# TECHNICAL & ECONOMIC STUDIES ON COLAR, COLUMBIA

MAY, 1979

JAPAN INTERNATIONAL COOPERATION AGENCY.

# FOREWORD

In compliance with the request of the Government of the Republic of Colombia, the Japan International Cooperation Agency dispatched a survey mission headed by Mr. Shigeo Kamatani of Kobe Steel, Ltd. to Colombia for the purpose of making a technical diagnosis and recommendations on the blast furnace plant of Colombiana de Arrabio Ltda.

During its four-week stay in Colombia from April 15, 1978, the mission visited and made technical and economic studies on the blast furnace at COLAR's CAJICA plant as well as the neighboring iron ore and coal mines, coking plant, limestone quarry and Paz del Rio Ironworks.

This report contains the findings of the study as complied by the mission based on the analysis of the data and samples of iron ore and coal collected in Colombia.

It is my sincere hope that the diagnosis and recommendations given herein will be found useful in promoting the development of Colombian iron and steel industry and in fostering the friendly relationship between our two countries.

I wish to express my gratitude to the authorities and officials concerned of Colombia for their very helpful assistance offered to the study mission.

Shinsaku Hogen
President
Japan International Cooperation Agency

May 1979

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# 1. INTRODUCTION

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## (1) Purposes and Objectives of the Dispatch of Blast Furnace Experts

According to the agreement concluded between the Colombian Government and the Japanese Government, the Japan International Cooperation Agency (JICA) dispatched a team of blast furnace experts to Colombia for a period of April 16 to May 10, 1978.
During their stay in Colombia, the team members conducted technical and economic diagnosis and recommendations of Colombiana de Arrabio Ltda. (hereinafter referred to as COLAR) with respect to the blast furnace and the relating facilities, their operations, and the entire process from the mining of raw materials all the way to products, and formulated recommendations germane to the upgrading of the entire system.

## (2) Formation of the Team

| Name | Affiliated company | Assignment |
|---|---|---|
| Shigeo Kamatani | Amagasaki Works, Kobe Steel, Ltd. | Blast furnace |
| Hiroshi Yuki | Mineral Resources Research Dept., Kobe Steel, Ltd. | Mining |
| Kan Aketa | Raw Material Planning & Control Section, Kobe Steel, Ltd. | Benefication |
| Shiro Omori | Overseas Project Dept., Kobe Steel, Ltd. | Cost accounting |
| Kenichi Nabeta | Plant Engineering Dept., Kobe Steel, Ltd. | Maintenance |
| Hiroaki Nakagawa | Training Div., JICA | Coordination |

(3) Colombian Representatives Left Out Prefixes from the Names

<u>Nacional de Planeacion</u>

Hania Isaber Vega (Jefe Division Politicas Industriares)

Alvanso Rosares (Tecnico Division Cooperacion Técnica Internacional)

<u>Instituto de Fomento Industrial (IFI)</u>

Oscar Gaviria Giraldo (Assistente de Gerencia)

Gustavo Zuluaga Zapata(Assistente de Sub-Gerencia de Inversiones)

Benedicto Romero (Jefe Depto. Coordinacion y Control de Inversiones)

Humberto Jonnergra M. (Assistente de Jefe Depto. Coordination y Control de Inversiones)

John Munévar Escobar (Tecnico Depto. de Proyectos)

<u>COLAR</u>

Pablo Castillo (Gerente)

Rossy Martinez G. (Assistente de Gerencia)

Roberto Torres B. (Superintendente de Planta de Cajica)

Gabriel O. Morales G. (Jefe Division Financiera)

Francisco Prada Ramirez (Jefe Division Relac. Industriales)

Tomas S. Espinosa (Jefe Division Comercial)

Laureano Rendon Ramerez (Ingeniero, Jefe de Depto. de Materias Primas y Suministros)

Julio Cesar Pinson (Jefe de Depto. de Control Calidad)

Jesus A. Gomez (Ingeniero, Administrador de Coqueria de Montecristo)

<u>Cyf Mineros</u>

Alvaro Tenjo Gutierrez (Ingeniero, Administrador Proyectos Mineros)

* left out prefixes from the names

Caqueza Caliza

Luis E. Valencia (Gerente)

Paz del Rio

Rafael Blanco M. (Superintendente de Alto Horno)

(4) Itinerary

| Date | | Place | Schedule |
|---|---|---|---|
| 1978<br>April 16 (Sun) | 17:40 | Bogotá | Arrived at Bogotá (AV-051) |
| April 17 (Mon) | 10:00 | do | Courtesy call at the Japanese Embassy, schedule arrangements |
| | 11:00 | do | Arrangements with COLAR executives at Japanese Embassy |
| April 18 (Tue) | 9:00 | Cajica | Inspection of COLAR Cajica Works, diagnosis and recommendations |
| | 15:00 | Ubate | Inspection of Minas Montecristo |
| | | do | Inspection of COLAR's Montecristo Coke Ovens and diagnosis |
| April 19 (Wed) | 9:30 | Pericos | (Raw Materials Group, Policy Group): Inspection of Pericos Iron Ore Mine, a captive mine of COLAR, and diagnosis |
| | 10:00 | Cajica | (Blast Furnace Group): Diagnosis and recommendations at Cajica Plant |
| April 20 (Thu) | 10:00 | Pacho | Inspection of Pacho Iron Ore Mine |
| | 15:00 | Cajica | Sampling of iron ore and coke at the stock yards of Cajica Plant |
| April 21 (Fri) | 11:00 | Tibirita | Inspection of Citenza Iron Ore Mine of Cyf Mineros, and diagnosis |
| April 22 (Sat) | 10:00 | Caqueza | Inspection of Caqueza Limestone Quarry, and diagnosis |

| Date | | Place | Schedule |
| --- | --- | --- | --- |
| 1978<br>April 23 (Sun) | | Bogotá | Discussions in the team; classification of data |
| April 24 (Mon) | 9:00 | do | Discussions with COLAR executives at the headquarter of COLAR; data collection at the headquarter of COLAR |
| April 25 (Tue) | 8:30 | do | (Policy Group): Courtesy call on the executives of IFI |
| | 11:00 | do | (Policy Group): Courtesy call on the executive officers of Nacional de Planeacion |
| | Noon | do | (Policy Group): Diagnosis and recommendations (at the head-quarters of COLAR) |
| | Noon | Cajica | (Blast Furnace Group): Diagnosis and recommendations (at Cajica Plant) |
| | 9:00 | do | (Raw Materials Group): Diagnosis and recommendations (at Cajica Plant) |
| April 26 (Wed) | 9:00 | Bogotá | (Policy Group): Diagnosis and recommendations (at the head-quarters of COLAR) |
| | 9:00 | Cajica | (Blast Furnace Group): Diagnosis and recommendations (at Cajica Plant) |
| | 9:00 | Ubate | (Raw Materials Group): Diagnosis and recommendations (at Montecristo Coke Ovens) |
| April 27 (Thu) | 10:00 | Paz del Rio | Inspection of Paz del Rio Iron Works |
| April 28 (Fri) | | Bogotá | Discussions in the team; classification of data |
| April 29 (Sat)<br>April 30 (Sun)<br>May 1 (Mon) | Holidays | do | do |
| May 2 (Tue) | 9:00 | do | (Policy Group): Diagnosis and recommendations (at the head-quarters of COLAR) |

| Date | | Place | Schedule |
|---|---|---|---|
| May 2 (Tue) | 9:00 | Cajica | (Blast Furnace Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| | 9:00 | do | (Raw Materials Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| May 3 (Wed) | 9:00 | Bogotá | (Policy Group):<br>Diagnosis and recommendations<br>(at the headquarters of COLAR) |
| | 9:00 | Cajica | (Blast Furnace Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| | 9:00 | do | (Raw Materials Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| May 4 (Thu) | Holiday | Bogotá | Intra-team discussions for preparation of interim report; classification of data |
| May 5 (Fri) | 9:00 | do | (Policy Group):<br>Diagnosis and recommendations<br>(at the headquarters of COLAR) |
| | 9:00 | Cajica | (Blast Furnace Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| | 9:00 | do | (Raw Materials Group):<br>Diagnosis and recommendations<br>(at Cajica Plant) |
| May 6 (Sat) | Holidays | Bogotá | Preparation of interim report |
| May 7 (Sun) | | do | do |
| May 8 (Mon) | | do | Preparation of interim report |
| | 14:00 | do | (Policy Group): Meetings<br>(at the Japanese Embassy) |
| May 9 (Tue) | 9:30 | do | Presentation of interim report to COLAR executives (at the headquarters of COLAR) |
| May 10 (Wed) | 11:15 | do | Left Bogota for Japan (BN-908) |

## (5) Summary of the Diagnosis and Recommendations by Experts

Taking account of the diagnosis and recommendations made by the blast furnace experts during their stay in Colombia and of the assay results of samples of raw materials (which arrived at the Central Research Institute of Kobe Steel, Ltd. on July 13, 1978, to which they belong) after their return home, the experts described in their respective fields, mining, beneficiation, agglomeration of raw materials, engineering of blast furnace and relating facilities, operations and business management, worked out diagnosis and recommendations with their own expertise as outlined below. For details, refer to the chapters to follow.

### 1) Technical aspect

a. The campaign exhibited by the first blast furnace during the period from its blowing-in in December 1972 till the emergency repair in March 1978 was far below an average acceptable level with a result that the fuel consumption was about 1,600 kg and productivity approximately 0.40 tons/$m^3$/day, though it had to turn out high-silicon foundry pig iron. From the viewpoint of facilities and operations (incl. raw materials), the following factors are considered responsible for this poor operation.

a) Factors concerning blast furnace facilities

i) The hearth diameter is too small compared with the throat diameter, belly diameter and inner volume; namely, the annular active zone in the hearth is constricted, limiting the output.

ii) Another factor is that there is not any cooling box installed in the top of the shaft. Considering the structural design of the wearing plate which is quite anomalous, it is inferred that the shaft lining may have slumped down to reduce the utilization of furnace gas owing to the development of circumferentially intermixed layer resulting from disturbance in the layer-by-layer descending of charges.

iii) Because of poor capacity of blast furnace gas purifier, dust-laiden gas attacked the fire bricks in the hot air stove, and failure to deliver high-temperature blast air resulted.

b) Factors concerning operations (incl. raw materials)

i) The coal used is high in fluidity and in dilatation and contraction. It is high volatile, and is comparatively low in carbonization for coking purposes. Thus, the produced coke shows a low stability index; this means that an expectedly large extent of degradation in the furnace blocks up the passages for gases and melts.

ii) The iron ore used is of the goethite group of low Fe and high silica contents. Consequently, it sends up a slag ratio, and is vulnerable to degradation in the furnace. In addition, the ore is problematic in high-temperature reduction and in the behavior of softening and melting.

iii) The size of limestone, iron ore and coke is too large, leaving much to be desired from the viewpoint of reaction efficiency in the furnace.

b. Points to be observed in blast furnace operation after emergency repair

The materials and methods applied for the repair this March involve various matters. Thus, the survey team can neither project nor warrant the furnace life.
For the furnace operations from now on, the following precautions should be strictly observed.

i) More intensified dousing on the hearth mantle, especially at the iron tap and slag notch.

ii) Rigorous cleaning and temperature control of mantle surfaces.

iii) Production of high-silicon low-sulfur pig iron.

It is also recommended to push forward a major rejuvenation program as detailed in the following paragraph.

c. Promotion of reconstruction plan for the future

For details, refer to Chap. 2.5. In the plan, the furnace profile has been optimized while maintaining the furnace height, belly diameter, throat diameter and iron tap level in view of dimensional interfaces with the existing peripheral installations. As a result, the furnace capacity can be increased some 10%. The implementation of this profile will lead to an increased output, and should be decided upon after due analysis of the future demand for foundry pig iron.
As regards the refractories for furnace lining, discussions are made in Chap. 2.6. For refractories, the proven and reliable manufacturers should be singled out.

d. Measures recommended for improvement in operational stability and campaign results

a) The quality of raw materials have a large bearing on the blast furnace operations. Also, the costs for the raw materials account for some two thirds of the total cost for pig iron production. In view of the above facts, COLAR should spare no pains to obtain the raw materials of high quality at low prices in a stable way.
The informations of mines concerned, however, have not been fully controlled by COLAR, and the geological, mineralogical and metallurgical studies of raw materials have not been well prepared by the mining firms concerned. It is therefore recommended to conduct basic geological studies and prospecting works of ore deposits, and researches and development of mines. These activities will call for superordinate expert knowledge, and should be left to the care of authoritative consultants.

It is also recommended to push forward exploration, prospecting and feasibility study for mine developments not only in the existing mines, but also in research of new resources.

b) Coking

For the purpose of maintaining stable furnace operations and reducing fuel consumption, the coke stability index ($T_{25}$) should be at least 50%. At present, however, $T_{25}$ is as low as 30 to 40%.
Efforts should be made to increase $T_{25}$ in step with the promotion of the measures recommended below;
for example, $T_{25}$ should be increased to more than 45% in the first stage and to more than 50% in the second stage.

Measures recommended

i) Honogenization of coal blending by grouping and pulverization.

ii) Well-balanced blending of inert materials (petroleum coke, anthracite) and/or low-volatile coals.

Note: The following effects are expected, though their degree may be dependent on the quality and nature of the coals used.
An addition of inert materials by some 5% will send up $T_{25}$ by about 5%.
Some 30% of addition of low-volatile coal produced in a country like U.S.A. will result in an increase of more than 15% in terms of $T_{25}$.

iii) Sizing of coke: 15 to 75 mm

iv) Improvement in coking process through the replacement of beehive coke ovens by chamber coke ovens and also through modern instrumentation.

c) Beneficiation of ore

i) Strict size control on iron ore and limestone.

The tolerance should be tightened from the hitherto 5 to 50 mm range to a narrower 5 to 30 mm range.

ii) Implementation of the ore bedding method already recommended, and the improving in its practice.

iii) The blast furnace burden are Pacho, Citenza, Nueva Vizcaya, Pericos Grueso and Caldera ores in the descending order of quality. Careful consideration is needed in selecting the main ore.

iv) Iron ore fines and coke breeze generated by crushing and sizing should preferably be sintered for recovery. For this purpose, a sintering machine of continuous rotary disc type is regarded as appropriate.
According to sintering test, self-fluxed sinters with a $CaO/SiO_2$ ratio of 1.13 was found to be qualifiable up to 900°C, but questionable in softening properties at higher temperatures.
Installation of the facility should be studied and implemented while progressively consolidating measures for improvement in high temperature properties through tests with higher $CaO/SiO_2$ ratio and addition of more fuel.

d) There is no particular problem to speak of the quality of pig iron, except high phosphorous and copper as a tramp element. These elements are almost totally fixed in pig iron, and it will be necessary to reduce the proportion of Pericos (P) and Citenza (Cu). If phosphorous can be reduced further by lowering the coke rate through improvement of blast furnace operating conditions, high-quality foundry pig iron salable at high prices will be produced.

## 2) Management

COLAR should apply themselves to taking the following measures in order to improve their profitability.

a. The annual production capacity of Cajica Plant is said to be 36,000 tons. The records of production and sales show that the annual production has been 27,000 to 28,000 tons at best. This low level of operation is the principal cause that the COLAR's business is in the red. Apart from technical problems which have prohibited the plant from working in full swing, the domestic market is to blame most for the cause of deficit as its demand remains as low as 15,000 tons a year. So long as COLAR adheres to the domestic market, the full operation cannot be expected.
COLAR should greatly promote the export of their products in order to raise the production level.

b. In order to increase export, COLAR's products must have price competitiveness in the international market. This necessitates sizable reduction in costs and expenses. COLAR, therefore, should pay much attention to the following points.

a) Reduction in unit consumption of coke

From technical point of view, the unit consumption of coke is too high with 1,600 kg. Technical improvements should be taken for reduction of the unit consumption.

b) Reduction of unit prices of iron ore and coke supplied from COLAR's captive mine and their own plant

The iron ore and coke from captive mine and coke ovens account a larger part of the total consumption.
Their prices are almost twice as much as those available from the contractors as their productivities are low.
Operating own mine and ovens is desirable to ensure stable supply of raw materials. The COLAR should make every effort to increase their productivities of iron ore mine and coke ovens or to commission the expert operate their mine and ovens.

c) Reduction of financial expenses

The financial expenses incurred by COLAR account for as much as 30 to 40% of the gross sales, squeezing COLAR's profit margins seriously.
This is due to the pressure of excess inventory and high rate of interest in the local capital market.
COLAR is recommended to exert themselves to work off the overstock and at the same time procure foreign loans with low rate of interest from Eurodollar Market, the Andes Development Authority or any other suitable financial sources that offer cheaper money. For the time being, COLAR is recommended to apply to IFI or other authorities concerned for interest subsidies or other suitable credit.

c. It has been proposed under item (1) above that COLAR should immediately be intent on sales campaign in the foreign markets for increasing its output. In addition, COLAR should also enter upon a long-term technical development for making high-quality pig iron with potential sales of high price.

d. The distance between the main office and the plant is as long as 40 Km and this is not desirable and convenient from the point of communication and staffing in view of the fact that pig iron alone is produced with as many as 250 employees.
It is therefore recommended to relocate the main office functions, including sales department, to Cajica Plant.
This will contribute to improve the communication between line and staff and reduce the number of administrative staff.

e. As already discussed, the raw materials are very important for blast furnace operations. In the case of COLAR, however, the functions relating to the raw materials are not under the command of the superintendent of Cajica Plant.
The organizational setup is recommended to be modified to bring such functions under the hand of the superintendent of Cajica Plant as it would probably lead to the improvement in the productivity of the blast furnace plant and at the same time to the stabilization of pig iron quality.

f. The blast furnace operations are much dependent on the experience of those who are engaged in them.
Cajica Plant is only five years old, and the engineering staff who must support the superintendent have not much experience. It is therefore strongly recommended that two engineers should be trained at an advanced iron-making plant either in Japan or other country, for about six months to one year, to have full knowledge about blast furnace operations and beneficiation and the technique in its practice.

# 2. EXISTING STATE OF THE TECHNICAL ASPECT, PROBLEMS INVOLVED, AND RECOMMENDATIONS

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## 2.1 Raw Material

### 2.1.1 Iron ore mines

Iron ores have been mainly supplied to Cajica Plant from three iron ore mines named Pericos, Pacho and Citenza.
Sporadically Caldera and Vizcaya iron ore mines, however, have so far been the supply sources.
Pericos is only the captive mine of COLAR, and others are contracted suppliers.
All these mines are within 100 km from the Plant, and iron ores have been hauled by truck. (Location of the mines shall be referred to the inset behind the beginning flyleaf.)
Followings are the overviews of these three major iron ore mines.

a) Pericos

Pericos is situated approximately 50 km northeast of Capital Bogota, and it takes about one hour and a half to reach there from Bogota by car.
Outcrops of the iron ore occur in the middle of the uplands having a relative height of some 500 meter (3,000 m above the sea level).
The mine consists of three concessions, namely Juqual, Curies and Samper.
The Pacho ore is of minette type consisting of a mixture of hematite, limonite and siderite. The ore bed is 8 to 10 m in thickness, and extending over about 1 km from south to north with the dip of 25 to 35 degrees to the west.
The total (proved, probable and possible) reserves are calculated at about 3 million tonnes of ore in the concession of Curies and Juqual. Particulars are left uncertain.
The ore grade on the average of the last two years (1976 and 1977) indicated as follows; Fe 45.3%, $SiO_2$ 17.63% and P 0.093%.
Namely, the ore has a little higher content of phosphorus than others.

There are the some vertical quality variations in the ore bed, namely the upper portion of ore bed shows less Fe, but more $SiO_2$ and P content, however there is little horizontal quality variation in the ore bed.

Out of poor management, a long strike sent the mine into closure in December 1977. When the experts visited there, the mine was standing ghoastly with two to three watchmen attending. The room and pillar mining system had been applied with pillars of 10 m square to the mine.

Three adits had been driven at three different levels north to south, and the raises provided at an interval of 10 m.

The blasted ore is loaded by a scraper into tubo (about 2 tonnes) and hauled out of the adits. The ore had been mainly mined from concession Curies.

The ores had been crushed into pieces of up to 60 mm through a primary crusher (Parker, U.K., opening 30" x 15") and then sent into a trommel where the pieces were washed and screened into three grades (60 to 15 mm; 15 to 6 mm; and up to 6 mm) and charged into the bins below as classified. Then, the ores were dumped into trucks through chutes for delivery.

The balance of dressed ore was as follows;

| | | | | |
|---|---|---|---|---|
| Lump, | 60 to 15 mm, | 65% wt. | } --- | delivered to Cajica Plant by truck |
| Smalls, | 15 to 6 mm, | 10% wt. | | |
| Fines, | up to 6 mm, | 25% wt. | --- | sold to a cement manufacturer |

49,958 tonnes and 29,628 tonnes of ore were produced respectively in 1976 and 1977.

The mine is scheduled to be reopened in November 1978.

It is reported that the mine will be mined at contract basis.

b) Citenza

Citenza is owned by Cyf Mineros Ltda., and located near Tibirita about 100 km northeast of Bogota. Taking Route 71 northeast, a point about 70 km from Bogota is Sisga Dam.

Taking off the route there and then turning eastward to the right, it is able to reach the mine site via Macheta.
The trip is about 2 hours and a half by car. The section between the mine site and Macheta, which is about 20 km, is left unpaved.
The iron ore occurrs in laminated form intruded between sandstone and limestone. The thickness of the ore bed is about 6 m, and the strike of bed is east to west with a north ward dip of 20 to 30 degrees. The ore has been mined by hand for some 10 years. The accessible outcrops have been almost mined out.
At present, geologists are preparing a survey report which will be finalized in a 3 months to come. Systematic mining methods shall be applied to the ore deposit according to the report.
The ore grade on the average of the last two years (1976 and 1977) was Fe 59.11%, $SiO_2$ 4.08%, $Al_2O_3$ 1.9% and P 0.014%.
At present, 18 employee are engaged in manual mining to crush the ore in sizes 50 mm to 15 mm at a monthly rate of 1,500 tonnes. The mined ores are transported by 8.5-ton trucks to Cajica Plant. The outputs in the last two years were as follows; 3,180 tonnes in 1976 and 11,262 tonnes in 1977.
About ten years ago, a small blast furnace was installed at the mine site by Citenza for the purpose of smelting iron.
But it has been left there without operation. Perhaps, its design may have been defective.

c) Pacho

Pacho is located about 47 km northwest of Cajica Plant, and owned by Continental Corporation. The very primitive mining method is applied to the Pacho iron ore deposit, because there are neither mining staff nor drawings, and the ore is mined at random by manpower of 25 to 30 employee. The mined ore is to be crushed into specified size of 50 to 15 mm, however the actual size is in the range of about 80 to 15 mm. Output in 1977 was 7,098 tonnes, and the ore grade was Fe 52.54%, $SiO_2$ 9.39%, $Al_2O_3$ 3.11% and P 0.049%.

The size distribution and chemical analysis of the ores used at Cajica Plant are shown in Tables 2.1-1 and 2.1-2.

Table 2.1-1 Size distribution of iron ores at Cajica Plant Ore Stockyard (%)

| Brand | +50mm | 50-25mm | 25-10mm | 15-6mm | -6mm |
|---|---|---|---|---|---|
| Pericos | 23 | 17 | 14 | 16 | 30 |
| Citenza | 57 | 23 | 7 | 3 | 10 |
| Pacho | 79 | 15 | 2 | 2 | 2 |

Table 2.1-2 Chemical analysis of iron ores and limestone used at Cajica Plant

| Minerals | COLAR | | | | | |
|---|---|---|---|---|---|---|
| | Minas | Chemical analysis % | | | | |
| | | Fe | $SiO_2$ | $Al_2O_3$ | P | S |
| Iron Ore | Pericos | 46.89<br>45.3 | 16.37<br>17.63 | 3.93 | 0.108<br>0.093 | 0.028 |
| | CYF(Citenza) | 54.83<br>59.11 | 9.81<br>4.08 | 1.78<br>1.97 | 0.011<br>0.136 | 0.012 |
| | Pacho | 52.72<br>52.54 | 9.53<br>9.39 | 2.92<br>3.11 | 0.079<br>0.049 | 0.043 |
| | Caldera | 43.03<br>50.5 | 16.00<br>12.76 | 4.53<br>2.62 | 0.068<br>0.08. | 0.011 |
| Limestone | Minas | Chemical analysis % | | | | |
| | | CaO | $SiO_2$ | P | | |
| | Planta de Soda | 52.10 | 4.25 | 0.080 | | |
| | Abofertil (Proyecto) | 45 | 9 | 0.065 | | |
| | A. Tenjo (Proyecto) | 52 | 4 | 0.045 | | |

(1) Upper column: Kobe's analysis

(2) Lower column: COLAR's analysis

### 2.1.2 Problems involved in the iron ore mines

a) Pericos

This mine is captive, but its mining cost is far higher than at other mines. Presumably, the operational management may be inefficient. At the time of survey by the experts, the mine was not operated. It is reported that the mine, when reopened, will be worked by a third party at contract basis. COLAR is requested not to rely entirely on the contractor, but to take upon itself to carry out at least the quality control.
The phosphorus control is very important, and COLAR should always be aware of phosphorus distribution by channel sampling from the sidewalls of adits.
While it will better to reduce the top size of the ore for the blast furnace burden, the thorough study of material balance and grain size distribution, etc. will be necessary as to the case where the setting of crusher is changed from the present 60 mm to below 50 mm.

b) Citenza and Pacho

So far, the geological study of ore deposits has not been made, and neither the reserves nor the occurrences of deposits been known. In absence of information permitting scientific approach, the mines are excavated at random from what ore is visible or from what permits easy access. In the long run, the mining activities will be sure to come to a deadlock. First of all, basic studies should be made, and then mining plans prepared.
As discussed in para. 2.2.2, the iron ore from Pacho seems likely to be the best among others, and immediate study should be started with Pacho. The major tasks involved in the study will be as follows;

1) Preparation of a topographic map ranging from a scale of 1:2,000 to 1:500.

2) Preparation of a geological map covering the iron ore deposits according to the topographic map prepared in step 1) above.

3) Diamond or percussion drillings at nodal points on a 200 m grid at the most promissing localities which will be estimated from the geological map.

4) Preparation of core logs and geological profiles according to the analysis of core samples.

5) Digging of test adits normal to the prevailing strike direction of the ore body, and preparation of basic data concerning mining and beneficiation.

6) Implementation of a feasibility study for development.

c) Prospecting for new sources in Cundinamarca

Pericos, Citenza and Pacho are the main sources of supply to Cajica Plant, but the quantity and quality of the ores they offer are not up to the needs.
Iron ores are staple feedstocks for iron making.
Thus, the government authorities concerned as well as COLAR should promote exploration and prospecting for alternative sources, say in Cudinamarca where COLAR's plant is located.
In view of the fact that the quality of the raw materials used is of governing importance to the blast furnace operations and that the raw materials account for as much as about two thirds of the total cost in the pig iron production, COLAR should spare no pains to obtain the raw materials of high quality stably on a long-term basis.

### 2.1.3 Coal mines

COLAR purchases coal from Montecristo Coal Mine about 10 km southeast of Ubate lying about 60 km northeast of Cajica, and is manufacturing coke by use of a beehive coke oven installed to the side of the entrance of that mine.
In addition, COLAR is purchasing coke from Cooprocarbon, Tinjaca and Penagos, etc., but is ill informed of what the origin of the coke is.

a) Montecristo

The size of the concession is 32 km south to north by 1 km east to west. The formation is running prevalent in the north-to-south trend with a westward dip of 20 degrees. Of the twelve seams from which coking coal is obtained, the seven seams, No.5, No.6, No.7, No.10, No.11 and No.12, show chemical and physical properties as listed in Table 2.3.1-a. The seams have an average thickness of 1 m each, and are mined by the room and pillar system.
The coal is carried out of the adit by tub.
It is stocked unclassified by seams; namely, the coal is stocked in the order loaded out.
There are no facilities for crushing, screening and dressing, and the run-of-mine coal is directly fed to the coke oven.
The reserve is said to be 300 mil. tonnes, but there is no knowing the full account of it.

### 2.1.4 Measures to be taken in coal mines

Measures are listed as follows;

a) Montecristo Coal Mine

(1) To prepare a long-term coal mining plan according to close geological survey and confirmation of reserves.

(2) To store the excavated coal as classified by seam.

(3) To install the crushing and screening plants.
(Refer to para. 2.3.5)

b) Cooprocarbon and other coke suppliers

(1) No details are known about the coking coals. It is necessary to have full knowledge about the sources from which coking coals are supplied as it is prerequisite to having coke of good quality.

### 2.1.5 Limestone mines

The limestone is supplied from a soda manufacturer at Cajica. Since its average phosphorus content is a little too much with 0.08%, studies are in progress about the feasibility of the use of limestone available from Caqueza, Tenjo, etc. Table 2.1-2 shows a chemical analysis of limestone by COLAR.

## 2.2 Iron Ores

### 2.2.1 Sizing and blending of iron ores

(1) Purpose

The smaller the size of the iron ore is, the more easily reducible it is. In the case of a shaft type like blast furnace, however, the more degraded iron ore are charged into the furnace the gas flow in it is the more affected and more segregated. In the worst case, hanging and slumping will result. The sum up, the grain size of ore has an upper limit from the viewpoint of reducibility and a lower limit from the viewpoint of gas permeability.

Ideally, the charged ore is required to be reduced uniformly in step with its downward motion.

In order to accomplish this, an uniform distribution of charges in the furnace is important. Namely, the size distribution of charges should be kept as uniform, that is, less in variation, as possible.

It is also required that the blast furnace burden are good, homogeneous and stable in quality.

The smaller the quality variation, the more stabilized the operation of blast furnace. This in turn leads to improved and stabilized quality of pig iron production and also to a sharp increase in operating efficiency. All these demand homogeneous blending of iron ore or coal both chemically and physically.

(2) Existing state of COLAR

a) Sizing of iron ore

Major suppliers of iron ore to Cajica Plant are Pericos, Pacho and Citenza. Of these three, Pericos ore is crushed and screened into sizes of 60 to 6 mm at the mine. But, the remaining two brands are subjected to manual crushing and selection to the specified sizes of 50 to 15 mm (in fact 80 to 15 mm).
The size distribution of iron ore at Cajica ore stockyard is as shown in Table 2.1-1; larges in excess of 50 mm are too much.
So far as the size distribution shows, it is evident that the reduction is poor and that the gas permeability is impaired because of heterogeneity and large variation of particle size.

b) Bedding

The COLAR has been practising bedding of the ore as recommended by Kobe Steel in August 1977.
Because of a large amount of big lump ores, segregation is noticed in the pile, spoiling the bedding practice. The blending has been practised since February 1978, but it would be too hasty to speak something or other of its effect because when the experts visited there the blast furnace was under relining to bring the blending operation to a premature suspension.

(3) Recommendations concerning crushing and sizing of iron ore

The sizing purposes to improve the gas permeability and reduction of charges in the blast furnace.
The size distribution of charges counts for much in the ascending motion of gases. If the sizes are controlled uniform, that is, if the size distribution is controlled within a narrow range, the total inter-particle void becomes large to make gas passage easy. If the size are uniform, the void becomes constant irrespective of the sizes.

In other words, the gas passage will be impeded if various sizes are mixed. Fig. 2.2-1 shows the relationship between the void and mix proportion of ore of two different sizes. Fig. 2.2-2 shows the relationship between the charge sizes and gas permeability from which it is evident that the total void can be held constant irrespective of sizes and that the gas flow gets restricted with reduction in the size of respective void owing to the increase in drag. The effeciency of reaction between charges and gas becomes larger the larger the area of contact surfaces is. Taking account of the permeability on the ascending gas, however, the size should be such that will not snap up the curve in Fig. 2.2-2.

The size should be determined in consideration of the furnace size, and the strength and size of coke.

In Japan, the sizing in the early times attached importance to limiting the size of lump, but its practice has made great progress with the development of theory. At present, smalls are screened out while the size of lump is reduced. The effects are as reported below.

i) Test for increasing the production through sizing at Nippon Steel, (Yahata Higashida No.3 BF, around 1961): Productivity of 1.98 was achieved with 50% sinters and 50% lump ore (10 to 25 mm) and with increased blast, but limitations were put on the tapping operation. (The standard productivity at that time was 1.0.)

ii) Tests for increasing the production using sized ore (Nippon Steel Hirohata Works, around 1964): Compared with 10 to 40 mm ore, the 10 to 20 mm ore when mixed with larges by 30% could reduce the coke rate by about 30 kg/T-P and increase pig iron production by some 8%.

iii) Sizing effects (Kawasaki Steel Corp. Chiba, around 1964): When the top size was adjusted to 40 to 35 mm for 40% lump ore, the coke rate could be reduced by 2 to 3 kg/T-P and the pig iron output increased by 5%.

All these demonstrate that the average size and the distribution of sizes (size ratio) have a great influence on the gas permeability and hence on the productivity of blast furnace. The results of the reports above are given in terms of the relationship between permeability index obtained from Ergun's formula and productivity in Fig. 2.2-3, telling volumes about the sizing effects.

In Japan, the size limits of charges in recent years are normally as follows.

Iron ore: Lower limit, 8 to 10 mm; Upper limit, 25 to 30 mm

Sinters: Lower limit, 5 to 6 mm; Upper limit, 50 to 70 mm

Coke: Lower limit, 15 to 30 mm; Upper limit, 75 to 90 mm

In the case of the COLAR, the sizes should be limited to 50 to 5 mm for iron ore and to 75 to 15 mm for coke until a facility for fine ore agglomeration is installed.

It is also recommended to size the ore in a manner to minimize the dust loss. According to property tests (see para. 2.2.2), COLAR's iron ore is found liable to be degraded in the furnace. This also dictates the screening-out of fines before charging. When a agglomeration plant is installed, the ore should preferably be regulated to within the range of 5 to 30 mm. The crushing and screening plants should be installed in the premises of blast furnace plant on condition that the agglomeration plant is to be installed at Cajica Plant.

The size of the broken pieces of ore is influenced more by the setting of crusher than the brand of ore and the size before breaking. For this reason, it is recommended to use a "Hydrocone" crusher in which the setting can easily be changed hydraulically.

The vibroscreen is most widely used, which is available in tie-rod type, low-head type and ripple-flow type.

The screening efficiency is governed largely by the stickiness of ore. As shown in Fig. 2.2-4, it should be borne in mind that the screening efficiency is greatly influenced by the moisture content in the ore.

A process flow sheet for the crushing and sizing facilities to be installed at Cajica Plant is illustrated in Fig. 2.2-5.
As for blending of iron ore, the best way is to mix up a small amount each of as many different brands as possible so that the total influence by the variation in quality of each brand will be decreased, achieving a target quality in a stabilized way. This is because each lot of each brand can be used for an extended period to minimize the change in quality.
For this reason, this practice is valued as "multi-brand blending effect." The multi-brand blending is carried out in various ways; one in which the blending is made by reclaiming bit by bit from piles of different brands at the stockyard, and another in which it is carried out by combining a small amount each of different brands discharged from respective bins. These methods, however, necessitate a large yard space and much construction cost.
In order to solve this problem, there is used the so-called bedding method in which different brands are spread in thin layers one upon another.
In the case of COLAR, Fe-content, P-content, etc. vary over a wide range depending on the brand.
The pig iron is the article of trade, and its chemical analysis is an important control item. It is particularly important to minize the change in chemical composition of furnace charges in the pre-treatment of raw materials. The COLAR is now practising the yard bedding for multi-brand blending at the instance of Kobe Steel in August 1977.
This blending method is respectable in that the amount of raw materials composed of blending pile stacking and shovel loader reclaiming can be reduced to as little as about 200 tons a day.
As already touched upon, the method has just started, and it must be waited and seen for some time now until its effect comes to a reality.
For the improvement of the practice, the top size of the ore should be smaller than 50 mm in order to prevent segregation at the time of stacking.

The importance of the obviation of segregation at the time of stacking will be well understood from Table 2.2-1 and Figs. 2.2-1, 2.2-6 and 2.2-7 as the size distribution governs chemical composition and characteristics (reducibility).
Whether the COLAR should go on with this recommended method should be determined after due consideration of the effects and investment cost.

(4) Problems left to future study

a) Sizing

i) Survey of the effects of sized ore on the blast furnace productivity in order to determine the optimum range of sizes.

ii) Study of installation of sizing facilities at Cajica Plant.

iii) Clarification of fine ratio by sizing, marketability of fine ore, and justifiability of fine ore processing plant.

b) Blending

i) Implementation of the bedding practice in current use.

Table 2.2-1 Chemical analysis of COLAR iron ore by size distribution

(%)

| Brand | Size distribution, mm | T.Fe | $SiO_2$ | $Al_2O_3$ | P | S | Ig.loss |
|---|---|---|---|---|---|---|---|
| Citenza | -6 | 45.64 | 18.93 | 5.33 | 0.032 | 0.024 | 6.21 |
| | 6 ∿ 15 | 48.52 | 16.92 | 3.62 | 0.023 | 0.027 | 5.62 |
| | 15 ∿ 25 | 51.67 | 12.98 | 2.81 | 0.016 | 0.022 | 6.38 |
| | 25 ∿ 50 | 52.58 | 12.76 | 2.02 | 0.009 | 0.022 | 7.55 |
| | +50 | 58.07 | 6.26 | 0.83 | 0.007 | 0.003 | 6.42 |
| Pacho | -6 | 46.09 | 15.95 | 4.97 | 0.110 | 0.042 | 10.45 |
| | 6 ∿ 15 | 48.41 | 13.81 | 4.72 | 0.095 | 0.042 | 10.70 |
| | 15 ∿ 25 | 52.91 | 8.69 | 2.92 | 0.061 | 0.045 | 11.04 |
| | 25 ∿ 50 | 52.30 | 9.03 | 3.21 | 0.059 | 0.043 | 10.75 |
| | +50 | 53.07 | 9.38 | 2.77 | 0.082 | 0.043 | 10.71 |
| Caldera | -6 | 40.23 | 21.98 | 7.07 | 0.117 | 0.042 | 10.30 |
| | 6 ∿ 15 | 49.11 | 12.45 | 3.19 | 0.111 | 0.022 | 10.81 |
| | 15 ∿ 25 | 45.18 | 16.18 | 4.95 | 0.075 | 0.039 | 10.67 |
| | 25 ∿ 50 | 48.01 | 15.54 | 4.05 | 0.058 | 0.018 | 10.53 |
| | +50 | 42.12 | 22.53 | 4.31 | 0.063 | 0.015 | 9.47 |
| Pericos | -6 | 44.98 | 17.58 | 4.87 | 0.114 | 0.023 | 8.68 |
| | 6 ∿ 15 | 47.56 | 14.88 | 4.11 | 0.113 | 0.020 | 8.79 |
| | 15 ∿ 25 | 47.62 | 14.78 | 4.25 | 0.106 | 0.022 | 8.91 |
| | 25 ∿ 50 | 45.62 | 18.45 | 3.30 | 0.125 | 0.025 | 8.15 |
| | +50 | 49.40 | 15.28 | 2.83 | 0.087 | 0.046 | 8.46 |

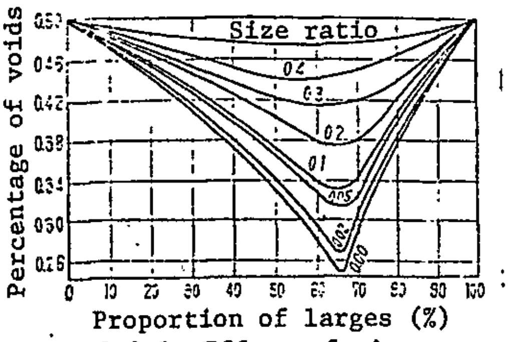



Fig. 2.2-1 Effect of size on percentage of voids

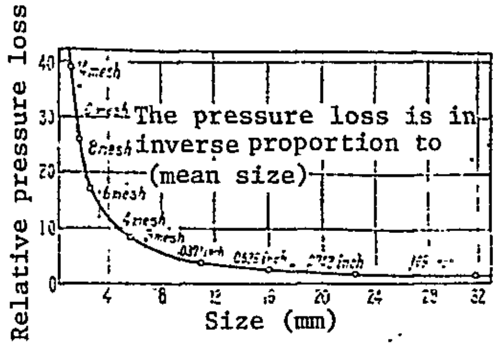



Fig. 2.2-2 Size vs. pressure loss

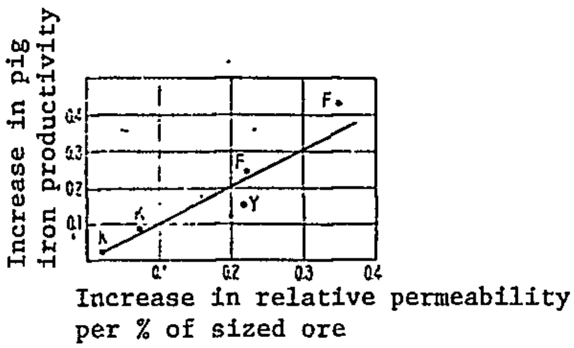



Fig. 2.2-3 Sizing effects

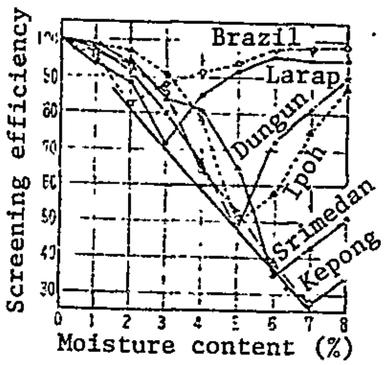



Fig. 2.2-4 Effects of moisture content on screening efficiency

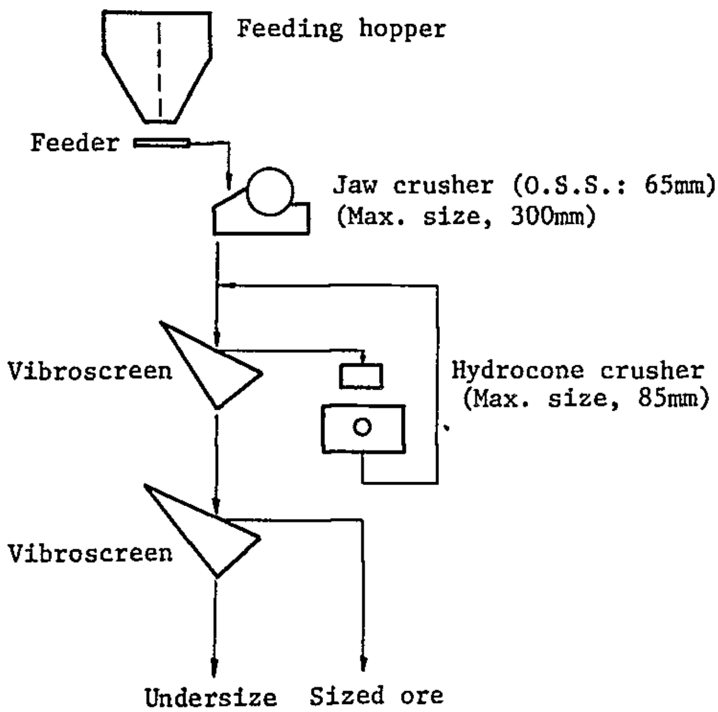



Fig. 2.2-5 Flow sheet for iron ore crushing and sizing facilities

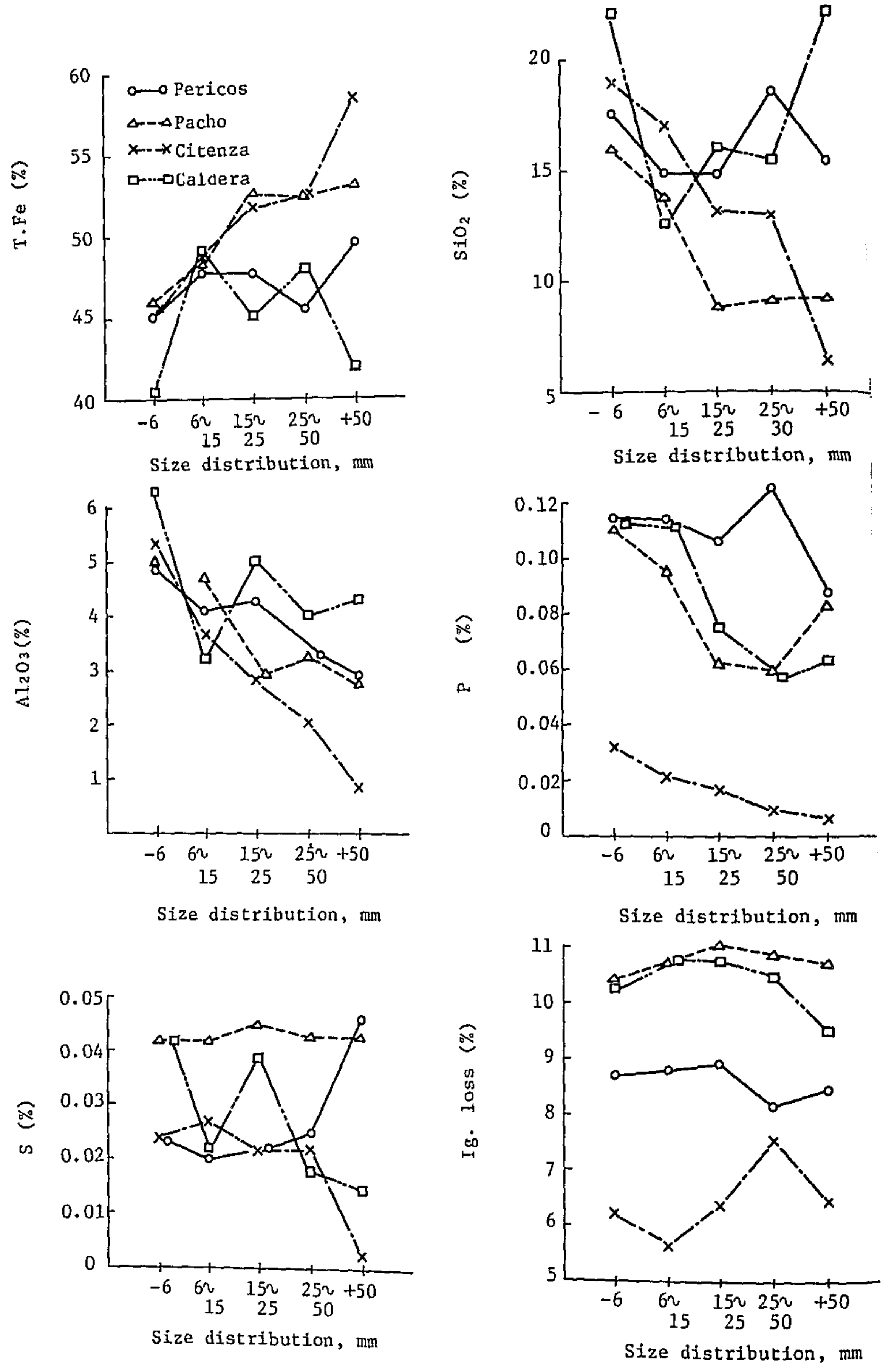



Fig. 2.2-6 Chemical analysis of COLAR iron ore by size

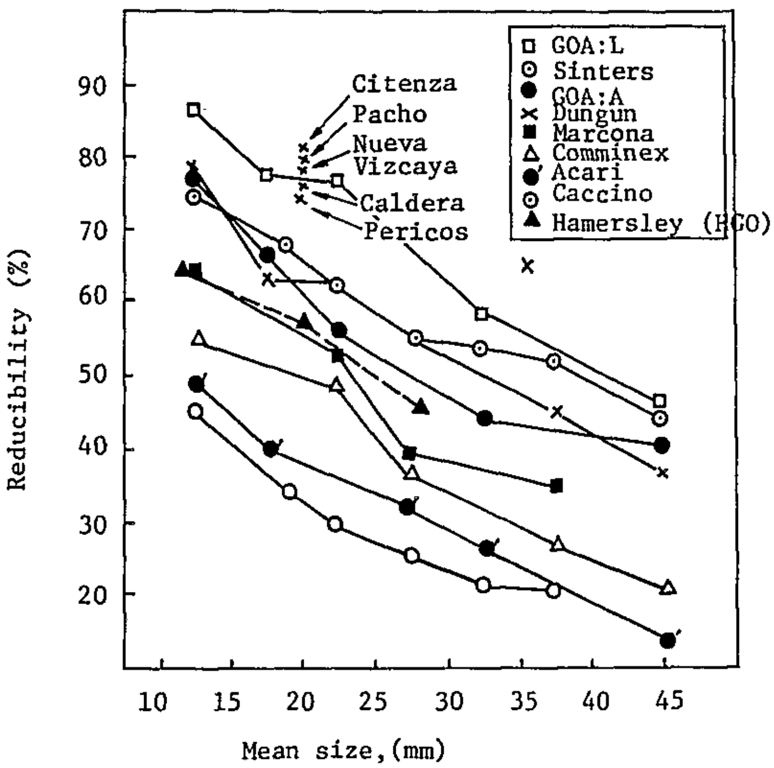



Fig. 2.2-7 Lump ore reduction test results by size

### 2.2.2 Evaluation of COLAR iron ore quality

The samples of COLAR ores were subjected to various characteristic tests, which have been taken by Kobe Steel as standard, for the purpose of evaluating the properties and quality of COLAR ores.

(1) Samples used

The samples used were five brands; Caldera, Pacho, Nueva Vizcaya and Pericos Grueso.
Even the same brand showed marked differences in appearance piece by piece, suggesting differences in quality.
In order to avoid sampling errors, the ore pieces that seemed representative were taken.
Sesa Goa ore which was similar in quality was also subjected to the same tests.

(2) Testing methods

The testing methods used are as listed in Table 2.2-2.

(3) Features of COLAR iron ores

The photos showing appearance, micrographs, chemical analysis (incl. porosity) and the results of differential thermal analysis are given in Photos 2.2-1, 2.2-2, Tables 2.2-3, 2.2-4 and Fig. 2.2-8. The differential thermal analysis was made on the samples carried by the experts back home.
The characteristics of the ores are as summarized below.

a) The ores are classified into the following two groups according to appearance, micrographs, porosity, etc.

i) Hard ores of compact crystal; Caldera, Pacho and Pericos.

ii) Porous ores of the low degree of crystallization; Citenza and Nueva Vizcaya.

The characteristics of each brand are detailed in Table 2.2-11.

b) Chemical composition

i) There are ores showing low Fe-content and high $SiO_2$ - content (particularly with Caldera, Pacho, and Pericos), high contents of tramp elements such as P (Pericos) and Cu (Citenza).

ii) From the data, including combined water content, results of differential thermal analysis, and decrease in combined water content of ore with temperature, it is judged that the COLAR iron ores are composed of chiefly goethite. (Kobe Steel's blast furnace charges show 65% Fe, 3% $SiO_2$, 1.5% $Al_2O_3$ and 1 to 2% C.W. on the average.)

(4) Test results

a) Low temperature tests (below 900°C)

These tests were conducted to evaluate the properties of the ores descending through the lumpy zone in the furnace.

i) Thermal degradation

Usually, the thermal degradation characteristic of iron ore is represented by Fig. 2.2-10 in relation to the combined water. The following is a list of characteristic zones and a brief explanation of each.

I zone: A zone containing much combined water, but insusceptible to thermal degradation because of high porosity.

II zone: A zone in which the thermal degradation takes place in proportion to the combined water content. (Degradation due to vapor pressure of the combined water)

III zone: A zone in which the thermal stress is a cause of thermal degradation without combined water.

The test results of COLAR iron ores are given in Table 2.2-5 and Figs. 2.2-11 and 2.2-12, and the samples after tests in Photo 2.2-3.

From the test results, it is found that Pacho, Citenza, and Nueva Vizcaya fall under I zone, and Caldera and Pericos under II zone.

During tests, Pericos gave off a decrepitating sound at 200 to 400°C, indicative of degradation.

All these are demonstrated by porosity and microscopic observations.

ii) Tumbler index after reduction degradation

Usually, the furnace charges are heated and reduced while descending and received some abrasive forces developed among them. The tumbler index after reduction is preferred as an index indicative of the strength in the furnace. The test results of COLAR iron ores are shown in Tables 2.2-6, -7, -8 and Figs. 2.2-13 and -14. The samples after tests are shown in Photos 2.2-4 and -5.

If -5 mm% is taken as index, Pericos shows the highest index, followed by Pacho, Nueva Vizcaya, Citenza and Caldera in turn. Citenza and Nueva Vizcaya, which showed excellent thermal degradation characteristics because of high porosity, may have disclosed a poor strength after reduction all the more for it.

Caldera showed a higher strength after reduction than Pacho when they both had almost the same value of porosity. This may be attributable to the difference in the size of pores between them.

(Caldera: Many number of small pores; Pacho: small number of large pores)

iii) JIS reduction test

The JIS reducibility of COLAR iron ores are shown in Table 2.2-9. The reducibility of common Australian lump ore which is widely used by Japanese iron and steel makers is about 50 to 60%.

Compared with this, every brand of COLAR iron ores shows an extremely high value.

This will probably be due to the effects of porosity and combined water. The differences among COLAR iron ores are generally related to porosity and gangue ($SiO_2$ + CaO + $Al_2O_3$ %).

b) High-temperature tests

These tests were conducted to evaluate the properties of the ores in the softening and melting zones in the furnace.

i) High-temperature reduction test

In this test, the ore was pre-reduced to FeO at 1,000°C as former stage and then examined at 1,250°C. Although there were some samples which started melting in a former stage, the data showed the reduction curves as illustrated in Fig. 2.2-17. The results obtained should be regarded as given by way of reference only.

ii) High-temperature softening test under load

The test was conducted in order to study how the furnace charges form a softened and melted zone in the lower part of the furnace at high temperatures. It is generally said that the furnace charges are desirable to show high softening and melting temperatures of a narrow width. Multi-brand blended charges show a higher permeability in the furnace if the component ores are closer in the behavior of softening and melting to each other.
The test results of COLAR iron ores are shown in Table 2.2-10 and Fig. 2.2-18. From the figure, the characteristics of each brand are summarized as follows.

Caldera ----- With much gangue ($SiO_2$), the ore picks up softening speed with temperature rise. It melts down quickly at 1,320°C.

Citenza --------- With a relatively small amount of gangue ($SiO_2$), the ore continues to soften with temperature rise up to around 1,000°C, but gets slower in softening at temperatures from 1,000°C up. At about 1,500°C, the ore melts down quickly.

Nueva Vizcaya --- Having a little content of gangue ($SiO_2$), the ore gets softened with temperature rise. At 1,400°C, the ore is fused away all of a sudden.

Pacho ----------- The ore becomes soft with increase in temperature. At around 1,480°C, the ore melts down quickly.

Pericos --------- With the highest content of gangue ($SiO_2$) of all the ores, the ore shows a higher softening temperature than any other ore, but its softening is quickened with temperature rise. No quick melt-down is noticed.

Compared with the Australian ore used by Kobe Steel, the COLAR ores show a lower softening temperature, but are higher in melting temperature with the exception of Caldera which shows a low melting temperature.
As shown in Figs. 2.2-19 and -20, the more the content of gangue ($SiO_2 + CaO + Al_2O_3$), the higher the softening temperature and the lower the melting temperature.
Taken altogether, Pacho and Citenza are acceptable from the viewpoint of high-temperature softening characteristics. Caldera, which melts down at far lower temperatures than other brands, should be used within moderate bounds.

(5) Appraisal of COLAR iron ores as furnace charges

The test results are summarized in Table 2.2-11.
The most crucial point to observe about COLAR ores is the fact that they are liable to develop extremely large quantities of fine in the blast furnace.
For example, Citenza, though excellent in resistance to thermal degradation, is unacceptably poor in the strength after reduction. The situation is just the reverse with Pericos.
Anyway, every brand is likely to be degraded when charged into the blast furnace. It is therefore important not only to make choice of brands, but to carry out sizing intensively.
Every brand showed a high JIS reducibility, and the differences among brands will pose no problem.
As regards the high-temperature characteristics, especially softening and melting, all the brands are nearly the same except for Caldera which melts down at much lower temperatures than others.
As listed in Table 2.2-12, the general rating of the five tested brands is as follows.
Pacho > Citenza > Nueva Vizcaya > Pericos Grueso > Caldera

(6) Blending proportion of COLAR iron ores

As the appraisal above shows, Pacho should be taken as main ore for the blast furnace so long as it is available.
Table 2.2-13 shows the blending proportions desired by COLAR, test results, and an optimum proportion figured out in view of chemical composition, together with weighted means of various factors.
The optimum proportion recommended will be nearly as follows.
Pacho: Pericos: Citenza = 50%: 25%: 25%

Table 2.2-2 Methods of testing the properties of iron ores (incl. sinteres)

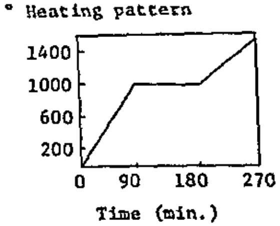
| | Thermal degradation test | Degradation reduction test and Tumbler test after reduction | JIS reduction test | High-temperature reduction test | High-temperature reduction test underload |
|---|---|---|---|---|---|
| Sample size, (mm) | 20 ∿ 25 | 20 ∿ 25 | 20 ± 1 | $14.5^{\phi} \times 15^{H}$ } Sample after preparatory reduction | $14.5^{\phi} \times 15^{H}$ |
| Sample weight (g) | 500 | 550 | 500 | 1 pc. | 1 pc. |
| Measuring temperature, (°C) | 700 | 700 (5°C/min.)<br>(sinters: 550°C) | 900 | 1,250 | 200 - melt-down temperature |
| Gas composition during open measurement air | In the open air | $CO/N_2$ : 30/70 | $CO/N_2$ : 30/70 | $CO/N_2$ : 30/70 | From 200°C up, $CO/N_2$ : 30/70 |
| Gas flow during measurement, lit./min. | - | 15 | 15 | 3 | 2 |
| Measuring time, min | 30 | 30 | 180 | 180 | Until molten down |
| Load on sample | nil | nil | nil | nil | 0.25 kg/cm²<br>(sinters: 0.5 kg/cm²) |
| | ° Samples charged into a furnace heated at 700°C for quick-heating<br>° Grading method: fine ratio or +10 mm index | ° Grading method for degradation-reduction test: fine ratio<br>* Tumber index after reduction: +10 mm samples after degradation test are charged into a drum, and the drum is run for 30 min. Then, the fine ratio is measured.<br>Drum: $130mm^{\phi} \times 200mm^{L}$ speed 30 rpm | ° Reducibility :<br>$(W_o - W_F) \times 100/W_1$<br>$(0.430A - 0.112B)$<br>where,<br>$W_1$: weight of sample before test<br>$W_o$: weight of sample immediately before reduction<br>$W_F$: weight of sample after reduction<br>A : total Fe in sample before reduction<br>B : FeO in the sample before reduction | ° Conditions for preparatory reduction<br>*Temperature: 1,000°C<br>*Reducing time: 270 min<br>*Gas composition: $CO/N_2$ = 40/60<br>*Gas flow rate: 3 lit./min.<br>° Reducibility: as per JIS reducibility<br>° Sinters:-<br>*Sample: 10∿13 mm, 20∿25 g<br>*Conditions for preparatory reduction<br>Temperature, 900°C<br>Reducing time, 120 min.<br>Gas composition, $CO/N_2$ = 60/40 | ° Index in terms of shrinkage due to softening at each temperature<br>° Heating pattern<br><br>° Sinters:-<br>*Sample: 10∿13 mm. 80∿90 g<br>Heating-up rate:<br>10°C/min. (up to 800°C)<br>5°C/min. (800°C up) |

Table 2.2-3 Chemical analysis of COLAR iron ores

(%)

| | TFe | FeO | $SiO_2$ | CaO | $Al_2O_3$ | $TiO_2$ | P | S | Cu | MgO | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Caldera | 52.70 | <0.1 | 10.69 | 0.01 | 2.83 | 0.13 | 0.082 | 0.010 | 0.051 | 0.01 | |
| " (Washing) | 51.74 | <0.1 | 14.15 | 0.01 | 1.54 | 0.09 | 0.016 | 0.009 | 0.078 | 0.02 | |
| Pacho | 56.13 | 0.14 | 6.58 | 0.02 | 2.43 | 0.12 | 0.051 | 0.037 | 0.018 | 0.07 | 0.20 |
| " (Washing) | 55.43 | <0.1 | 5.41 | 0.01 | 1.70 | 0.09 | 0.024 | 0.031 | 0.021 | 0.01 | |
| Citenza | 57.52 | 0.43 | 3.93 | 1.45 | 0.81 | 0.07 | 0.005 | 0.007 | 0.130 | 0.13 | 0.24 |
| " (Washing) | 59.36 | 0.14 | 1.81 | 1.91 | 0.35 | 0.04 | 0.005 | 0.009 | 0.711 | 0.12 | |
| Nueva Vizcaya | 55.32 | <0.1 | 0.50 | 0.04 | 0.35 | 0.04 | 0.011 | 0.033 | 0.128 | 0.36 | 0.76 |
| " (Washing) | 57.64 | <0.1 | 1.50 | 0.03 | 0.15 | 0.06 | 0.075 | 0.037 | 0.022 | 0.36 | |
| Pericos Finas | 48.83 | <0.1 | 14.59 | 0.05 | 4.14 | 0.18 | 0.102 | 0.024 | 0.031 | 0.05 | 2.39 |
| " (Washing) | 48.56 | <0.1 | 14.08 | 0.04 | 4.13 | 0.19 | 0.107 | 0.025 | 0.023 | 0.04 | |
| Pericos Grueso | 49.59 | <0.1 | 14.18 | 0.05 | 3.32 | 0.15 | 0.137 | 0.014 | 0.023 | 0.02 | 0.54 |
| " (Washing) | 43.44 | <0.1 | 21.90 | 0.04 | 3.84 | 0.21 | 0.092 | 0.023 | 0.048 | 0.02 | |
| SESAGOA | 66.24 | 4.03 | 1.40 | 0.03 | 1.23 | 0.05 | 0.042 | 0.007 | 0.004 | 0.07 | 0.48 |

| | $CO_2$ | Combined water | Porosity | Ig.loss |
|---|---|---|---|---|
| Caldera | 0.26 | 10.89 | | 11.43 |
| " (Washing) | 0.36 | 8.39 | 25.29 | 9.61 |
| Pacho | 0.32 | 10.53 | | 11.35 |
| " (Washing) | 0.68 | 10.61 | 26.90 | 11.20 |
| Citenza | <0.1 | 5.82 | | 6.59 |
| " (Washing) | 1.69 | 6.15 | 38.83 | 7.45 |
| Nueva Vizcaya | 0.25 | 6.86 | | 7.49 |
| " (Washing) | 0.30 | 9.58 | 33.29 | 10.11 |
| Pericos Finas | 0.41 | 8.59 | | 9.16 |
| " (Washing) | 0.38 | 8.78 | | 9.12 |
| Pericos Grueso | 0.17 | 9.41 | | 9.58 |
| " (Washing) | 0.31 | 7.81 | 19.96 | 8.03 |
| SESAGOA | <0.1 | 3.60 | | 2.84 |

Table 2.2-4 Chemical analysis of COLAR iron ores (brought home by the experts)

(%)

| | T.Fe | FeO | $SiO_2$ | CaO | $Al_2O_3$ | MgO | Mn | Cu |
|---|---|---|---|---|---|---|---|---|
| Pericos (Cocopan) | 48.84 | 0.14 | 14.18 | 0.05 | 4.15 | 0.04 | 0.51 | 0.025 |
| Pericos (Adit) | 55.08 | 0.14 | 5.50 | 0.07 | 2.48 | 0.02 | 0.61 | 0.013 |
| CYF Mineros | 63.25 | 0.14 | 1.62 | 0.12 | 0.15 | 0.14 | 0.98 | 0.072 |
| Pocho | 55.92 | 0.14 | 5.66 | 0.01 | 2.22 | 0.03 | 0.39 | 0.023 |
| Paz del Rio | 40.49 | 25.92 | 14.54 | 4.60 | 4.24 | 0.66 | 0.39 | 0.038 |
| | P | S | Cr | Co | Sn | $TiO_2$ | V | Na |
| Pericos (Cocopan) | 0.112 | 0.037 | 0.006 | 0.009 | 0.011 | 0.15 | <0.001 | <0.001 |
| Pericos (Adit) | 0.412 | 0.035 | 0.002 | <0.001 | 0.007 | 0.07 | <0.001 | <0.001 |
| CYF Mineros | 0.007 | 0.009 | <0.001 | 0.002 | 0.009 | 0.04 | <0.001 | <0.001 |
| Pacho | 0.023 | 0.038 | <0.001 | 0.008 | 0.006 | 0.09 | <0.001 | <0.001 |
| Paz del Rio | 1.670 | 0.189 | 0.008 | 0.001 | 0.008 | 0.17 | <0.001 | <0.001 |
| | K | As | Ig.loss | $CO_2$ | Combined water | | | |
| Pericos (Cocopan) | 0.04 | 0.001 | 9.50 | 0.47 | 7.30 | | | |
| Pericos (Adit) | 0.02 | 0.002 | 11.11 | 0.25 | 10.75 | | | |
| CYF Mineros | 0.01 | 0.002 | 5.54 | 0.32 | 5.27 | | | |
| Pacho | 0.15 | 0.001 | 11.13 | 0.67 | 10.45 | | | |
| Paz del Rio | 0.01 | 0.008 | 13.75 | 11.63 | 5.09 | | | |

Table 2.2-5 Degradation ratio due to thermal degradation

(%)

| | -1 mm | 1 ∿ 3 mm | 3 ∿ 5 mm | 5 ∿ 10 mm | +10 mm |
|---|---|---|---|---|---|
| Caldera | 1.49 | 2.80 | (6.94)<br>2.65 | 5.31 | 87.74 |
| Pacho | 0.56 | 0.79 | (1.98)<br>0.63 | 1.78 | 96.23 |
| Citenza | 0.17 | 0.09 | (0.3)<br>0.04 | 0.09 | 99.61 |
| Nueva Vizcaya | 0.16 | 0.11 | (0.43)<br>0.16 | 0.16 | 99.42 |
| Pericos Grueso | 4.40 | 6.73 | (18.28)<br>7.15 | 14.27 | 67.46 |
| SESAGOA | 0.31 | 0.62 | (1.44)<br>0.51 | 0.95 | 97.61 |

Values in parentheses refer to -5 mm%.

Table 2.2-6 Reduction degradation ratio

(%)

| | -1 mm | 1 ∿ 3 mm | 3 ∿ 5 mm | 5 ∿ 10 mm | +10 mm |
|---|---|---|---|---|---|
| Caldera | 1.52 | 1.29 | 1.29 | 2.98 | 92.92 |
| Pacho | 0.55 | 0.40 | 0.22 | 0.57 | 98.26 |
| Citenza | 0.92 | 1.30 | 0.45 | 0.47 | 96.86 |
| Nueva Vizcaya | 1.55 | 1.26 | 0.74 | 1.50 | 94.95 |
| Pericos Grueso | 1.18 | 1.29 | 1.73 | 8.13 | 87.66 |
| SESAGOA | 0.38 | 0.24 | 0.27 | 0.96 | 98.09 |

Table 2.2-7 Degradation ratio by tumbler test of sample pieces of +10 mm up after reduction degradation

(%)

| | -1 mm | 1 ∿ 3 mm | 3 ∿ 5 mm | 5 ∿ 10 mm | +10 mm |
|---|---|---|---|---|---|
| Caldera | 14.31 | 8.91 | 5.56 | 15.02 | 56.19 |
| Pacho | 15.13 | 1.93 | 0.81 | 2.02 | 80.13 |
| Citenza | 20.39 | 4.91 | 1.90 | 6.07 | 66.74 |
| Nueva Vizcaya | 18.55 | 4.14 | 2.28 | 7.35 | 67.69 |
| Pericos Grueso | 6.74 | 2.04 | 2.25 | 7.79 | 81.18 |
| SESAGOA | 12.7 | 3.27 | 2.87 | 10.27 | 70.87 |

Table 2.2-8 Degradation ratio/compensated for tumbler index of +10 mm up after reduction degradation

(%)

| | -1 mm | 1 ∿ 3 mm | 3 ∿ 5 mm | 5 ∿ 10 mm | +10 mm |
|---|---|---|---|---|---|
| Caldera | 15.4 | 9.6 | (31.0)<br>6.0 | 16.2 | 52.8 |
| Pacho | 15.4 | 2.0 | (18.2)<br>0.8 | 2.1 | 79.7 |
| Citenza | 21.1 | 5.1 | (28.2)<br>2.0 | 6.3 | 65.5 |
| Nueva Vizcaya | 19.5 | 4.4 | (26.3)<br>2.4 | 7.7 | 66.0 |
| Pericos Grueso | 7.7 | 2.3 | (12.6)<br>2.6 | 8.9 | 78.5 |
| SESAGOA | 12.9 | 3.3 | (19.1)<br>2.9 | 10.5 | 70.4 |

The values in parentheses refer to -5 mm%.

Table 2.2-9 Chemical analysis (%) after JIS reduction test and JIS reducibility

| | T.Fe | FeO | M.Fe | $SiO_2$ | Cao | $Al_2O_3$ | P | Compressive strength* (kg/p) | Reducibility (%) |
|---|---|---|---|---|---|---|---|---|---|
| Caldera | 75.40 | 31.00 | 49.71 | 11.92 | 0.03 | 3.58 | 0.066 | 79.8 | 76.58 |
| Pacho | 81.19 | 24.64 | 59.24 | 7.75 | 0.02 | 2.79 | 0.039 | 60.6 | 80.82 |
| Citenza | 83.48 | 25.15 | 61.44 | 6.22 | 0.59 | 0.80 | 0.017 | 23.2 | 81.40 |
| Nueva Vizcaya | 82.90 | 26.63 | 59.22 | 2.09 | 0.05 | 0.24 | 0.051 | 31.4 | 79.75 |
| Pericos Grueso | 66.37 | 24.86 | 45.33 | 22.54 | 0.08 | 4.08 | 0.146 | | 75.75 |
| SESAGOA | 78.62 | 62.27 | 24.54 | 3.02 | 0.03 | 1.22 | 0.052 | 212.4 | 50.90 |

* To be taken for reference only because many of samples were deformed.
Pericos denied sampling because of many degradations.

Table 2.2-10 Softening and melting temperatures of ores

| Brand | Softening temperature* | Melting temperature | ΔT ** |
|---|---|---|---|
| Caldera | 935 °C | 1320 °C | 385 °C |
| Citenza | 945 | 1500 | 555 |
| Nueva Vizcaya | 820 | 1400 | 580 |
| Pacho | 915 | 1480 | 565 |
| Pericos Grueso | 1000 | 1440 | 440 |

* Temperature at which the test subject has shrunk by 10%.

** ΔT = Melting temperature - softening temperature

Table 2.2-11 A comprehensive list of iron ore test results

| Brand | Chemical analysis (%) | | | | Combined water (%) | Porosity (%) | Mineral of ore | Microscopic structure | Thermal degradation (-5mm%) | Reduction degradation (-5mm%) | Tumbler index after reduction (-5mm%) | JIS reducibility (%) | High-temperature reducibility (at 1250 °C %) | High-temperature reduction under load | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.Fe | $SiO_2$ | $Al_2O_3$ | P | | | | | | | | | | Softening temperature °C | Melting temperature °C |
| Caldera | 52.70 | 10.69 | 2.83 | 0.082 | 10.89 | 25.29 | Clay bearing massive goethite | Compact crystal with little void | 6.94 | 4.10 | 31.0 | 76.58 | | 935 | 1320 |
| Pacho | 56.13 | 6.58 | 2.43 | 0.051 | 10.53 | 26.90 | Massive porons goethite | Compact, but having large voids and including amorphous body. | 1.98 | 1.17 | 18.2 | 80.82 | 42 | 915 | 1480 |
| Citenza | 57.52 | 3.93 | 0.81 | 0.005 | 5.82 | 38.83 | Massive hematite and massive goethite | Poor in crystallization, presenting thread-lace structure (amorphous body) | 0.3 | 2.67 | 28.2 | 81.40 | 48 | 945 | 1500 |
| Nueva Vizcaya | 55.32 | 0.50 | 0.35 | 0.011 | 6.86 | 33.29 | Porous goethite partially compact goethite | Including many voids like Citenza (amorphous). | 0.43 | 3.55 | 26.3 | 79.75 | | 820 | 1400 |
| Pericos Grueso | 49.59 | 14.18 | 3.32 | 0.137 | 9.41 | 19.96 | Massive compact silicious goethite | Compact, large crystals having spot of high crystallinity. Small quantity of voids. | 18.28 | 4.2 | 12.6 | 75.75 | 35 | 1000 | 1440 |
| SESAGOA | 66.24 | 1.40 | 1.23 | 0.042 | 3.60 | | Porous hematite and partially limonite | Large crystals and many large voids. Partially including magnetite. | 1.44 | 0.89 | 19.1 | 50.90 | 75 | | |

Table 2.2-12 General rating of COLAR ore quality

| | Resistivity to degradation * | | | JIS reducibility | High-temperature character-istics, rating | Composite rating |
|---|---|---|---|---|---|---|
| | Thermal degradation | Tumbler index after reduction | Rating | | | |
| Caldera | (62) ○ | (0) ● | 4 | ○ | ● | 5 |
| Pacho | (89) ○ | (41) ◎ | 1 | ◎ | ◎ | 1 |
| Citenza | (98) ◎ | (9) ○ | 3 | ◎ | ◎ | 2 |
| Nueva Vizcaya | (98) ◎ | (15) ○ | 2 | ○ | ○ | 3 |
| Pericos Grueso | (0) ● | (59) ◎ | 4 | ○ | ○ | 4 |

Legend: ◎ excellent, ○ good, ● fair

The values parethesized are given in percentage with "degradation free" as 100% and "most degraded" as 0%.

## Table 2.2-13 Cases of COLAR iron ore mix proportion

| | | Chemical analysis(%) | | | Test results | | | | | Cases of blending proportion | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T.Fe | $SiO_2$ | P | Thermal degradation (%) | Tumbler index after reduction(%) | JIS reducibility (%) | Softening temperature °C | Melting temperature °C | I | II | III | IV |
| Pericos | | 49.59 | 14.18 | 0.137 | 18.28 | 12.6 | 75.75 | 1000 | 1440 | 50 | 60 | 70 | 25 |
| Citenza | | 57.52 | 3.93 | 0.005 | 0.3 | 28.2 | 81.40 | 945 | 1500 | 30 | 40 | | 25 |
| Pacho | | 56.13 | 6.58 | 0.051 | 1.98 | 18.2 | 80.82 | 915 | 1480 | 20 | | 30 | 50 |
| Caldera | | 52.70 | 10.69 | 0.082 | 6.94 | 31.0 | 76.58 | 935 | 1320 | | | | |
| Nueva Vizcaya | | 55.32 | 0.50 | 0.011 | 0.43 | 26.3 | 79.75 | 820 | 1400 | | | | |
| | | | | | | | | | | | | | |
| Weighted means for respective cases | T.Fe | | | | | | | | | 53.28 | 52.76 | 51.55 | 54.84 |
| | $SiO_2$ | | | | | | | | | 9.59 | 10.08 | 11.90 | 7.82 |
| | P | | | | | | | | | 0.080 | 0.084 | 0.111 | 0.061 |
| | | | | | | | | | | | | | |
| | Thermal degradation | | | | | | | | | 9.6 | 11.1 | 13.4 | 5.6 |
| | Tumbler index after reduction | | | | | | | | | 18.4 | 18.8 | 14.3 | 19.3 |
| | | | | | | | | | | (29.0) | (29.9) | (27.7) | (24.9) |
| | JIS reducibility | | | | | | | | | 78.5 | 78.0 | 77.3 | 79.7 |
| | | | | | | | | | | | | | |
| | Softening temperature | | | | | | | | | 967 | 978 | 975 | 944 |
| | Melting temperature | | | | | | | | | 1466 | 1464 | 1452 | 1475 |

Cases I through III: Proportions desires by COLAR.
Case IV : Recommended proportion

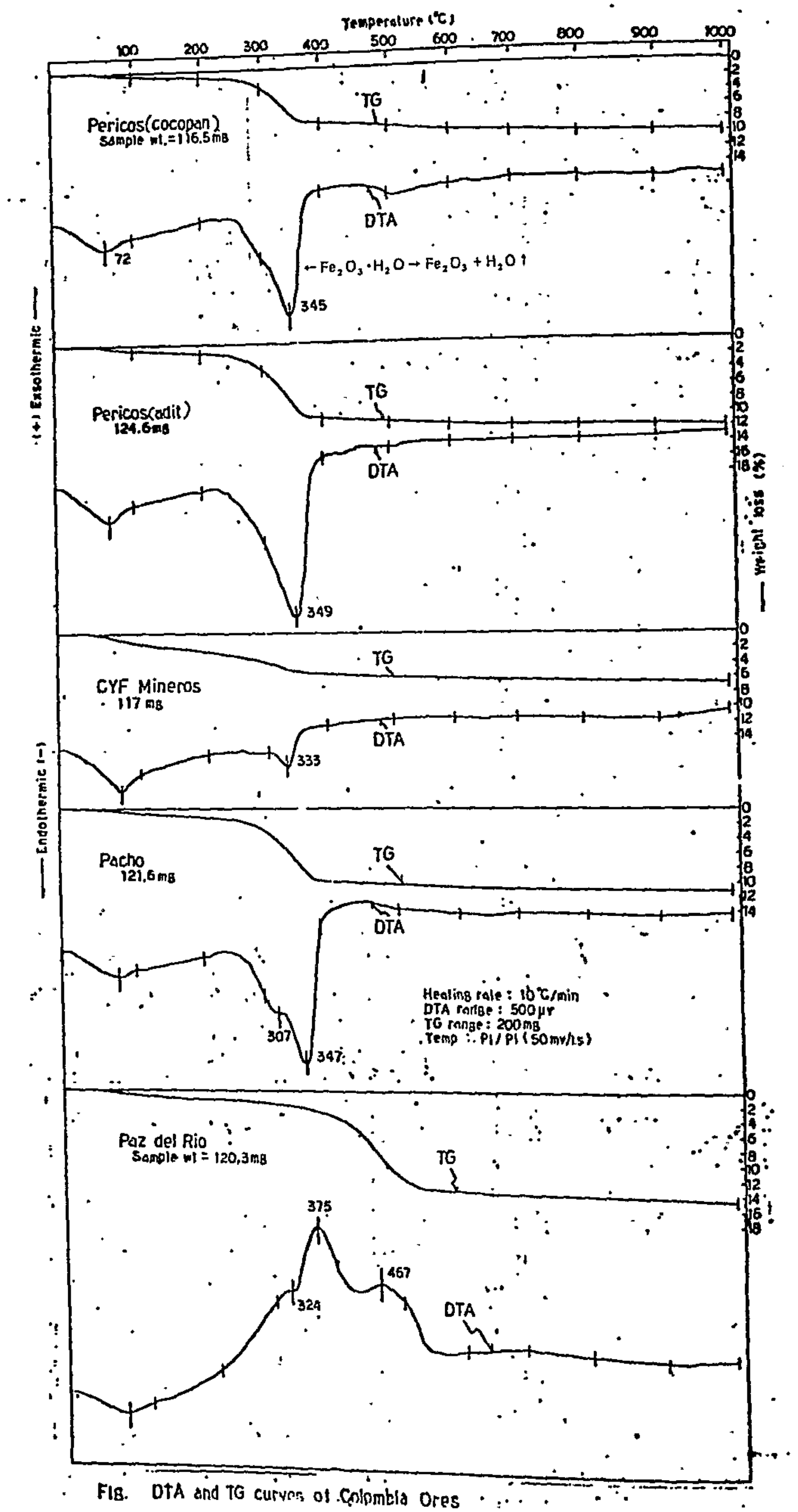



Fig. 2.2-8 Results of differential thermal analysis of Colombian ores

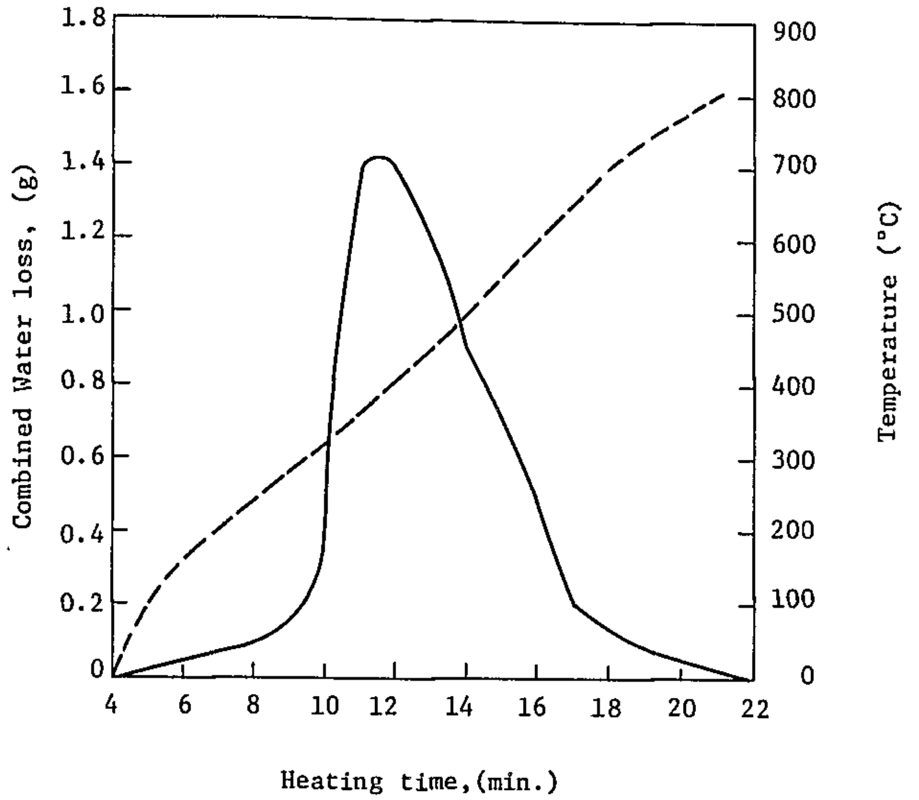



Fig. 2.2-9 Loss of combined water in ore vs. temperature

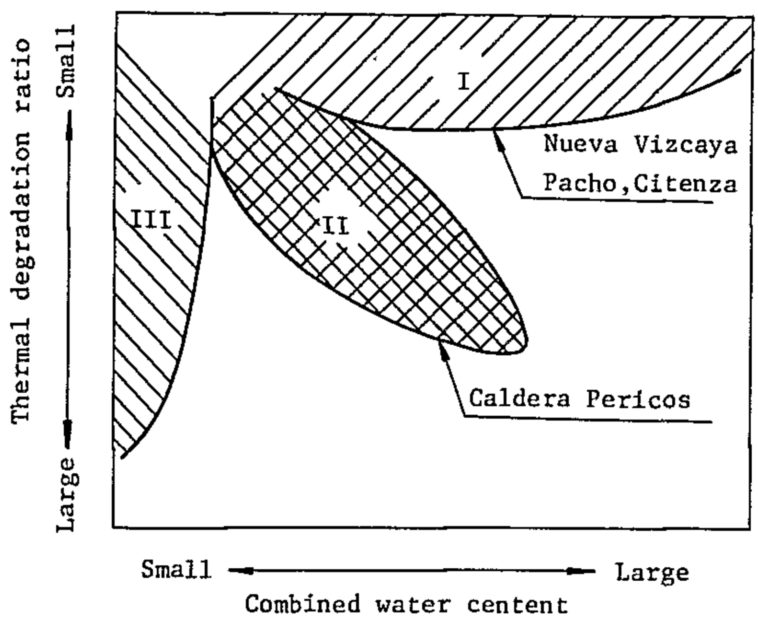



Fig. 2.2-10 Thermal degradation vs. combined water of iron ores

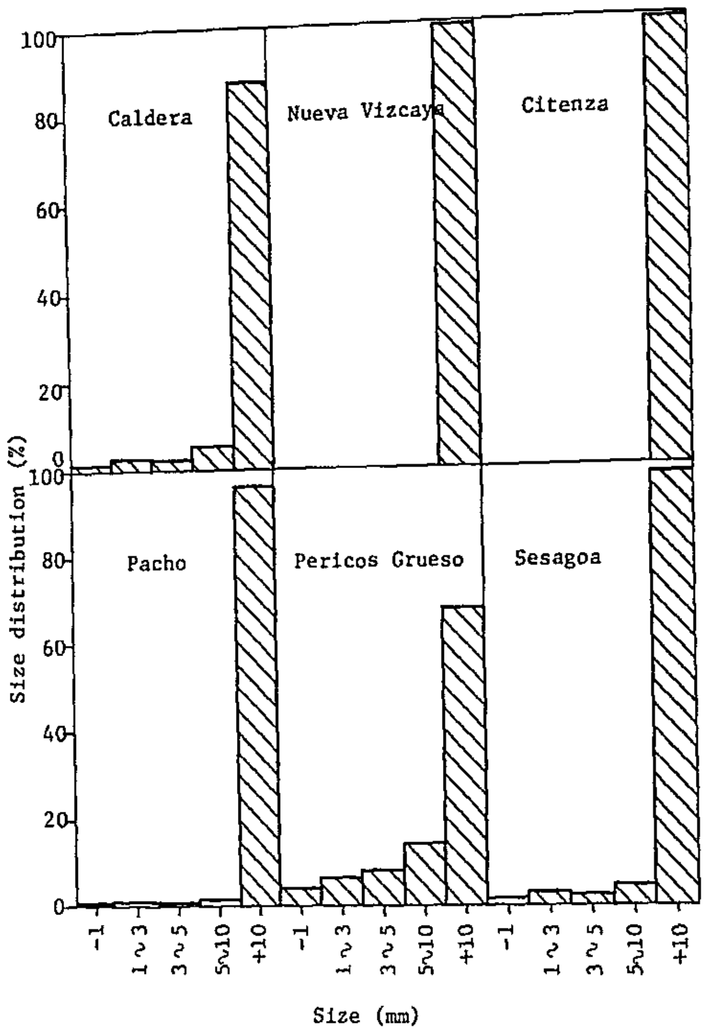



Fig. 2.2-11 Size distribution after thermal degradation (I)

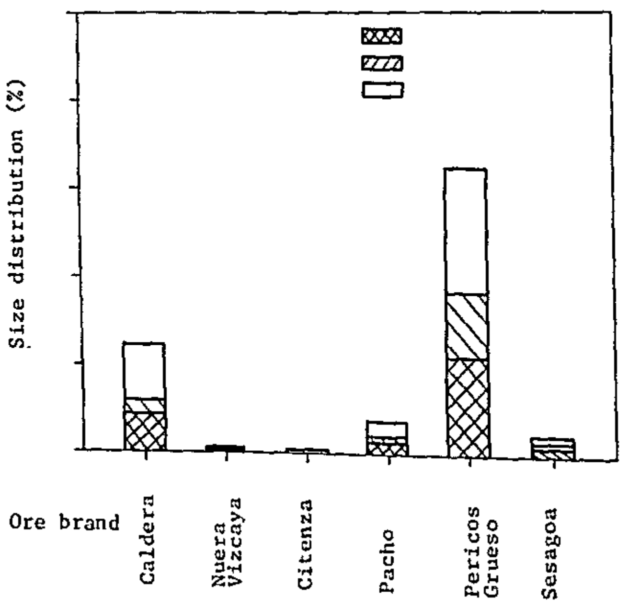



Fig. 2.2-12 Size distribution after thermal degradation (II)

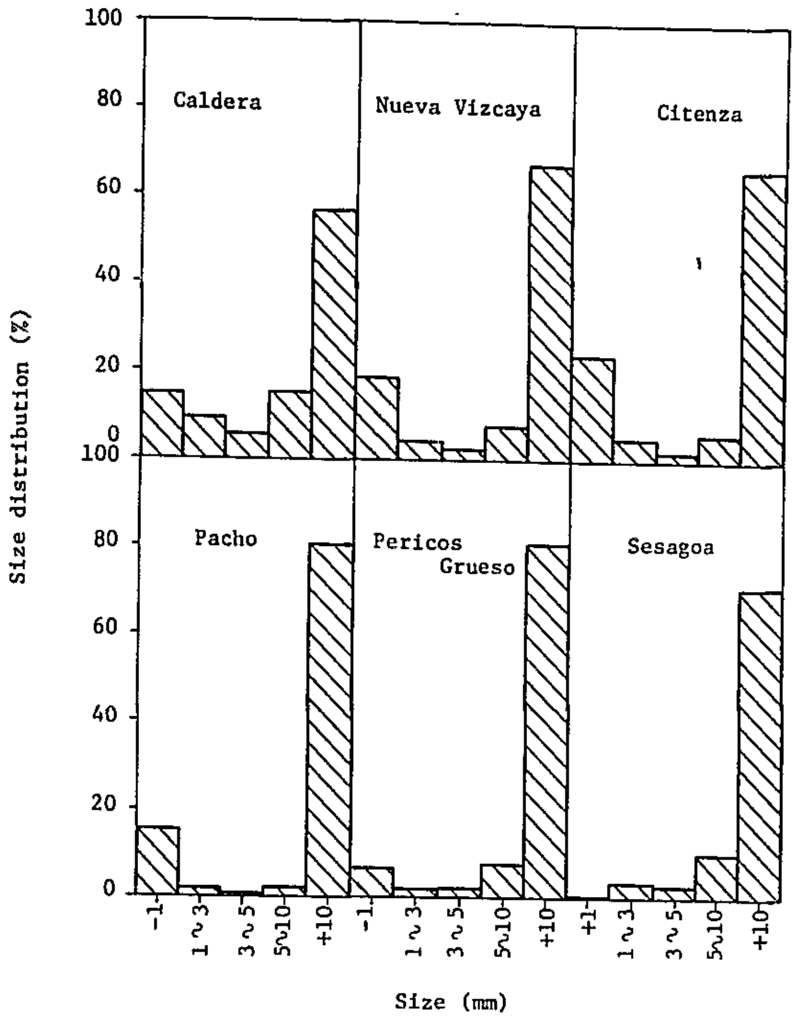



Fig. 2.2-13 Size distribution after tumbler test following reduction degradation test (I)

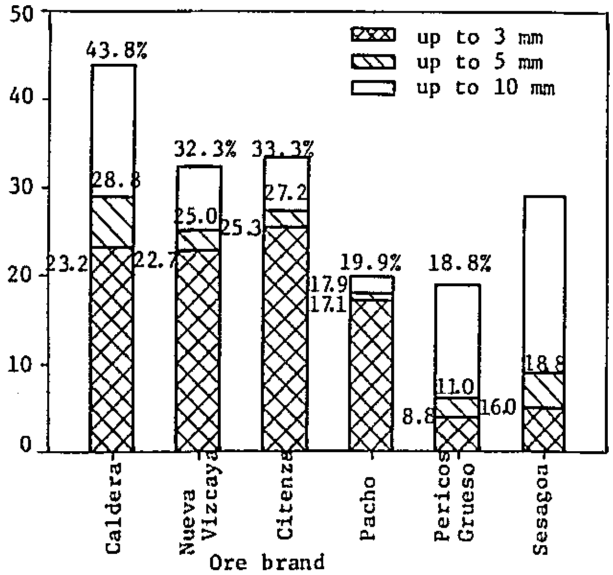



Fig. 2.2-14 Size distribution after tumbler test following reduction degradation test (II)

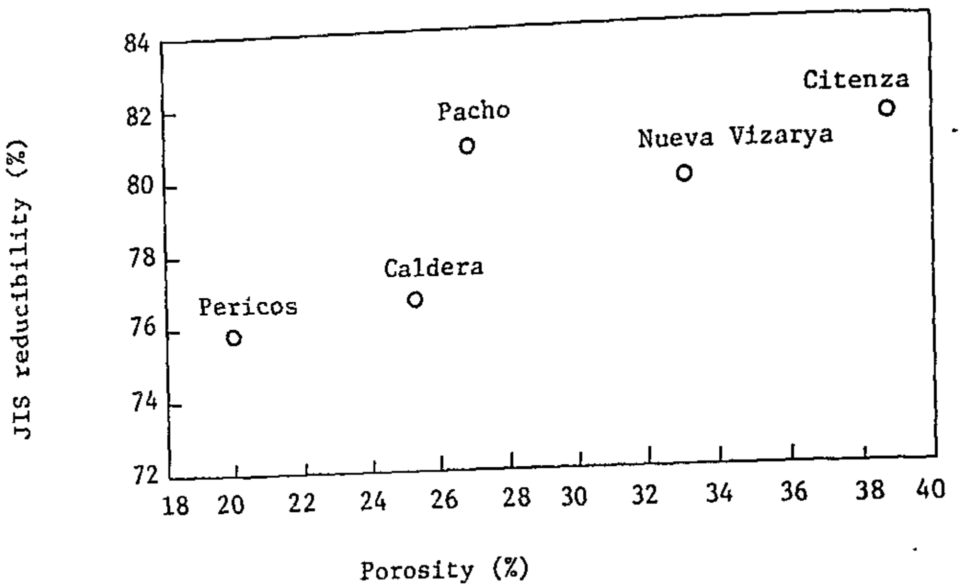



Fig. 2.2-15 Porosity vs. JIS reducibility

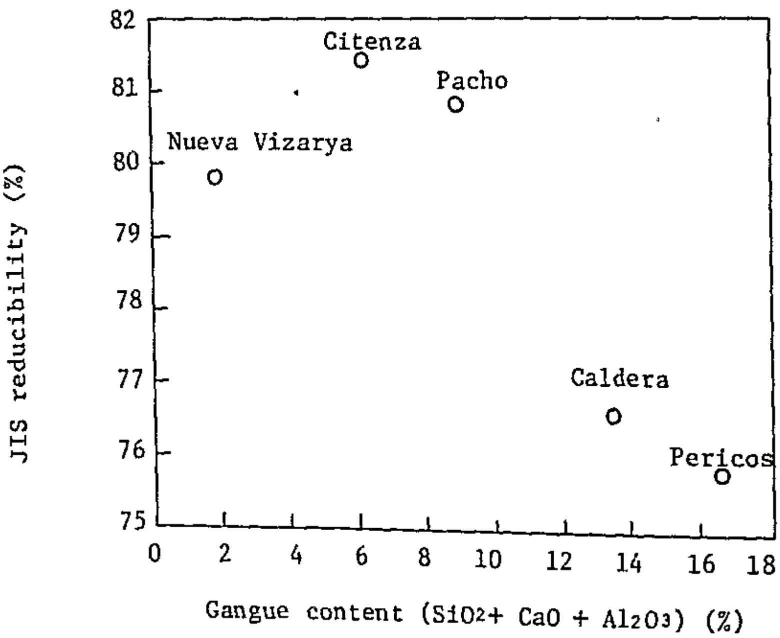



Fig. 2.2-16 Gangue content vs. JIS reducibility

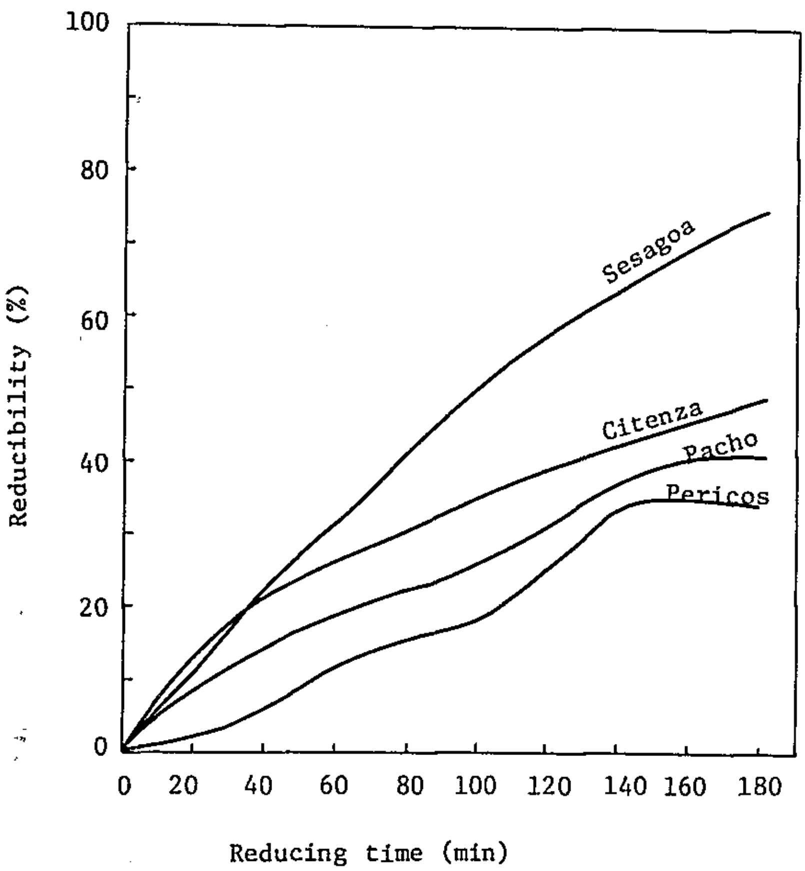



Fig. 2.2-17 Curves of reduction at 1,250°C

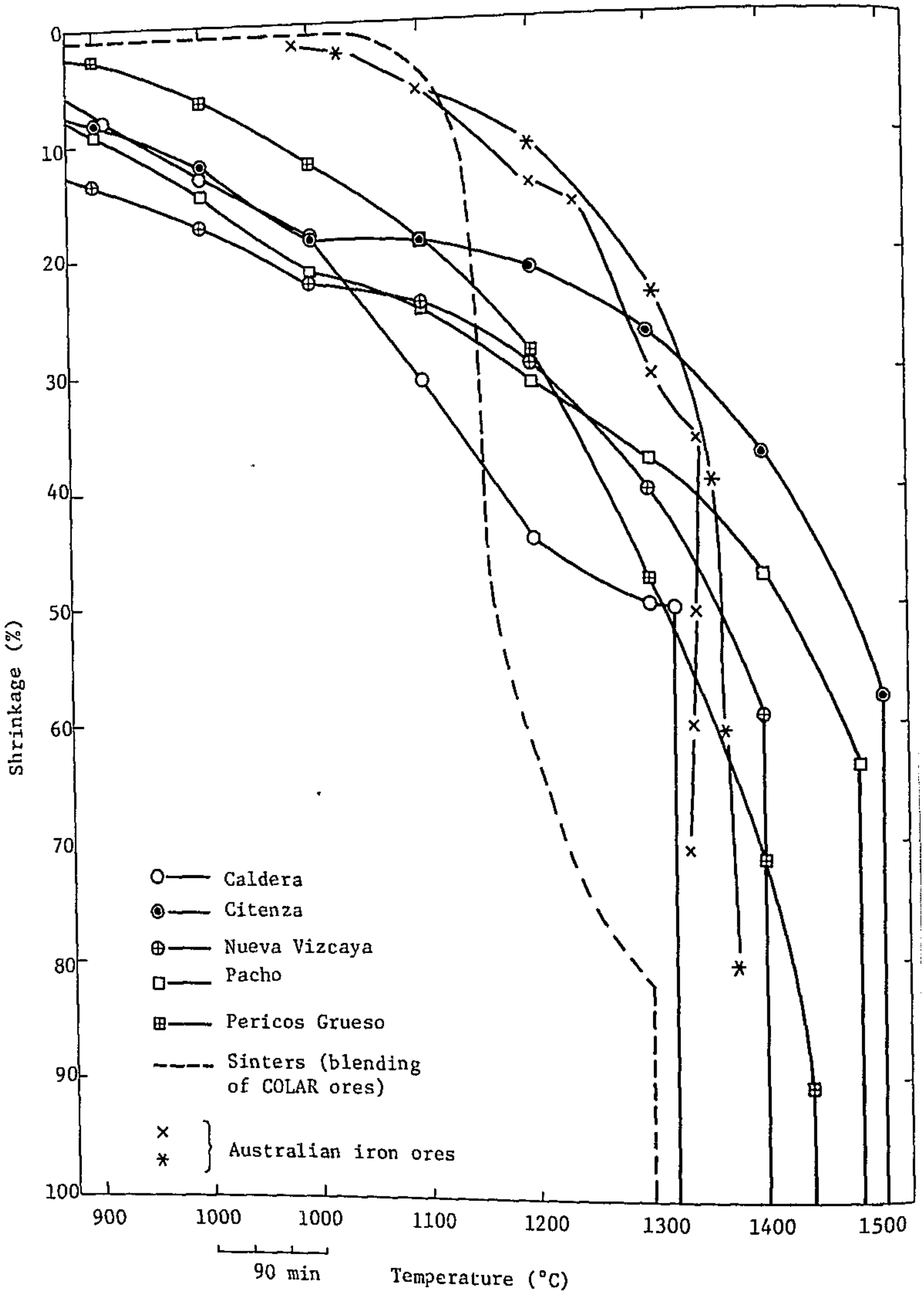



Fig. 2.2-18 Iron ore softening curves

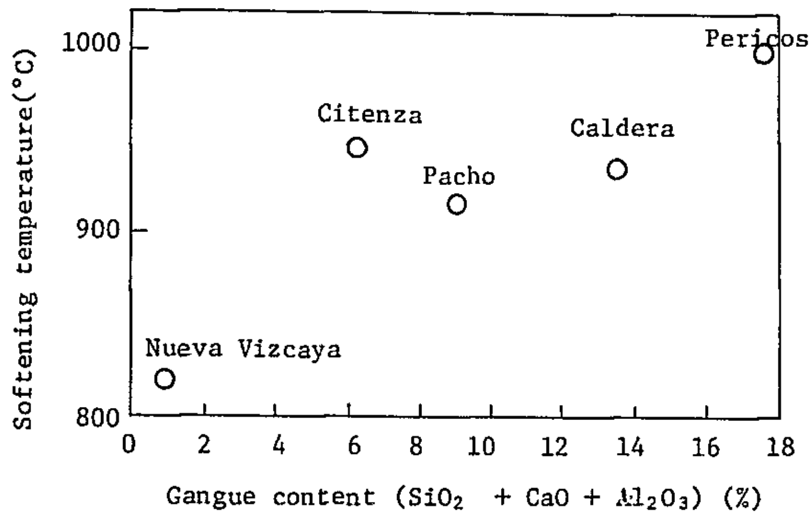



Fig. 2.2-19 Gangue vs. softening temperature

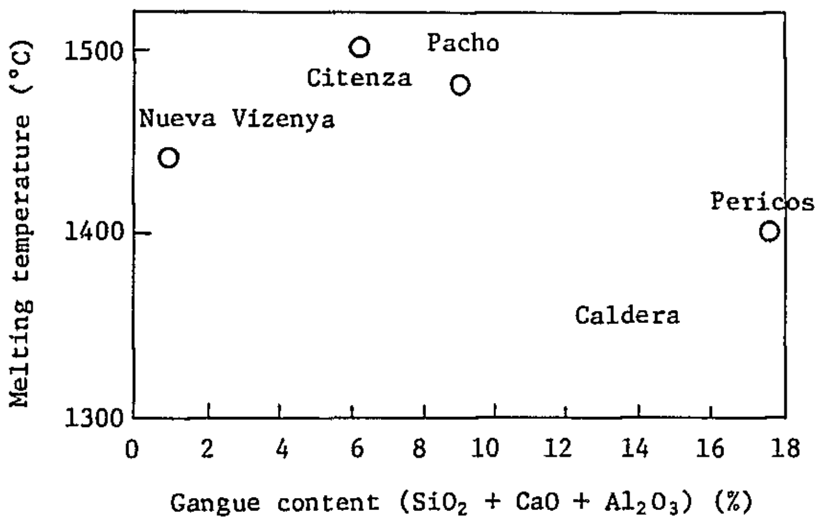



Fig. 2.2-20 Gangue vs. melting temperature

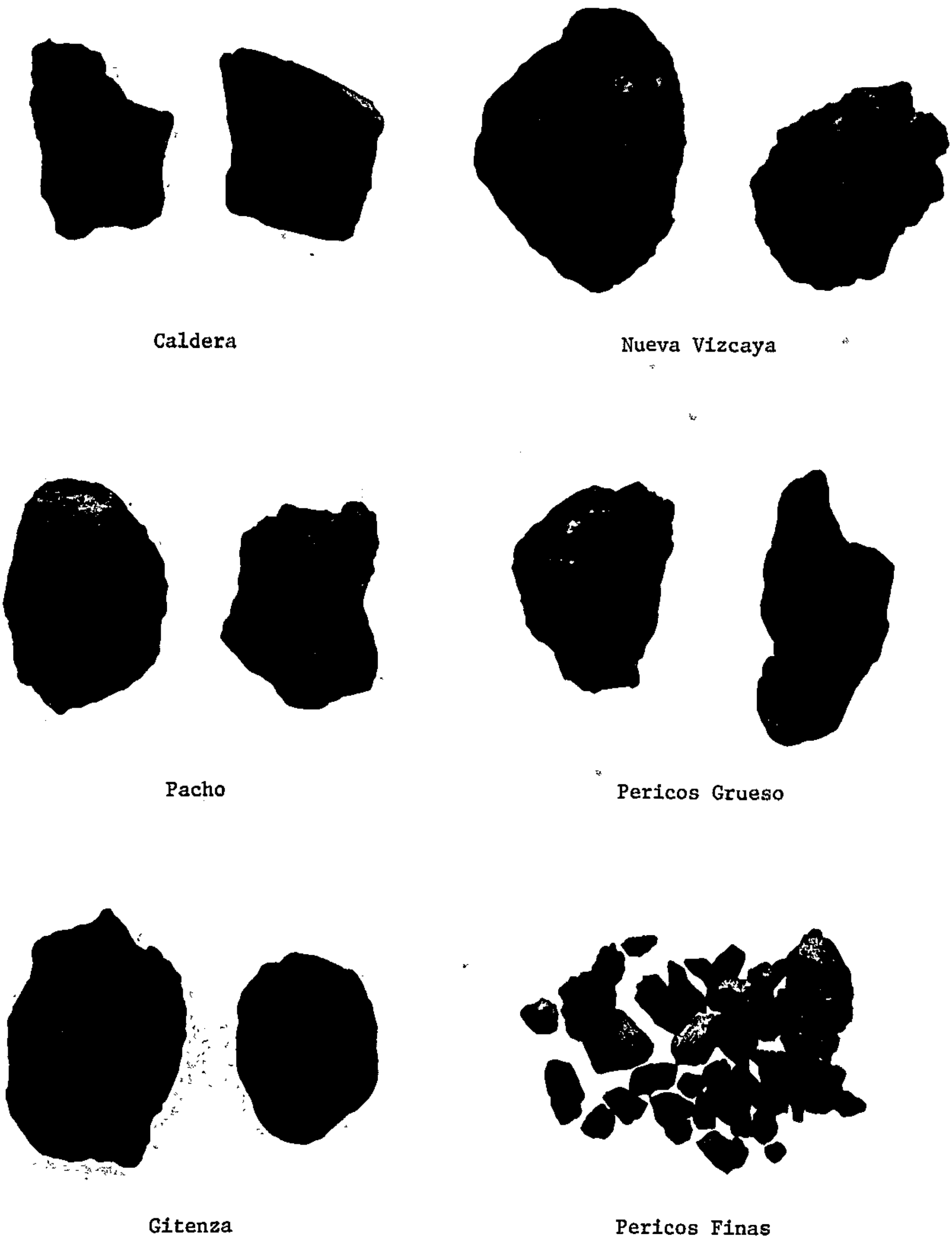
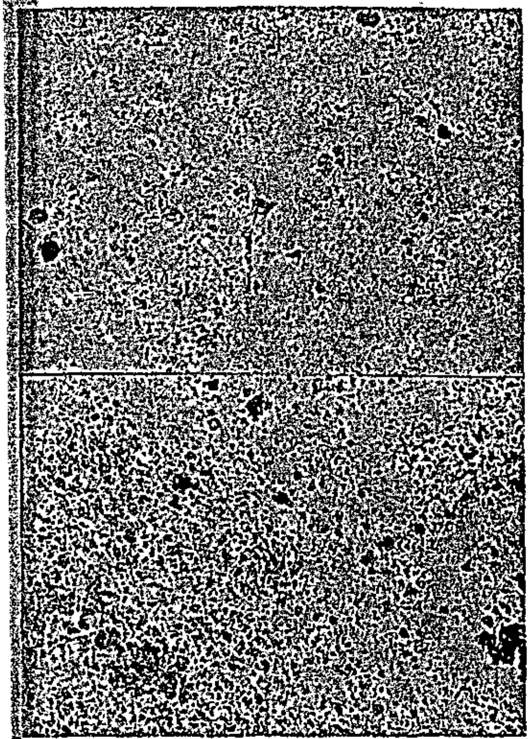
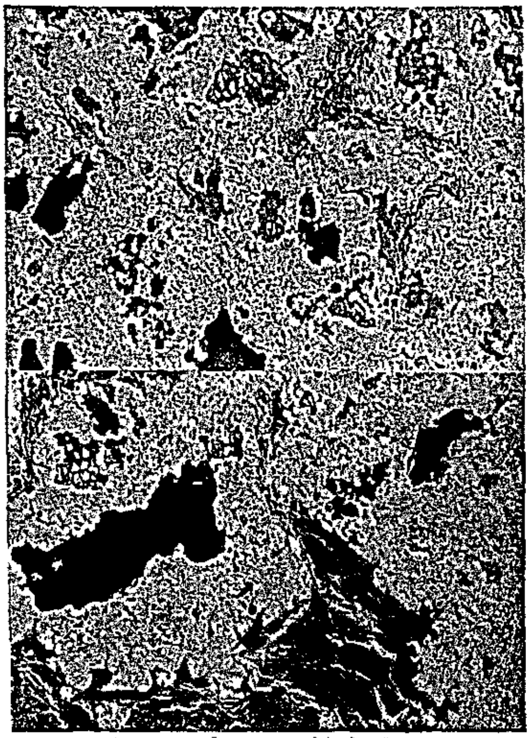


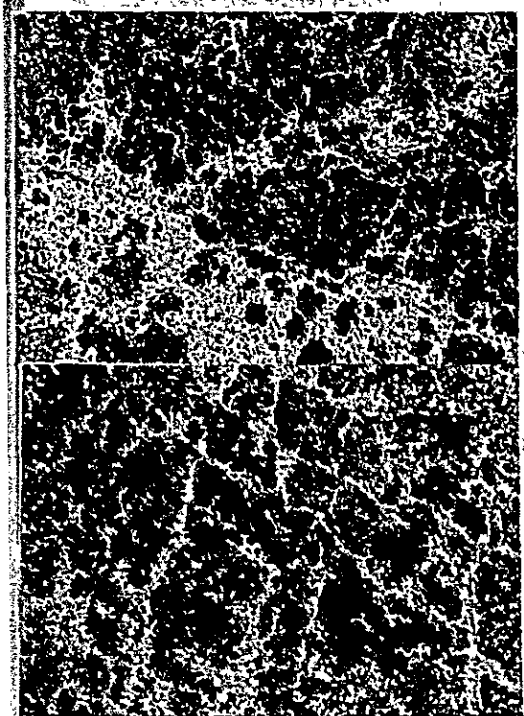

Photo 2.2-1 Appearance of COLAR iron ores



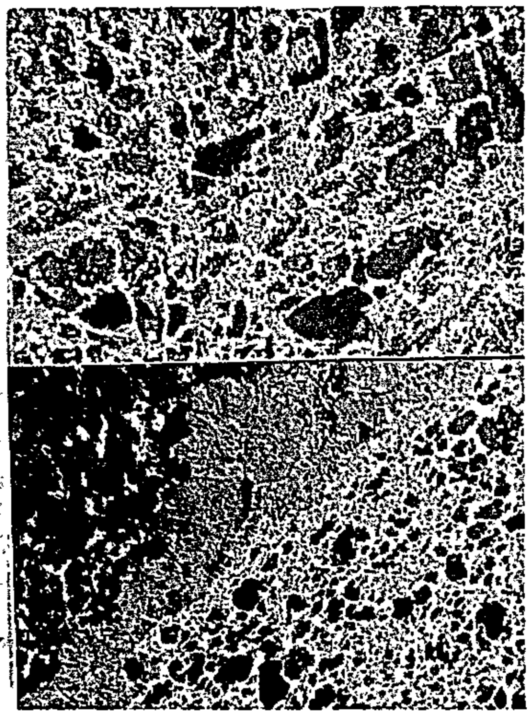
Caldera



Pacho



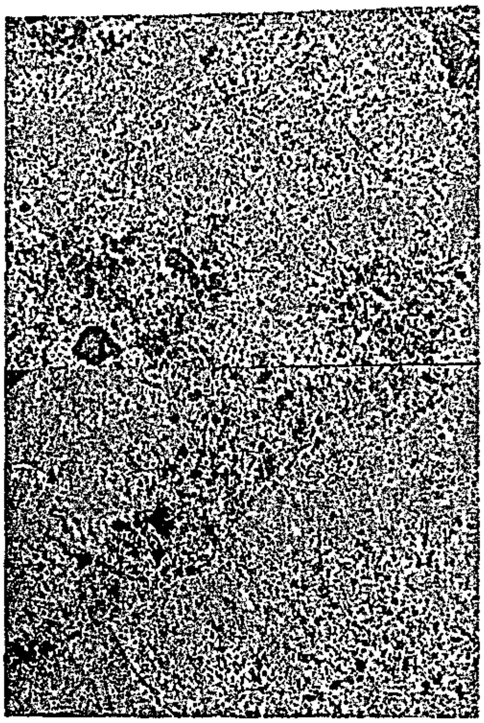
Citenza



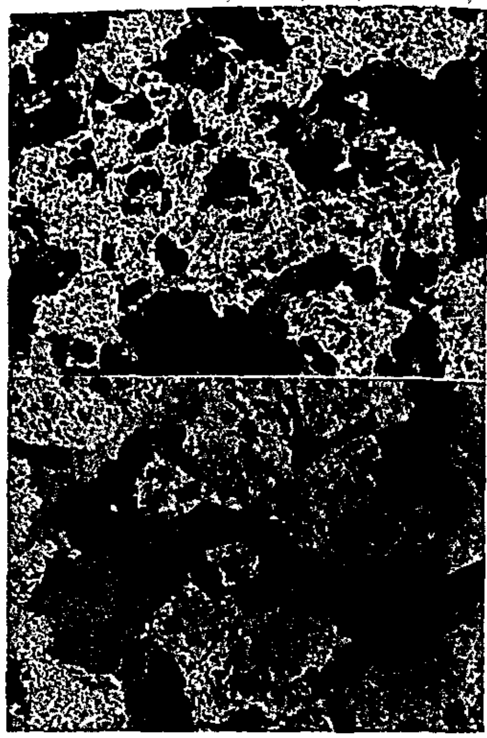
Nueva Vizcaya

H: Hematite
G: Goethile

Photo 2.2-2 Micrographs of COLAR iron ores

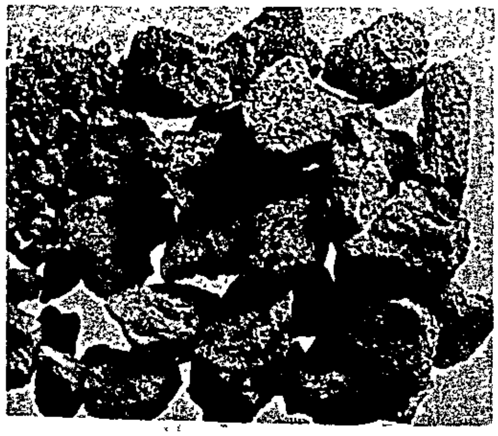


Pericos Grueso



Sesagoa

Caldera



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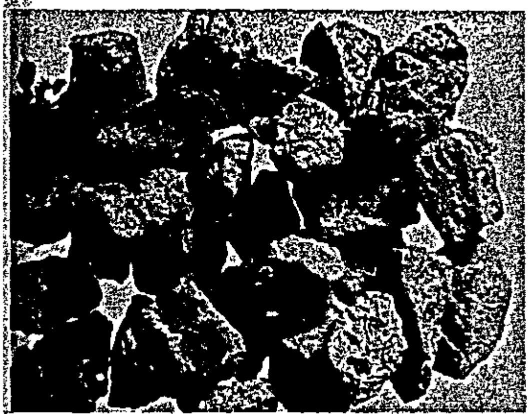
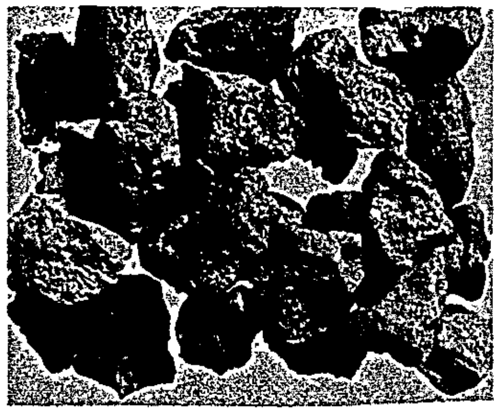
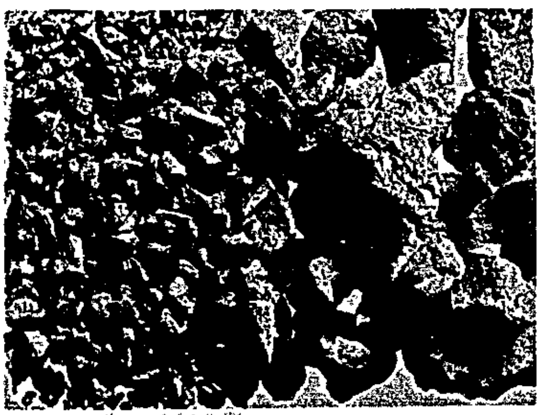


Citenza



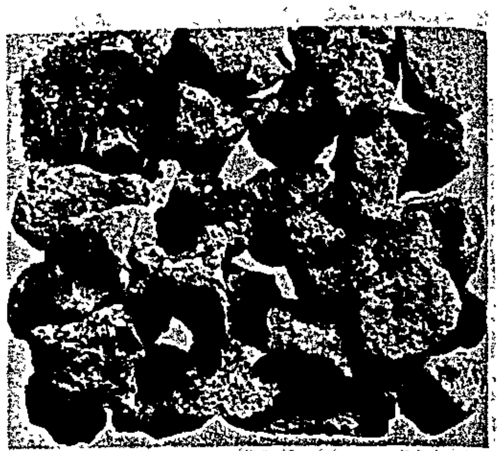
Nueva Vizcaya



Pericos Grueso

Photo 2.2-3 Samples after thermal degradation test

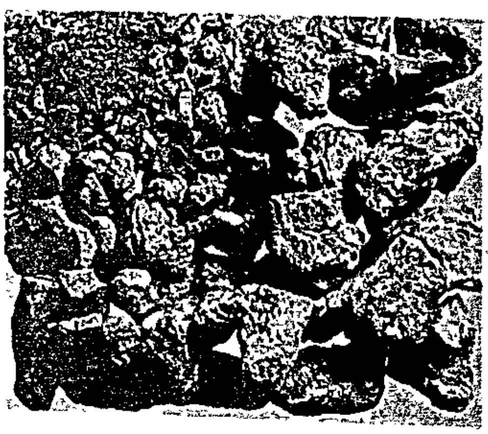
Caldera



Pacho

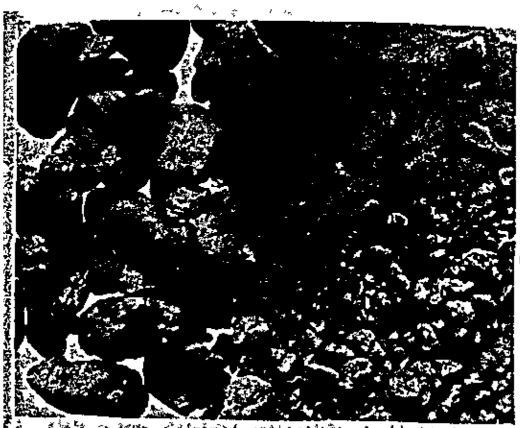
Citenza

Nueva Vizcaya

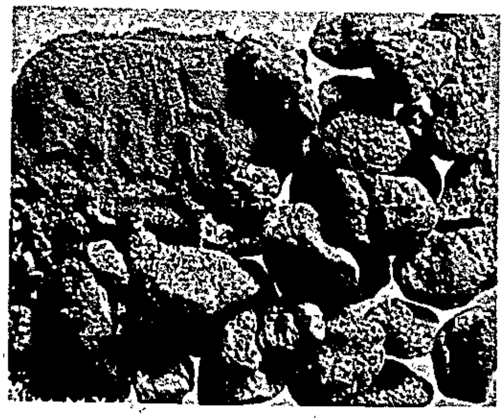


Pericos Grueso

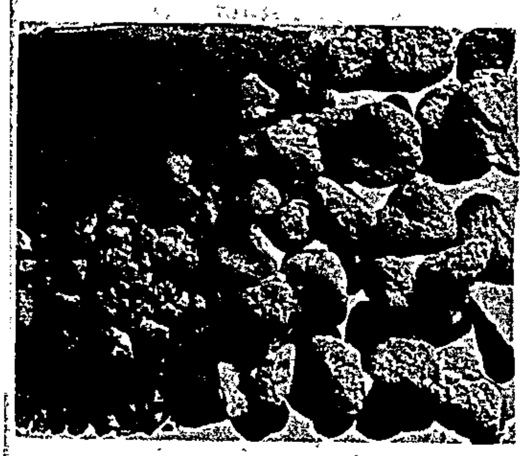
Photo 2.2-4 Samples after reduction degradation test



Caldera

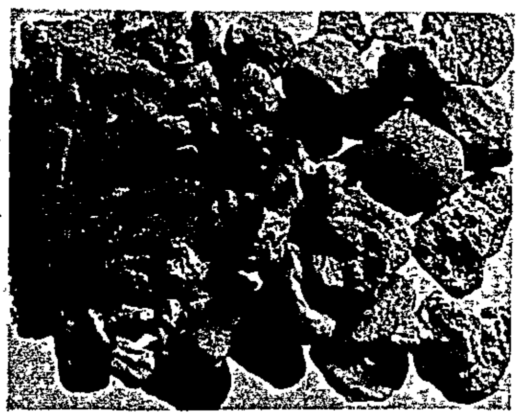


Pacho



Citenza

Vizcaya



Pericos Grueso

Photo 2.2-5 Samples after tumbler test