SOME ASPECTS OF THE DEFINITION OF IRON ORE[1)]

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ABSTRACT

Several aspects of the definition of iron ore, as presented in the "Survey of World Iron Ore Resources" of the United Nations, are reviewed.

Due to the variety of iron ore formations no general cut-off grade can be indicated.

Some outside factors can be of decisive importance for an iron-bearing formation reaching the "ore" status.

INTRODUCTION

In: Survey of world Iron Ore Resources (United Nations, New York 1970) iron ore is defined as follows:

A natural occurrence of iron-bearing material that is or may be used for the extraction of metallic iron as the principal product under existing or anticipated economic and technical conditions.

The above cited definition of iron ore halts between several opinions:

Since pellets are made from taconite, which is a "natural occurrence", taconite is for the miner some type of iron ore; for the steelmaker, however, pellets are considered as iron ore, as they are used for the "extraction of metallic iron". However, 2 to 2.5 tons of taconite of 25-30% Fe are required for the production of 1 ton of pellets of 60-65% Fe. Thus statistics could show different figures if taconite-tonnages were taken into account instead of pellet-tonnages as iron ore production figures.

Another point is that "economic conditions" can be quite different in a country with free enterprise compared with a planned-economy country. Also "technical conditions" can be interpreted differently by a miner and by a steelmaker. For instance, although the producer might technically be able to mine an iron ore, the consumer might not want to use it because of the technical conditions of his steelplant.

And lastly, a factor that has not been mentioned specifically in the definition of iron ore, is the influence of transportation. As producers and consumers are not always located in the same place, about 35% of the iron ore products mined world-wide is nowadays transported overseas. If transport costs to the steelplant would be too high, the iron formation would not be considered an iron ore, in spite of all other requirements being fulfilled.

Because of all these different aspects, this lecture has been divided into the following chapters:

I Which are the requirements of the steelmaker for an iron ore?

II How can the iron ore mining industry meet these requirements?

III What can be the influence of transportation on the definition of iron ore?

WORLD SITUATION

The iron ore mining industry is world-wide dependent on the steel industry, because the steel demand regulates the iron ore demand. This is demonstrated in fig. 1, where the world raw steel production figures centrally.

When in 1971 a slump occurred in the steel industry, iron ore production increased. The next year the steel industry recovered, but then the iron ore production lagged, as large stocks still existed. Thus the iron ore production, in following the raw steel production, was out of phase. It is clear that in this case iron ore production did not involve "iron ore" as per the U.N. definition, but as products of iron ore, such as run-of-mine, coarse, fines, concentrates and pellets, which shall be called iron ore products here.

In the course of the last decennia, the average ratio of iron ore products against raw steel has decreased. This can be explained by the fact that the grade of iron ore products had risen, also by using an increasing proportion of pellets – nowadays more than 15% – which are partly made from low-grade ores. The average ratio of pig iron against raw steel increased because of decreasing amounts of scrap used. This can be explained on the one hand by the fact that the availability of scrap decreased, on the other hand by the increasing application of oxygen blowing processes – now more than 60% – which diminish technically the possibility of using scrap by up to 25-30%.

1) Edited version of a lecture held in Delft on 21st February 1974 for the Mining Division of the Royal Institute of Engineers and the "Mijnbouwkundige Vereeniging".

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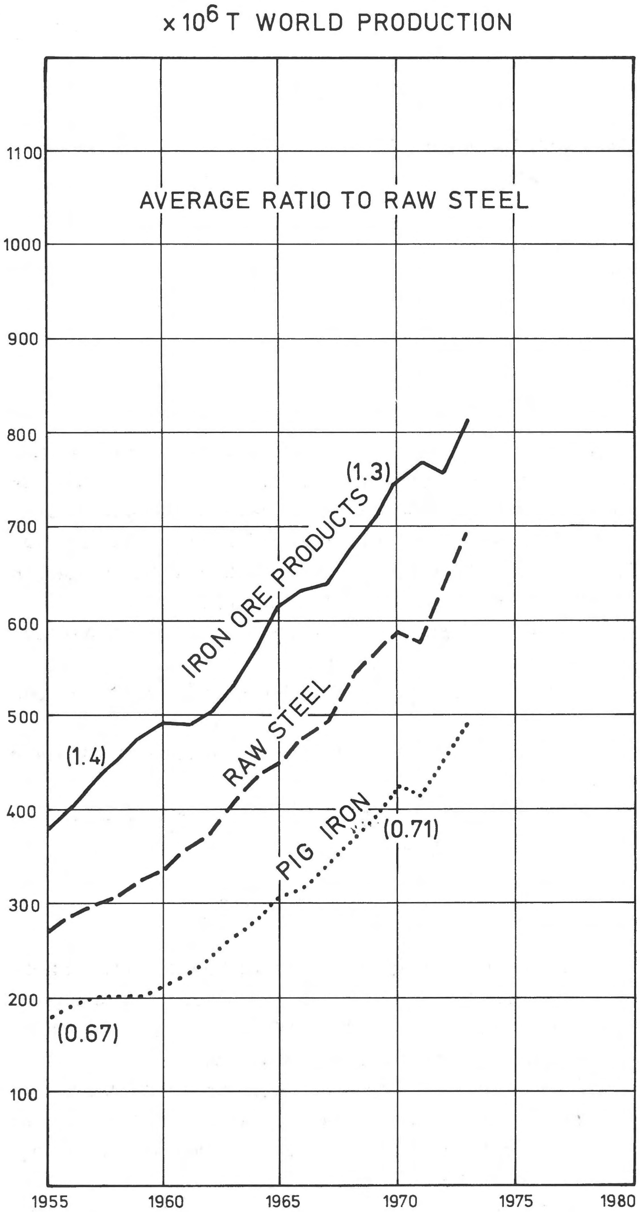


Fig. 1
This graph can be read as follows: (In rounded figures):
In 1973, out of 800 million tons of iron ore products, 500 million tons of pig iron was produced. Out of this amount, and 200 million tons of scrap added, 700 million tons of raw steel was produced. These figures are approximate, because no distinction was made between indirect and direct reduction methods, the latter being responsible for less than 10% of total production.

THE STEEL INDUSTRY

Because of its strength and durability, steel is the most used metal and at the same time the cheapest. Its use in the world is increasing, although not so much in the advanced industrial countries, where consumption may eventually become saturated.

Another phenomenon can be observed in modern steel constructions: a bridge can be built with less steel than before because new types of steel are stronger. However, steel production rises world-wide because of the increasing population and the increasing consumption per capita in the less industrialized countries.

A blast furnace, called "tall furnace" in other European languages, is a vertical counter current reactor, in which solids react with gases. As hot iron and slag are tapped in turns, it is not a continuous process. As a fuel coke must be used because coke has a threefold function:

1° to produce, through combustion, a temperature of about 1150°C. At this temperature iron, in which up to 4% carbon is dissolved, becomes an eutectic mixture with a relatively low smelting point.

2° to form CO – as in the Boudouard equilibrium – which reduces the greater part of iron oxyde. Therefore this process is called indirect reduction.

3° to remain as long as possible solid in order to support the load of the burden and to let the gases through.

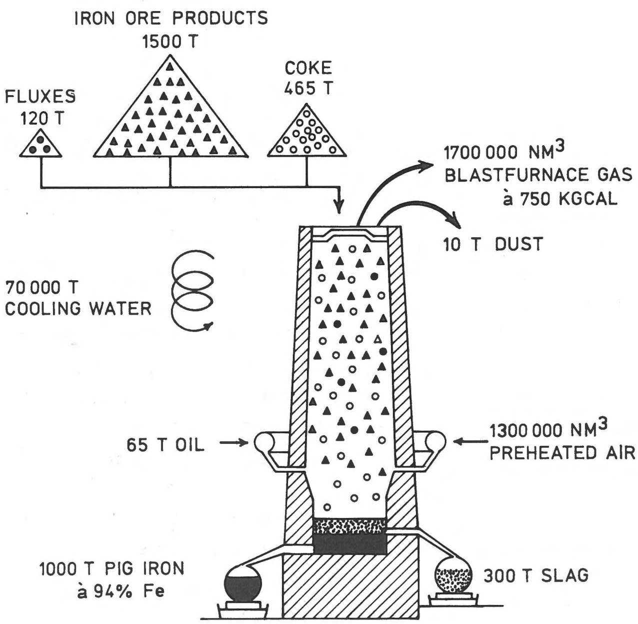


Fig. 2
Typical average blast furnace performance based on 1,000 tons of pig iron production.

In view of these functions, coke can be substituted by other fuels only to a limited extend: e.g. up to about 15% by fueloil. other fuels only to a limited extent: e.g. up to about 15% by fueloil. Because of possible lack of coke in future, research is aimed at making artificial coke. However, it is not expected that the coke-metallurgy will be substituted by other methods. In Japan plans are ready to build the biggest blast furnace in the world with a production capacity of 15,000 tons pig iron per day.

The direct reduction process uses much smaller units and is suitable for the socalled mini-steelworks. This process, in which iron oxyde is also reduced by gas, requires high-grade iron ore products, but has the advantage that it works in a more direct way: making sponge iron by not reducing the other elements that have a higher affinity to oxygen than iron. The blast furnace has a rough way of reducing other elements. Those elements for which the affinity to oxygen is about the same as for iron are reduced as well, entering the pig iron as impurities, which at a later stage will have to be removed.

Sulphur, that enters the blast furnace also as a part of the coke, is removed for a great deal with the slag. Though a minimum quantity of slag is aimed at, also in view of coke economy, a quantity sufficient to remove the sulphur will always be necessary. For the properties of steel, especially phosphorus and sulphur are disastrous, while other elements, such as nickel or chrome, which are necessary to give special properties to steel, should not already be present in the iron ore. For this reason the Conakry laterite iron mine in Guinea was closed in 1967: the ore contained 1.8% Cr and, consequently, became unsaleable.

Thus the pig iron, after the reduction in the blast furnace, contains apart from carbon, other reduced elements as well, such as silicium, phosphorus, titanium, etc. For the removal of these elements a selective oxydation process must be applied:

1° *in convertors*

In a convertor, oxygen is blown with a lance on the top of the hot iron which is mixed with a limited quantity of scrap. This method, invented after World War II by the Austrian steel industry at Linz and Donawitz – and therefore called L.D. – is a variation on the Bessemer process of steel making. More than a hundred years ago, Bessemer invented steel making by blowing air through holes in the bottom of a convertor. This method could only be applied if the pig iron did not contain too much phosphorus, as this element could not be removed. Therefore, low-phosphoric iron ores are still called "Bessemer" ores: the Lake Superior Bessemer ores contain a maximum of 0.045% P.

Thomas introduced the possibility to remove the phosphorus with lime using a basic refractory. The phosphorus-containing slag was used as fertilizer. With this system phosphorus-containing ores, like those from Sweden, could be used.

2° *In hearth furnaces*

A generally applied steel making process was the open hearth, invented by Siemens in Germany and by Martin in France. This method is still in use in those countries where steel making started. In IJmuiden the hearth furnace has been taken out of production, mainly because of pollution problems. However, it had the advantage that it could be charged up till 100% with scrap. In order to introduce oxygen, a special type of big lumps of iron ore was used: open hearth lump.

The electric furnaces are also of the "hearth" type, but electrically heated with electrodes or by induction. These furnaces are of smaller capacities and iron ore products of high grade can be charged, like pre-reduced pellets with scrap. By adding other elements, such as Mn, Ni, Cr, Mo, V, Co, special steels, like stainless steels, can be made. There may now exist more than 10,000 different kinds of steel.

THE STEELMAKERS' REQUIREMENTS OF AN IRON ORE PRODUCT

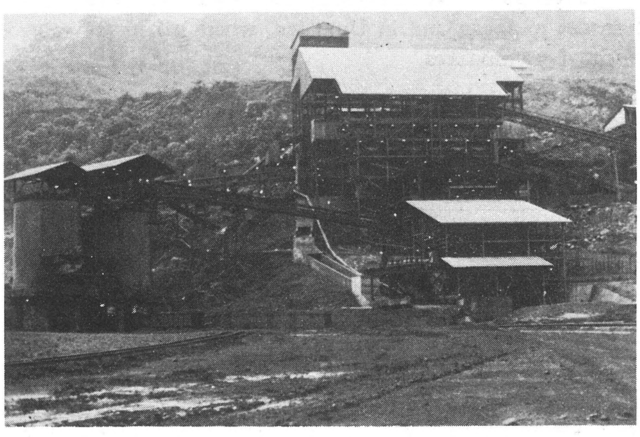
1° *Chemical composition*

The iron ore product must be high in iron content, free of silicium, phosphorus, titanium, etc. For the removal of these elements must have the desired basicity, which is defined as the ratio between $CaO + MgO$ and $SiO_2 + Al_2O_3 + TiO_2$.

The influence of other elements is extensively described in the chapter "Impurities in iron ore" by J.R. Miller in the aforementioned Survey of World Iron Ore Resources. They will not be diseribed here, with the exception of a case with titanium. The iron sands of New Zealand contain about 35% titanomagnetite; with magnetic separation a concentrate of 57% Fe with 7-8% TiO_2 is obtained. This concentrate is used for a kiln-type-direct-reduction-electric-melting operation in New Zealand. It is also shipped as slurry to Japan. American and European steelmakers reject this material as iron ore on account of its high titanium content, but for New Zealand and Japan it is an "iron ore".

2° *Mechanical composition*

By crushing and screening, iron ore is separated into coarse and fine products. Depending on what type of beneficiation system is used, such as gravity separation, magnetic separation or flotation, iron concentrates are made.



Beneficiation plant of Mano River, Liberia, of National Iron Ore Company (85% Liberian shareholding)

If the resulting concentrates are too fine for sinterfeed, they become pelletfeed. There are only a few mines that ship pelletfeed; in such cases the pelletfeed is a byproduct of a concentrating process for other elements (Palabora-TRANSVAAL = copper ore, Tasu-BRITISH COLUMBIA = copper ore, and Marcona-PERU, where the iron ore has to be ground very finely in order to be able to lower its copper and sulphur content.)

A coarse ore or coarse iron product must resist attrition during handling. This resistance can be verified with the tumbling test; the hardness of a pellet can be measured with the cold compression test. On the one hand the product must be hard, while on the other hand it must be sufficiently porous in order to be easily reduced in the blast furnace. Its reducibility is an important specification for evaluating an iron ore, as this relates to coke consumption.

The upper dimension of a coarse product must be such that a maximum reducibility can be obtained, the lower limit such that the grains are not carried along by the gases in the blast furnace. A current dimension for blast furnace feed is 1" to $\frac{1}{4}$"; it is also called "natural pellet" – analogue to pellet sizes.

It is normal practice to sinter the fines at the blast furnace, where also other materials, such as blast furnace dust, etc. are added. For sintering, the upper size limit is the lower limit of the coarse ore, while for the under limit the permeability of the sinterbed is decisive.

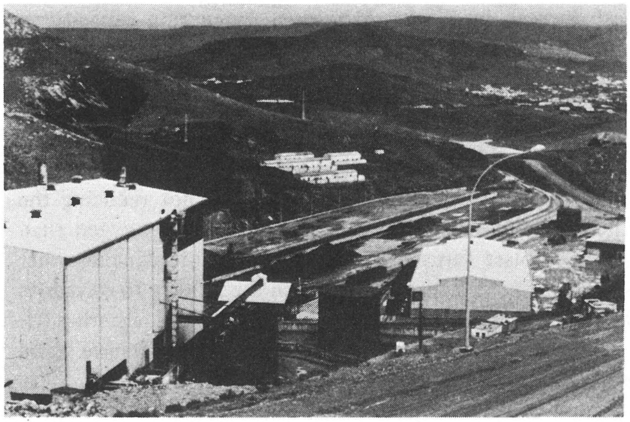
It is difficult to indicate a certain size as this depends on the nature of the ore. Some concentrates consist of specularite, the shape of which, when mixed with other fines, adds to maintain the permeability. Fines of earthy ores act as binder and help to form micropellets, increasing thus the permeability of the mixture of ore and coke breeze on the sinterstrand. In practice, the lower limit is around 100 mesh or 150 micron. From fines and concentrates below this size limit, an artificial coarse product has to be made. Normally pelletizing is already done at the mine or at the harbour, before shipping. As the product has been fired, the transport of excessive moisture is thus avoided.

Exceptions to this practice are found at some blast furnaces in Japan and in IJmuiden, where pellets are being made of ore mixtures.

Fig. 3
A shift to products of lean iron ores can be expected in the future, which adds value to the raw material.

IRON ORE PRODUCTS

	Run of Mine + Rubble ore x mill.t	%	Screened fines + pellets of natural fines x mill.t	%	Concentrates + pellets of concentrates x mill.t.	%	World Total xmill.t	%
1960	250	50	190	38	60	12	500	100
1970	240	32	290	39	220	29	750	100
1980	200	20	400	40	400	40	1000	100



Pelletfactory of the Société d'Exploitation des Mines du Rif, Morocco, Here Mildrex shaft furnaces are used for pellet firing. On the background the abandoned furnaces for roasting the pyrite out of the iron ore.

For the finished pellet the Blaine number in cm^2/g is determined as a measure of the porosity of the pellet.

Table 3 shows that the quantity of rubble ores diminishes proportionally over the years. In former times it could even happen that only the coarse product was shipped and thus became "iron ore", whereas the fines, with the same chemical composition, were left behind. The price difference – which in part consists of sintering costs – added to the transportation costs proved to be too large to promote these fines to "iron ore". A run- of- mine ore can only be accepted by steelworks with screening facilities.

3° *No decrepitation*

In the upper zone of the blast furnace, no decrepitation of the coarse ore may occur. Some types of iron ore, especially hematites which have been built up by negative enrichment (= natural removal of silica of quartz banded iron formation) can have this inconvenience.

A poor outcome of the tumbling test and decrepitation is an indication for dust formation in the blast furnace.

4° *No plastic deformation*

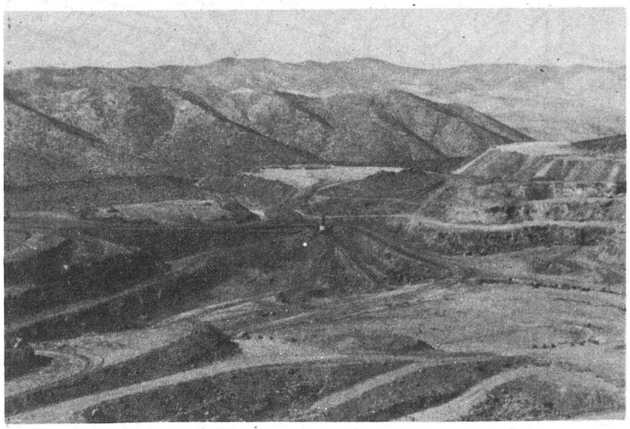
In the lower, hotter zone of the blast furnace, no plastic deformation of the iron ore products may occur during the reduction phase. The "Burghardt" test of "reduction softening under load" gives an indication of this defect: the ore or pellets become soft or swell and form a barrier for the passage of gases in the blast furnace.

In the definition of iron ore all these specifications are taken together under the heading "technical conditions", but it must be realized that these requirements are made by the consumers.

As can be surmised, an iron ore that passes with honour all these examinations and is not too expensive, rarely occurs. And if it would occur somewhere, it would already have been mined or it would be situated in a region which the Germans call "menschenfeindlich".

THE IRON ORE MINING INDUSTRY

For almost a century the Lake Superior district supplied the American steel industry with iron ore of 52% Fe average. When after World War II these ores became depleted, a world-wide exploration for iron ore was organized. At the same time the protore of Lake Superior: taconite, started to be used for making pellets.



Tom Price of Hamersley Iron Pty. Ltd. in West Australia. A mountain of iron ore

The first overseas iron ores for the U.S.A. came from Peru and Chile after the opening of the Panama canal in 1913. After World War II, iron ores from Venezuela, West-Africa and Brazil arrived in large quantities at the American and European steel plants. Already earlier Swedish, Spanish and North African iron ores had found their way to Western Europe.

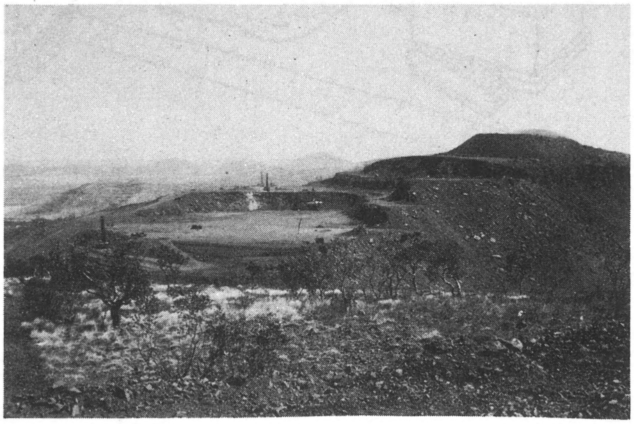
Fig. 4
The trend of increased iron ore imports implies more steelmaking activities in coastal areas.

AUTOCHTONOUS IRON ORE CONSUMPTION
in %

	1950	1960	1970
China	100	100	100
U.S.S.R.	100	100	100
U.S.A.	90	69	60
Japan	38	10	2
W. Germany	49	21	7
France	99	93	75
Britain	44	32	25

China exported some iron ore to Japan from Hainan Island in the Tonkin Bay, but recently China has started to import high grade iron ore from Australia and Brazil. Russia not only covers completely its own needs, but supplies also iron ore to the Comecon countries as well as to W. Europe and Japan. Germany has always been importing much Swedish iron ore, but after closing its own iron ore mines, has now also iron ore mining interests in Liberia and in Brazil.

As soon as Britain had a larger port, it became easier to import iron ore from as far away as Australia. France, by erecting new steel plants on the coast, has now also become increasingly an iron ore importing country. The Netherlands, having no domestic iron ore, not only imports all the iron ore, but also for 100% the coking coal. The coastal position with deep water at IJmuiden is therefore ideal. Japan, having become the third steel producer of the world only a few years ago, has its steel plants close to deep water as it has become almost completely dependent on imported raw materials.



El Algarrobo of Compañía Acero del Pacífico, Chile, On the background the Andes Mountains

Australia since the outbreak of World War II had banned the export of iron ore. When it became known that in West Australia large iron formations were available and its export became economically feasible with giant ore carriers, after the suez-crisis in 1956 – the ban was lifted. By establishing long term contracts with Japan, even of 22 years' duration, the financing of these ventures with their heavy infrastructure became possible. For a 10 million ton per year mining venture, the investments run into $ 30 to $ 35 per ton year production, as also railway, port and townships had to be included. Not only Japan supplied equipment, but on account of those long term contracts also loans could be obtained. In other words, the iron ore product was sold "in situ" and for geologists it meant that their reports could be used for banking on the future.

Cut-off grade

For other ores, as a rule of thumb a general cut-off grade can be assumed, but for iron ores, this varies from case to case. An example of the lowest cut-off grade for iron ore is cited in a paper presented to the American Mining Congress by McArthur and Porath (1965). It describes how a high grade magnetic concentrate is recovered from alluvial

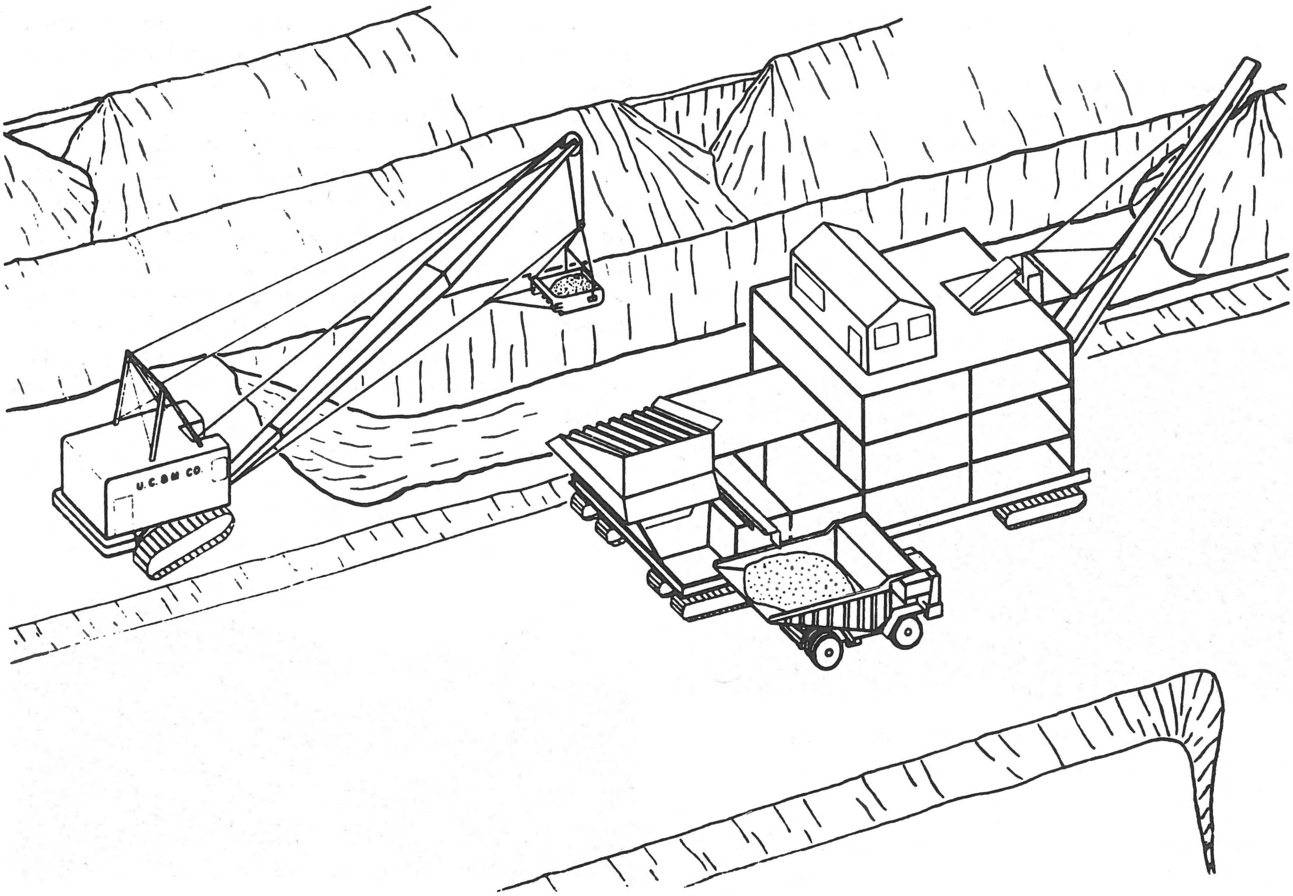


Fig. 5
Utah Construction & Mining Co.

deposits of the Iron Springs in Utah. Integration of mining, milling and waste disposal into one compact mobile operation, attended by a crew of 8 men per shift, has made possible the economic recovery of 25,000 tons of iron concentrate per month from 300,000 tons of crude ore with a cut-off grade of 6% Fe. This is only slightly above the Clarke number of 5.06% for iron in the earth's crust.

A mine manager will always try to mine the ore with the lowest admissible cut-off grade, as in this way the reserves will be used to the fullest possible extent. Once a mine has offered a description of the quality of the ore to its clients, it is a first requirement to abide by this description.

It has been demonstrated in the steel plant that the highest efficiency and the best possibility to automatize the operation can be obtained if the feed is of constant quality. For this purpose bedding systems are used before sintering or pelletizing. At Bong mine in Liberia even the taconite is mixed in a bedding system before concentrating.

Outside factors

In practice, sometimes an outside factor, can be decisive for an iron formation becoming an "iron ore".

In Baffinland in North Canada, a huge high grade iron formation occurs which under normal conditions would already be in exploitation. However, its potential harbour is free of ice for only 2 months of the year and no solution has been found to solve this problem, since the trial with the "Manhattan" to transport Alaska oil through the Northwest Passage, failed.

Iron ore deposits situated in desert countries require high investments for infrastructure. In spite of the efforts of the mining companies to build comfortable living quarters, with communications, school, hospital, recreation, etc., the labour turnover proves often to be excessive, sometimes 200% per year. Especially in the case of a highly mechanized operation, the training of new operators may cause a bottleneck. In desert-like countries the lack of fresh water may be a drawback, not only for the people, but also for the processing of the ore. Extreme heat or cold, a nuisance for living conditions, has also its effect on mining.

In Canada, concentrates are dried in order to avoid freezing. At some receiving ports, especially where it can be very windy, dry ores are moistened in order to avoid dust problems.

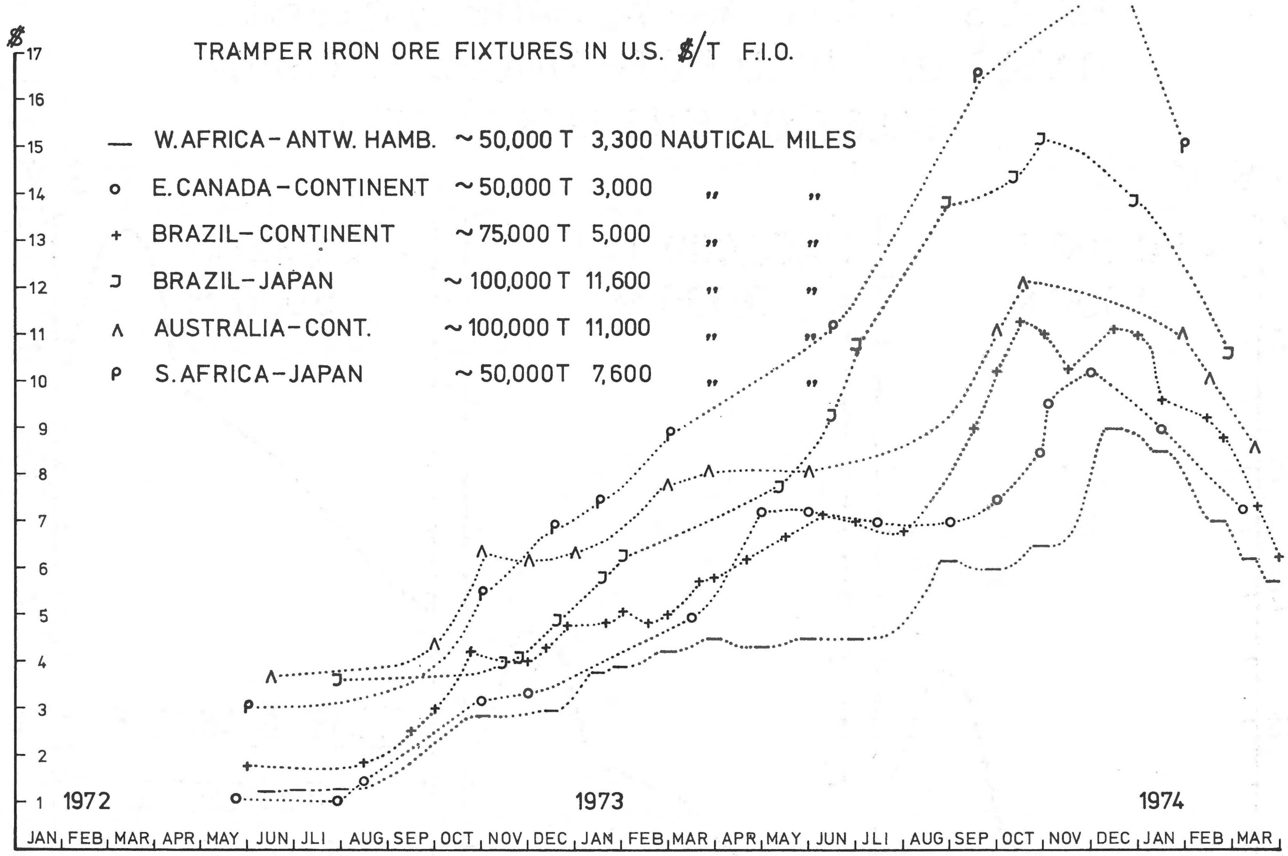


Fig. 6
Tramper iron ore fixture in U.S.$/ton, f.i.o.
Showing a tentative correlation of tramper freight rates, which may vary according to shipsize.

Heavy rains do not only hamper the open pit mining operation, but can also give an excessive moisture to the ore. Too much moisture in certain concentrates can render a cargo dangerous for shipping, because of the risk of shifting. Typhoons have interrupted mining and transportation in W. Australia. Some harbours need special protection against gales and the resulting waves. Also high tidal differences necessitate special loading arrangements. The Ungava Bay project in Labrador has not yet been put into production, as frequent fogs and ice-bergs seem to hamper regular shipping from that region. The Swedes, who work at the open pit Nimba mine in Liberia, consider low hanging clouds at certain times of the day, more troublesome than the winter-darkness they are accustomed to at Kiruna, although this is an underground mine.

TRANSPORTATION

Iron ore is, after oil, the most transported raw material over sea.

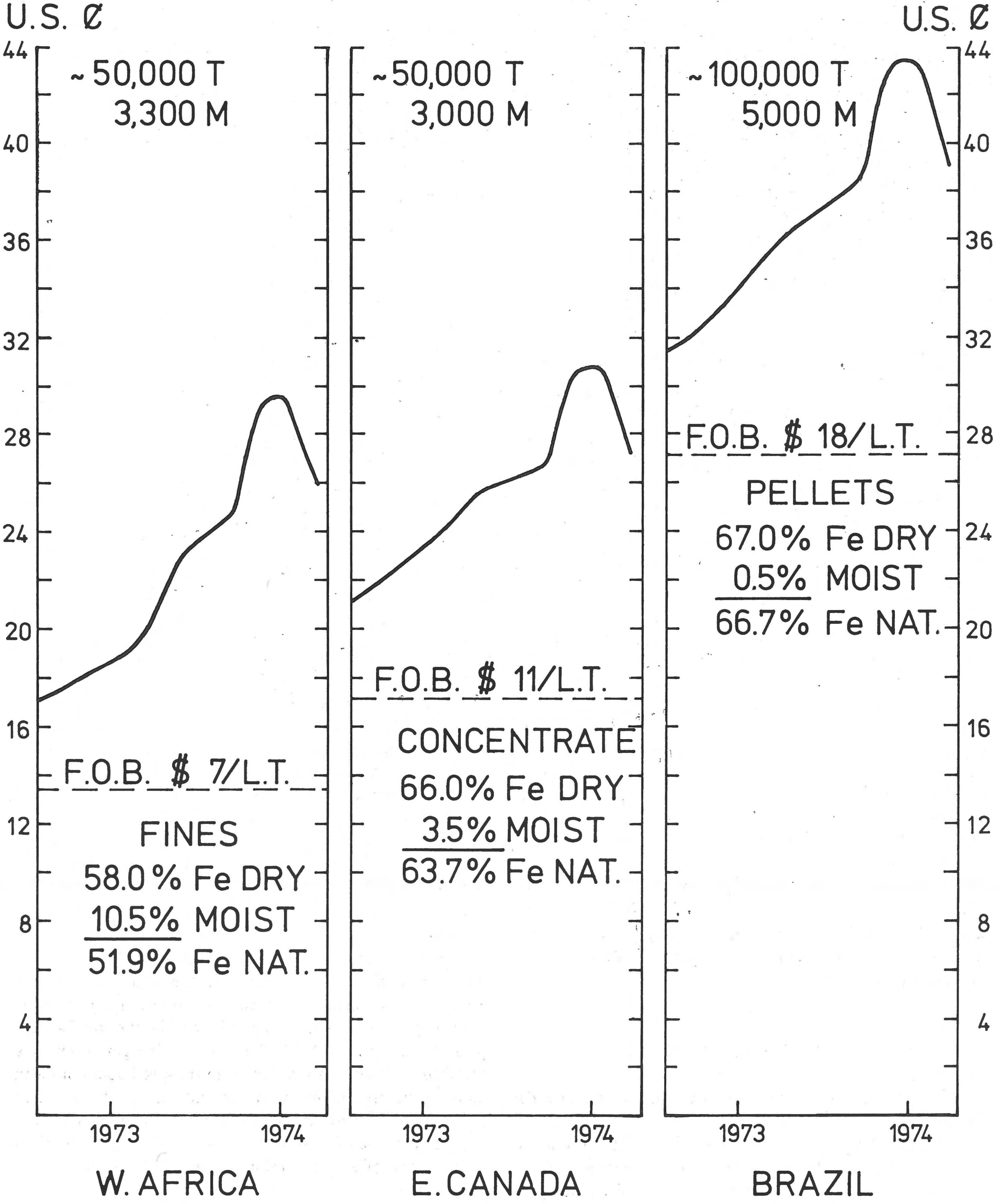
Whereas oil tankers can more easily be loaded and unloaded, for iron ore heavy constructions are needed and the ship has to be close to the quay. Therefore the economy of using mammoth oil tankers is not the same as for ore carriers. Slurry transport of iron ore can remedy this inconvenience to a certain extent: if the ore is loaded as slurry with seawater, the ore has to be washed again in order to get rid of the alkali contents, which are harmful for the refractory lining of the furnace. In that case the advantage of cheaper handling costs is offset by the necessity of a washing plant at the receivers' end, for which fresh water is needed.

Furthermore, as only very fine iron ore can be slurried, thus unavoidably becoming a pellet feed, at present only few steel works in the world can use this material.

The oil crisis

The 4th Arab-Israelian war, in October 1973, had an unexpected oil crisis as a result. In the iron ore sector the effect of this political crisis was mostly felt in higher prices for energy as well as in an acute lack of bunker oil for shipping at some places. A 140,000 tons deadweight vessel, at a speed of 15 knots – for a ship, a slower speed does not mean more economy, taking into account its fixed costs and availability – consumes about 100 tons of bunker oil per day. An increase of $ 50 per ton in the price of bunker oil on a round trip of 28 days means $ 1 per ton of higher freight costs for the ore.

EFFECT OF TRAMPER IRON ORE FREIGHT RATES ON C.I.F. ANTW./HAMB. ¢/%Fe/L.T. BASED ON FIXED F.O.B. PRICES FOR SPOT SALES ON END 1973 LEVEL.



The effect of the lack of bunker oil was felt more in the Pacific Ocean than in the Atlantic basin. Therefore, there was more shipping space available on the Atlantic, also due to the switching of O.B.O. carriers (oil bulk ore) to dry cargo.

Fig. 6 deals only with the transport of spot sales of iron ore on the freight market, not with long term sales covered by long term charter contracts.

The freight rates had already begun to climb due to increased grain transports to planned-economy countries and also as a consequence of the U.S. dollar devaluations.

In order to show only the effect of increased transport costs in the price of delivered iron ore, changes in the iron ore prices were not taken into consideration. Due to the successive dollar-devaluations – iron ore prices are mostly expressed in U.S. dollars on the world market – iron ore f.o.b. prices (free on board) have also been corrected. For the steel works accounts the iron ore product as delivered: c.i.f. price (cost-insurance-freight); thus the mineowners, receiving the f.o.b. price, do not reap much benefit from the increased delivered prices. Though higher fuel prices affect both iron ore mines and steel works, pellets made out of hematite require more fuel than those made out of magnetite, because of magnetite's built-in heat.

Conclusion

Although iron formations are abundant all over the world, the availability of some form of energy i.c. of coking coal or fuel oil, can act as growth limit.

For the time being, steel does not have to fear competition from alternative materials such as aluminium or plastics; its substitution can reach about 5% in weight.

Rather a combination of the various materials would be preferable so as to lessen corrosion, which causes steel to return to what it came from: iron oxyde.

Fig. 7
Effect of tramper iron ore freight rates Antwerp/Hamburg range on c.i.f. ore prices, based on fixed f.o.b. ices for spot sales on end 1973 level.
Iron ore prices are expressed in U.S. dollar cents per iron unit and per long ton.
The f.o.b. price difference between concentrates and pellets of same origin can indicate the approximate co of pelletizing.