation and quality control of process metallurgy including treatment, plant flow sheets, design parameters and operation. I was responsible for the research and engineering conclusions, flow sheet design, engineering and equipment specifications, construction and ultimately operation of the world's largest low grade iron ore beneficiation complex at Minntac in Minnesota.

(d) As well as iron ore, I have had overall responsibility for the limestone, coal, zinc and uranium operations of U.S. Steel in Pennsylvania, West Virginia, Alabama, Kentucky, Tennessee, Texas, Colorado and Utah.

(e) I have delivered a major paper to the Annual International Mining Show and Convention of the American Mining Congress on the State of the Iron Ore Industry. I have been a visiting lecturer on iron ore matters on behalf of the American Iron and Steel Institute to seminars of national economists held at the University of Chicago.

(f) Since my retirement from U.S. Steel I have engaged in consulting work including a review of mining plans, beneficiation plant and flow sheets, infra-structure details and economic planning for the Chit-a-Shan Iron Ore Project, People's Republic of China.

EXHIBIT "36" - Affidavit of Christian Frederick Beukema dated 22.6.83

2. I have been retained by solicitors acting on behalf of the first to fifth Defendants ("H. & W.") to advise in relation to disputes

between H. & W. and the Plaintiff ("H.I.") concerning royalties payable under an agreement made in 1962 under which H. & W. sold to H.I. the right to mine iron ore in certain areas in Western Australia.

3. On 16th August 1982 I inspected the mine operated by H.I. at Tom Price and the wet screening and concentrator plants. I have read copies of the affidavits of Colin Roy Langridge sworn 2nd September 1982 and 24th May 1983, Niles Earl Grosvenor sworn 27th October 1982, Peter Forbes Booth sworn 27th October 1982, Alban Jude Lynch sworn 22nd May 1983, Arthur Noel Pritchard sworn 24th May 1983, Robin John Batterham sworn 25th May 1983, Desmond Evered Wright sworn 20th May 1983, Douglas Frederick Tompsitt sworn 24th May 1983 and John Roberts sworn 1st June 1983 and copies of the exhibits to all those affidavits.

4. As to Mr. Grosvenor's affidavit, I say that the meanings he attributes to the terms "beneficiation", "treatment", crushing" and "screening" in paragraphs 5, 6, 7, and 8 of his affidavit accord with my experience. I agree with Mr. Grosvenor's statements as to the nature and operation of wet screening processes contained in paragraphs 9, 10, 11, and 12 of his affidavit. I agree with and adopt the recommendations on page 17 of the Allis-Chalmers publication (Exhibit "NEG 4") and in general terms the design criteria set out in Table 11, although the particular application of those criteria will depend on the circumstances in any given case. I also agree with what Mr. Grosvenor says in paragraph 12 as to the use of the term "wet screening" and in paragraph 13 as to the knowledge of wet screening in the processing of iron ore in 1962. I agree with what Mr. Grosvenor

says in paragraph 14 as to the description of the wet screening at Tom Price and I share the opinions he expresses in paragraphs 15, 16, and 17. I agree with his description in paragraph 17 of the beneficiation process at Tom Price and his opinion expressed in paragraph 19 and I also agree with the matters he deposes to in paragraph 20, which accord with my experience.

5. As to Mr. Booth's affidavit, I agree with the meanings he attributes to the terms "beneficiation", "treatment", "crushing", and "screening" in paragraphs 5, 6, 7, and 8 of his affidavit. I agree with what Mr. Booth says as to the nature and function of wet screening in paragraphs 10, 11, 12, 13, 14, and 15 and as to the installations at Tom Price in paragraph 16. I agree with the opinions expressed by Mr. Booth in paragraphs 17, 18, 19, 20 and 21 of his affidavit.

6. In my 40 years experience of mineral dressing (including coal, zinc and limestone as well as iron ore) I have never heard a suggestion that wet screening was not "screening" or that, because some particular purpose was intended, what would otherwise be wet screening ceased to be regarded or referred to as such. "Screening" is screening - whether wet or dry. Similarly, wet screening in my experience must of necessity involve washing. I have never been aware of a wet-screening process not being regarded or referred to as such because it also involved washing.

7. During all my years of responsibility for mineral operations including responsibility for negotiations of hundreds of leases both as lessor and as lessee I have never been aware of any legal definition of screening that limited the beneficiation term to

dry screening as distinguished from wet screening nor have I been aware of any royalty term distinction as applied differently to wet from dry screening.

8. In a number of affidavits filed on behalf of H.I. it is stated that, to the knowledge of the deponents, there were in 1962 no examples of iron ore processing plants either in Australia or overseas where a wet process was in use "solely as an adjunct to crushing and screening without some further process in view". It is also stated that within the deponents' knowledge, no such process exists at the present time. In this regard I refer to Dr. Lynch's affidavit paragraph 7 the last sentence, Mr. Pritchard's affidavit paragraph 4 the last sentence, Mr. Batterham's affidavit paragraph 4 the second last sentence, Mr. Wright's affidavit paragraph 3 the third sentence.

9. If the passages in the H.I. affidavits to which I have referred are intended to convey the impression that in 1962 wet screening of iron ore (either in Australia or overseas) did not occur without having some "further process in view", then such is plainly not the case. In the Mesabi Range in Minnesota, U.S.A. (which has produced more iron ore than any other locality in the world) from before World War I until 1962 and beyond, a substantial portion of the iron ore production consisted of washed ores. The basic process was described by S.E. Erickson "Iron Ore Beneficiation - Present Practices and Trends", cited in "Beneficiating Iron Ore (North American Practices)" by John D. Sullivan (Survey of World Iron Ore Resources, United Nations (1955)). Now produced and shown to me marked "CFB 1" is a copy of Mr. Sullivan's Article. I refer particularly to page 112, and figure 19.

EXHIBIT "36" - Affidavit of Christian Frederick Beukema dated 22.6.83

J.P.

10. Sometimes the processes in Mesabi plants involved devices such as log-washers which were a form of scrubber. Typically they consisted of a shaft 20-25 feet long to which were attached paddles. Often the log-washers were included in the process before the wet screens, there being no further treatment (except for reclamation of fines from the wash water) until the ore was loaded into railroad trucks for shipment. One of many examples was the process used at the Trout Lake Plant Unit 2 in 1954. Thus anybody familiar with iron ore operations in the Mesabi Range up until 1962 (and indeed beyond) would know that -

(a) washing by wet screening was generally carried out without any further treatment at all (at least of the over-size ore) prior to shipment.

(b) Often the only further treatment of the under-size ore was by a mechanical classifier, which itself acted as a sizer, to recover the fines from the wash water because of the non-development at the time of fine screening equipment competent for this purpose such as D.S.M. screens, high velocity dewatering screens etc.

(c) If scrubbing was to be introduced into the process it would usually take the form of a log-washer or properly designed drum scrubber in which the ore tumbled in a bath of water for a period of the order of 5 minutes abraiding adhering fines from the ore particles, and disintegrating materials such as clay and soft shales bonded into coarse conglomerated chunks. These are a far cry from the simple feed chute like those feeding the screens at Tom Price.

<u>EXHIBIT "36"</u> - Affidavit of Christian Frederick Beukema dated 22.6.83

J.P.

11. The Mesabi iron ore wet washing plants were not hidden in obscurity. As a matter of fact there were in excess of twenty simple wash plants on the Mesabi Range and additional such plants in other iron ore mining districts in the United States. These plants received substantial publicity over the years in trade journals, and the United States steel industry recognised that without iron ore production from these wash ore plants the peak use demands of World War I and World War II to support the industrial effort would not have been attained. In later years many simple washing plants were augmented by supplementary ore treatment technology. As volumes of ores refractory to simple washing treatment were encountered, retreat circuits of heavy media separation, cyclone and spiral concentration and other technologies were added to plant flow sheets. However, in general all treatment plants provided for ores to be handled by simple washing technology only, whenever possible.

12. Since 1962 iron ore plants involving wet screening without further processes have included those in operation at the Aguas Claras Mine, Brazil, Mano River and Lamco operations in Liberia, the El Pao Mines of Venezuela, the U.S. Steel Sherman Screening Plant and the Pioneer Mine in Minnesota.

13. Reference is made in a number of H.I.'s affidavits to "scrubbing" and it is suggested that the process in the chutes immediately before the wet screening at Tom Price can be described as "scrubbing". In my opinion these chutes would not normally be described as "scrubbers" or considered as involved in a "scrubbing" process. Scrubbing as usually understood, both now and in 1962, involved the use of very different devices, such as log washers,

trommels, and drum scrubbers. In one, literal, sense any washing involves "scrubbing" because particles of foreign matter are being removed from the material being washed. The chutes at Tom Price certainly do not look like scrubbers and I do not believe they would ever normally be described as such, nor can they impart the tumbling abrasive contact between the freely falling particles which is the essence of "scrubbing".

14. For any screening of iron ore, whether wet or dry, it is necessary to have a chute or similar device to feed the material onto the screens. If wet screening is to be carried out, it is usual to pre-wet the material in the chute for the reasons given by Mr. Grosvenor and Mr. Booth. Indeed, I have never known of wet screening of iron ore to occur without a chute in which wetting takes place such as occurs at Tom Price. Generally screening handbooks stress the importance of achieving wetness of the material before it reaches the screen. I consider that the chute at Tom Price is an attempt to meet this requirement.

15. In 1962 the known technology of iron ore production involved the following types of beneficiation processes:

(a) crushing;

(b) screening;

(c) washing;

(d) jigging;

(e) heavy media separation;

(f) magnetic concentration;

(g) floatation.

EXHIBIT "36" - Affidavit of Christian Frederic Beukema dated 22.6.83

16. All these processes included crushing and/or screening as an initial step. The ore was first classified by screening,

While combinations of processes were conducted in differing flow sheets, generally all processes included crushing and screening as early steps and frequently additional stages of crushing and screening occurred in subsequent treatment. Certainly in heavy media separation the ore treatment would be commenced by crushing and wet screening.

17. I say in relation to Dr. Lynch's affidavit that I do not think it can properly be said that "scrubbing" in any accepted sense takes place in the chute. Scrubbing does take place, but only to a limited extent, on the screens as is the case in any washing process on a screen. The shortness of the time the ore spends in the chute and the insignificant tumbling particle to particle abrasion means that any "scrubbing" effect is minimal. This step is in my view essentially no more than an attempt at the ore wetting which should occur in any screen feed chutes as an integral part of wet screening. When the ore is on the screens I cannot see how the treatment can be regarded as anything other than wet screening - however much water is used or however much the ore is cleaned. I cannot accept the proposition that the chute has been designed so as to maximise any scrubbing effect. If that had been the purpose the design should have been quite different. In particular, the design would provide for the tumbling and consequent abrasion of the particles rather than a free fall. In my opinion the function of the chute is to wet the ore and feed it onto the screens as should happen in any normal wet screening treatment.

<u>EXHIBIT "36"</u> - Affidavit of Christian Frederick Beukema dated 22.6.83

18. I do not accept the arguments put by Dr. Lynch in paragraphs 5 to 10 inclusive of his affidavit and supported by other deponents

J.P.

of affidavits filed on behalf of H.I. that the place at which beneficiation (other than crushing and screening) begins is where the feed is first wet in the washing and screening house. The introduction of water is to make the screening process as effective as possible. The objective of wet screening is no different from that of dry screening in that it is the separation of ore particles by size. However in this respect wet screening is more effective than dry screening, particularly on the finer sizes and on ore of this character.

SWORN at Melbourne in)
the State of Victoria)
the 22nd day of June)
1983.)

Before me:

A Justice of the Peace

Filed on behalf of the first to fifthnamed Defendants.

EXHIBIT "36" - Affidavit of Christian Frederick Beukema dated 22.6.83

EXHIBIT "36CFB1" - Copy United Nations Survey of World Iron Ore Resources, 1955

SURVEY

OF

WORLD IRON ORE RESOURCES

Occurrence, Appraisal and Use

UNITED NATIONS

1955

EXHIBIT "36CFB1" - Copy United Nations Survey of World Iron Ore Resources, 1955

BENEFICIATING IRON ORE
(North American Practices)

By John D. SULLIVAN, *Battelle Memorial Institute, Columbus, Ohio*

CONTENTS

This paper summarizes recent work in iron ore beneficiating techniques, and served as a background for the Committee's consideration of the changing concepts of usefulness of various types of ores. The subject is discussed broadly, with highlights from the literature on beneficiation techniques, particularly that published since 1940 on United States practices. Minute details of processing are not given, nor specific plant flowsheets. Instead, typical layouts are discussed. The layout in any given plant may vary from the generalized schemes shown here. Bibliographical references are given on virtually all phases of iron ore beneficiation.

Whether a given mineral aggregate can be beneficiated to a useful product depends on technical and economic considerations. A given iron ore presents a challenge to the ore-dressing engineer or scientist. He examines the ore and establishes its mineral constitution, determines the associated minerals and considers the amount of grinding necessary to effect the degree of liberation required to yield concentrates of a given grade. When this information is known, he applies existing knowledge of concentration techniques to do the best job possible at the lowest cost. With complex ores two or more general methods may have to be used. Sometimes chemical treatment is necessary as a step, but it is not used in connexion with iron ores in the United States.

If the iron minerals are present as oxides, one can choose fairly straightforward beneficiation methods. If the oxide is magnetic, magnetic concentration will be considered and investigated unless liberation is at such a coarse size that gravity methods are applicable. If the oxide is nonmagnetic, the procedure will be governed in part by the fineness of grinding required for mineral liberation. If extremely fine grinding is required, it m[illegible] be necessary to resort to flotation or to magnetic roa[illegible]ing, followed by magnetic concentration. If, on the oth[illegible] hand, the iron exists in the form of a simple or compl[illegible] silicate, it may never be possible to concentrate it to [illegible] grade satisfactory for economic utilization. Some of th[illegible] hornblendes, for example, fall into this category.

Economic factors, however, are as important as tech[illegible]cal ones in deciding if an ore is to be concentrated. [illegible] good example is the present taconite beneficiation [illegible] Minnesota. New techniques, including cheaper mini[illegible] and agglomeration to make suitable blast furnace fe[illegible] have made it economically feasible to concentra[illegible] taconites. All of the companies now going into producti[illegible] are employing magnetic ores. At the present time evide[illegible] points to the cheaper production by magnetic concent[illegible]tion of the natural magnetic ores than by any process [illegible] far commercially developed for hematite ores. This sit[illegible]tion may not be permanent; perhaps in the not too dis[illegible] future nonmagnetic taconites will be concentrated ei[illegible] by flotation or by some method of magnetic roas[illegible] followed by magnetic concentration.

Economic factors in some instances influence the [illegible]cision not to concentrate. An example of this is [illegible] self-fluxing ores of the Birmingham, Alabama, region [illegible] ores in other parts of the world where it is cheaper [illegible] smelt the ore directly rather than to beneficiate it [illegible] In most cases, as in Birmingham, the blast furnac[illegible] built close to the mine.

Ore and smelting economists have made many stu[illegible] on the cost of gangue elimination by concentration [illegible] by smelting. This is a subject in itself, outside the sc[illegible]

EXHIBIT "36CFB1" - Copy United Nations Survey of World Iron Ore Resources, 1955

›f a paper of this nature. The costs depend on factors hat frequently are local in nature. Such elements as the ·elative costs of labour and fuel may in one instance ndicate an advantage for beneficiation and in another :ase for smelting. Each case must be studied and judged ›n its own merits.

Pig-iron, which is made primarily from iron ore, coke and limestone flux, is the primary raw material for the production of all iron and steel products. Although scrap is used in steel production, its original genesis was from iron ore.

Table 10 gives statistics of iron ore production in the United States for the period 1945 to 1948. The data[1] show the relative size of the industry, the types of ore, the significance of ore dressing and other beneficiation. Table 11 gives data for 1951 on ore deliveries.

Iron ore production is no longer the simple problem that it was a few decades ago. In 1906, of a total of 25,613,041 gross tons of ore shipped from Minnesota mines, not one ton was concentrated and only 146,503 tons was crushed or screened or both crushed and screened.[2] This contrasts with a total of 79 million tons in 1951, of which 23 million tons — 29 per cent — was concentrated. Of the total of concentrates, which also includes ore sintered only, 15 million tons was beneficiated

[1] United States Department of the Interior, Bureau of Mines, *Minerals Yearbook, 1948* (Washington, D.C., 1950), page 628.

[2] Henry H. Wade and Mildred R. Alm, "Mining Directory of Minnesota, 1952", *Bulletin of the University of Minnesota*, vol. 55, No. 19 (Minneapolis, Minnesota, May 1952), pages 241 and 242.

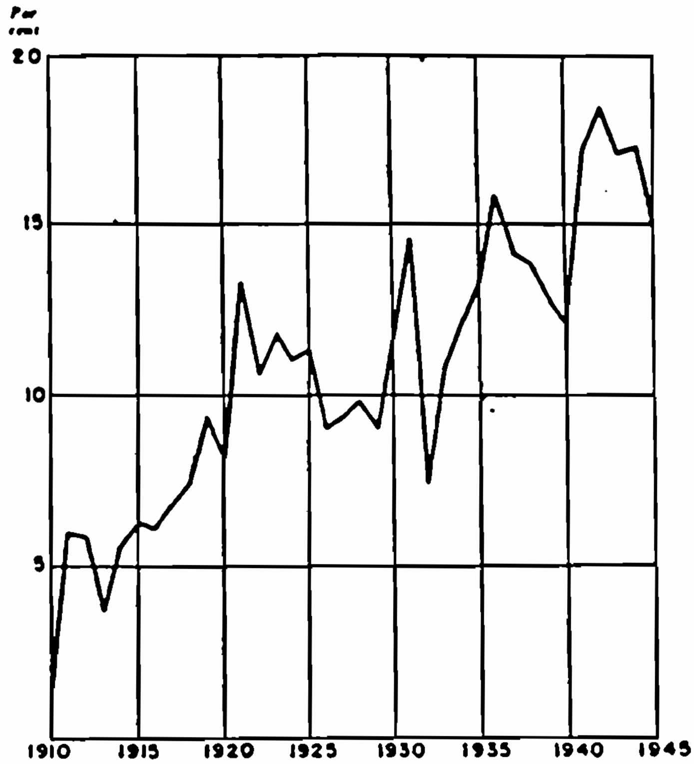


Figure 13. Percentage of Ore in Lake Superior Shipments Concentrated by Washing, Jigging and Heavy-media Processes, 1910 to 1945

(*Source:* "Mining Directory of Minnesota" and United States Bureau of Mines, *Minerals Yearbook*)

Table 10. United States: Iron Ore Production and Beneficiation, 1945 to 1948

(Gross tonnage)

Category and item	1945	1946	1947	1948
TOTAL PRODUCTION, CRUDE IRON ORE	106,312,399	84,194,481	113,972,214	126,225,172
Production by types of ore:				
Hematite	92,161,239	74,127,099	96,869,038	103,529,946
Brown ore	4,397,650	3,598,474	5,579,464	9,077,191
Magnetite	9,752,711	6,468,184	11,523,620	13,618,035
Carbonate	799	724	92	—
TOTAL PRODUCTION, USABLE IRON ORE*	88,376,393	70,843,113	93,091,520	101,003,492
Production of usable ore by types:				
Hematite	81,294,688	65,728,172	84,535,465	90,686,138
Brown ore	942,910	686,402	1,201,408	2,176,149
Magnetite	5,620,810	3,920,986	6,811,876	7,661,207
Carbonate	545	650	48	—
By-product material (pyrites cinder and sinter)	517,440	506,903	542,723	479,998
Production of usable ore by types of product:				
Direct	67,768,993	54,014,466	71,121,676	76,882,338
Concentrates	16,812,961	13,799,046	17,058,162	19,055,357
Sinter	3,276,999	2,522,698	4,368,959	4,585,799
By-product material (pyrites cinder and sinter)	517,440	506,903	542,723	479,998

Source: United States Bureau of Mines, *Minerals Yearbook, 1948* (Washington, D.C., 1950), page 628.

* Less than 5 per cent manganese.

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Table 11. United States: Iron Ore Deliveries, by Source, 1951

Origin and type	Gross tonnage
TOTAL DELIVERIES FROM DOMESTIC SOURCES	117,037,607
ake Superior deposits:	
Open-pit, direct-shipping ore	54,000,000
Gravity concentrates from open-pit mines	21,000,000
Ore from underground mines	19,400,000
Taconite concentrates	137,607
TOTAL	94,537,607
)ther domestic sources:	
South-eastern mines	8,400,000
North-eastern mines	5,100,000
Western mines	8,400,000
Pyrite sinter, other iron-bearing residues	600,000
TOTAL	22,500,000

Source: *Steel*, vol. 131, No. 5 (Cleveland, Ohio, 1952), page 65.

by simple washing operations, 435,000 tons by drying, 720,000 tons by jigging, 138,000 by magnetic concentration, 195,000 by sintering, and 4.45 million by heavy-media concentration.

Figure 13 shows graphically the increasing use of concentration processes on Lake Superior ores from 1910 to 1945. In 1948, 17.4 per cent of all ore in Lake Superior shipments was concentrated by washing, jigging and heavy-media processes. This corresponds to 19.8 per cent of usable ore shipments. However, total beneficiation in 1948, including sinter, sinter-dried ore and dried ore as well as ore-dressing concentrates, comprised 26.0 per cent of all Minnesota shipments, based on usable ore. In 1951 the percentage was 28.7.

Concentration

Many excellent papers have been written on the subject of current concentrating practices and equipment; this report merely points out highlights. The references supplied give a good picture of what is being done and of the trends. For the sake of convenience, the discussion will be devoted to (a) Lake Superior ores, which furnish the bulk of United States iron ores, on which diversified types of beneficiation are employed; (b) "north-eastern" ores, which are treated by magnetic concentration; and (c) Alabama ores, which are washed. Before discussing typical flowsheets, a few remarks are made about general methods of iron ore concentration and on concentrating equipment.

Consideration of Equipment Used

Log Washers

Washing is a relatively simple operation, practised on coarse ore. Essentially, silica fines and argillaceous matter are removed but coarse unaltered formation material also is rejected. The log washer is a classifier, and large quantities of water are used.[3] Ore at a size of 4 inches to 6 or 7 inches goes to a scalping vibrating screen or chain grizzly to remove the coarse material. In some plants all this may be rejected while in others hand picking or sorting may serve to select ore for subsequent crushing and washing. The undersize pieces go to secondary crushers, sometimes with an intermediate wet vibrating screen to remove any less than about one and one-half inches. The screened oversize pieces may be hand-picked to remove quartz or unaltered taconite. While this oversize may in some cases be a final product for the ore bins, it more often, after picking, joins the undersize as feed to the log washer. A final concentrate is raked out in the washer, and the overflow passes to screw-type or rake-type classifiers to remove fine concentrates and a waste overflow, which goes to the tailings pond. A generalized flowsheet is shown in figure 14.

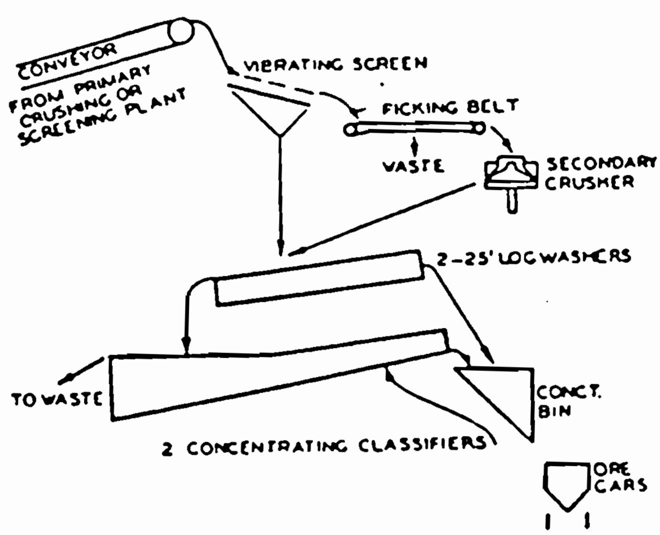

Figure 14. Generalized Flowsheet for Washing Mesabi Ores

(T. B. Counselman, "Concentration of Iron Ores in the United States", *Proceedings* of the Blast Furnace and Raw Materials Committee, Iron and Steel Division, American Institute of Mining and Metallurgical Engineers, vol. 3 (New York, 1943), pages 32 to 60; and *Metals Technology*, vol. 7, December 1943, T.P. 1629)

Jigs

Although log-washer operations are cheap and produce the largest percentage of the ore concentrated today, some ores cannot be brought up to grade by this simple method. The old, classical method, still widely practised, is jigging.[4] The ore is crushed prior to jigging, with hand-

[3] Grover J. Holt, "Mining and Washing of Iron Ore at Galbraith Plant of Butler Brothers at Nashwauk", *Skillings Mining Review*, vol. 30, No. 7 (Duluth, Minn., 1941), page one.

[4] Robert H. Richards and Charles E. Locke, *A Text Book of Ore Dressing*, chapter XI (McGraw-Hill, New York, 1925), 2nd ed.

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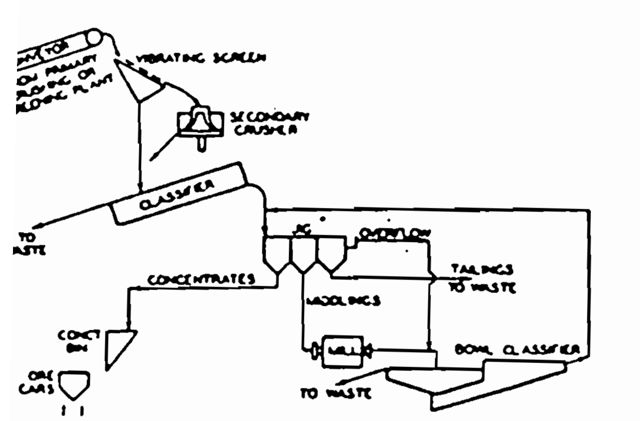

ure 15. Typical Simplified Flowsheet Showing ·ent Practice in Jigging Mesabi Iron Ores

(*Source:* See figure 14)

lping of coarse gangue prior to crushing. In some es the jig feed is about the same size as in log washers, ile with other ores crushing as fine as less than one-f inch is required. A classifier employed between the sher and the jig removes the fine-size gangue. Figure shows a generalized flowsheet employing jigging.

Heavy-media Separation Processes

A heavy-media process was first commercially applied zinc ores by the American Zinc, Lead and Smelting mpany at Mascot, Tennessee. It was introduced on the yuna Range in 1937. At that time galena (PbS) was d as the medium but later this was changed to mag-ic ferrosilicon, which is easy to recover from the cuit for re-use. The general principles of the heavy-dia process are also employed in the Chance cone for l washing, although there are marked differences in quipment.

In a heavy-media process the ores are crushed and t-screened to pass about one and one-half inches, and fines, ordinarily all less than one-quarter inch, are noved by screening. The sized material then goes rough the heavy-media process, which has been de-ribed repeatedly in articles and books. A number of ferences are given here.

gineering and Mining Journal (New York, N. Y.)

Anonymous. How New Units, New Uses Widen Scope of Sink-Float. vol. 152, No. 7, 1951, pp. 130-133.

Bitzer, E. C. Finding a Way to Handle the HMS Middlings Problem. vol. 152, No. 11, 1951, pp. 91-95.

Britton, S. A. Heavy-Density Separation Cuts Brown Ore Treatment Cost, vol. 151, No. 7, 1950, pp. 68-70.

Cooke, S. R. B. Mineral Dressing, vol. 143, No. 2, 1942, pp. 80-82.

Erickson, S. E. How to Simplify Testing for Sink-Float Separation, vol. 152, No. 6, 1951, pp. 88-89.

Ramsey, R. H. Revised Processes Challenge Flotation's Thirty-Year Rule, vol. 152, No. 2, 1951, pp. 116-118.

Rudolph, J. Iron-Ore Beneficiation. vol. 141, No. 2, 1940, pp. 83-84.

Snook, A. M. Blackburn Heavy-Density Plant Opens New Brown Iron Ore Reserves. vol. 151, No. 9, 1950, pp. 78-81.

Iron Age (New York, N. Y.)

Hedges, R. W. High Grade Iron Ore from Low Grade Deposits, vol. 166, 3 August 1950, pp. 79-84.

Mining and Metallurgy (New York, N. Y.)

Beall, J. V. Recent Developments in Heavy-Density Separation, vol. 29, 1948, pp. 488-492.

Benedict, C. H. Ore Concentration and Milling, vol. 22, 1941, pp. 70-73.

Mining Engineering (New York, N. Y.)

Anonymous. Heavy-Media Separation Increases Brown Ore Reserves, vol. 2, 1950, pp. 1236-1237.

Mining Technology (New York, N. Y.)

McNeill, H. L. Selective Media Concentration — A New Tool for the Mining Industry, vol. 10, No. 6, 1946, T.P. 2084.

Quarterly of the Colorado School of Mines (Golden, Colo.)

Hyer, J. W., Jr. Heavy-Density Separation — A Review of its Literature, vol. 43, No. 1, 1948.

Figures 16 and 17 show diagrammatically a conventional heavy-media flow scheme, in which ferrosilicon is used as the media, and a classifier-type vessel used for iron ore.

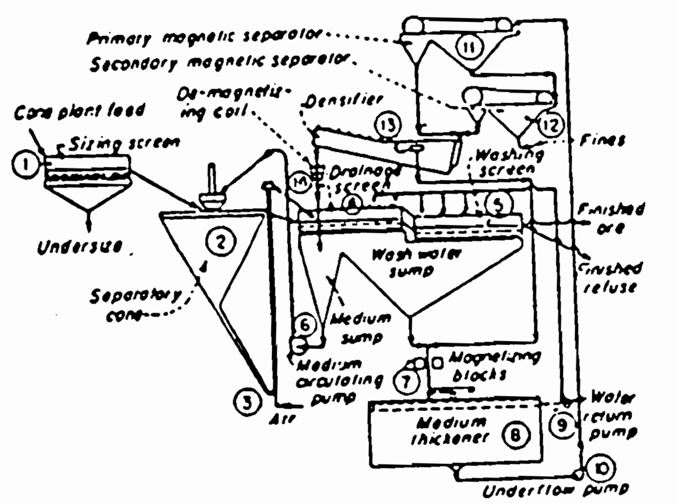

Figure 16. Standard Heavy-media Flowsheet using Ferrous Media

(John T. Sherman, "Sink-Float Processes", *Chemical Engineering*, vol. 56, No. 1, 1949, pages 106 to 109)

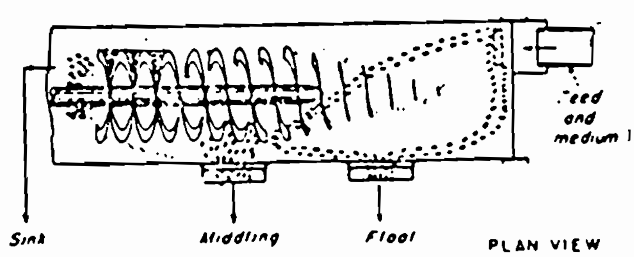

Figure 17. Classifier Type Sink-float Vessel used for Iron Ore

(*Source:* See figure 16)

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The heavy medium (ferrosilicon), being smaller in size than the ore being treated, is removed on perforated screen plates and is then recovered by a magnetic separator. In general, heavy-media processes are used on ores that formerly would have been treated in jigs.

An excellent review of heavy-media separation processes by Hyer[6] contains a bibliography of ninety-four references on the process and on its applications to iron ore and other raw materials. The bibliography includes innovations such as the Dutch State Mines cyclone.

The Dutch State Mines Cyclone

The Dutch State Mines or Driessen cyclone process, commonly termed the "cyclone" process, permits the extension of the heavy-media separation process into the finer size ranges. The most effective size range of particles treated is minus one-quarter inch plus 100 mesh, although separations are possible at finer sizes. The major use of the cyclone to date has been for thickening operations. It is reported that sharp separations in connexion with iron ore concentration are being obtained experimentally. Capacities of four to eight tons per hour, depending on the ore, for a six-inch diameter cone and ten to twenty-five tons per hour for a fourteen-inch cone have been reported. The large capacity of this relatively small piece of equipment makes it potentially attractive for use in concentrating low-grade ores.

The cyclone process is described in the following:

Canadian Mining and Metallurgical Bulletin (Montreal, Canada)

HOLT, G. J. Progress in Iron Ore Beneficiation, vol. 43, No. 463, November 1950, pp. 636-638.

Engineering and Mining Journal (New York, N. Y.)

ANONYMOUS. Cyclones Set Pace in Milling, vol. 153, No. 2, February 1952, p. 128.

Mine and Quarry Engineering (London, England)

DOUGHTY, F. T. C. The Cyclone — Its Use for Mineral Concentration, vol. 14, No. 11, November 1948, p. 337.

Transactions of the American Institute of Mining and Metallurgical Engineers (New York, N. Y.)

DAHLSTROM, D. A. High-Speed Classification and Desliming with the Liquid-Solid Cone, vol. 190, 1951, p. 153.

Tables

Years ago tables were used, but because of their low capacity they are not widely employed today in iron ore concentration.

Hydraulic Classification

Various types of hydraulic classifiers have been used and are still being used. Some of these are fairly complex; others are simple. Among simple hydraulic classifiers in use may be mentioned the Hydrotator, Fahrenwald and the Dorrco. They all operate on fine-sized ore, usually less than one-quarter inch.

Double Classification

Double classification is currently employed to treat sizes less than one-quarter inch, the coarse fraction going to heavy-media or jig treatment. The flow scheme is simple and involves first a standard classifier operating in the range of 48 to 100 mesh. The overflow is tailings waste, and the rake product goes to a second classifier from which the rake product is a final concentrate. The overflow goes to vibrating screens, 28 to 48 mesh, from which coarse silica oversize goes to waste and the undersize is recirculated to the head of the first classifier. This latter step serves in a measure as a "heavy-media".

Wash and jig tailings segregate more or less in sands and slimes in tailings dumps. The coarser portions are to a limited extent being treated by a double-classification method.

Combination Centrifugal-Hydraulic

A recently developed machine is being used on ore less than one-quarter inch in size. It is essentially an inverted cone rotating within a stationary conical shell. The waste is discharged by a swirling motion at the water level of the shell. Concentrates are cleaned by ascending currents of water and are discharged at the base of the shell into a chain-type of drag. The process and equipment have been described by G. J. Holt.[6]

Bird Centrifugal Classifier

The Bird centrifugal classifier is being used experimentally in at least one plant. It offers possibilities in desliming and also for dewatering. Capacities are high, and power consumption is reasonably low.

Humphreys Spiral

The success of the Humphreys spiral in the treatment of gold and titanium-zirconium sands has led to study of its possible application in other fields, including iron ore concentration.[7] While it works best on a classified feed and in common with other launders works best as an intermediate rougher, because launders do not lend themselves particularly well to obtaining both grade and recovery, it has possible use in iron ore concentration, particularly in the treatment of certain sizes. It has been considered as a possible rougher in the elimination of gangue prior to fine grinding in taconite concentration.

At the Cleveland-Cliffs Iron Company, eighty-four spirals treat 100 tons per hour of iron ore of the type usually concentrated in jigs.[7]

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[6] J. W. Hyer, Jr., "Heavy-Density Separation — A Review of its Literature", *Quarterly of the Colorado School of Mines*, vol. 43, No. 1 (Golden, Colorado, 1948).

[6] Grover J. Holt, "Late Developments in the Beneficiation o[f] Lake Superior Iron Ores", *Blast Furnace and Steel Plant*, vol. 34 No. 1 (Pittsburgh, Pa., 1946), pages 77 to 84.

[7] W. E. Brown and L. J. Erck, "Humphreys Spiral Concentratio[n] on Mesabi Range Ores", *Transactions* of the American Institute o[f] Mining and Metallurgical Engineers, vol. 184 (New York, 1949) page 187; and James V. Thompson and Whitman E. Brown, "Th[e] Humphreys Spiral — Some Present and Potential Applications *Engineering and Mining Journal*, vol. 151, No. 8 (New Yor[k] 1950), pages 87 to 89.

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Flotation

Concentration by flotation of classifier overflows is being studied on a pilot-plant scale in laboratories on Lake Superior ores.

Sintering and Drying

There are two types of merchantable ores that are treated on a small scale. In one the analysis and physical structure are satisfactory but the moisture content is high. This type of material is dried before shipment to lessen shipping charges. Several drying plants once operated on the iron range, but in 1951 there was only one. The other type has satisfactory analysis except for high moisture content but the structure is too fine for blast-furnace use. This material is sintered before shipping. In 1951 only one plant was in operation in Minnesota but a second one was under construction. References are given in a later section of this paper.

Concentration processes and flowsheets

THE LAKE ORES

Diff nt classifications of ores can be used but perhaps t. e is simpler than that given by S. E. Erickson,[8] who broadly grouped types of ores from a beneficiation point of view as follows:

1. Merchantable ores
2. Wash ores
3. Intermediate ores
4. Taconites

The term "taconite" applies to Mesabi ore but sometimes is used in a generic sense to include other iron formation materials such as the Michigan "jaspers".[9]

L. J. Erck[10] suggested a somewhat different classifi-)ion:

1. Merchantable ores
2. Wash ores
3. Retreat ores, jig ores or crude ores that can be beneficiated by present-day practices
4. rmediate ores
5. Taconites:

(a) Magnetic

(b) Oxidized

(c) Complex, which by virtue of chemical composition does not lend itself to present ore-dressing practices

Erickson[11] has given several flow schemes employed in concentrating various iron ores, particularly the Lake ores. Because they are typical, several are presented in figures 18 to 22.

Merchantable Ores

Most of the ore in the class of merchantable ore is high enough grade chemically to be shipped without beneficiation except for structure improvement. This takes the form of elimination of the large chunks, so that the material reduces more rapidly in the blast furnace. A flow scheme illustrating the general methods of beneficiating merchantable ores is given in figure 18. "O.S." and "U.S." in the figure refer to "oversize" and "undersize", respectively. For details as to the physical size of the material handled, the reader is referred to the original publication. The following quotation from Erickson's paper is typical:

> On direct-shipping material, the ore from the mine is passed over a scalping screen, which usually removes the material that is over four to six inches in size. The screen may be vibrating, a stationary grizzly, or a moving-chain grizzly. The oversize material is crushed and then recombined with the undersize for shipment.

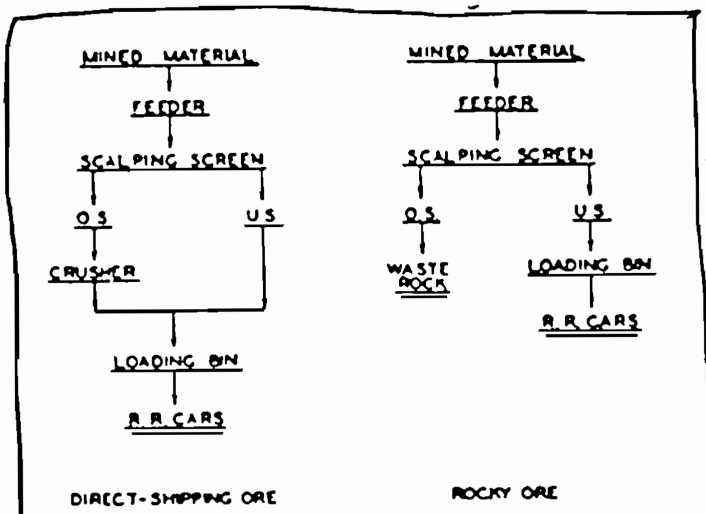

Figure 18. Flow Schemes for Merchantable Ore

(S. E. Erickson, "Iron-Ore Beneficiation — Present Practices and Trends", *Proceedings* of the Blast Furnace, Coke Oven and Raw Materials Conference, American Institute of Mining and Metallurgical Engineers, vol. 10 (New York, 1951)

Wash Ores

Erickson grouped wash ores to include true wash ores and also a small tonnage of off-grade merchantable ore. There is a content of coarse gangue which can be removed by screening, but there is also sand or fine low-grade material present. Beneficiation is done to recover such values. He describes the general operation for simple wash-ore treatment in the following paragraph.

[8] Stephen E. Erickson, "Iron-Ore Beneficiation — Present Practices and Trends", *Proceedings* of the Blast Furnace, Coke Oven and Raw Materials Conference, American Institute of Mining and Metallurgical Engineers, vol. 10 (New York, 1951), pages 4 to 18.

[9] "Iron to be Recovered from Michigan Jasper in New Project Cleveland Cliffs, Ford", *Engineering and Mining Journal*, vol. 152, No. 12 (New York, 1951), page 128.

[10] L. J. Erck, Discussion of the Erickson paper, *loc. cit.*

[11] See footnote 8.

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The simple wash-ore treatment is as follows. The scalping screen usually is a vibrating screen with openings from four to six inches. The oversize, or rock, goes to waste and the undersize is washed on a vibrating screen that has openings from one-half inch to one and one-half inches. The washing-screen oversize goes to cars for shipment and the undersize goes to a mechanical classifier. This classifier is essentially a screening device, used because economical and efficient fine-mesh screens have not yet been developed. The classifier undersize goes to waste and the oversize joins the screen oversize for shipment. The classifier undersize is minus 28 to 65 mesh, depending on the ore being treated.

Figure 19 illustrates schematic flowsheets for both simple and complex wash ores.

Intermediate Ores

Intermediate ores, for purposes of classification, are considered to be those ores characterized by having larger amounts of coarse gangue than the wash ores—gangue which cannot be removed by simple washing; therefore more refined concentration is employed. The flow scheme of figure 20 illustrates a typical method on simple intermediate ore. As will be noted, the oversize from the washing screen goes to a crusher. After crushing, the product joins with the undersize from the first washing screen and both go to a second sizing screen. The undersize is treated in much the same manner as is complex wash ore (figure 19). The oversize, which is above three-sixteenths-inch size, is treated by means of the heavy-media process.[12]

When the gangue content of the fine sizes is too high, the oversize from the classifier must be treated further to obtain a shipping-grade concentrate. This can be done by the modification shown in figure 21. The essential difference from the previous flowsheet is that the classifier oversize instead of going to loading bins goes to fine ore treatment. The type of treatment depends on the character of the ore. In the earlier plants jigging was widely employed. The double-classification process, already described, has been used as a substitute for jigging. With

[12] See footnote 8.

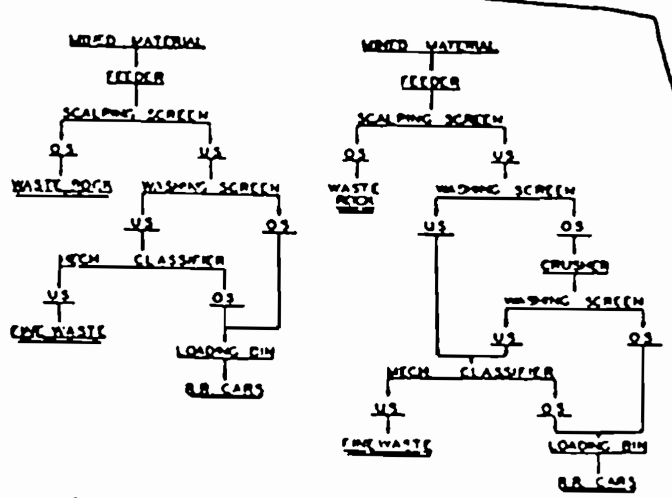


Figure 19. Flow Schemes for Wash Ores
(*Source*: See figure 18)

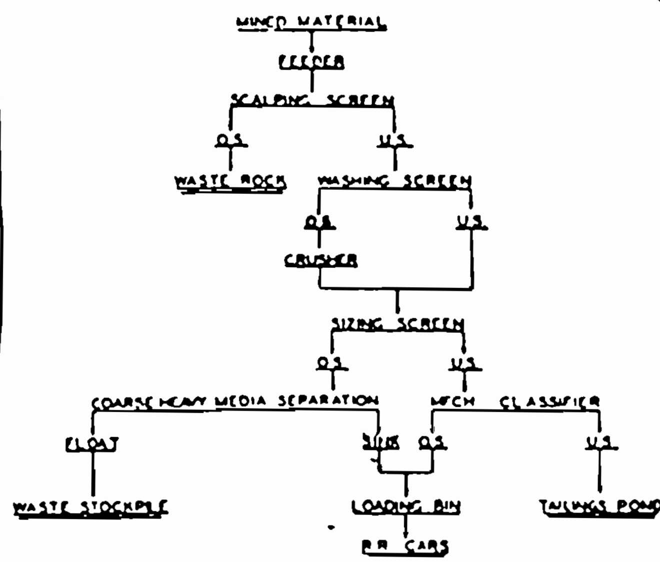


Figure 20. Flow Scheme for Simple Intermediate Ore
(*Source*: See figure 18)

some ores differential grinding has been used to advantage. A recent development on fine sizes is the Dutch State Mines cyclone process,[13] already discussed. It is claimed that the process is applicable in the size range from three-eighths of an inch to about 65 mesh.

Erickson gave a flowsheet (figure 22) to illustrate the trend of schemes for intermediate-ore beneficiation. It should be pointed out that such a flowsheet is not employed at any given plant. Flotation,[14] except experimentally, is not employed on iron ores, but it is likely that the method will gain a foothold as attempts are made to increase yield and to improve the grade of concentrates.

Taconites

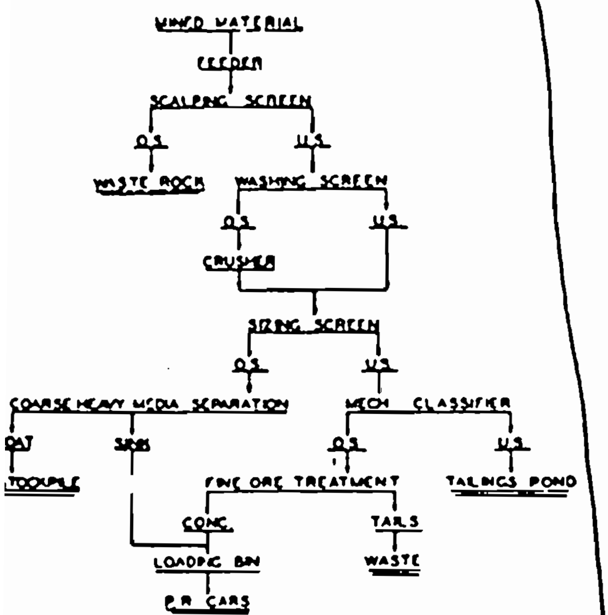
As time goes on, it will be necessary to depend more and more on the "formation materials" as a source of iron ore. These are adjacent to current workings of high-grade ores, and the tonnages are enormous, estimated by some geologists as being many billions of tons. These materials in the Mesabi Range, commonly called "taconites", contain approximately 30 per cent of iron. Uses of these ores and methods of beneficiation are described in the following:

Blast Furnace and Steel Plant (Pittsburgh, Pa.)

SYKES, W. The Future of the Steel Industry, vol. 35, 1947, pp. 695-701.

[13] Stephen E. Erickson and Earl C. Herkenhoff, "Cyclone Separator May Be Solution for Fine Ore Problem", *Engineering and Mining Journal*, vol. 151, No. 6 (New York, 1950), pages 71 to 73.

[14] W. E. Keck and Poavo Maijala, "Iron Concentration Tests Lick Hard-Water Problem", *Engineering and Mining Journal*, vol. 145 (New York, 1944), pages 79 to 80; Donald W. Scott, A. C. Richardson and Nathaniel Arbiter, "Amine Flotation of Gangue from Magnetite Concentrates", *Mining Technology*, vol. 9 (New York, 1945), T. P. 1902; J. B. Clemmer and C. Rampacek, "Method of Concentrating Iron Ore", U. S. patent 2,403,481, July 1946.



: 21. Flow Scheme for Complex Intermediate Ore

(*Source*: See figure 18)

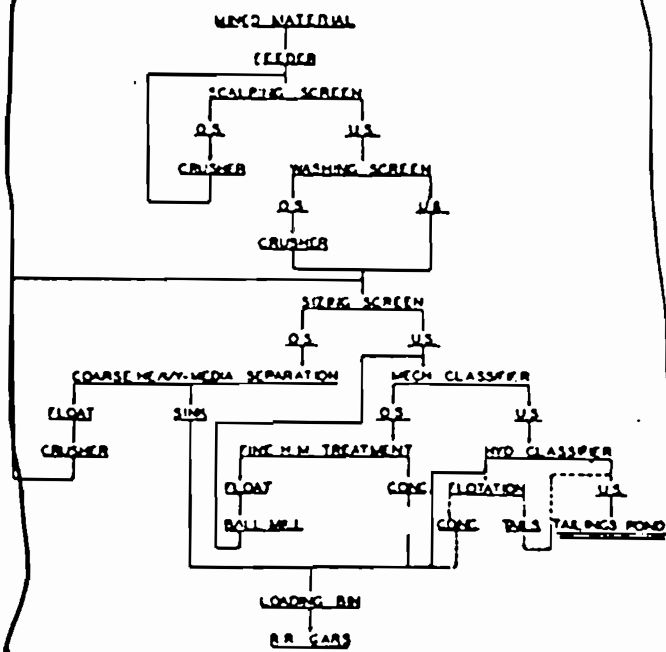


Figure 22. Trend of Beneficiation of Intermediate Ore

(*Source*: See figure 18)

ering and Mining Journal (New York, N. Y.)

YMOUS. Full-Scale Taconite Beneficiation Nearer, vol. 152, . 11, 1951, pp. 102-103.

, E. W. When Will We Mine Taconite?, vol. 145, 1944, . 82-85.

, L. J. Iron Ore Beneficiation, vol. 144, No. 2, 1943, . 100-101.

ELL, A. H. Work on Taconite Now Heads toward Com-rcial Goal, vol. 153, No. 7, 1952, pp. 72-75.

L. A. Taconite Plants, New Processes Come First in Iron e Plans, vol. 153, No. 2, February 1952, p. 125.

ARON, F. X. Iron Ore Beneficiation Shows Healthy Growth, . 149, [illegible], 1948, pp. 110-113.

ge (New York, N. Y.)

YMOUS. Taconite — New Project Enters Race, vol. 169, . 8, 1952, p. 57.

D, B. Taconite is Steel Industry's Ace-in-the-Hole, vol. 167, 51, pp. 105-106.

Engineering (New York, N. Y.)

ARD, J. J. A New Approach to Taconite Utilization, vol. 2, 50, pp. 560-563.

E, N. M. Taconites beyond Taconites, vol. 4, No. 4, 1952, 361-363.

HELL, W., JR., SOLLENBERGER, C. L., and MISKELL, F. F. ctors in the Economics of Heat-Treated Taconites, vol. 4, . 10, 1952, pp. 962-967.

dings of the Blast Furnace, Coke Oven and Raw Materials mmittee, Iron and Steel Division, American Institute of ning and Metallurgical Engineers (New York, N. Y.)

IN, H. K. Proposed Flowsheet for Taconite Concentration Babbitt, vol. 7, 1948, pp. 68-72.

States Steel News (Pittsburgh, Pa.)

YMOUS. Drama of the Iron Range, 1948, pp. 10-15.

not the function of this paper to discuss the y of the iron formation materials. Suffice it to say far as the Mesabi is concerned they fall into two broad classes — slaty and cherty. Mineralogical examination of taconite samples shows that the dissemination is so great and such fine grinding is required that the slaty material can for the present be ruled out of consideration for concentration. All attention, therefore, has been focused on the cherty taconites.

From a broad qualitative standpoint the taconites may be divided into two classes, based on the nature of the gangue. In group I are those in which the iron exists predominantly as oxide and the gangue principally as quartz. In group II the iron exists partly as oxide and partly as ferruginous carbonate or silicate or both; the gangue is complex, containing such minerals as minnesotaite, greenalite, stilpnomelane, glauconite, clay and serpentine. In the case of ferruginous carbonate or siderite-type of taconites, the iron carbonate occurs in intimate association with submicrocrystalline and amorphous silica and some of the iron oxide is replaced with manganese oxide, magnesia and lime (CaO). Obviously, there are all degrees of variation from group I to group II, and one might expect mixtures from most mining operations. Group I may be broken down further into those in which the oxide is predominantly magnetic and those in which it is predominantly nonmagnetic or hematitic.

Taconites are finely disseminated, requiring grinding to about 150 mesh to liberate the iron materials. It is possible, in the case of the simple gangue types, to get liberation of some of the gangue at a fairly coarse size, say on the order of 48 or 65 mesh. This might be eliminated by a roughing operation prior to fine grinding. In the eastern Mesabi, the iron oxides are predominantly magnetite, in the extreme western Mesabi they are largely hematite, and in between the ratio varies. The first

EXHIBIT "36CFB1" - Copy United Nations Survey of World Iron Ore Resources, 1955

STATE OF MINNESOTA
DEPARTMENT OF CONSERVATION
DIVISION OF LANDS AND MINERALS

IRON ORE MINING LEASE

MINNESOTA STATUTES 19___, SECTION 93.20
as amended.

Lease No. ____________ Prospecting Permit No. ____________

[Sec. 93.20, Subd. 4.]

This indenture, made this ______________ day of ______________, 19___, by and between the State of Minnesota, party of the first part, and

part_____ of the second part, WITNESSETH:

1. [TERM: DESCRIPTION OF MINING UNIT.] That the party of the first part, for and in consideration of the sum of ______________________________ Dollars to it in hand paid by the part_____ of the second part, being the payment of rental for the unexpired portion of the first quarter, hereinafter provided for, the receipt whereof is hereby acknowledged, and in further consideration of the covenants and conditions hereof, to be kept and performed by the part_____ of the second part, does hereby lease and demise unto the part_____ of the second part for the term of 50 years from and after the __________ day of ____________, 19_______, the following described land, situated in the County of ______________, in the State of Minnesota, to-wit:

2. [PURPOSE OF LEASE; RIGHT OF LESSEE TO CONTRACT WORK. Subd. 5.] The above described premises are leased to the part____ of the second part for the purpose of exploring for, mining, taking out and removing the iron ore found on or in said land, together with the right to construct or make such buildings, excavations, openings, ditches, drains, railroads, roads and other improvements upon said premises as may be necessary or suitable for such purposes. The part_____ of the second part may contract with others for doing any work authorized or required hereunder, or for the use of said land or any part thereof for the purposes hereof, but no such contract shall relieve the part____ of the second part from any duty, obligation, or liability hereunder. Three executed duplicates of every such contract shall be filed with the commissioner of conservation before it shall become effective for any purpose.

3. [STATE'S RIGHT TO LEASE SURFACE AND SELL TIMBER. Subd. 6.] The party of the first part reserves the right to sell and dispose of, under the provisions of law now or hereinafter governing the sale of timber on state lands, all the timber upon the land hereby leased, and reserves to the purchaser of such timber, his agents and servants, the right at all times to enter thereon, and to cut and remove any and all such timber therefrom, according to the terms of the purchaser's contract with the state, and without let or hindrance from the part... of the second part; but such purchaser shall not unnecessarily or materially interfere with the mining operations carried on thereon. The party of the first part further reserves the right to grant to any person or corporation the right-of-way necessary for the construction and operation of one or more railroads over or across the land thereby leased, without let or hindrance from the part... of the second part; but such railroads shall not unnecessarily or materially interfere with the mining operations carried on thereon. The party of

the first part further reserves the right to grant leases, permits or licenses to any portion of the surface of the demised premises to any person or corporation under authority of *Minnesota Statutes, Section 92.50, or other applicable laws,* without let or hindrance from the part.. of the second part, but such leases, permits or licenses shall not unnecessarily or materially interfere with the mining operations carried on thereon.

4. [MINIMUM RENTAL OR ROYALTY. Subd. 7.] The part... of the second part covenants and agrees to pay to the treasurer of said state rental for said premises at the rate of $1,250 for the first year after the date of this lease and $5,000 per year for the remainder of the term hereof; provided, that in case and so long as this lease is designated as a taconite iron ore mining lease the rate for the first five years after the date hereof shall be $400 per year and the rate for the remainder of the term hereof shall be $1,600 per year. Such rental shall be payable quarterly on or before the 20th day of April, July, October, and January each year during the term hereof. *Each quarterly payment shall cover the rental at the rates hereinbefore specified for the calendar quarter or fraction thereof ending on the last day of the calendar month next preceding the due date for such payment. The rental for any fraction of a quarter shall be computed proportionately at the applicable rate. Any amount paid for rental accrued during any calendar year shall be credited on any royalty that may become due for iron ore removed hereunder during the same calendar year but no further, and any amount paid for such royalty in excess of such credit during such year shall be credited on rental, if any, subsequently accruing during such year but no further.*

5. [DEFINITIONS OF "DRIED IRON" AND "TON." Subd. 8.] The term "dried iron" as used herein shall mean iron ore dried at 212 degrees Fahrenheit; and the word "ton" shall mean a gross ton of 2240 pounds.

6. [ESCALATOR CLAUSE. Subd. 9] (1) *The royalties to be paid by the part... of the second part to the party of the first part on ore removed in each calendar year that this lease remains in force as hereinafter specified shall be increased or decreased for that calendar year in the same proportion that the market value of standard grade Mesabi Non-Bessemer iron ore containing 51.50 per cent iron, natural analysis, at lower lake ports, as of April first of that year, is increased or decreased above or below the corresponding market value of such standard ore that prevailed at the time of submission of the application for a prospecting permit on the mining unit covered by this lease; provided, that, in no case shall such royalties be less than the minimum royalties prescribed by law. For the purposes hereof, the market value of such standard ore as of the date of application for a prospecting permit on the mining unit covered by this lease, as determined by the commissioner of conservation was .... Dollars ($................). As soon as practicable after April first of each year, the commissioner of conservation shall determine the market value of such standard grade of Mesabi Non-Bessemer ore as of said date, shall file his order thereon in his office, shall file certified copies thereof in the offices of the state treasurer and state auditor, and shall mail a certified copy thereof to the part... of the second part. The market value so determined shall govern for the purpose of computing royalties due under this lease on ore removed during such calendar year. If such determination is not made in time for use in computing any such royalty, such royalty shall be computed and paid when due at the last rate theretofore in force under the provisions hereof, subject to adjustment as hereinafter provided. Upon the determination by the commissioner of the applicable market value of ore, if it appears that the amount theretofore paid for any royalty subject to such determination was less or greater than the correct amount based on such determination, any deficiency in such payment shall be added to and paid together with the rental or royalty due at the next following quarterly payment date hereunder, and any excess in such payment shall be applied as a credit upon rentals or royalties subsequently due hereunder as the case may be.*

(2) If the part... of the second part shall dispute any determination by the commissioner of the market value of such standard ore, the royalties affected thereby shall nevertheless be paid when due at the rates based on such determination; provided, that upon making any such payment when due, the part... of the second part may file with the commissioner a protest against such determination, specifying the amount alleged to be the true market value of such standard ore for the purpose of computing such royalty. If the dispute involves the determination of the market value of such standard ore as of the date of application for a prospecting permit, as set forth in Subd. 9 (1) above, such protest shall be filed once only and then within 30 days after the first royalty payments are due. Within 30 days after filing such protest, the part... of the second part may bring an action against the commissioner in the district court for Ramsey County for a declaratory judgment determining the market value of the ore in dispute as stated in the protest. Upon the taking effect of final judgment in such action, the value determined thereby shall supersede the value determined by the commissioner for the purposes hereof, and adjustment of the amounts paid or payable for

royalties shall be made accordingly in like manner as hereinbefore provided upon determination of market value by the commissioner. If such action is not brought within the time aforesaid, the commissioner's determination of market value shall be final. In case the part... of the second part shall be entitled to any adjustment on account of overpayment of royalties hereunder, and the rentals or royalties subsequently due on or before the termination of this lease are not sufficient to make such adjustment as hereinbefore provided, the excess of such royalties paid above the amount adjustable against subsequent rentals or royalties shall be refunded to the part... of the second part as provided by Minnesota Statutes 1949, Section 6.136.

7. [METHOD OF COMPUTING ROYALTY RATES. Subd. 10.] *In computing royalty rates hereunder, any fraction of a cent less than five-thousandths shall be disregarded and any fraction amounting to five-thousandths or more shall be counted as one-hundredth of a cent.*

The method of computing increased rates upon analysis illustrated by the following example shall apply in all cases hereunder, with such changes as may be necessary for adaptation to a particular schedule. Assuming that the royalty rate for the lowest grade of ore, with analysis 25.49 per cent or less, is 18 cents per ton the rate will be 18.9 cents per ton for all dried iron analyses higher than 25.49 per cent but less than 26.50 per cent; 19.85 cents per ton for all dried iron analyses higher than 26.49 per cent but less than 27.50 per cent; and so on, adding to the amount of royalty for a given grade five per cent thereof for an increase in dried iron content of one per cent or fraction thereof.

8. [DEFINITIONS OF ORE MATERIAL UNDER EACH SCHEDULE AND ROYALTIES TO BE PAID THEREON. Subd. 11.] Subject to the foregoing provisions, the royalties to be paid by the part... of the second part to the party of the first part shall be as hereinafter specified.

Schedule 1. [OPEN PIT DIRECT SHIPPING ORE. Subd. 12.] Direct shipping open pit ore shall be understood to mean all ore lying beneath the final stripped area of the particular mine in which it shall be situated and lying within reasonably safe mining slopes therein, that is shipped in its natural state without beneficiation of any kind other than crushing or dry screening.

On a ton of direct shipping open pit ore averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased five per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

Schedule 2. [OPEN PIT WASH ORE CONCENTRATES. Subd. 13.] Open pit wash ore concentrates shall be understood to mean all concentrates produced from open pit ore which, in accordance with good engineering and metallurgical practice, requires treatment by straight washing to make it suitable for blast furnace use.

On a ton of open pit wash ore concentrates averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased four and one-half per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

Schedule 3. [OPEN PIT SPECIAL CONCENTRATES. Subd. 14.] Open pit special concentrates shall be understood to mean all concentrates produced from open pit ore which, in accordance with good engineering and metallurgical practice, requires treatment by roasting, sintering, agglomerating, or drying through the use of fuel, or by jigging, or by heavy medium separation to make them suitable for blast furnace practice.

On a ton of such open pit special concentrates averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased four per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

Schedule 4. [UNDERGROUND DIRECT SHIPPING ORE. Subd. 15.] Underground direct shipping ore shall be understood to mean all ore in any particular mine, other than open pit ore, that is shipped in its natural state without beneficiation of any kind other than crushing or dry screening.

On a ton of underground direct shipping ore averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased three and one-half per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

Schedule 5. [UNDERGROUND WASH ORE CONCENTRATES. Subd. 16.] Underground wash ore concentrates shall be understood to mean all concentrates produced from underground ore which, in accordance with good engineering and metallurgical practice, requires treatment by straight washing to make it suitable for blast furnace use.

On a ton of underground wash ore concentrates averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased three per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

<u>EXHIBIT "37"</u> - Copy State of Minnesota Iron Ore Mining lease 1941

Schedule 6. [UNDERGROUND SPECIAL AND FINE TAILINGS SPECIAL CONCENTRATES. Subd. 17.] Underground special concentrates shall be understood to mean all concentrates produced from underground ore which, in accordance with good engineering and metallurgical practice, require treatment by roasting, sintering, agglomerating, or drying through the use of fuel, or by jigging, or by heavy medium separation to make them suitable for blast furnace practice.

Ponded fine tailings special concentrates shall be understood to mean all concentrates produced from fine tailings stored in tailings ponds which, in accordance with good engineering and metallurgical practice, require additional treatment by one or more of the types described in schedules 2 and 3 to make them suitable for blast furnace practice.

On a ton of such underground special concentrates or pounded fine tailings special concentrates, averaging in dried iron 25.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased two per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

Schedule 7. [TACONITE ORE; TACONITE CONCENTRATES. Subd. 18.] Taconite ore shall be understood to mean a ferruginous chert or ferruginous slate in the form of compact siliceous rock, in which the iron oxide is so finely disseminated that substantially all of the iron bearing particles of merchantable grade are smaller than 20 mesh.

Taconite concentrates shall be understood to mean the merchantable product, suitable for blast furnace use, which, in accordance with good engineering and metallurgical practice, has been produced from taconite ore which requires treatment by fine grinding, magnetic separation, flotation, or some other method or methods other than or in addition to one or more of the methods specified in schedules 1 to 6, inclusive.

On a ton of taconite concentrates averaging in dried iron 40.49 per cent or less, the royalty shall be ____________ cents. The royalty rate shall be increased one per cent for each increase of one per cent, or fraction thereof, in dried iron analysis.

In lieu of payment of such royalty on the taconite concentrates, royalty payments may be made on the taconite ore as set forth in Minnesota Statutes, Section 93.201.

9. [QUARTERLY ROYALTY PAYMENT ON ORE REMOVED. Subd. 19.] The part... of the second part covenant... and agree... to pay to the treasurer of said state, on or before the twentieth day of April, July, October, and January in each year during the period this lease continues in force royalty at the rates hereinbefore specified for all the iron ore mined and removed from said land during the three months preceding the first day of the month in which such payment is due as hereinbefore provided.

10. [LESSEE TO TRANSMIT STATEMENT OF ORE REMOVED AND ROYALTY DUE. Subd. 20.] The part... of the second part at the time of such payment shall transmit to the commissioner of conservation an exact and truthful statement of the amount of iron ore removed under each schedule during the three months for which such payment is made and the royalty due thereon, determined as hereinafter provided. The part... of the second part shall provide for all the operations required for such determination except as otherwise specified.

11. [RAIL SHIPMENTS REQUIRED; SAMPLING AND ANALYSES OF ORE; APPROVAL OF CHEMIST. Subd. 21.] *Except as otherwise hereinafter provided, all iron ore removed from said land hereunder shall be shipped by rail. Each shipment shall be sampled in accordance with standard practice so as to show the true grade of the ore contained therein under each schedule, taking specimens from five carloads to make up a sample for analysis; provided, that with the approval of the commissioner of conservation a sample may consist of specimens from any other number of carloads. The ore in each sample shall be thoroughly mingled and then split into two portions, both of which shall be properly marked for identification. One portion shall be delivered to the commissioner of conservation or his authorized agent, and the other retained by the part... of the second part. Each sample, dried at 212 degrees Fahrenheit, shall be analyzed for iron and manganese, and also, if directed by the commissioner or his agent, for silica, phosphorus, and alumina, at the expense of the part... of the second part, by a competent chemist approved in writing by the commissioner.*

12. [METHOD OF WEIGHING ORE; TRANSMISSION OF WEIGHT BILLS AND MONTHLY REPORTS; RIGHT OF LESSEE TO COMPUTE ROYALTIES ON A CALENDAR MONTH BASIS; ADDITIONAL ROYALTY FOR MANGANESE. Subd. 22] *The iron ore so taken and shipped shall be weighed by the railroad carrier. Weight bills or certificates, signed by the weigher, shall be transmitted to the commissioner at the close of each day when ore is shipped. Except as otherwise permitted by the commissioner of conservation, the part... of the second part shall transmit to the commissioner on or before the tenth of each month a statement in such form as the commissioner shall prescribe, covering all ore removed from said land during the*

preceding calendar month, showing the weight and analysis of the ore under each schedule, the royalty computed to be due thereon, and such other information pertaining thereto as the commissioner may require. The amount of royalty due upon the ore under each schedule shall be determined according to the percentage of iron shown by the analysis at the rates hereinbefore prescribed. If the manganese content is four per cent or more, the royalty due thereon shall be determined and paid as provided by law. With the approval of the commissioner, for the purpose of computing and accounting for royalty, ore may be considered as removed from said land in the month in which it was weighed as shown by the weight bills or certificates, but the party of the second part shall nevertheless be liable for the royalty on all ore from and after the actual time of removal from said land. With the approval of the commissioner the royalty on all the ore under a given schedule removed during a given calendar month may be computed on the average dried iron analysis thereof. The grades and weights of ore as set forth in said monthly statements shall be prima facie binding as between the parties, but the party of the first part shall have the right at any time, and in such manner as it may see fit, to sample the ore, check the analyses, and inspect, review, and test the correctness of the methods, books, records, and accounts of the part... of the second part in sampling, analyzing, recording, and reporting such grades and weights, and to inspect, review, and test the correctness of the scales and other equipment used in weighing the ore and of the weights reported as aforesaid, it being understood that any errors in these respects, when ascertained, shall be corrected. Should the party of the second part desire to remove crude ore for experimental purposes from the demised premises, the commissioner of conservation may prescribe the method of such removal and the method of sampling and weighing such crude ore for the purpose of determining the amount of royalty due.

13. [BENEFICIATION; DISPOSITION OF RESIDUE; LESSEE LIABLE FOR ALL ORE REMOVED FROM PREMISES. Subd. 23.] The part... of the second part shall have the right to beneficiate and treat, for the purpose of improving the character or quality thereof, any iron ore which without such treatment or beneficiation will not meet general market requirements at the time. Subject to the approval of the commissioner of conservation, such ore may be so beneficiated or treated either upon the demised premises or elsewhere. The part... of the second part agree.. that any treatment or beneficiation of ore conducted hereunder shall be done with suitable and proper machinery and appliances, and in a careful, good and workmanlike manner, according to good engineering practice, and so as not to cause any greater waste of the ore mined than is necessary in order to produce an ore concentrate of proper composition and character for satisfactory furnace use. No ore shall be treated or beneficiated which, without treatment or beneficiation, will meet general market requirements at the time. As to any ore so beneficiated or treated during any quarter year, royalty at the rates per ton hereinbefore provided for such ore shall be paid upon the merchantable product of such beneficiation or treatment and not upon the ore as mined. The residue of such treatment or beneficiation may be deposited upon the demised premises, in such place or places as shall not unnecessarily hinder or embarrass the future operation of the mine or mines therein, or on other state-owned lands conveniently located for the purpose, or may be otherwise disposed of in such manner as the commissioner of conservation may approve. The merchantable product of such beneficiation shall be sampled, analyzed and weighed and the royalty thereon determined in like manner as hereinbefore provided for direct shipping ore. The part... of the second part shall nevertheless be liable for royalty on all ore removed from the demised premises for beneficiation or treatment from and after the actual time of removal. If any such ore shall not be beneficiated or treated or if the royalty due thereon shall not be determined and accounted for as herein otherwise provided by the next quarterly payment date after the end of the quarter in which such ore is removed from the demised premises, the commissioner may determine such royalty by such method as he deems appropriate and give the part... of the second part written notice thereof, whereupon such royalty shall be due and payable within 20 days after the mailing or delivery of such notice, unless the time therefor shall be extended by the commissioner.

14. [METHOD OF SAMPLING AND WEIGHING CONCENTRATES AND CRUDE ORE STOCKPILED OFF PREMISES. Subd. 24.] It is understood and agreed that should the part... of the second part desire to stockpile concentrates off the demised premises or on land not owned by the state, the parties shall agree upon a method of sampling and weighing such concentrated ore for the purpose of determining the amount of royalty due, and in case they are unable to agree, each shall choose a referee and the two referees so chosen shall choose a third. The decision of such board of referees shall be binding on the parties in interest as to the methods to be employed in such sampling and weighing only. Should the party of the second part desire to stockpile crude ore off the demised premises for a temporary period not to exceed one year, the commissioner of conservation may prescribe the method of removal and the method of sampling and weighing such crude ore for the purpose of determining the amount of royalty due.

EXHIBIT "37" - Copy State of Minnesota Iron Ore
Mining lease 1941

15. [STATE INSPECTION; SPECIAL INSPECTORS AT PLANTS TREATING ORE FROM MORE THAN ONE MINE. Subd. 25.] The party of the first part shall have the right to enter upon and into said premises at any time, and to inspect and survey the same, and to measure the quantity of ore which shall have been mined or removed therefrom, not unreasonably hindering or interrupting the operations of the part... of the second part.

The part... of the second part shall provide, upon written request from the commissioner of conservation, a suitable room in the dry or wash house or in some other suitable place on said premises, with water, light and heat free, for the use of the commissioner or his agents in the work of inspection on said premises, such room to be at least equal in size and equipment to that customarily furnished for the use of the mining captain or superintendent at mines comparable to the mine or mines on said premises. The commissioner or his agents shall have the right to enter and inspect at any time any plant where ore from said land is treated or beneficiated, and to take such samples and make such tests as may be necessary to determine the effects of such treatment or beneficiation. *In case ore from more than one state mining unit or other property is treated or beneficiated at the same plant, the commissioner may appoint such special inspectors for such plant as he deems necessary to insure proper accounting and protect the interest of the state, and the part... of the second part shall reimburse the state monthly for the cost of all such inspection service, upon notification thereof by the commissioner.*

16. [ADDITIONAL MONTHLY AND ANNUAL REPORTS TO BE FURNISHED BY LESSEE: EXPLORATION, MINE AND MILL SAMPLES REQUIRED. Subd. 26.] *In addition to other reports or statements required hereunder, the part... of the second part shall furnish the commissioner of conservation with the following:*

(1) Copies of all exploration reports, concentrating plant reports, mine maps, analysis maps, cross-sections and plans of development made and used in the operations on said leased premises;

(2) At least a quarter portion of all exploration samples, and, when requested by the commissioner in writing, a quarter portion of mine or mill samples;

(3) A monthly report showing the estimated weight and analysis of all ore material stockpiled according to each classification, whether merchantable, concentratable, or non-merchantable;

(4) A monthly report showing the estimated weight and analysis of concentrated ore when stockpiled on state-owned land;

(5) A monthly report of all ore beneficiated, showing the tonnage and analysis of crude ore treated, the tonnage and analysis of concentrates recovered, and a record of any analysis made of tailings and rejects.

(6) Not later than February 1st of each year during said term, a summary statement of the tonnage of all iron ore and other iron-bearing material mined on said land during the previous calendar year under each schedule or classification, showing the average analysis of iron, silica, phosphorus, alumina, and manganese on all merchantable ore, such analysis as the commissioner may require on other iron-bearing material, and such other information as to the grade, character and disposition of such ore and other material as the commissioner may direct.

17. [LESSEE TO PAY ALL TAXES. Subd. 27.] The part... of the second part further covenant... and agree... to pay all taxes, general and specific, which may be assessed against said land and the improvements thereon made, used or controlled by said part... of the second part, and the iron ore product thereof, and any personal property thereat owned, used, or controlled by the part... of the second part, in all respects as if said land was owned in fee by the part... of the second part.

18. [OPERATIONS TO BE CONDUCTED IN ACCORDANCE WITH GOOD MINING ENGINEERING. Subd. 28.] It is further understood and agreed as follows:

(1) The part... of the second part will open, use and work the mine or mines on said land in such manner only as is usual and customary in skillful and proper mining operations of similar character when conducted by the proprietors on their own land and in accordance with the requirements, methods, and practices of good mining engineering, and in such manner as not to cause any unnecessary or unusual permanent injury to such mine or mines or inconvenience or hindrance in the subsequent operation of the same or in the development, mining, or disposal of any iron ore or other valuable mineral left on or in said land.

(2) [DISPOSAL OF IRON ORE AND OTHER MATERIALS NOT OTHERWISE LAWFULLY DISPOSED OF.] Subject to the approval of the commissioner of conservation, all iron ore and other material produced or accumulated in connection with any operations hereunder and not otherwise lawfully disposed of shall be deposited or disposed of by the part... of the second part at such places and in such manner as will not hinder or embarrass such subsequent operations or activities; provided, that any such material containing iron or other minerals in such quantity or form as to have present or potential value shall be deposited only on the land covered by this lease, or on other land belonging to the state and available for the purpose, unless the commissioner of conservation shall approve in writing its disposal in some other manner.

(3) [LAND CONVEYED TO THE STATE FOR STOCKPILING PURPOSES.] *Land conveyed to the state upon condition that it shall be used for the storage of iron ore or other materials having present or potential value belonging to the state, subject to termination or reversion of title when no longer needed or used for that purpose, shall be deemed suitable and available therefor. The Commissioner may accept such a conveyance in behalf of the state if he shall determine that the conditions thereof conform with the foregoing provisions and will fully protect the interest of the state in the materials to be so stored, but no consideration shall be paid for such conveyance unless authorized by law. The existence of mineral reservations with rights to use or destroy the surface in connection therewith, shall not prevent lands being deemed suitable and available if the commissioner finds that the lands are located off the generally recognized limits of the iron formation, and the commissioner finds that no minerals of any present or foreseeable commercial value are known to exist thereon. The provisions of Minnesota Statutes, section 500.20 shall not apply to any conveyance of land to the state pursuant to this subdivision and shall not limit the duration of any covenant, condition, restriction, or limitation created by any such conveyance.*

19. [LESSEE TO ACQUIRE NECESSARY RIGHTS TO SURFACE NOT OWNED BY STATE. Subd. 29.] *It is understood and agreed that in case any interest in the land covered by this lease or in any minerals therein is owned by anyone other than the state, this lease shall not be construed as authorizing any invasion of or trespass upon such other interest, that in case it shall be necessary to make use of any such other interest in connection with any operations hereunder, the part... of the second part shall obtain all necessary legal rights therefor before proceeding therewith, that the part... of the second part shall be liable for all damages to any such other interest caused by any operations hereunder, and that the state shall not incur or be subject to any liability therefor.*

20. [SUPPLEMENTAL AGREEMENT PERMISSIBLE COVERING CERTAIN MATTERS. Subd. 30.] In case it shall become impossible or impracticable at any time during the term of this lease to comply with the provisions hereof relating to sampling, analysis, shipping, or weighing of ore, or in case methods for any of said operations shall be developed which appear to be superior to those herein prescribed and which will not result in any loss or disadvantage to the state hereunder, the commissioner of conservation, with the approval of the executive council, may make a supplemental agreement with the part... of the second part, modifying this lease so as to authorize the adoption of such other methods for any of said operations so far as deemed expedient.

21. [REMITTANCES. Subd. 31.] *All remittances by the part... of the second part hereunder shall be made payable to the state treasurer and shall be transmitted to the commissioner of conservation, who shall audit the same, take such action as may be necessary on account of any error or discrepancy discovered, and deposit all remittances found due with the state treasurer.*

22. [STATE LIEN FOR UNPAID SUMS DUE. Subd. 32.] The party of the first part reserves and shall at all times have a lien upon all ore mined and upon all improvements made by the part... of the second part upon the land covered by this lease for any unpaid sums due hereunder.

23. [LESSEE'S RIGHT TO TERMINATE LEASE. Subd. 33.] The part... of the second part shall have the right at any time to terminate this lease in so far as it requires the part... of the second part to mine ore on said land, or to pay royalty therefor, by delivering written notice of such intention to terminate to the commissioner of conservation, who shall in writing acknowledge receipt of such notice, and this lease shall terminate sixty days after such delivery unless such notice is revoked by the part... of the second part by further written notice delivered to the commissioner before the expiration of said sixty days, and all arrearages and sums which shall be due under this lease up to the time of such termination shall be paid upon settlement and adjustment thereof by the part... of the second part.

24. [LESSOR'S RIGHT TO TERMINATE LEASE UPON DEFAULT. Subd. 34.] This lease is granted upon the express condition that if any sum owing hereunder by the part... of the second part for rental, royalty, taxes, or otherwise shall remain unpaid after the expiration of sixty days from the time when the same became payable as herein provided, or in case the part... of the second part or any agent or servant thereof shall knowingly or willfully make any false statement in any statement, report, or account submitted to the state or to the commissioner of conservation or any of his agents pertaining to any matter hereunder, or in case the part... of the second part shall fail to perform any of the covenants or conditions herein expressed to be performed by said part... of the second part, then it shall be the duty of the commissioner of conservation to cancel this lease, first having mailed or delivered to the part... of the second part at least twenty days notice in writing thereof, whereupon this lease shall terminate at the expiration of said twenty days, and the party of the first part shall re-enter and again possess said premises as fully as if no lease had been given

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to the part... of the second part, and the part... of the second part and all persons claiming under such part... shall be wholly excluded therefrom except as hereinafter provided, but such termination and re-entry shall not relieve the part... of the second part from any payment or other liability thereupon or theretofore incurred hereunder.

25. [RIGHTS OF LESSOR AND LESSEE DURING 90 DAY PERIOD FOLLOWING TERMINATION. Subd. 35.] It is mutually agreed that upon the termination of this lease, whether by expiration of the term thereof or by act of either party, the part... of the second part shall have ninety days thereafter in which to remove all equipment, materials, railroad tracks, structures, and other property placed or erected by the part... of the second part upon said land, and any such property not removed within said time shall become the property of the party of the first part; but the part... of the second part shall not remove or impair any supports placed in any mine or mines on said land, or any timber or frame work necessary to the use or maintenance of shafts or other approaches to such mine or mines or tramways within the same. Subject thereto, it is understood and agreed that upon the termination of this lease by expiration of the term thereof or otherwise, the part... of the second part will quietly and peaceably surrender possession of the land covered thereby to the party of the first part.

26. [LEASE BINDING ON ASSIGNEES AND SUCCESSORS. Subd. 36.] The covenants, terms and conditions of this lease shall run with the land and shall extend to and bind all assignees and other successors in interest of the part... of the second part.

27. SPECIAL CONDITIONS, IF ANY, PRESCRIBED BY THE COMMISSIONER OF CONSERVATION PERTAINING TO THE UNIT HEREIN, UNDER AND PURSUANT TO LAWS 1951, CHAPTER 547, SECTION 1, SUBD. 2, ARE ATTACHED HERETO AS EXHIBIT "A" AND MADE A PART HEREOF.

28. THIS LEASE IS ISSUED UNDER ALL APPLICABLE PROVISIONS OF M. S. 19______, CHAPTER 93.

IN TESTIMONY WHEREOF, The party of the first part, by and through its commissioner of conservation, with his official seal attached, has caused this instrument to be executed, and the part... of the second part... hereunto set _________ hand_____ and seal_____, the day and year first above written.

Signed in Presence of:	STATE OF MINNESOTA
	DEPARTMENT OF CONSERVATION
____________________	____________________ Commissioner of Conservation
____________________ As to State	By ____________________ Deputy
____________________	____________________
____________________	
____________________	____________________
____________________	
____________________ As to Lessee	____________________

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STATE OF ____________________)
) SS
COUNTY OF ____________________)

On this ____________ day of ________________, 19____, before me, a Notary Public within and for said county and state, personally appeared ____,

to me personally known who, being duly sworn by me on oath, did say that he ____________ the person who signed the foregoing instrument and acknowledged that he signed the same as ______________ free act and deed for the uses and purposes therein set forth.

____

Notary Public, ____________________ County ____________
My Commission expires ______________________________

STATE OF ____________________)
) SS
COUNTY OF ____________________)

On this ____________ day of ________________, 19____, before me, a Notary Public, appeared ______________________________ and ______________________________________, to me personally known, who, each being by me first duly sworn, did say that ______________________________ is the ______________________________ and ______________________________ is the ______________________________ of the ______________________________, a ______________________________ corporation, that the seal affixed to the foregoing instrument is the corporate seal of said corporation, and that said instrument was executed in behalf of said corporation by authority of its Board of Directors; and said ______________________________ and ______________________________ each acknowledged said instrument to be the free act and deed of said corporation.

____

Notary Public, ____________________ County ____________
My Commission expires ______________________________

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EXHIBIT "A"

The special conditions prescribed under Paragraph 27 by the Commissioner of Conservation are as follows:

(1) If the leased premises shall not have been fully explored by drilling within ten years from the date of the lease, unless the lease is designated at the time as a taconite iron ore mining lease, the commissioner of conservation, by written notice mailed or delivered to the lessee, may require the lessee to make such further exploration of the premises by drilling as the commissioner may direct in the notice or otherwise. Such drilling shall be commenced within one year after the giving of such notice, and shall be completed within three years after the giving of such notice unless such time shall be extended by the commissioner in writing. After the expiration of 15 years from the date of the lease, in case the commissioner shall have determined from the results of such exploratory drilling or otherwise that there is in the premises any ore subject to classification under Schedules 1 to 6, inclusive, he may, by written notice mailed or delivered to the lessee, specify the estimated amount of such ore and notify the lessee to comply with the requirements for mining the same or paying advance royalty thereon as hereinafter provided. Commencing with the next calendar year beginning not less than six months after the giving of such notice, the lessee shall mine and remove from the leased premises during each calendar year of the remainder of the term of the lease a quantity of such ore computed by dividing the total quantity specified in such notice by the number of calendar years of the remainder of the term of the lease, commencing with the year when such mining is required to begin as aforesaid. In case the quantity of the ore mined in any year of such remaining period shall exceed the amount required to be mined hereunder, such excess shall be credited on the requirements for succeeding years. In case the lessee shall fail during any year of such remaining period to mine the quantity of ore required hereunder, upon written notice from the commissioner of the tonnage of the deficiency and the amount due on account thereof, the lessee shall pay to the state at the next regular due date for payment of royalty occurring not less than twenty days after the giving of such notice, an amount equivalent to the royalty that would have been payable on the tonnage of the deficiency at the rates applicable hereunder if such tonnage had been mined during such year, computed on a pro-rata basis in proportion to the quantities of ore under the respective schedules specified in the commissioner's estimate aforesaid, assuming an average dried iron analysis of 57.00 per cent for all schedules. Such payment shall be in addition to any minimum rental required hereunder, shall be deemed advance royalty, and shall be credited on any royalty becoming due on ore removed from the leased premises hereunder within two years after the end of the calendar year in which the deficiency occurred. Any estimate of ore made by the commissioner as hereinbefore provided shall be binding unless disputed by the lessee by written notice given to the commissioner within 90 days after the giving of the notice of the estimate. In case of such dispute, unless the commissioner and the lessee shall agree upon the quantity of ore involved, the question shall be referred to a board of referees, of whom the commissioner and the lessee shall each choose one and the two thus selected shall choose a third. The decision of such referees shall be final and binding for the purposes hereof. In case of such dispute and pending the determination thereof, the estimate made by the commissioner shall be effective for all purposes hereunder, provided, that upon determination of the dispute, proper adjustment of the accounts of the lessee shall be made in accordance therewith.

(2) In case the lease is a taconite iron ore mining lease, within 25 years after the date of the lease, if originally so designated, or, if subsequently so designated, within 25 years thereafter, the lessee shall be actively engaged in mining taconite upon the leased premises or within 50 miles therefrom in the State of Minnesota, and shall have produced at least 300,000 tons of commercial iron ore concentrates within a consecutive period of 12 months from taconite mined from the leased premises or within 50 miles therefrom in the State of Minnesota, and shall continue to produce such concentrates at such rate each calendar year during the remainder of the term of the lease, commencing with the 26th full calendar year after the date of the lease or the subsequent designation thereof as a taconite iron ore mining lease, as the case may be, unless these requirements shall be suspended or modified by the commissioner of conservation, with the approval of the executive council, upon application of the lessee and for good cause shown. If, at any time during the term of this lease when taconite is not being mined on the leased premises, information shall be acquired by the commissioner of conservation disclosing that the lands covered thereby may contain merchantable deposits of iron ore of the classes defined in Schedule 1 to 6, inclusive of Section 93.20, the commissioner may require, by written notice mailed or delivered to the lessee, additional drilling and exploration to determine whether or not the premises are principally valuable for taconite. In case the lessee shall fail to comply with the aforesaid requirements during any calendar year, the lessee shall pay to the state the sum of $5,000 at the next regular due date for payment of royalty hereunder after the end of such calendar year, which payment shall be in addition to any minimum rental required hereunder, shall be deemed advance royalty, and shall be credited on any royalty becoming due on ore removed from the leased premises hereunder within two years after the end of the calendar year in which the default occurred.

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(signed) ____________________

Commissioner of Conservation