Nevertheless, construction and operation of the coke making plant in the site will certainly have environmental impacts through exhaust gas and effluent. It is desirable, therefore, to consider pollution control facilities and equipment which will comply with environmental standards in Maracaibo, as well as those in Japan, to be ready for the case that pollution further aggravates and more strict environmental regulations are imposed.

It should be noted, however, that environmental loads to the lake may decrease after 1994 during which regulations to control industrial effluent are scheduled to be enforced, or a final sewage treatment plant in the City of Maracaibo is completed and starts operation.

(3) The Puerto Siderurgico site

There is no weather data available in and around the site. Ciudad Bolívar, 100km west to the site, reports the annual average temperature of 27.5°C centigrade, and annual precipitation of 1,022mm. Rainfall mainly occurs during the rainy season between May and October. The weather pattern seems to be applicable to the site.

Effluent from the site will be discharged to the Orinoco river. The plant is required to comply with environmental standards applied to areas which discharge waste water directly to rivers, as well as those applicable to exhaust gas. While the Puerto Ordaz district seems to exhaust waste gas (smoke) most actively in the country, air pollution is expected to be improved after April 1995, when exhaust gas regulations will be officially enforced after a grace period.

4.1.15 Other Industries

In Venezuela, characteristics of industrial activities vary between states and regions. The 3 states which contain the candidate sites

(1) Tachira State (Santo Domingo)

The state is lagged behind in industrialization. There is relatively a small number of industries to support the proposed plant, including machine assembly and maintenance, compared to other two sites.

However, the state has large coal mines and small-scale beehive coke ovens are operated, which make it distinguishable from other sites.

(2) Zulia State (La Cañada)

The state produces 70% of petroleum in the country and has a variety of industries, including petroleum refining, petrochemical, cement, and beer. There are numerous machine shops with skilled workers to provide maintenance for these plants.

(3) Bolívar State (Puerto Siderurgico)

Large-scale industrial development projects have progressed in the state during the past two decades, and heavy industries including hydropower plants, steel mills, and aluminum smelting plants are operated. To serve these plants, machine shops have also increased with machinists.

4.2 Comparison of Candidate Sites

Based on evaluation in 4.1, the 3 candidate sites were compared for key factors, as follows.

	Santo Domingo	La Cañada	Pto. Ordas
1) Site Name		Municipio de la Cañada de Urdaneta en la Zona de la Ensenada de Urdaneta	Urbanisumo Industrial Cana Veral
2) Zoning	None-industrial area	Heavy industry zone	Heavy industry zone
3) Current Site Condition	Undeveloped	Subdivision/site preparation completed	Subdivision/site preparation completed
Site Area		6,800ha	562ha
4) Land Cost	Land acquisition incomplete 2,500-10,000Bs/ha	Land acquired 260/Bs/sq.m	Land acquired 597/Bs/sq.m
5) Coal Type	Tachira Coal	Guasare Coal	None
6) Coal Transportation cost	383Bs/ton (4.3US$/ton)	1,485Bs/ton (16.5US$/ton)	3,813Bs/ton (42.4US$/ton)
Coke Transportation Cost	1,315Bs/ton (14.6US$/ton)	0	0
7) Coke Shipping Point	Puerto Ordaz or Maracaibo	The port within the site	The port planned to be constructed in the industrial park
8) Domestic Market for Coke	None	None	For anode production and ferro-silicon
9) Coke Oven Gas (COG)	Fuel for private power plant	Sold to the thermal power plant as fuel	Industrial use
10) Domestic Market for By-products	No market for crude tar, benzene and ammonia. Ammonia can be used to produce fertilizer through reaction with another by-product, sulfuric acid.	No market for crude tar, benzene and ammonia. ammonia may be sold to the Zulia complex, and certain market can be expected for sulfuric acid.	No market for crude tar, benzene and ammonia. Ammonia can be used to produce fertilizer through reaction with another by-product, sulfuric acid.
11) Industrial Water	Water in the nearby Uribante River or its underground flow	Well water 2.75Bs/m ^{3}	Well water 0.125Bs/m ^{3}
12) Electricity	8.0Bs/KWH	1.2 Bs/KWH	1.2 Bs/KWH
	2.0Bs/l	3.5 Bs/Nm ^{3}	1.4 Bs/Nm ^{3}

	Santo Domingo	La Cañada	Pto. Ordas
13) Labor Force	Highly available, but skills not unknown.	Available from surrounding areas in terms of number and skills.	Available from surrounding areas in terms of number and skills.
14) Environment	Surrounded by agricultural and livestock farming areas. Mostly undeveloped. Adjacent to Santo Domingo Airport, and design consideration may be needed to avoid disturbance with air traffic	Reserved as industrial land. Typical undeveloped savanna.	Reserved as industrial land. Subdivision mostly completed.
15) Other Industries	Primitive coke ovens, small-scale cement and ceramic factories.	Near a petrochemical complex, a cement mill, a beer brewery, and numerous oil drilling and loading facilities.	Near a steel mill, aluminum smelting works, ferro-silicon plant, and power plant.
Maintenance Services	Not available locally, requiring own maintenance shop.	Maintenance shops for the above facilities are available.	Maintenance shops for the above facilities are available.

4.3 Selection of the Most Suitable Site

In selecting the most suitable site among the 3 candidate sites, the following criteria were established:

1) The site should be zoned as the heavy industrial area.
2) There is a market for COG.
3) Coal and coke can be transported smoothly and economically.

Based on the above criteria, the La Cañada in Zulia State was selected as the most suitable site for the proposed coke making plant.

Chapter 5 Evaluation of Raw Coals

Chapter 5 Evaluation of Raw Coals

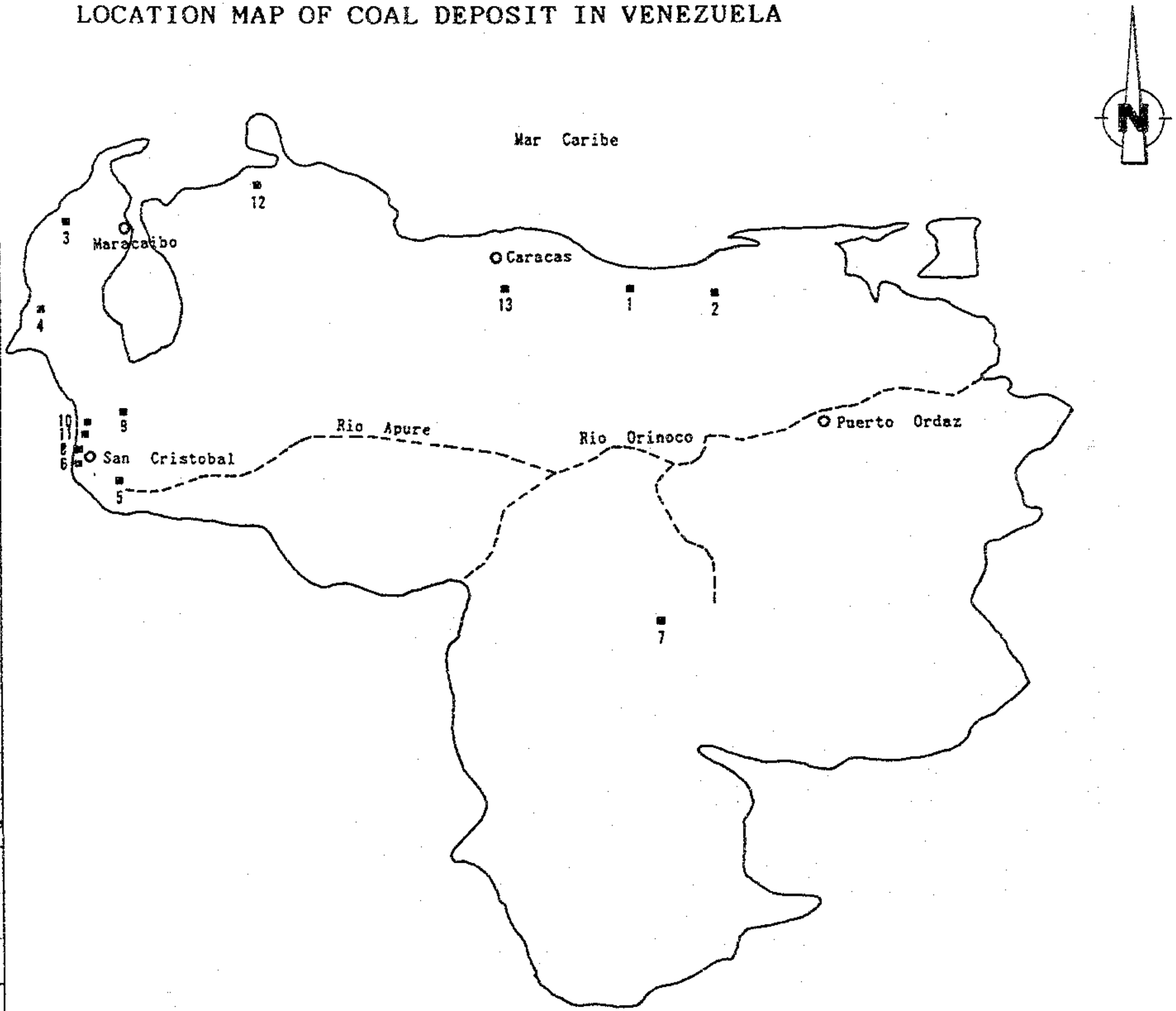
5.1 Coking Coal Resources in Venezuela and Colombia

Major coal resources in Venezuela are located in 5 states, Zulia, Tachira, Anozoategui, Falcon, and Aragua. Total coal reserves amount to 10,215 million tons (1992), and proven reserves 576 million tons. 95% of coal reserves are located in two western states, Zulia and Tachira. The geologic age of these coal resources ranges between Paleocene and Eocene epochs. Despite the relatively young formation, however, these coals are bituminous or sub-bituminous due to the effect of geological tectonic movement.

To this date, 13 coal deposits have been confirmed, and preliminary properties have been identified. From data on coal analysis, including volatile matters and reflectivity of vitrinite, coal deposits in Tachira have high potential to contain coal for blast-furnace coke making required for the project.

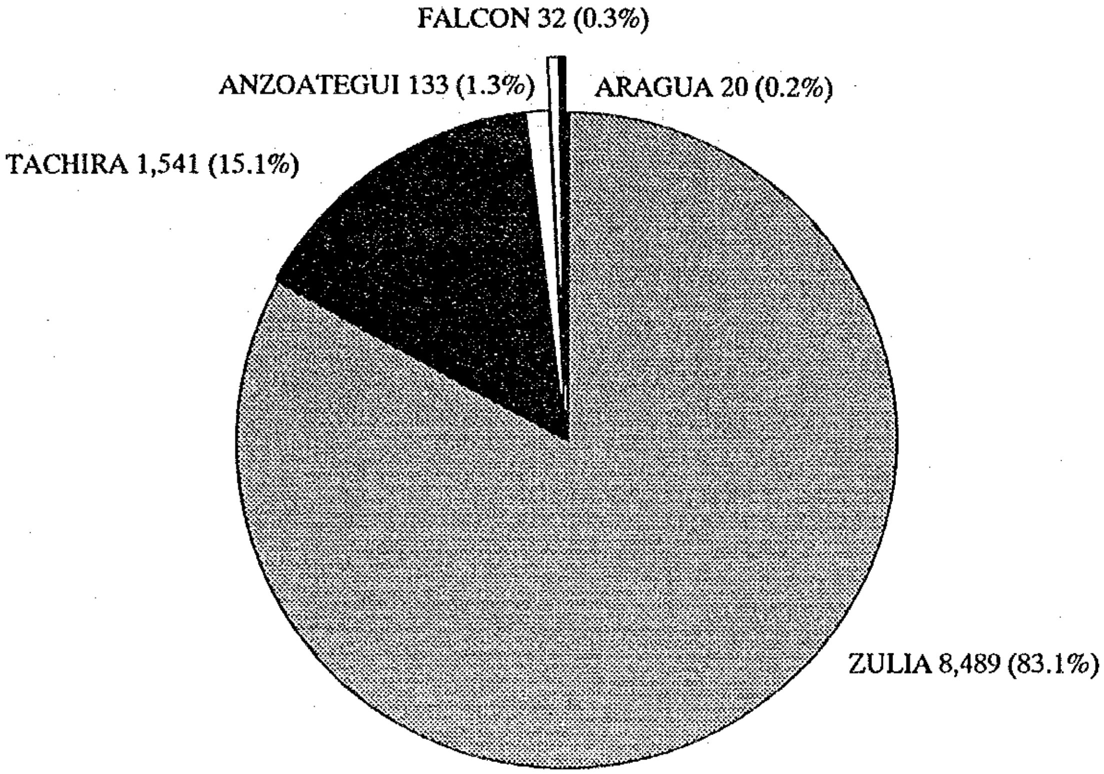
Location, coal reserve by states, coal property and reserves, other data on each deposit are summarized in Figures 5-1 and 5-2, and Table 5-1. In general, exploration of coal resources in Venezuela is in the initial stage. If extensive and systematic exploration activities are initiated, coal reserves and properties will be assessed with a much higher accuracy.

LOCATION MAP OF COAL DEPOSIT IN VENEZUELA



No.	Deposit	Location State	Formation	Geological Age
1	Fila Maestra	Anzoategui	Quebradon	Miocene
2	Maricual	Anzoategui	Maricual	Oligocene
3	Guasare	Zulia	Marcelina	Palaeocene
4	Aricuaisa	Zulia	Carbonera	Eocene
5	Sant Domingo	Tachira	Carbonera	Eocene ?
6	Las Adjuntas	Tachira	Los Cuervos	Palaeocene
7	Impacto	Bolivar	?	Miocene ?
8	Hato la Virgen	Tachira	Carbonera	Eocene
	Others	Tachira		
9	Santa Teresa	Merida	Carbonera	Eocene
10	San Pedro	Tachira	Los Cuervos	Palaeocene
11	Lobatera	Tachira	Carbonera	Eocene
12	Pedregal	Falcon	Cerro Pelado	Miocene
13	Taguay	Aragua	Chaguaramas	Miocene
	Total			

Fig.5-1 LOCATION MAP OF COAL DEPOSIT IN VENEZUELA



Note : Total coal reserves are 10,215 million tons

Source : Ministry of Energy and Mine

Fig.5-2 COAL RESERVE IN VENEZUELA

Table5-1 COAL RESERVES AND QUALITY IN VENEZUELA

Source : Ministry of Energy and Mine (October in 1991)

No.	Deposit	Location	Formation	Geological	Reserves(1,000,000t) in 1992				Proximate Analysis		Volatile	Calory	Sulfur	Maceral Analysis			Ro	Classification
		State		Age	Proven	Probable	Possible	Total	Ash	Volatile	(d.a.f)	BTU	%	Vitrinite	Exinite	Inertinite		ASTM
1	Fila Maestra	Anzoategui	Quebradon	Miocene	5	9	66	80	10.3	43.1	48.0	12,400	2.28	87.4	5.5	0.8	0.53	Bituminous,H-V C
2	Naricual	Anzoategui	Naricual	Oligocene	30	7	16	53	3.1	54.0	55.7	13,400	2.20	-	-	-	0.61	Bituminous,H-V B
3	Guasare	Zulia	Marcelina	Palaeocene	353	2,083	6,053	8,489	3.8	35.8	37.2	14,380	0.58	85.3	0.9	11.4	0.60	Bituminous,H-V B
4	Aricuaisa	Zulia	Carbonera	Eocene	0	0	0	0	9.8	40.7	45.1	11,330	2.60	83.5	4.3	0.2	0.42	Sub-bituminous B
5	Sant Domingo	Tachira	Carbonera	Eocene?	135	145	22	302	7.0	43.4	46.7	11,880	0.50	86.7	2.7	6.7	0.38	Sub-bituminous B
6	Las Adjuntas	Tachira	Los Cuervos	Palaeocene	29	61	224	314	4.7	37.3	39.1	14,500	0.61	95.5	0.0	0.1	0.74	Bituminous,H-V A
7	Impacto	Bolivar	?	Miocene?	0	0	0	0	1.4	47.3	48.0	11,790	0.85	84.6	14.6	0.0	0.35	Sub-bituminous A
8	Hato la Virgen	Tachira	Carbonera	Eocene					4.6	43.5	45.6	14,670	1.39	95.8	3.3	0.0	0.56	Bituminous,H-V A
	Others	Tachira			21	86	795	902										
9	Santa Teresa	Merida	Carbonera	Eocene	0	0	0	0	1.9	52.4	53.4	15,000	0.72	75.2	23.7	0.6	0.47	Bituminous,H-V A
10	San Pedro	Tachira	Los Cuervos	Palaeocene	0	0	0	0	12.8	33.3	38.2	13,090	0.85	93.9	0.0	3.6	0.74	Bituminous,H-V A
11	Lobatera	Tachira	Carbonera	Eocene	3	14	6	23	7.5	49.8	53.8	11,200	0.86	86.5	8.4	0.6	0.56	Bituminous,H-V C
12	Pedregal	Falcon	Cerro Pelado	Miocene	0	0	32	32	18.4	37.7	46.2	10,500	3.60	91.7	2.6	0.6	0.66	Bituminous,H-V C
13	Taguay	Aragua	Chaguaramas	Miocene	0	0	20	20	9.2	41.8	46.0	11,640	2.50	94.8	1.4	0.1	0.55	Bituminous,H-V C
Total					576	2,405	7,234	10,215										

Geological Age:Paleogene (Paleocene (Eocene (Oligocene),Neogene (Miocene (Pliocene)

Ro (Vitrinite Maximun Reflectance):One of measuring methods to evaluate coalification.

5.1.1 Outline of Coal Fields

The objective of the Study is to examine technical, financial and economic feasibility of the project alternatives of constructing and operating the coke plant through utilization of the domestic coking coal to be exploited in the Tachira Coal Mine for which the study has been completed by "JICA" in September 1992. Accordingly the present study is conducted mainly on focusing the coal field in Tachira State.

(1) Tachira State

In Tachira State, there are 5 coal fields, FNO (Franja Nororiental), SAN (San Félix), LOB (Lobatera), HAT (Hato de la Virgen), and LAS (Las Adjuntas). Coals from these field contain high volatile matter. Only coal with medium volatile matter are reserved in FNO according to the existing data. A general outline of each field on the basis of geological information obtained by the study team is shown below. Geological sequences in the study areas and classification of coals are as follows.

GEOLOGICAL SEQUENCE OF STUDY AREAS

Geological Era	Name	Thickness	Remarks
Eocene epoch	Carbonera formation (C.B. Formation)	400m	Coal–bearing formation
Paleocene – Eocene epoch	Mirador formation	200m	Massive sandstone
Paleocene epoch	Los Cuervos formation (L.C. Formation)	130 – 250m	Coal– bearing formation

CLASSIFICATION OF COAL

Low Volatile Content Coal	Volatile content 14 – 22%	Dry ash free (d.a.f.) base
Medium Volatile Content Coal	Volatile content 22 – 31%	Dry ash free (d.a.f.) base
High Volatile Content Coal	Volatile content 31% or over	Dry ash free (d.a.f.) base

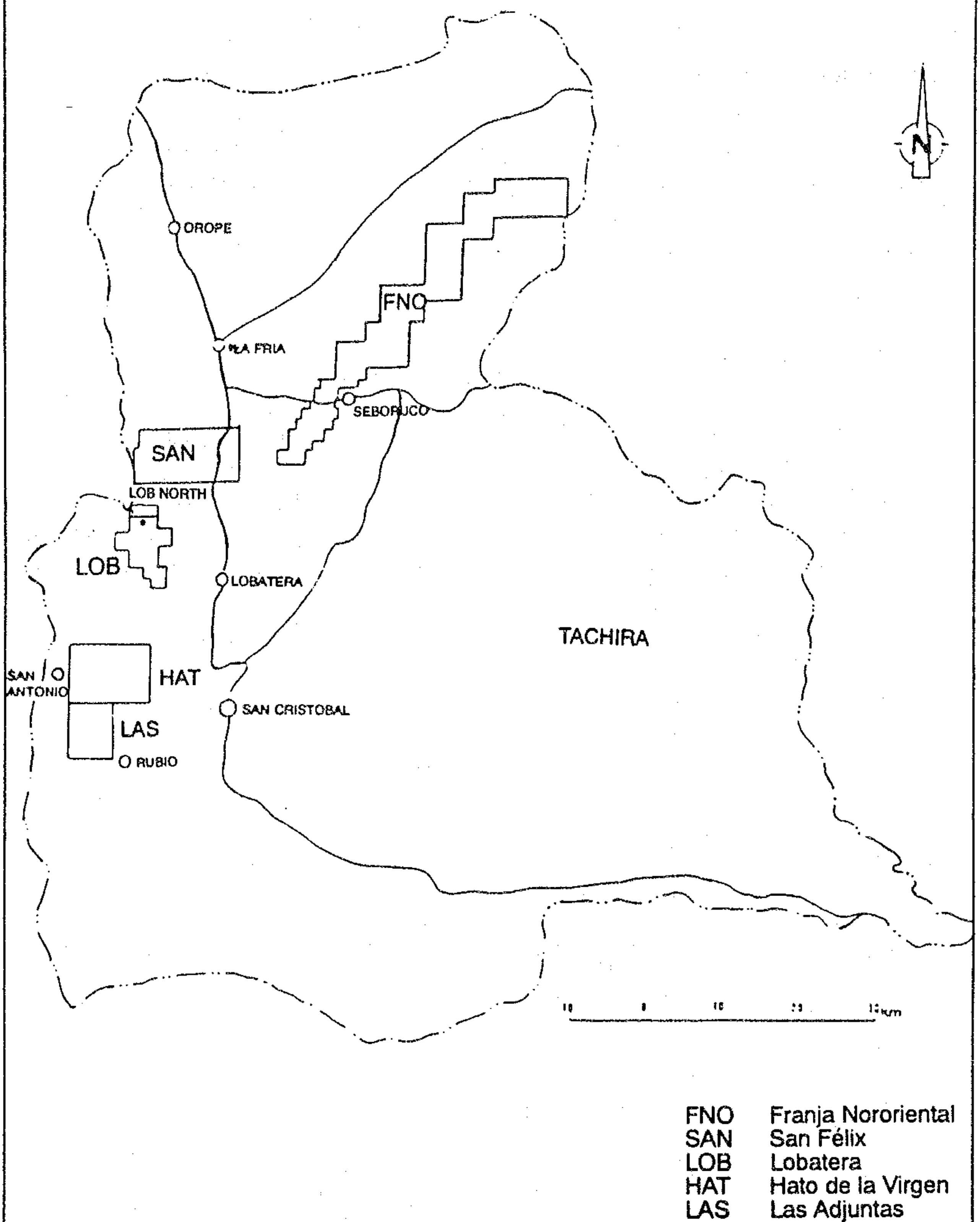


Fig.5-3 LOCATION OF COKING COAL DEPOSIT IN TACHIRA

1) FNO

FNO is located at the northern end of Tachira State and forms a long strip of coal-bearing formation along the strike of stratum (NE-SW). The strike in the southwest area (Block 1), approximately 1.5km long, is steeply dip monocline structure and is known to contain medium volatile content coal, according to the results of previous exploration surveys. JICA's report "Feasibility Study on Coal Resource Development Project in Tachira State: 1992" estimates proved coal reserves of round 3 million tons.

CARBOSUROESTE stated full-scale geological survey in October, 1991 and reported its result in June, 1993. The result of the surface survey in the area on a block-by-block basis is summarized below.

Fig.5-4 shows general arrangement of blocks.

Block 1 (600ha)

The block is divided into north and south portions over a fault.

The northern portion has not been investigated in detail, and detailed data including coal reserves are not available. Nevertheless, the area does not show much development potential judging from a very narrow strike (1km) and the productive seams tend to thin out northward.

As for the southern portion, CARBOSUROESTE has conducted extensive surface survey. As a result, minable coal seams (L.C.Formation: Nos.25 and 30) extending 1.5km continuously have been identified. Although the dip inclines steeply at 50 - 60 degrees, presence of continuous outcrops has been confirmed to suggest stable geological structure.

It should be noted, however, that the steep dip structure makes it difficult to investigate a deeper portions by test drilling.

Block A (350ha)

The block is adjacent to the southwestern part of Block 1.

The dip inclines steeply at 50 - 60 degrees . While minable coal seams (Nos.25 and 30) have been confirmed, the area containing coal seams is very small and is interrupted by the Vega de Pato fault in the middle, likely to limit the mining area.

Block B (11,017ha)

This block is characterized by a group of faults running in a northeast direction and steep dip structure. The Umuquena fault between the Umuquena and Bocono rivers governs geological structure in the area. The dip in the west side of the fault accompanies fold and partially form a vertical and tarmover.

Thus, geological structure in the area is expected to be very complex due to potential interruption by fault related to the Umuquena fault, disturbance of layers, and other factors. Thus, the area offers unfavorable conditions for mining.

The east side of the fault does not have much outcrop and sequence is not known.

At present, evaluation of coal seams is not possible, and thus the number of minable coal seams and coal reserves are not known.

Block C (5,956ha)

The block generally forms steep dip (50 – 60 degrees) monocline structure, estimated to be interrupted by fault at an around 500m interval. No detailed data are available.

Unexplored area (Block 2)

Block-2 is located adjacent to Block-1 and Block-B, thus presence of C.B. Formation and L.C.Formation is expected. According to the result of the previous geological survey, C.B. Formation shows a low rank of coalification and is not suitable for coke making coal.

On the other hand, coal seam Nos.25 and 30 in L.C. Formation, as confirmed in Block-1, contain medium-volatile coke making coal. It should be noted, however, that the both coal seams are gradually thinning from south to north. (At the known northern end, 0.4m for the No.25 seam, and 0.6m for the No.30 seam)

A detailed geological structure is not known because no surface exploration (1/5000 scale) has been conducted. As seen from aerial photographs available, presence of a few faults is anticipated. The angle of dip is 50 – 60 degrees in Block-1, and vertical (reverse in part) in Block-B. Thus, Block-2, located in between, is expected to have a steep dip.

Volatile content is 25.8% (d.a.f.) in Block-1 and 40.2% in Block-B. Thus, the area containing medium-volatile coke making coal (volatile content of less than 31%), required by the coke oven plant, seems to be fairly limited.

In conclusion, Block-2 is not likely to contain coal seams that are economically suitable for the project.

FNO has been expected as a source of medium volatile content coking coal in the state. The survey result reveals that medium volatile content coking coal is limited to seams present in L.C. Formation in Blocks 1 and A. Proven coal reserves in the two blocks are estimated at 578,000 tons. Unfortunately, medium volatile content coal reserves of this volume is very small for production of cokes to be exported. Also, the steep dip, monocline structure requires a special mining technique. On the other hand, other blocks contain high volatile content coking coal, and geological structure seems to be fairly complex due to interruption by faults. All in all, the area shows very low development potential.

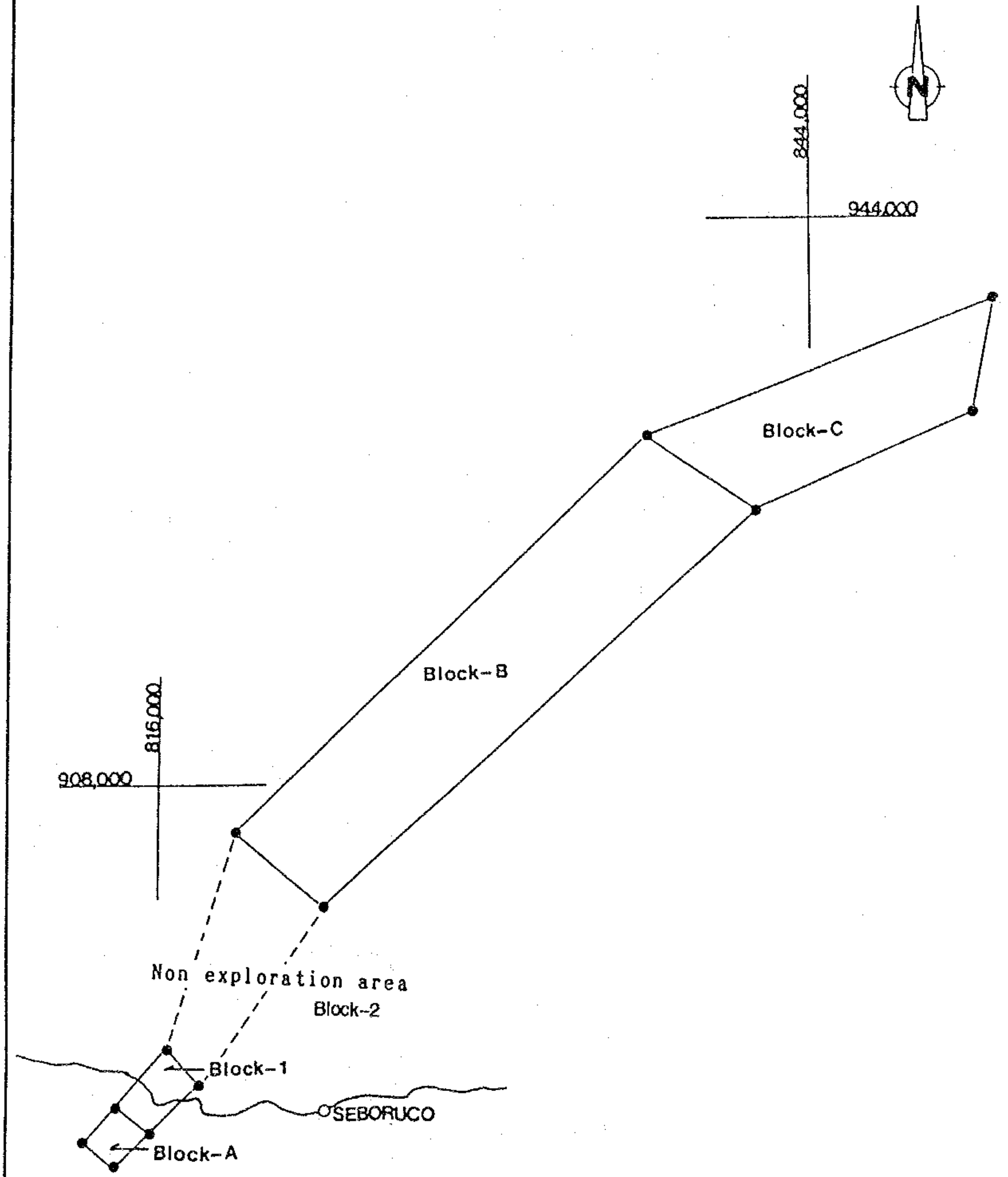


Fig. 5-4 EXPLORATION AREA OF FNO

2) SAN

Geological exploration is still at the initial stage and no detailed data, including coal reserves, qualities, and geological structure, are available.

3) LOB

This is only one field commercially mined in the state.

Coal production was started in 1953, with the accumulated total reaching 2,656,000 tons. Workable coal seams show high volatile content (52.2%), and together with relatively high sulfur content (1.6%), they seem not to be suitable for coke making.

4) HAT

HAT is divided into Clemones and San.Joaquin areas.

Clemones Area

Series of exploration surveys covering C.B. Formation have been completed, and tunnels have been bored since November, 1992. Coal seams contain high volatile content coal (47%, d.a.f.) and are not suitable for coke making.

San. Joaquin area

Up until 1992, CARBOSUROESTE conducted systematic geological surveys, including surface exploration, drilling of 11 holes, and adit survey, and confirmed presence of 17 coal seams having thickness of over 0.6m in L.C. Formation. The geological structure shows a gentle dip, and the flat area on the top can be strip mined in part.

In 1993, 3 holes were drilled to determine coal properties of deeper coal seams that are expected to contain medium-volatile coking coal. As a result, the previous interpretation of the geological structure and correlation of coal seams has been modified. Previous Nos.27, 29 and 30 seams have been renamed to Nos.25, 29, and 30 seams. It has been estimated that proven coal reserves in the three seams amount to 2,303,330 tons, with volatile content of 30.9% (d.a.f.), thus classified as medium-volatile coal.

Assuming that each coal seam is at least 0.8m thick and the mining yield is 80% (according to the "short slashes of advance" mining method used in HAT's Clemones area), CARBOSUROESTE estimates that coal reserves available to the coke oven plant total 1,007,000 tons, equivalent to 10-year supply at a rate of 100,000 tons per year. At present, detailed coal reserves, properties, and other data are being determined.

Note that coal reserves and properties in the area, as shown in Table 5-2, are the data prior to July 1993.

5) LAS

In 1992, JICA conducted a feasibility study, as shown in the report "Feasibility Study on Coal Resource Development Project in Tachira State."

Annual production of 400,000 tons over 15 years is expected.

6) Lobatera North

This area has been recommended by the JICA study team during the first field survey (1993) to conduct a detailed survey for the purpose of securing medium-volatile coal resources in place of the FNO deposit.

The survey covers L.C. formation present in a 322 ha area extending over three deposits, Arenales, Paso Azul, and Cazaderoll.

Since November 1993, CARBOSUROESTE has been conducting surface exploration on a 1/5000 scale, which has revealed the following geological conditions:

- 14 outcrops of coal seams which have the thickness 0.8m and more have been verified.
- The geological structure is monoclinal with a southward dip at 10 – 20 degrees.

Currently, further exploration and analysis are under way.

(2) Guasare coal in Zulia State (Fig.5–5)

The Guasare mine lot in Zulia State has proved coal reserves of 983 million tons, probable reserve of 2,060 million tons, and possible reserve of 3,600 million tons. The planned annual coal production from Paso Diablo is 3 million tons in 1993 and 4 million tons in 1994 through 1997.

In 1998, production in Socui is scheduled to start, and annual production will range between 10 million tons and 18 million tons.

A principal productive seam is found in the No.4 seam in Marcelina Formation (geological age: Eocene – Paleocene; around 550m thick; comparable to L.C. Formation in Tachira), which is 10m thick and generally flat with a dip of 10 degrees. At present, Guasare coal is used to fuel at power station as well as blast furnaces.

The average purchase price at the coke plant (delivered to the coal yard) ranges between US$20 – 22 per ton if the coal are usable as coking coal.

CARBOZULIA

CUENCA CARBONIFERA DEL GUASARE

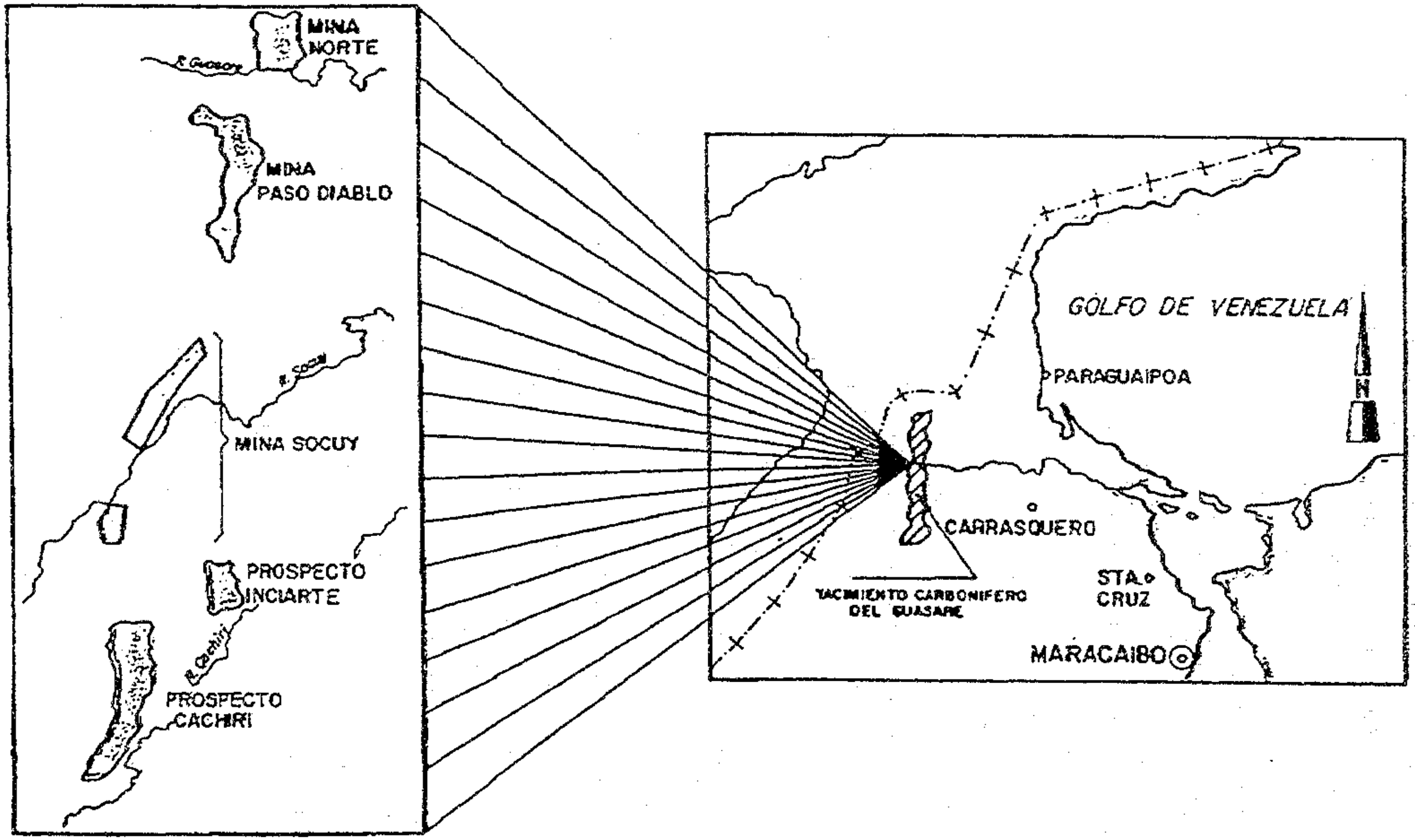


Fig.5-5 LOCATION OF COKING COAL DEPOSIT OF GUASARE AND SOCUI

(3) Colombian coal

Field study in colombia is not included for this study. Therefore, the details about coking coal in Colombia are not known. However CARBOSUROESTE provided following information.

1) Boyaka coal

Data on Boyaka coal obtained from CARBOSROSUROESTE are summarized as follows:

Mining company	:	Industria de Carbones Metalurgicos Ltd.
Production	:	10,000 tons per month
Mining method	:	Underground
Mining cost	:	US$12 - 16/ton
Transporation cost	:	US$12/ton (Boyaca ---> San Cristóbal: 15 hours)

Coal Seam	M1	M2
Coal Quality		
Moisture content (%)	0.13	0.15
Ash content(%, d.b)	7.41	5.78
Volatile matters (%, d.a.f)	21.46	31.53
Fixed carbon (%)	78.36	68.47
Total sulfur (%)	0.71	0.80
Calorific value (Btu/Lb)	15,484	15,543
F.S.I	7.0	8.5

Coal reserves : Proven reserve of the M-1 seam which contains low volatile content coal required to be mixed for coke making is around 1 million tons.

2) Socha-Socota coal

Data on Socha-Socota coal obtained from CARBOSUROESTE in September 1993 are summarized as follows.

Productive Coal Seam	M-20	M-10	P-20
Production (ton/year)	18,000	12,000	24,000
Mining cost(US$/t)	23	23	20
Reserve (t)			
Proved	250,000	150,000	400,000
Probable	400,000	250,000	600,000
Possible	600,000	350,000	850,000
Total	1,250,000	750,000	1,850,000
Coal quality			
Ash content (%, d.b)	10	10	10
Volatile content (%, d.a.f.)	25.6	26.1	34.4
Total sulfur (%)	1.0	1.0	1.0
F.S.I	5 - 8	5 - 8	5 - 8
Total dilatation (%)	40	50	120
Maximum reflectance	1.30	1.34	0.71

2 coal seams, M-20 and M-10, contain medium volatile content coal which can be used for coke making, but proved reserve is small and requires relatively a high mining cost (US$23/ton). Thus, Socha-Socota coal has not been included in further evaluation.

5.1.2 Coal Reserves and Quality

Coal reserves of the above depostis estimated from available data and coal quality data obtained through Venezuela are summarized in Table 5-2.Based on the above analysis, possible availability of coking coals including Colombian coals is summarized as follows.

Deposits	Production (ton/year)	Proved Reserve (L.C.Formation)	Coal Qualiry (Rank fo V.M.)[1)	Period (year)
FNO : Block-1	60,000	476,000	M	7.8
Blok-A	9,600	101,700	M - H	10.4
Northern LOB Under exploration				
HAT Under exploration	100,000		M - H	54.4
LAS	400,000	12,222,250	H	30.6
Colombia				
(Boyaca, M-1)	120,000[2)	1,000,000	L	13.3
(Socota,M-20,10)	30,000	400,000	M	3.3

Notes: 1) Rank of V.M. : L - Low volatile matter M - Medium volatile content
H - High volatile matter
2) Possible export quantity is 50,000ton/year

Table 5-2 COAL RESERVES AND QUALITY

Aea	Block	Formation	Seam	Reserves(1000t) Proved	Probable	Possible	Total	(D.A.F) V.M(%)	T.S	F.S.I
FNO	I (600ha)	C.B	34	289.6	321.2	414.5	1,025.3	35.5	-	-
		C.B	40/1	922.4	943.2	761.7	2,627.3	37.2	1.4	-
		C.B	40/2	523.3	521.5	774.9	1,819.7	35.8	0.7	-
			subtotal	1,735.3	1,785.9	1,951.1	5,472.3			
		L.C	25	172.9	314.9	244.6	732.4	26.9	1.0	-
		L.C	30	303.1	340.4	402.3	1,045.8	24.6	0.7	-
			★subtotal	476.0	655.3	646.9	1,778.2			
			Total	2,211.3	2,441.2	2,598.0	7,250.5			
	A (350ha)	C.B	5 Sample[1)]	787.9	2,365.6	3,236.0	6,389.5	37.0	-	8
		L.C	★1 Sample[1)]	101.7	303.5	505.8	911.0	31.6	-	6
			Total	889.6	2,669.1	3,741.8	7,300.5			
	B 11017ha	C.B	11Sample[1)]	677.5	1,256.4	811.7	2,745.6	45.8	0.8	2to9
		L.C	★62Sample[1)]	10,576.3	27,216.3	35,778.1	73,570.7	40.2	1.4	0to8.5
			Total	11,253.8	28,472.7	36,589.8	76,316.3			
	C (5956ha)	C.B	2 Sample[1)]	482.6	1,420.5	1,805.6	3,708.7	48.6	-	4.5
		L.C	22Sample[1)]	2,989.9	10,122.5	9,515.3	22,627.7	46.7	-	0to5.5
			Total	3,472.5	11,543.0	11,320.9	26,336.4			
SAN				Non exploration area						
LOB	CAZ-12	C.B	40	2,014.1	-	-	2,014.1	52.2	1.6	3
	North	L.C	(10,11,20)	Sampling, Recommended Area						
HAT	Clemones	C.B	20	3,142.1	1,301.0	1,651.0	6,094.1	45.8	5.2	-
		C.B	24	3,729.1	2,325.6	2,722.4	8,777.1	46.5	1.2	6
			total	6,871.2	3,626.6	4,373.4	14,871.2			
	San. Joaquin	L.C	10	747.5	1,073.2	1,218.8	3,039.5	34.1	2.5	7
		L.C	15	2,353.2	3,664.1	3,999.9	10,017.2	34.0	1.4	4
		L.C	20	1,440.1	1,807.4	1,657.8	4,905.3	32.5	0.9	6
		L.C	26	163.4	435.5	650.0	1,248.9	30.8	0.6	-
		L.C	27	276.4	744.7	1,111.5	2,132.6	36.2	0.5	-
		L.C	28	122.5	326.6	487.5	936.6	33.5	0.5	-
		L.C	29	52.8	360.8	516.8	930.4	32.3	0.7	7
		L.C	30	288.6	703.3	934.7	1,926.6	29.2	0.6	5
			★Total	5,444.5	9,115.6	10,577.0	25,137.1			
LAS		L.C	20	5,214.2	1,740.2	2,429.5	9,383.9	43.1	1.8	6
		L.C	25	3,385.7	933.5	895.0	5,214.2	42.1	0.6	6
		L.C	30	3,622.6	641.3	1,150.5	5,414.4	38.6	0.6	5.5
			★Total	12,222.5	3,315.0	4,475.0	20,012.5			
Guasare	Paso Diablo		No 4	983,000	2,060,000	3,600,000	6,643,000	39.0	0.5	6
Colombia	Boyaca		★ M-1	1,000				21.5	0.7	7

Note: ★ This reserves are available for coking coal resourses.

1) Seam No's are not known. Coal reserve is assumed from the place where samples are taken.

5.1.3 Evaluation of Tachira Coal

The relationship between proved reserves and volatile matters (d.a.f) of each field obtained from geological data is plotted in Fig.5-6. The correlation between voltaile contents in coal seam Nos.25 and 30 and respective areas is shown in Fig.5-7, for the purpose of determining the direction of coalification.

As shown in Fig.5-7, the degree of coalification in Tachira increases northward from the southern area, around the LAS field, to the FNO field (i.e., volatile content decreases) and decreases northward from the FNO field. This suggests that the center of coal basin in Tachira exists between LOB and FNO.

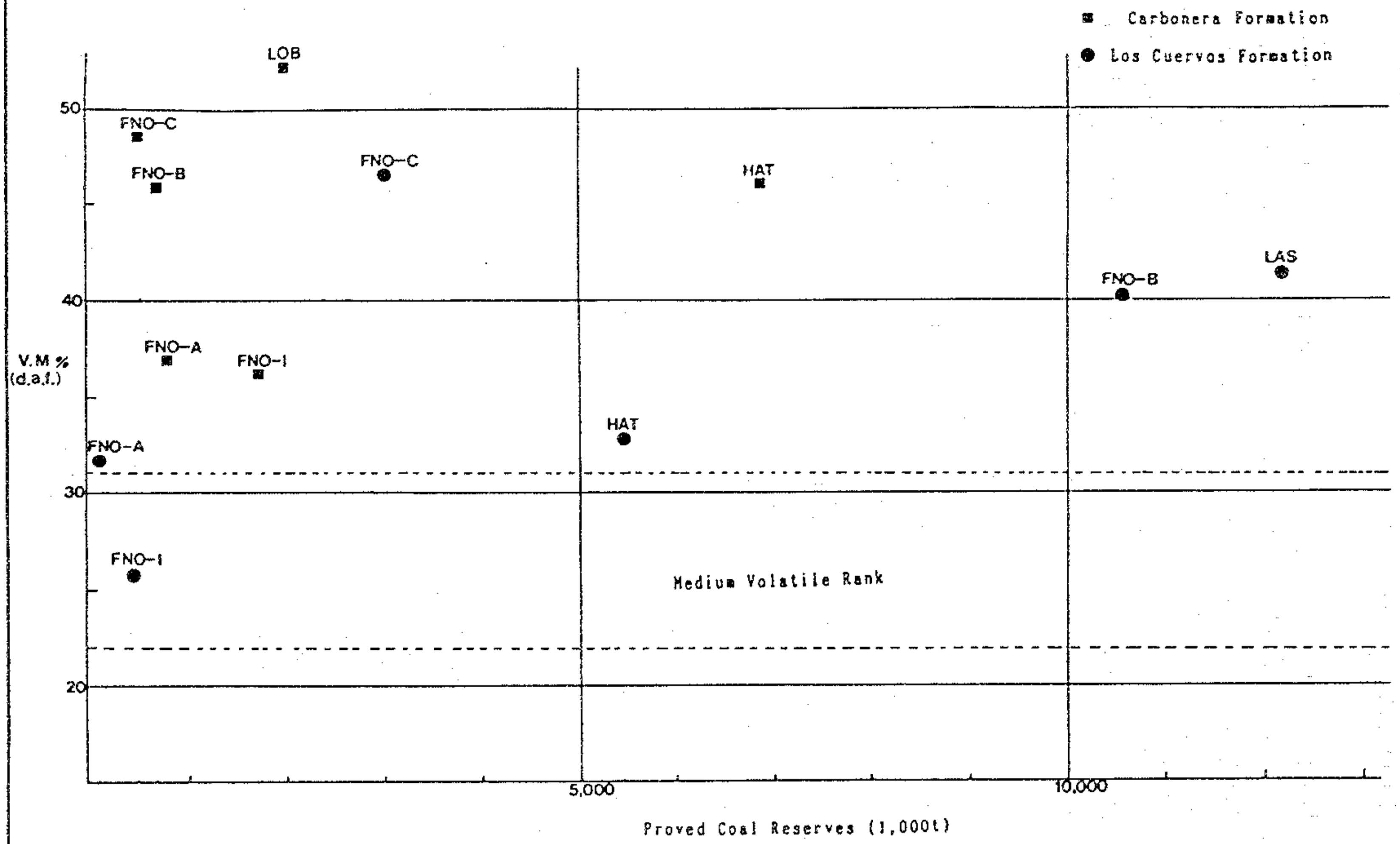


Fig.5-6 THE RELATIONSHIP BETWEEN V.M. AND PROVED COAL RESERVES IN TACHIRA

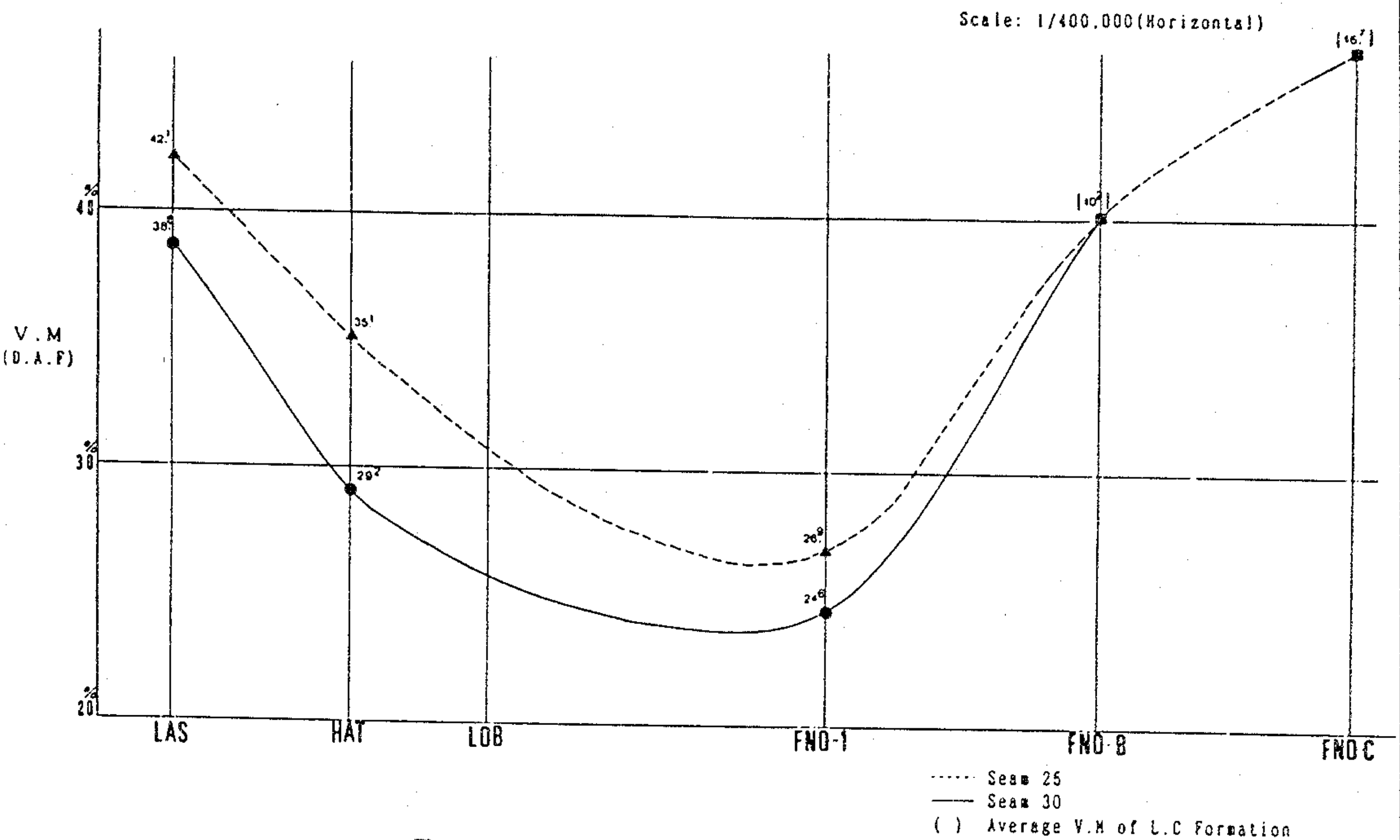


Fig.5-7 TENDENCY OF V.M. IN THE STATE OF TACHIRA

5.2 Coal Test

5.2.1 Sampling

In July and August 1993, the study team and local CARBOSUROESTE counterparts collected samples from representaive coal seams of each field.

Sampling method	: Fresh coals were collected from experimental crosscut, adits[1] and trenches, both channel and bulk samples. Boyaka coals were supplied by CARBOSUROESTE and Guasare coals[2] by CORPOZULIA.
Packing and transportation methods:	The channel samples were packed in plastic bags and cloth bags, which were placed in trunks carried by the study team members. The bulk samples were crushed to 8mm or less grain sizes for volume reduction, which were packed in plastic bags. After being placed in used oil drums, they were transported to Japan by air freight.
Notes	: To remove weathered coals, each sample was checked to see if the F.S.I. value[3] is 5 or more. The sample from the northern LOB field was collected as the reference sample because of time constraint.

Sampling locations are shown in Fig.5-8, and a general outline of sample is summarized in Table 5-3.
Columnar sections of coal seams from which sampling was made are shown in Fig.5-9.

1) Adit - experimental tunnel

2) In January 1994, sample of Guasare coal are collected and analyzed at CICASI Laboratory in Zulia. Possibility of blending Guasare Coal is studied in Annex-1.

3) F.S.I. (free swelling index) - one of measuring methods to evaluate coking coal
The method was used to check weathered coals which coking property deteriorates significantly.

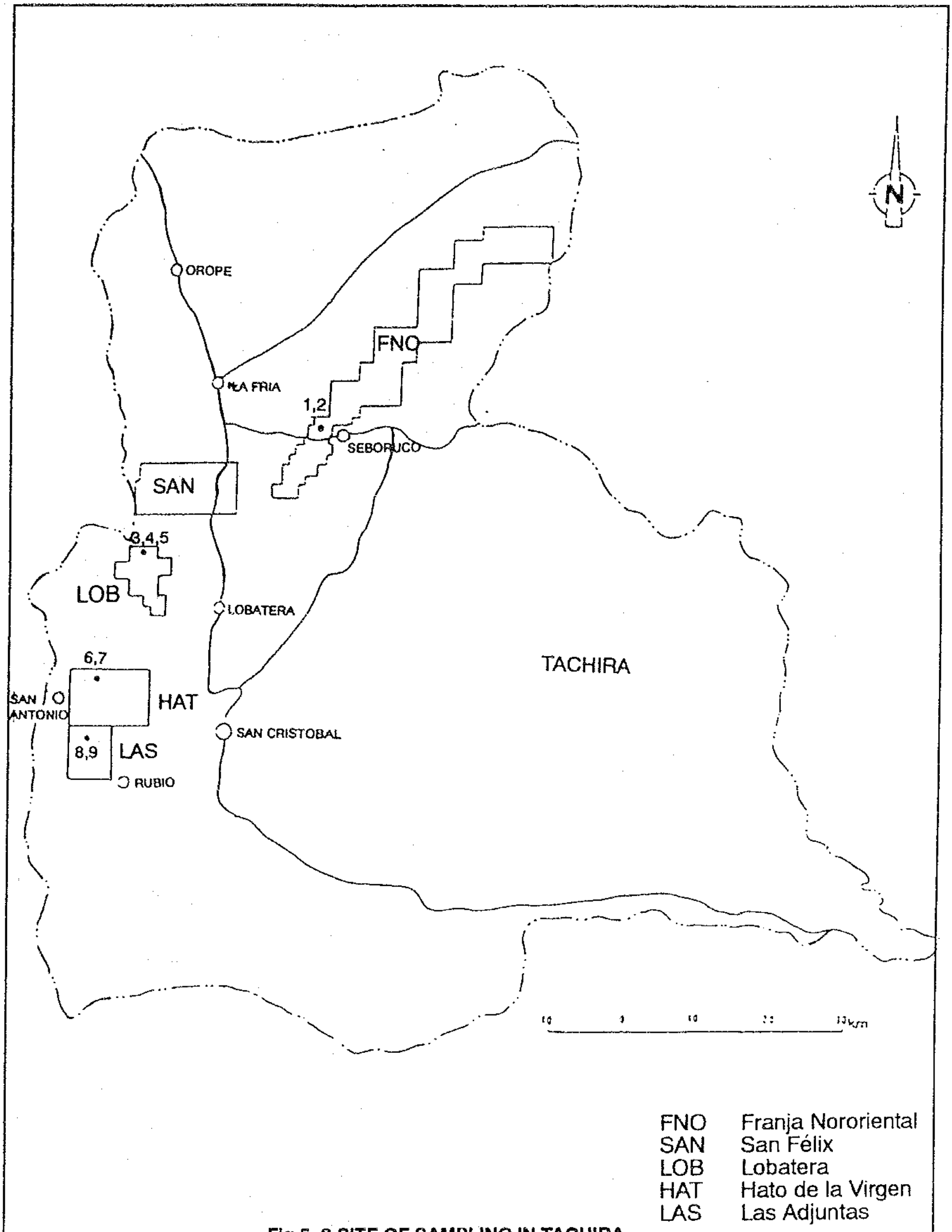


Fig.5-8 SITE OF SAMPLING IN TACHIRA

Table 5-3 OUTLINE OF THE SAMPLING FOR COKING TEST

No	Coal field	Coal seam	Site of sampling	Sample No. (Study team)	Channel (kg)	Bulk (kg)	Remarks
1	FNO	LC-25	ADITS	93-FNO-LC25	5		
		LC-30	ADITS	93-FNO-LC30	5	1000	
2	SAN		Exploration is early stage. Therefore, this is no sampled.				
3	LOB	LC-10	OUTCROP	93-LOB-LC10	5		
4		LC-11	OUTCROP	93-LOB-LC11	5		
5		LC-20	ADITS	93-LOB-LC20	5		
6	HAT	LC-15/1	ADITS	93-HAT-LC15/1	5		
7		LC-20/1	ADITS	93-HAT-LC20/1	5		
8		LC-20	ADITS (P11Area)	93-LAS-LC20	5		
9	LAS	LC-25	CROSSCUT No. 1, P3Area	93-LAS-LC25	5	500	Blended 1000
		LC-30	CROSSCUT No. 1, P3Area	93-LAS-LC30	5	500	
10	Guasare (Zulia)	No. 4	Open-pit	93-GUASARE-No4	5		
11	Boyaca (Colombia)	M-1	Underground	93-COLOMBIA-M1	5	400	

LC: Los Cuevos Formation   CB: Carbonera Formation

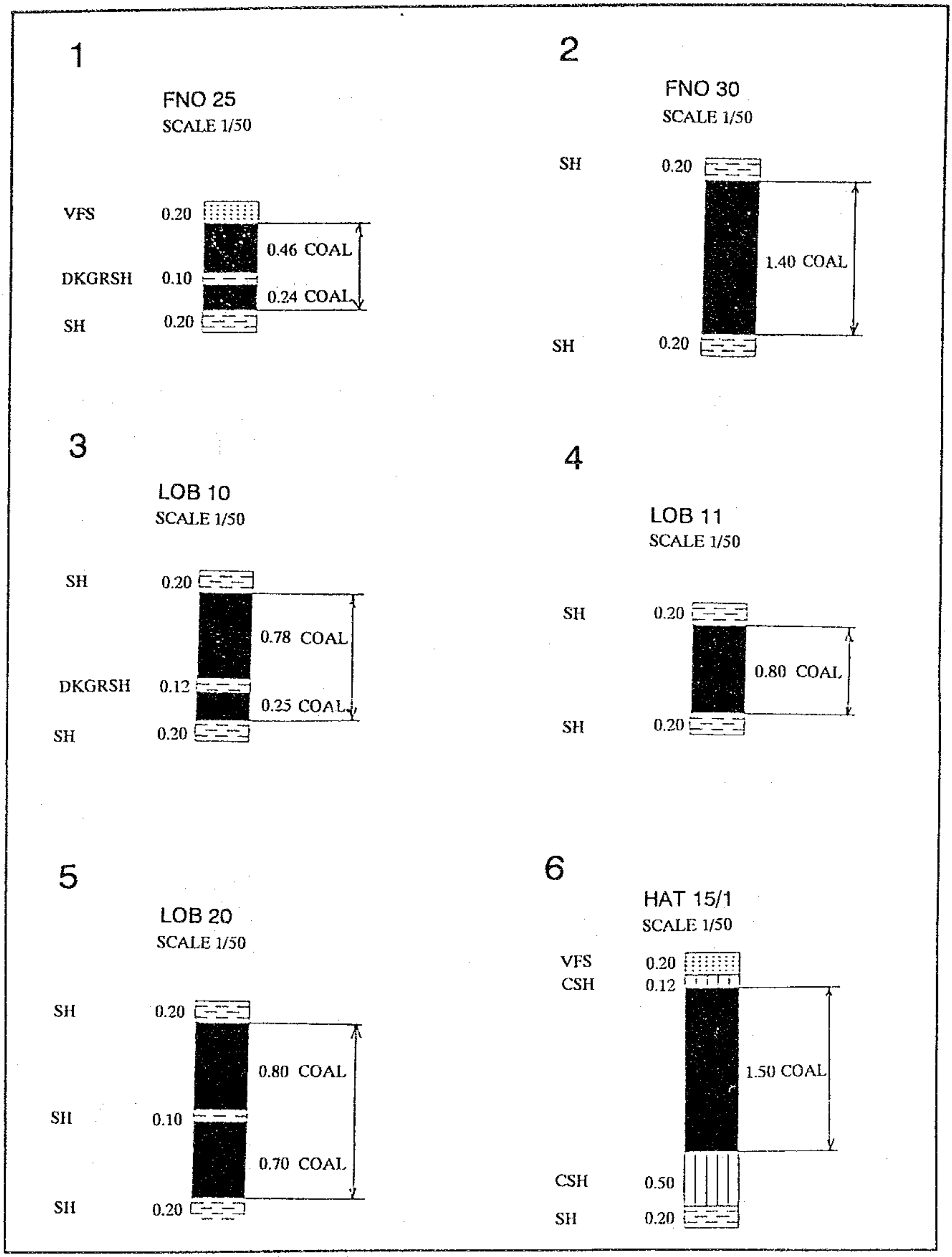


Fig. 5-9 COLUMNAR SECTION OF SAMPLE IN TACHIRA (1/2)

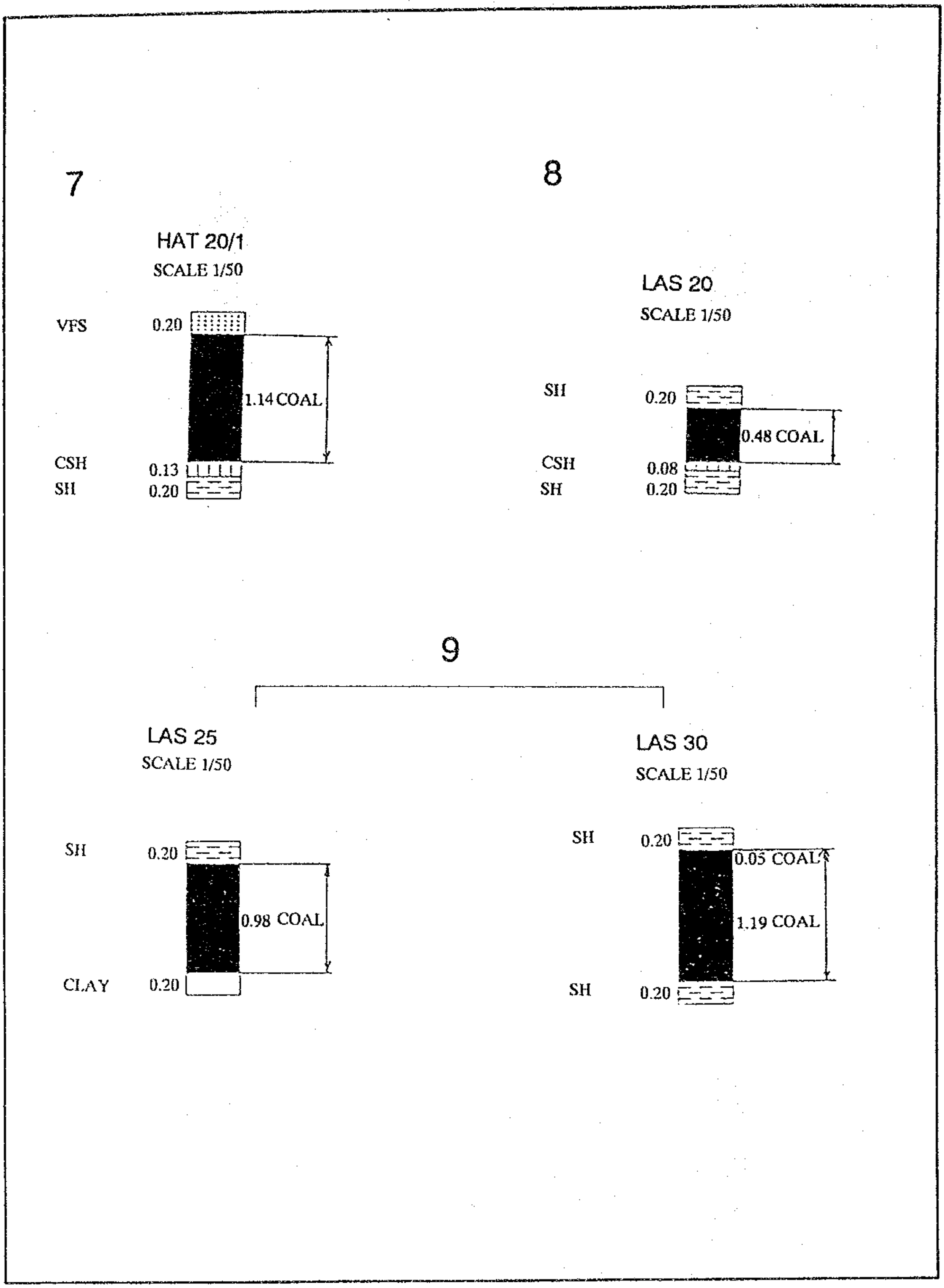


Fig. 5-9 COLUMNAR SECTION OF SAMPLE IN TACHIRA (2/2)

5.2.2 Quality of Raw Coals

Properties of raw coals were evaluated on the basis of the result of proximate analysis, calorific value, sulfur content, and forms of sulfur and FSI values by type of coal. Table 5-4 shows the analytical result and evaluation.
Also, density gravity and yield from coal preparation were estimated by the sink-and-float test. The channel sample was used for the raw coal analysis and the sink-and-float test.

The float-and-sink test has been conducted to select an appropriate specific gravity for coal dressing required to maintain clean coal ash of the coal used in the coking test at around 8%, and the need for coal dressing. The result of the float-and-sink test for each sample is summarized in Table 5-5.
Coals in FNO-LC-25, LOB-LC-11, HAT-LC-15/1 LC-20/1, LAS-LC-(25+30), and Guasare deposits does not require intensive cleaning since ash content is less than 5%. However, a simple classifier is needed to prevent deterioration of coal quality due to the inclusion of adventitious muck during mining operations,
Coals in FNO-LC-30, LOB-LC-10, LOB-LC-20, LAS-LC-20, and Boyaca deposits contain more than 8% ash and require cleaning.
Note that the float-and-sink test conducted in the study analyzed one sample for each seam taken from the face. Thus, design of an actual coal preparation facility should reflect the result of selection as to which coal seams are to be mined in what proportions.

5.2.3 Cleaning of Coal

Raw coals were cleaned to produce clean coal used for the above analysis and test. The channel sample was used for analysis of coal properties and evaluation of grindability and coking property. The bulk sample was used for the coking test by selecting clean coal in terms of selection gravity forecast from the result of the sink-and-float test.

5.2.4 Quality of Clean Coals

Coal property evaluation was conducted in accordance with work flow shown in Fig.5-10. Using clean coal prepared from coking coal, the test is designed to evaluate suitability of coking coal by analyzing the degree of coalification, caking property, and contents of various components. The degree of coalification is determined by volatile matters, carbon content, and the mean reflectance of vitrinite. On the other hand, caking property is evaluated by F.S.I., the maximum fluidity measured by Gieseler plastometer, and the total dilatation measured by dilatometer. Also, ash content, total sulfur, and ash composition were analyzed. Based on these analyses, suitability of coking coal was evaluated.

The analysis was conducted at a laboratory and testing methods are summarized in Table 5-6.

Table 5-4 QUALITY OF RAW COAL

Sample No.	1	2	3	4	5	6	7	8	9	10 (Zulia)	11 (Colombia)
Abbreviation	93-FNO LC25	93-FNO LC30	93-LOB LC10	93-LOB LC11	93-LOB LC20	93-HAT LC15/1	93-HAT LC20/1	93-LAS LC20	93-LAS LC(25+30)	93-Guasare NO. 4	93-Boyaca M1
T. Moisture % (As received)	1. 3	0. 7	5. 7	4. 0	6. 8	3. 6	4. 7	4. 2	1. 5	3. 3	1. 1
Proximate Analysis (Air dried basis)											
Moisture %	1. 2	0. 6	5. 4	2. 3	3. 6	3. 1	1. 0	1. 5	1. 3	3. 0	1. 0
Ash %	2. 0	16. 0	8. 4	2. 7	9. 7	5. 2	2. 3	12. 8	4. 6	2. 1	12. 3
Volatile Matter %	24. 3	21. 4	32. 4	35. 8	32. 9	29. 1	32. 0	40. 4	37. 1	36. 4	19. 8
Fixed carbon %	72. 5	62. 0	53. 8	59. 2	53. 8	62. 6	64. 7	45. 3	57. 0	58. 5	66. 9
Calorific value cal/g (Dry ash free)	8, 760	8, 760	7, 980	8, 540	8, 220	8, 340	8, 830	8, 580	8, 620	8, 310	8, 740
Total sulphur(a. d. b)%	0. 96	0. 73	0. 84	0. 70	1. 11	0. 76	1. 35	6. 59	0. 62	0. 42	1. 18
Forms of sulphur(d. b)											
Sulfate sulphur %	0. 04	0. 01	0. 03	0. 01	0. 03	0. 02	0. 12	0. 33	0. 02	0. 04	0. 05
Pyritic sulphur %	0. 35	0. 22	0. 23	0. 04	0. 35	0. 04	0. 48	5. 10	0. 09	0. 03	0. 38
Organic sulphur %	0. 58	0. 50	0. 63	0. 68	0. 77	0. 72	0. 76	1. 26	0. 52	0. 36	0. 76
F. S. I(d. b)	8. 5	8	2. 5	8. 5	3. 5	5	7. 5	4	6	3	8
Clean coal											
Dencity of preparation	1. 80	1. 55	1. 80	1. 80	1. 80	1. 80	1. 80	1. 45	1. 80	1. 80	1. 80
Yield %	99. 1	78. 5	92. 4	99. 5	96. 9	99. 2	99. 0	75. 7	98. 8	99. 0	92. 1
Remarks	Medium volatile - coking coal. Ash content of LC-30 is too high and yield is low.		High Volatile coking coal. Sulfur content of LC20 is high. Therefore this seam will be more high horizon. F. S. I. of LC10 and LC20 are low. Therefore they will be weathered coal			High volatile coking coal. They are upper hoeizon. Therefore lower seam will be possible to be medium volatile coal.		High volatile coking coal. Sulfur content of LC20 is too high and ash is slightly high.		Low ash, low sulfur steam coal	Low volatile coking coal. Ash, sulfur contents are slightly high.

Table 5-5 RESULTS OF FLOAT-SINK TEST

Sample NO.	Abbreviation	Preparation Density	Weight (%)	Ash (%)	ΣWA/ΣW	Preparation for clean coal,ash cont.less than 8%
1	93-FNO-LC25	-1.80	99.1	1.5	1.5	
		+1.80	0.9	50.5	1.9	NO need
2	93-FNO-LC30	-1.40	59.9	3.1	3.0	
		1.40~1.45	5.8	13.9	4.1	
		1.45~1.50	4.5	22.2	5.2	
		1.50~1.55	8.3	28.5	7.7	1.55
		1.55~1.60	7.1	33.9	9.9	
		+1.60	14.4	56.0	16.5	
3	93-LOB-LC10	-1.80	92.4	5.6	5.6	1.80
		+1.80	7.6	61.2	9.9	
4	93-LOB-LC11	-1.80	99.5	2.4	2.4	
		+1.80	0.5	61.8	2.7	NO need
5	93-LOB-LC20	-1.40	82.4	5.1	5.1	
		1.40~1.60	12.8	20.8	7.2	
		1.60~1.80	1.7	38.2	7.8	1.80
		+1.80	3.1	67.0	9.6	
6	93-HAT-LC15/1	-1.80	99.2	4.4	4.4	
		+1.80	0.8	64.7	4.9	NO need
7	93-HAT-LC20/1	-1.80	99.0	1.8	1.8	
		+1.80	1.0	45.9	2.2	NO need
8	93-LAS-LC20	-1.40	69.6	7.3	7.3	
		1.400~1.425	2.7	15.0	7.6	
		1.425~1.450	3.4	16.0	7.9	1.45
		1.45~1.50	4.6	17.1	8.5	
		1.50~1.60	7.7	20.9	9.6	
		1.60~1.80	7.6	26.7	10.9	
		+1.80	4.4	50.4	12.7	
9	93-LAS-LC(25+30)	-1.80	98.8	3.9	3.9	
		+1.80	1.2	60.6	4.6	NO need
10	93-GUASARE-No4	-1.80	99.0	1.2	1.2	
		+1.80	1.0	75.6	1.9	NO need
11	93-BOYACA-M1	-1.40	80.2	4.3	4.3	
		1.40~1.45	5.0	11.8	4.7	
		1.45~1.50	2.3	17.9	5.1	
		1.50~1.60	2.4	23.8	5.6	
		1.60~1.80	2.2	36.0	6.3	1.80
		+1.80	7.9	75.0	11.7	

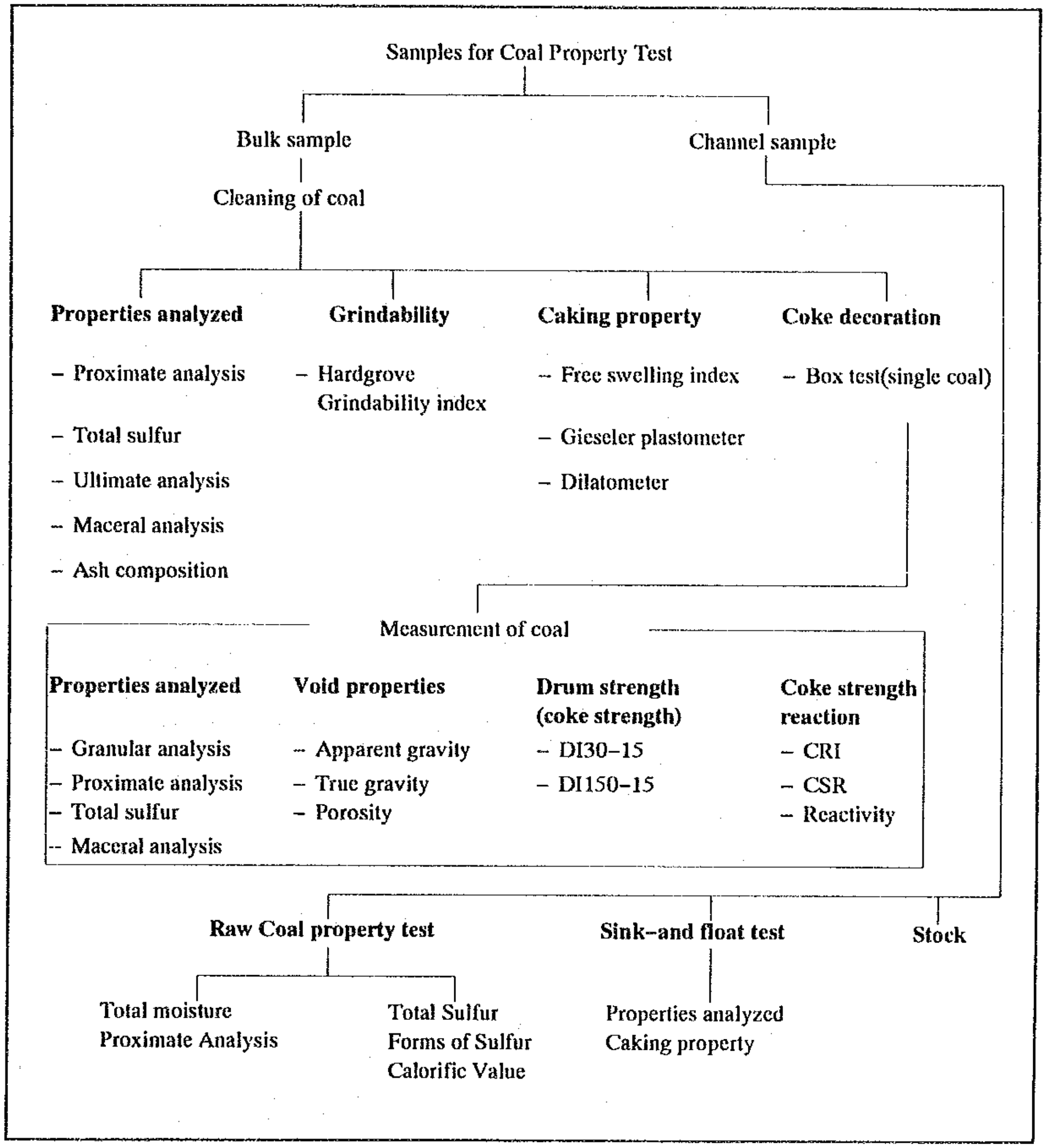


Fig.5-10 FLOW OF COAL PROPERTY EVALUATIION

Table 5-6 LIST OF TESTING METHODS

Standard and Literature	Measurement Items
Method for Testing of Coal JISM8801-1979	F.S.I., Gieseler plastometer, dilatometer, box test, grindability index, grain size distribution
Method of Proximate Analysis of Coals and Cokes JISM8812-1979	Constant humidity content, ash content, volatile matters, fixed carbon
Method of Ultimate Analysis of Coal and Coke JISM8813-1988	Carbon, hydrogen, sulfur, nitrogen, total oxygen, sulfur in ash
Method for Measuring Calorific Values of Coals and Cokes JISM8814-1972	Calorific value
Method of Microrganic Scopical Measurement for the Macerals JISM8816-1986	Maceral content analysis of coals, and measurement of vitrinite reflectance
Method for Testing of Cokes JISK2151-1977	Grain size distribution, true gravity, apparent gravity, porosity, TI25, DI30-15, DI50-15, reactivity, and ash fisibility
Analysis of Coal and Coke Ash Composition JISM8815	Method for coal and coke, JISM8815-1976
Coke Circular 30, P239 (1981)	SCO test
Coke Circular 23, P82 (1974)	CSR test
Coke Circular 32, P55 (1983)	Method of anisotropic texture

(1) Properties of Venezuelan and Colombian coals

1) FNO channel sample coals (LC–25, LC–30)(Table 5–8)

The degree of coalificatin of the FNO field is volatile matter of 24.29 – 24.45 (%, d.a.f.) on a pure coal substance basis, carbon content of 88.69 – 89.07% (%, d.a.f.) in ultimate analysis, vitrinite's mean reflectance of 1.25 – 1.28 (%, oil), ranked as medium volatile matter coal. As F.S.I. is 9, Maximum Fluidity (M.F.) measured by Gieseler plastometer is 2.27 – 2.83 (log DDPM), and total dilatation measured by dilatometer, 69 – 146%, caking property is sufficient for coking coal. From the above data on coalification and caking property, coal produced from the FNO field is considered to be heavy coking coal of medium volatile matter.

Characteristically, ash content is low. LC–25 is very low at 1.46 (%, d.) and LC–30 is also low at 7.63 (%, d.) as coking coal.

Total sulfur is the average level for coking coal. Total sulfur of LC–25 is 0.71(%, d.) and one of LC–30 is 0.63(%, d.).

As for Maceral composition, total inert content is high at 41.4 – 44.4(%, vol.). As a result, CBI is high at a level comparable to the Australian coal.

Grindability index is 100 – 103 (H.G.I.) and indicates that these coals are highly grindable and suitable for coke making.

As for ash composition, Al_2O_3 ranges between 17% – 21%, lower than ordinary coking coal.

Comparing L–25 and L–30, coalification of LC–30 is higher than LC–25 as judged from volatile matter, carbon content, and vitrinite's mean reflectance. On the other hand, oxygen content of LC–30 is 3.62% (%, d.a.f.), lower than 4.11 (%, d.a.f.) of LC–25. As a result, caking property of LC–30 is significantly higher in terms of F.S.I., M.F., total dilatation, Overall, LC–30 has better properties than LC–25.

As a result, coal in the FNO field is considered as high quality, heavy coking coal of medium volatile matter, while coking property varies with seams.

2) LOB channel sample coals (LC–10, LC–11, LC–20) (Table 5–9)

Degree of coalification of the LOB field is volatile matter of 35.83 – 37.07 (%, d.a.f.) on a pure coal substance basis, carbon content of 82.20 – 84.68 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 0.82 – 0.85 (%, oil). Thus coal from the field is classified as high volatile matter coal.

As F.S.I. ranges from 3 to 9, M.F. ranges from 0.95 to 3.16 (log DDPM), and total dilatation ranges from 0 to 108(%), caking property is varying greatly between seams.

From the above coalification and caking property data, coal in the LOB field is considered to be weakly coking coal of high volatile matter.

Ash content is low for coking coals, LC–11 at 2.31 (%, d.), LC–10 at 4.55 (%, d.), and LC–20 at 7.74 (%, d.).

Total sulfur content varies greatly between seams. LC–11 is lowest at 0.74(%, d.), followed by LC–10 at 0.92% and LC–20 at 1.24% (%, d.).

Regarding Maceral composition, total inerts content is in a low range between 11.8 – 20.6 (%, vol). As a result, CBI is relatively low between 0.38 and 0.74.

Grindability is 59 – 80 (H.G.I.), comparable to a level of ordinary weakly coking coal of high volatile matter.

Degree of coalification in terms of volatile matter, carbon content, and vitrinite's mean reflectance does not show significant difference between LC–10, 11 and 20. On the other hand, caking property is highest in LC–11, as seen in F.S.I., M.F. and total dilatation, which has the best quality as weakly coking coal of high volatile matter. On the other hand, LC–10 and LC–20 show high sulfur content and low caking property, not suitable for coking coal.

The above results indicate that, in the LOB field, only LC–11 is considered to be weakly coking coal of high voaltile matter.

3) HAT channel sample coals (LC–15, LC–20/1)(Table 5–10)

As for degree of coalification of the HAT field, volatile matter is 31.06 – 32.32 (%, d.a.f.) on a pure coal substance basis, carbon content of 85.09 – 89.62 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 0.99 – 1.00 (%, oil), classified as high volatile matter coal.

As F.S.I. ranges from 1.5 to 9, M.F. ranges from 0.00 – 4.31 (log DDPM), and total dilatation ranges from 0 to 310(%), caking property is varying greatly between seams.

The above degree of coalification and caking property data indicate that coal in the HAT field is medium coking coal of high volatile matter. However, coal in LC–15 do not show fluidity and dilatation at all, although F.S.I. is 51/2, and they are considered as non–caking coal. Difference in caking property within the same field seems to come from weathering, judging from the fact that oxygen content found in ultimate analysis is much higher in LC–15 (7.61%, d.a.f.) than LC–20 (3.22%, d.a.f.). Non–weathered coal in the LC–15 seam, if any, is expected to have caking property equivalent to that of LC–20, rated as medium coking coal.

Ash content is very low for LC–20 (1.71%, d.) and low for LC–15 (4.86%, d.).

Total sulfur content is high for coking coal, 0.86 (%, d.) for LC–15 and 1.15 (%, d.) for LC–20.

As for Maceral composition, total inert content is very low at 23.5 – 24.5 (%, vol), and CBI is at a level comparable to heavy coking coal of medium volatile matter in U.S.A.

Grindability is very high (H.G.I. 90 – 93).

The above results indicate that the non–weathered LC–20 seam in the HAT field is rated as medium coking coal with high caking property. On the other hand, coal in the LC–15 seam has turned into non–caking coal due to weathering and are not suitable for coking coal.

4) LAS channel sample coals LC–20, LC–(25+30)(Table 5–11)

Degree of coalification of the LAS field is volatile matter of 38.81 – 46.70 (%, d.a.f.) on a pure coal substance basis, carbon content of 83.60 – 85.52 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 0.69 – 0.85 (%, oil). Thus coal from the field are classified as high volatile matter coal.

Caking property is very high: F.S.I. is 41/2 – 7; M.F. is 4.14 – 4.61 (log DDPM); and total dilatation is 201 – 212(%).

From the above degree of coalification and caking property data, coal in the LAS seam are considered to be weakly coking coal of high volatile matter.

Ash content is relatively high in LC-20 8.24 (%, d.) and low in LC-(25+30) 4.44 (%, d.).

Total sulfur content is very high in LC-20 at 4.11(%, d.). Compared to the figure reported in JICA's "Feasibility Study on Development of Coal Fields in Tachira State - 1992," 1.39(%, d., the mean value of 28 samples), the above figure is considered to be a local one. Thus, although LC-20 is a high sulfur content seam, it can be used for coking coal if mixed with other low sulfur content coals.
LC-(25+30) shows relatively high sulfur content, but it can be used for coking coal.

As for Maceral composition, total inert content is low at 10.2 - 25.2(%, vol) and vitrinite content is high.

Grindability is H.G.I. 55 - 59, which is within the range of ordinary weakly cokig coal of high volaitle matter. As for ash composition, P_2O_5 in LC-(25+30) is very low at 0.08(%).

Comparing LC-20 and LC-25, the latter shows a higher degree of coalification in terms of volatile matter, carbon content, and vitrinite's mean reflectance. However, no significant difference is seen in caking property.

The above result indicates that coal in the LC-(25+30) seam of the LAS field are rated as high quality, weakly coking coal of high volatile matter. On the other hand, coal in the LC-20 seam have high sulfur content, while caking property is high, and need to be mixed with low sulfur content coal if they are to be used for coking coal.

5) Guasare coal (M4) (Table 5-12)

Guasare coal is classified as high volatile matter coal measured by degree of coalification, with volatile matter of 39.61 (%, d.a.f.) on a pure coal substance basis, carbon content of 83.08 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 0.76% (%, oil). Caking property is very low, with F.S.I. of 21/2, M.F. of 0.48 (log DDPM), and total dilatation of 0(%). From the above degree of coalification and caking property data, coal in the Guasare seam are considered to be noncaking coal of high volatile matter.

Ash content is characteristically very low at 1.04(%, d.) and sulfur content is also low at 0.41(%, d.)

Grindability is low at H.G.I.50, which is difficult to crush but the average hardness for steam coal.

The above result shows that Guasare coal is low ash content, low sulfur steam coal. Despite good quality, however, caking property largely limits their use for coking coal.

The data analyzed from the sample collected in January 1994 are detailed on Annex-1.

6) Boyaca coal (M1) (Table 5-13)

Boyaca coal has volatile matter of 22.03 (%, d.a.f.) on a pure coal substance basis, carbon content of 88.75 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 1.60 (%, oil). Thus it is classified as low volatile matter coal.
As F.S.I. is 81/2, M.F. is 1.08 (log DDPM), and total dilatation is 41(%), caking property is the average level for coking coal. From these degree of coalification and caking property data, Boyaca coal is classified as heavy coking coal of low volatile matter.

Ash content is low at 6.52(%, d.), but total sulfur content is high at 0.83(%, d.).

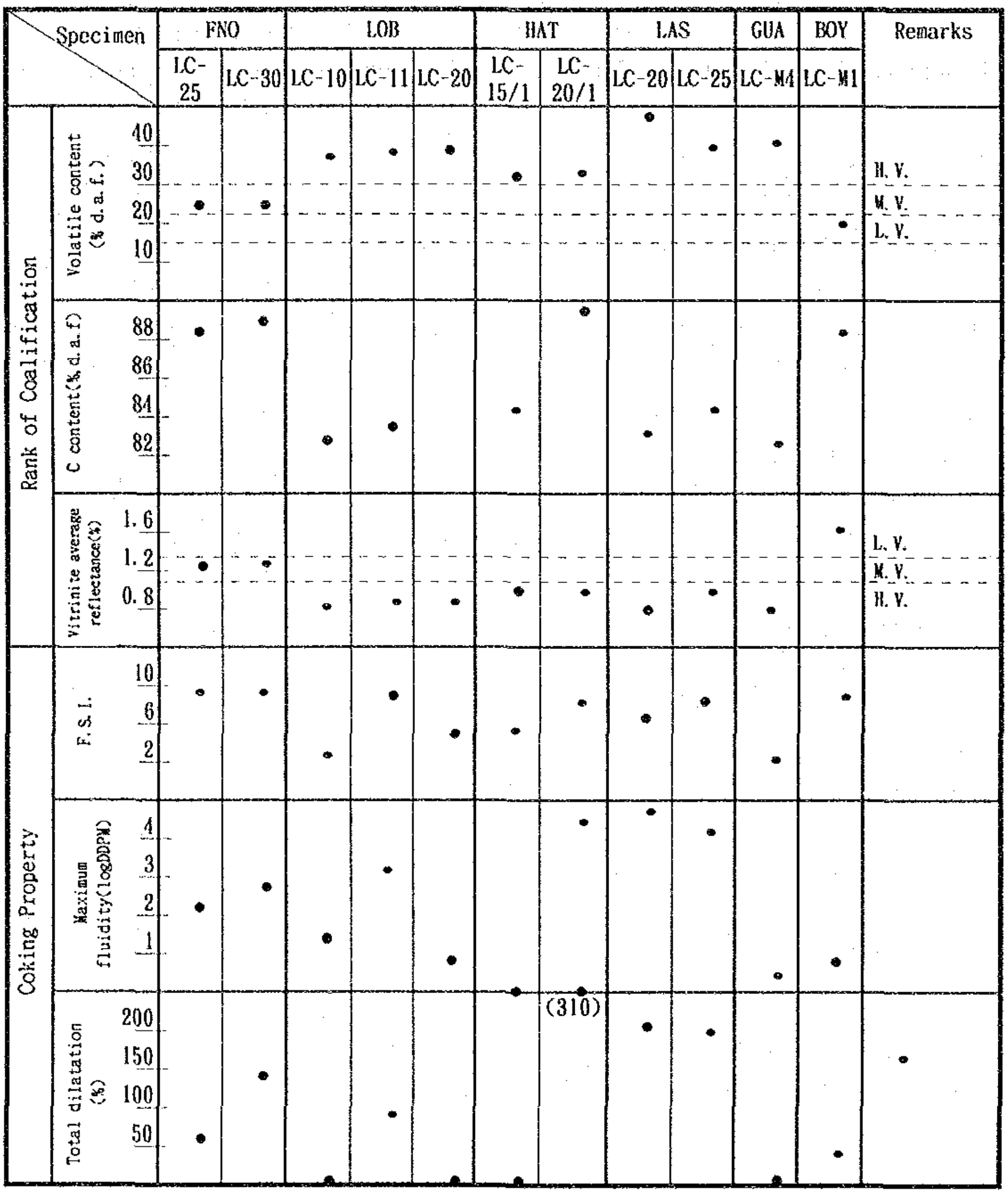
Maceral composition measured by total inert content is 29.9(%, vol), comparable to low volatile matter coal in U.S..
Grindability is H.G.I.99 to indicate that Boyaca coal is highly crushable and suitable for coke making.

As for ash composition, Na_2O content is slightly high at 1.04% and does not present a problem.

From the above result, Boyaca coal is considered to be heavy coking coal of low volatile matter with relatively high sulfur content.

7) Evaluation of channel sample coals as coal for coke making

Based on the result of analysis of the channel clean coals, evaluation of coking coals is summarized in Fig.5-11 and Table 5-7. As seen in the table, coals suitable for coke making are FNO-LC-25, FNO-LC-30, HAT-LC-20/1, LOB-LC-11, LAS-LC-(25+30), and Boyaca coals. Note that HAT-LC-20/1 has high sulfur content and must be blended with low sulfur content coal when it will be used for coking coal.



Note: Carbon content varies due to maceral composition and weathering of coal and becomes low in relation to volatile content.

H.V. =High volatile content coal M.V. =Medium volatile content coal

L.V. =Low volatile content coal

Fig5-11 COMPARISON OF PROPERTIES OF CHANNEL COALS

Table 5-7 EVALUATION OF CHANNEL CLEAN COALS AS COKING COALS

S.No.	Coal Field	Seam	Characteristics as Coking Coals	Evaluation
1	FNO	LC-25	Medium volatile matter, heavy coking coal with low ash	Good
2		LC-30	Medium volatile matter, heavy coking coal with low ash and sulfur content	Good
3	LOB	LC-10	High sulfur content and low caking property	Poor
4		LC-11	Low ash content, high volatile matter coal with high caking property	Good
5		LC-20	High sulfur content, low caking property	Poor
6	HAT	LC15/1	Caking property is very low (weathered coal)	Poor
7		LC20/1	Los ash content coal with high caking property, while sulfur content is high (1.15%)	Good
8	LAS	LC-20	Very high sulfur content	Poor
9		LC-25 LC-30	Low ash content, high volatile matter coal with high caking property	Good
10	GUA	M-4	Low ash content, low sulfur content, non-caking coal	Poor
11	BOY	M-1	Low volatile matter, heavy coking coal	Good

Table 5-8 PROPERTIES OF FNO (FRANJA NORORIENTAL) CHANNEL CLEAN COAL

Sample	FNO-LC25	FNO-LC30
Inherent moistuer(%)	1.35	0.98
Proximate analysis		
Ash (%, d.)	1.46	7.63
V.M. (%, d.)	24.09	22.44
F.C. (%, d.)	74.45	69.93
V.M. (%, d.a.f.)	24.45	24.29
Total sulfur(%, d.)	0.71	0.63
Ultimate analysis		
C (%, d.a.f.)	88.69	89.07
H (%, d.a.f.)	4.93	5.14
N (%, d.a.f.)	1.55	1.49
S (%, d.a.f.)	0.72	0.68
O (%, d.a.f.)	4.11	3.62
F.S.I.	9	9
Giesceler plastometer		
I.S.Temp. (℃)	428	415
M.F.Temp. (℃)	466	466
Solid.Temp.(℃)	494	506
M.F. (LogDDPM)	2.27	2.83
Dilatometer		
I.S.Temp. (℃)	391	384
Max. Cont.Tem. (℃)	438	418
Max. Dilat.Tem.(℃)	499	505
Percentage Cont.(%)	25	28
Percentage Dila.(%)	44	118
Total Dilatation(%)	69	146
Maceral analysis (%, Vol.)		
Vitrinite	52.9	49.7
Exinite	0.0	0.0
Micrinite	25.7	23.9
Semi fusinite	17.2	17.6
Fusinite	3.3	4.5
Mineral matter	0.9	4.3
Total inerts	41.4	44.4

Sample	FNO-LC25	FNO-LC30
Vitrinite type (%, Vol.)		
V11	8.5	5.9
V12	37.0	23.4
V13	7.4	19.9
V14	0.0	0.5
Mean Max.Reflect. (%, oil)	1.25	1.28
SI	4.77	5.02
CBI	2.57	3.18
H.G.I.	103	100
Calorific value (cal/g, d.a.f.)	8704	8721
ASH fusibility(℃)		
Softening point	1370	1540
Melting point	1380	1590
Flow point	1390	>1600
ASH composition (%)		
SiO_2	34.80	67.40
Al_2O_3	17.68	20.95
Fe_2O_3	43.98	7.30
CaO	0.85	0.35
MgO	0.27	0.25
MnO	0.05	0.02
TiO_2	0.81	1.75
P_2O_5	0.36	0.06
SO_3	0.18	0.10
K_2O	0.33	0.72
Na_2O	0.35	0.26

Table 5-9 PROPERTIES OF LOB (LOBATERA) CHANNEL CLEAN COAL

Sample	LC10	LC11	LC20
Inh. moistuer(%)	4.50	2.35	3.36
Proxi. analysis			
Ash (%, d.)	4.55	2.31	7.74
V.M. (%, d.)	34.20	35.88	34.20
F.C. (%, d.)	61.30	61.81	58.06
V.M. (%, d.a.f.)	35.83	36.73	37.07
T. sulfur(%, d.)	0.92	0.74	1.24
Ultima. analysis			
C(%, d.a.f.)	83.12	84.68	82.20
H(%, d.a.f.)	4.48	5.57	5.56
N(%, d.a.f.)	1.61	1.72	1.80
S(%, d.a.f.)	0.96	0.75	1.34
O(%, d.a.f.)	9.83	7.28	9.10
F.S.I.	3	9	5
Gies. plastometer			
I.S. Temp.(℃)	406	406	419
M.F. Temp.(℃)	442	445	440
Sol. Temp.(℃)	463	478	464
M.F. (LogDDPM)	1.56	3.16	0.95
Dilatometer			
I.S. Temp. (℃)	361	340	356
Max. Cont. Tem. (℃)	500	415	500
Max. Dilat. Tem. (℃)	-	478	-
Percentage Cont. (%)	17	26	33
Percentage Dila. (%)	-17	82	-33
Total Dilatation(%)	0	108	0
Maceral analysis (%, Vol.)			
Vitrinite	75.8	78.2	86.4
Exinite	1.7	1.4	1.2
Micrinite	13.2	12.1	5.7
S-fusinite	5.8	5.0	1.8
Fusinite	0.9	1.9	0.5
M. matter	2.6	1.4	4.4
T. inerts	20.6	18.7	11.8

Sample	LC10	LC11	LC20
Vitrini. type (%, Vol.)			
V 6	1.5	0.0	0.0
V 7	24.3	6.3	13.8
V 8	49.2	68.0	69.1
V 9	0.8	3.9	3.5
Mean Maximum Rflectance(%)	0.82	0.85	0.84
SI	2.88	2.92	2.80
CBI	0.74	0.64	0.38
H.G.I.	80	79	59
Calorific value (cal/g, d.a.f.)	8004	8517	8189
Ash fusibility			
Soft. point(℃)	1520	1470	1560
Melt. point(℃)	1550	1520	1580
Flow point (℃)	1590	1590	>1600
Ash composition (%)			
SiO_2	43.80	46.60	52.70
Al_2O_3	29.85	27.68	28.34
Fe_2O_3	21.96	14.17	14.52
CaO	1.17	3.34	0.35
MgO	0.63	0.83	0.38
MnO	0.03	0.31	0.02
TiO_2	1.93	1.43	1.75
P_2O_5	0.43	0.12	0.17
SO_3	0.11	1.57	0.03
K_2O	0.35	1.04	1.08
Na_2O	0.34	0.50	0.40

Table 5-10 PROPERTIES OF HAT (HAT DE LA VIRGEN) CHANNEL CLEAN COAL

Sample	HAT-LC15	HAT-LC20
Inherent moistuer(%)	3.11	1.47
Proximate analysis		
Ash (%, d.)	4.86	1.71
V.M. (%, d.)	29.55	31.77
F.C. (%, d.)	65.59	66.52
V.M. (%, d.a.f.)	31.06	32.32
Total sulfur(%, d.)	0.86	1.15
Ultimate analysis		
C (%, d.a.f.)	85.09	89.62
H (%, d.a.f.)	4.77	4.36
N (%, d.a.f.)	1.63	1.63
S (%, d.a.f.)	0.90	1.17
O (%, d.a.f.)	7.61	3.22
F.S.I.	5 1/2	9
Gieseler plastometer		
I.S. Temp. (℃)	448	391
M.F. Temp. (℃)	460	452
Solid. Temp. (℃)	463	491
M.F. (LogDDPM)	0.00	4.31
Dilatometer		
I.S. Temp. (℃)	381	357
Max. Cont. Tem. (℃)	500	395
Max. Dilat. Tem. (℃)	-	502
Percentage Cont. (%)	26	27
Percentage Dila. (%)	-26	283
Total Dilatation(%)	0	310
Maceral analysis (%, Vol.)		
Vitrinite	73.4	74.4
Exinite	0.0	0.0
Micrinite	14.7	15.1
Semi fusinite	6.4	6.3
Fusinite	2.7	3.0
Mineral matter	2.8	1.2
Total inerts	24.5	23.5

Sample	HAT-LC15	HAT-LC20
Vitrinite type (%, Vol.)		
V 8	0.0	0.0
V 9	45.5	37.2
V10	27.9	35.7
V11	0.0	1.5
Mean Max. Reflect. (%, Oil)	0.99	1.00
SI	3.72	3.75
CBI	0.81	0.78
H.G.I.	90	93
Calorific value (cal/g, d.a.f.)	8345	8728
ASH fusibility(℃)		
Softening point	>1600	1380
Melting point	>1600	1400
Flow point	>1600	1420
ASH composition (%)		
SiO_2	53.60	30.10
Al_2O_3	30.96	23.98
Fe_2O_3	9.15	38.66
CaO	0.92	1.85
MgO	0.59	0.50
MnO	0.03	0.03
TiO_2	2.03	1.56
P_2O_5	0.69	1.43
SO_3	0.06	0.32
K_2O	0.89	0.44
Na_2O	0.41	0.29

Table 5-11 PROPERTIES OF LAS (LAS ADJUNTAS) CHANNEL CLEAN COAL

Sample	LAS-LC20	LAS-LC (20+30)
Inherent moistuer(%)	1.72	1.37
Proximate analysis		
Ash (%, d.)	8.24	4.44
V.M. (%, d.)	42.85	37.09
F.C. (%, d.)	48.91	58.47
V.M. (%, d.a.f.)	46.70	38.81
Total sulfur(%, d.)	4.11	0.81
Ultimate analysis		
C (%, d.a.f.)	83.60	85.52
H (%, d.a.f.)	6.36	5.85
N (%, d.a.f.)	1.86	1.76
S (%, d.a.f.)	4.48	0.85
O (%, d.a.f.)	3.70	6.02
F.S.I.	4 1/2	7
Gieseler plastometer		
I.S.Temp. (℃)	394	396
M.F.Temp. (℃)	433	444
Solid.Temp.(℃)	476	480
M.F. (LogDDPM)	4.61	4.14
Dilatometer		
I.S.Temp. (℃)	338	355
Max. Cont.Tem. (℃)	394	402
Max. Dilat.Tem.(℃)	487	496
Percentage Cont.(%)	25	27
Percentage Dila.(%)	187	174
Total Dilatation(%)	212	201
Maceral analysis (%, Vol.)		
Vitrinite	78.4	68.8
Exinite	11.2	3.7
Micrinite	4.3	14.9
Semi fusinite	0.5	6.8
Fusinite	0.0	3.2
Mineral matter	5.6	2.6
Total inerts	10.2	25.2

Sample	LAS-LC20	LAS-LC (20+30)
Vitr. type(%, Vol.)		
V 6	45.5	0.0
V 7	32.9	16.5
V 8	0.0	39.9
V 9	0.0	11.0
V10	0.0	1.4
Mean Max.Reflect. (%, oil)	0.69	0.85
SI	2.55	3.03
CBI	0.36	0.94
H.G.I.	55	59
Calorific value (cal/g, d.a.f.)	8596	8589
ASH fusibility(℃)		
Softening point	1390	1540
Melting point	1400	1580
Flow point	1410	>1600
ASH composition (%)		
SiO_2	29.60	54.00
Al_2O_3	17.14	29.26
Fe_2O_3	51.74	10.35
CaO	0.59	1.43
MgO	0.28	0.90
MnO	0.04	0.03
TiO_2	1.35	1.29
P_2O_5	0.67	0.08
SO_3	0.04	0.10
K_2O	0.51	1.05
Na_2O	0.29	0.46

Table 5-12 PROPERTIES OF GUA (GUASARE) CHANNEL CLEAN COAL

Sample	GUA-M4
Inherent moistuer(%)	3.44
Proximate analysis	
Ash (%, d.)	1.04
V.M. (%, d.)	39.19
F.C. (%, d.)	59.77
V.M. (%, d.a.f.)	39.61
Total sulfur(%, d.)	0.41
Ultimate analysis	
C (%, d.a.f.)	83.08
H (%, d.a.f.)	5.50
N (%, d.a.f.)	1.52
S (%, d.a.f.)	0.40
O (%, d.a.f.)	9.50
F.S.I.	2 1/2
Gieseler plastometer	
Initial Softening Temp.(℃)	424
Maximum Fluidity Temp. (℃)	436
Solidificastion Temp. (℃)	448
Maximum Fluidity (LogDDPM)	0.48
Dilatometer	
Initial Softening Temp. (℃)	390
Maximum Contraction Temp.(℃)	500
Maximum Dilatation Temp. (℃)	-
Percentage Contraction (%)	47
Percentage Dilatation (%)	-47
Total Dilatation (%)	0
Maceral analysis (%, Vol.)	
Vitrinite	76.2
Exinite	3.8
Micrinite	11.4
Semi fusinite	5.3
Fusinite	2.7
Mineral matter	0.6
Total inerts	18.2

Sample	GUA-M4
Vitrinite type(%, Vol.)	
V 6	5.3
V 7	59.5
V 8	11.4
V 9	0.0
Mean Maximum Reflectance (%, oil)	0.76
SI	2.79
CBI	0.67
H.G.I.	50
Calorific value (cal/g, d.a.f.)	8260
Ash fusibility	
Softening point(℃)	
Melting point (℃)	
Flow point (℃)	
Ash composition (%)	
SiO_2	44.80
Al_2O_3	27.90
Fe_2O_3	11.95
CaO	5.50
MgO	3.82
MnO	0.08
TiO_2	0.92
P_2O_5	0.23
SO_3	2.46
K_2O	0.26
Na_2O	1.63

Table 5-13 PROPERTIES OF BOY (BOYACA) CHANNEL CLEAN COAL

Sample	BOY-M1
Inherent moistuer(%)	1.20
Proximate analysis	
Ash (%, d.)	6.52
V.M. (%, d.)	20.59
F.C. (%, d.)	72.89
V.M. (%, d.a.f.)	22.03
Total sulfur(%, d.)	0.83
Ultimate analysis	
C (%, d.a.f.)	88.75
H (%, d.a.f.)	4.90
N (%, d.a.f.)	1.88
S (%, d.a.f.)	0.86
O (%, d.a.f.)	3.61
F.S.I.	8 1/2
Gieseler plastometer	
Initial Softening Temp. (℃)	448
Maximum Fluidity Temp. (℃)	475
Solidificastion Temp. (℃)	494
Maximum Fluidity (LogDDPM)	1.08
Dilatometer	
Initial Softening Temp. (℃)	414
Maximum Contraction Temp. (℃)	443
Maximum Dilatation Temp. (℃)	499
Percentage Contraction (%)	18
Percentage Dilatation (%)	23
Total Dilatation (%)	41
Maceral analysis (%, Vol.)	
Vitrinite	66.3
Exinite	0.0
Micrinite	17.0
Semi fusinite	11.5
Fusinite	1.5
Mineral matter	3.7
Total inerts	29.9

Sample	BOY-M1
Vitrinite type(%, Vol.)	
V13	0.7
V14	11.9
V15	14.6
V16	30.5
Mean Maximum Reflectance (%, oil)	1.60
SI	7.06
CBI	3.92
H.G.I.	99
Calorific value (cal/g, d.a.f.)	8669
Ash fusibility	
Softening point(℃)	1500
Melting point (℃)	1540
Flow point (℃)	1590
Ash composition (%)	
SiO_2	61.20
Al_2O_3	24.60
Fe_2O_3	6.16
CaO	2.59
MgO	0.50
MnO	0.03
TiO_2	1.53
P_2O_5	0.97
SO_3	0.98
K_2O	0.73
Na_2O	1.04

(2) Properties of bulk samples

Properties of bulk samples were examined to check if FNO-LC-30, LAS-LC-(25+30), and Boyaca coals, which were sampled for the coking test, have expected properties, and to collect basic data for blending design.

1) FNO-LC-30 coal (Tables 5-14 and 5-15)
Grain size distribution of the bulk sample coal is similar to that of ordinary coal charge because it has been crushed to 8mm or smaller in size.

Major data on proximate analysis are ash content of 7.55(%, d.), volatile matter of 23.21(%, d.), and fixed carbon of 69.24(%, d.) which do not show much difference from those of the channel clean coals. Total sulfur is 0.85(%, d.).

Caking property is high, with F.S.I. of 9, M.F. of 2.96(log DDPM), and total dilatation of 124(%), which do not show significant difference from those of the channel clean coals.

SI and CBI calculated from Maceral analysis are 5.06 and 2.39, respectively, which are more or less the same as those of the channel clean coals.

Coke properties are shown in Table 5-15. Coke made from FNO-LC-30 coal has ash content of 9.40(%, d.), CSR of 70.0, and DI_{150-15} of 85.8, thus characterized by high coke strength and CSR. The high CSR seems to come from much coarse mosaic and fibrous texture components, as shown on photos and optical anisotropic texture analysis data. From these points, the FNO-LC-30 coal is considered to be high quality, medium volatile matter, heavy coking coal.

2) LAS-LC-(25+30) coal (Tables 5-14 and 5-15)
As mentioned in FNO-LC-30, grain size distribution of the bulk sample coal is similar to that of ordinary coal charge, as raw coal has been crushed to 8mm or smaller in size.

The results of proximate analysis are ash content of 3.94(%, d.), volatile matter of 37.91(%, d.), and fixed carbon 58.15(%, d.), which are similar to those of the channel clean coals. Total sulfur is 0.59(%, d.).
Caking property is high, with F.S.I. of 7, M.F. of 4.10(log DDPM), and total dilatation of 203(%), which are similar to those of the channel clean coals.

SI and CBI calculated from Maceral analysis are 2.86 and 0.85, respectively, with no significant difference from those of the channel clean coals.

Coke properties are summarized in Table 5-15. Coke made from LAS-LC-(25+30) coal has low ash and sulfur contents, 5.84(%, d.) and 0.50(%, d.) respectively, with low CSR and DI_{150-15}. These data indicate that LAS-LC-(25+30) coals are high volatile matter, weakly coking coals with high caking property and low ash and sulfur contents.

3) Boyaca coal (Tables 5-16 and 5-17)

Grain size distribution is similar to that of ordinary charging coal because raw coal have been crushed to 8mm or smaller in size, as seen in FNO-LC-30 and LAS-LC-(25+30) coals.

Proximate analysis data show ash content of 7.45(%, d.), volatile matter of 21.37(%, d.), and fixed carbon of 71.18(%, d.), which show no significant difference from those of the channel clean coals. On the other hand, total sulfur is 0.95(%, d.), higher than 0.83(%, d.) of the channel clean coal.

Caking property is F.S.I. of 8, M.F. of 1.04 (log DDPM), and total dilatation of 41(%), which are similar to those of the channel clean coal, and show good caking properties as low volatile matter coal.

SI and CBI calcualated from Maceral analysis are 6.91 and 4.91, which more or less the same as those of the channel clean coal.

Coke properties are shown in Table 5-17. Coke made from Boyaca coal shows high CSR and DI_{150-15}. These data indicate that Boyaca coal is high quality, low volatile matter, heavy coking coals.

Table 5-14 PROPERTIES OF FNO AND LAS BULK CLEAN COAL

Sample	FNO-LC30	LAS-LC25
Inherent moistuer(%)	0.98	1.40
Proximate analysis		
Ash (%, d)	7.55	3.94
V.M. (%, d)	23.21	37.91
F.C. (%, d)	69.24	58.15
V.M. (%, d.a.f.)	25.11	39.46
Total sulfur(%, d.)	0.85	0.59
Ultimate analysis		
C (%, d.a.f.)	89.09	84.00
H (%, d.a.f.)	5.04	5.85
N (%, d.a.f.)	1.54	1.80
S (%, d.a.f.)	0.92	0.59
O (%, d.a.f.)	3.41	7.76
F.S.I.	9	7
Gieseler plastometer		
I.S.Temp (℃)	418	400
M.F.Temp (℃)	464	440
Solid.Temp.(℃)	502	480
M.F. (LogDDPM)	2.96	4.10
Dilatometer		
I.S.Temp (℃)	382	352
Max. Cont.Tem. (℃)	420	401
Max. Dilat.Tem (℃)	500	497
Percentage Cont.(%)	24	28
Percentage Dila.(%)	100	175
Total Dilatation(%)	124	203
Maceral analysis (%, Vol.)		
Vitrinite	58.0	71.1
Exinite	0.4	4.5
Micrinite	23.6	15.7
Semi fusinite	10.5	4.8
Fusinite	3.2	1.7
Mineral matter	4.3	2.2
Total inerts	38.1	22.8

Sample	FNO-LC30	LAS-LC25
Vitr. type(%, Vol.)		
V	V11: 4.7	V7: 29.9
V	V12: 31.3	V8: 39.1
V	V13: 20.3	V9: 2.1
V	V14: 1.7	
Mean Max. Reflect. (%, Oil)	1.28	0.81
SI	5.06	2.86
CBI	2.39	0.85
H.G.I.	101	59
Calorific value (cal/g, d.a.f.)	8757	8605
ASH fusibility(℃)		
Softening point	1570	1440
Melting point	>1600	1560
Flow point	>1600	>1600
ASH composition (%)		
SiO_2	66.40	54.10
Al_2O_3	21.23	29.00
Fe_2O_3	7.52	10.42
CaO	0.42	1.42
MgO	0.27	0.80
MnO	0.02	0.03
TiO_2	1.73	1.26
P_2O_5	0.07	0.07
SO_3	0.08	0.11
K_2O	0.72	1.03
Na_2O	0.28	0.48
Grain size distribution (%)		
10.0-6.0mm	3.0	4.6
6.0-3.0mm	10.0	17.2
3.0-1.2mm	23.2	32.0
1.2-0.5mm	25.9	28.4
0.5-0.3mm	13.2	11.4
-0.3mm	24.7	6.4

Table 5-15 PROPERTIES OF COKE FROM FNO AND LAS BULK CLEAN COAL

Sample	FNO-LC30	LAS-LC25
Grain size distri.		
125-100mm (%)	4.5	11.3
100- 75mm (%)	22.9	15.8
75- 50mm (%)	57.7	29.3
50- 25mm (%)	11.4	32.3
25- 15mm (%)	1.0	6.3
-15mm (%)	2.5	5.0
Proximate analysis		
Ash (%,d.)	9.40	5.84
V.M. (%,d.)	0.50	0.80
F.C. (%,d.)	90.10	93.36
T.S. (%,d.)	0.71	0.50
Apparent specific gravity (-)	1.12	1.00
True speific gravity (-)	1.96	1.92
Porosity (%)	43	48

Sample	FNO-LC30	LAS-LC25
Anisotropic texture anaiysis (%, Vol.)		
isotropic	6.5	1.8
fine mosaic	4.9	81.3
coarse mosaic	39.1	1.9
fibrous	23.3	1.0
leaflet	0.0	0.0
inert	26.2	14.0
Reactivity(%)	10	11
Coke strength aftre reaction		
CRI	23.0	33.6
CSR	70.0	41.4
M.S.I.	34.0	39.9
Coke strength		
DI_{30-15}	94.9	68.7
DI_{150-15}	85.8	40.3

Photo 5-1 COKE STRUCTURE OF FNO LC-30 (X 700)

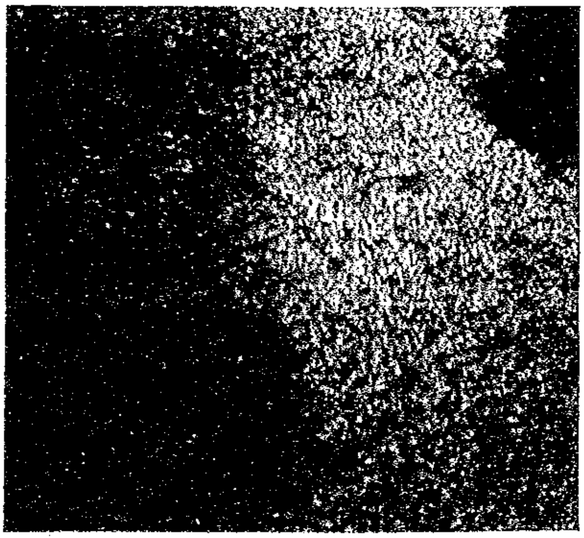


Photo 5-2 COKE STURCTURE OF LAS LC-24 (X 700)

Table 5-15 PROPERTIES OF COKE FROM FNO AND LAS BULK CLEAN COAL

Sample	FNO LC30	LAS LC25
Grain size distri.		
125 100mm %	4.5	11.3
100 75mm %	22.9	15.8
75 50mm %	57.7	29.3
50 25mm %	11.4	32.3
25 15mm %	1.0	6.3
15mm %	2.5	5.0
Proximate analysis		
Ash %.d.	9.40	5.84
V.M. %.d.	0.50	0.80
F.C. %.d.	90.10	93.36
T.S. %.d.	0.71	0.50
Apparent specific gravity	1.12	1.00
True specific gravity	1.96	1.92
Porosity %	43	48

Sample	FNO LC30	LAS LC25
Anisotropic texture analysis (% Vol.)		
isotropic	9.5	1.8
fine mosaic	1.9	81.3
coarse mosaic	39.1	1.9
fibrous	23.3	1.0
leaflet	0.0	0.0
inert	26.2	14.0
Reactivity %	10	11
Coke strength aftre reaction		
CRI	23.0	33.6
CSR	70.0	11.4
M.S.I.	34.0	39.9
Coke strength		
DI	91.9	68.7
DI	85.8	40.3

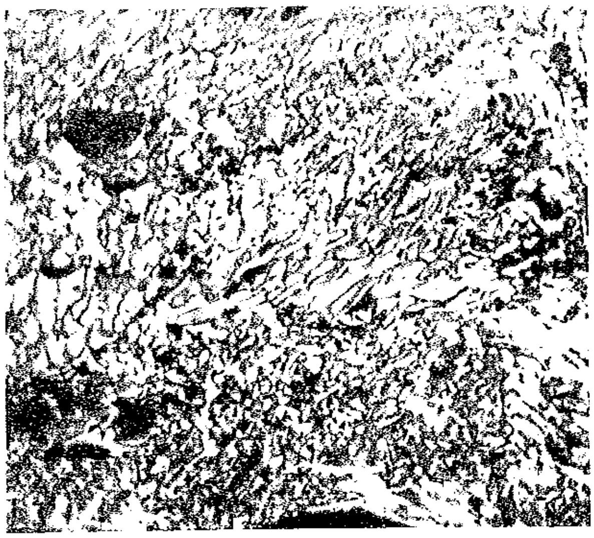


Photo 5-1 COKE STRUCTURE OF FNO LC-30 (X 700)

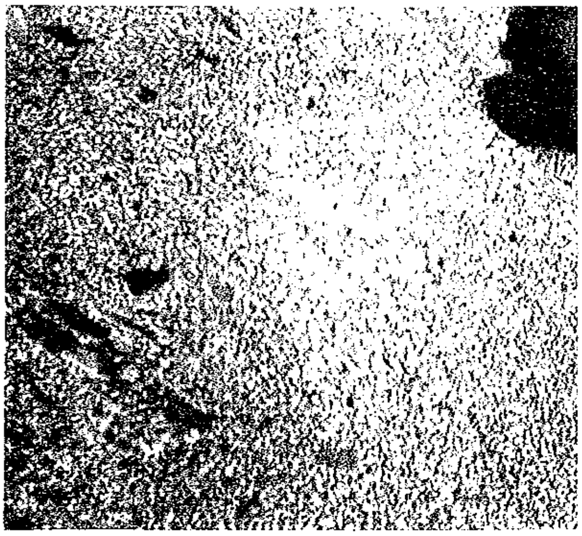


Photo 5-2 COKE STURCTURE OF LAS LC-24 (X 700)

Table 5-16 PROPERTIES OF BOYACA BULK CLEAN COAL

Sample	BOYACA
Inherent moistuer(%)	1.21
Proximate analysis	
Ash (%, d.)	7.45
V.M. (%, d)	21.37
F.C. (%, d)	71.18
V.M. (%, d.a.f.)	23.09
Total sulfur(%,d.)	0.95
Ultimate analysis	
C (%, d.a.f.)	89.05
H (%, d.a.f.)	4.88
N (%, d.a.f.)	1.87
S (%, d.a.f.)	0.90
O (%, d.a.f.)	3.30
F.S.I.	8
Gieseler plastometer	
Initial Softening Temp. (℃)	449
Maximum Fluidity Temp. (℃)	478
Solidificastion Temp. (℃)	497
Maximum Fluidity (LogDDPM)	1.04
Dilatometer	
Initial Softening Temp. (℃)	415
Maximum Contraction Temp. (℃)	442
Maximum Dilatation Temp. (℃)	501
Percentage Contraction (%)	17
Percentage Dilatation (%)	24
Total Dilatation (%)	41
Maceral analysis (%, Vol.)	
Vitrinite	60.5
Exinite	0.0
Micrinite	22.0
Semi fusinite	11.2
Fusinite	2.0
Mineral matter	4.3
Total inerts	35.8

Sample	BOYACA
Vitrinite type (%, Vol.)	
V14	13.2
V15	18.7
V16	20.6
V17	7.3
V18	0.7
Mean Maximum Reflectance (%, oil)	1.59
SI	6.91
CBI	4.91
H.G.I.	92
Calorific value (cal/g, d.a.f.)	8734
Ash fusibility	
Softening point(℃)	1430
Melting point (℃)	1530
Flow point (℃)	1580
Ash composition (%)	
SiO_2	60.20
Al_2O_3	25.09
Fe_2O_3	6.09
CaO	2.60
MgO	0.51
MnO	0.03
TiO_2	1.57
P_2O_5	0.96
SO_3	0.95
K_2O	0.70
Na_2O	1.12
Grain size distribution (%)	
10.0-6.0mm	3.8
6.0-3.0mm	12.1
3.0-1.2mm	26.5
1.2-0.5mm	30.5
0.5-0.3mm	15.8
-0.3mm	11.3

Table 5-17 PROPERTIES OF COKE FROM BOYACA BULK CLEAN COAL

Sample	BOYACA	Sample	BOYACA
Grain size distribution		Anisotropic texture analys-is (%, Vol.)	
125-100mm (%)	7.9	isotropic	3.5
100- 75mm (%)	25.6	fine mosaic	24.0
75- 50mm (%)	43.3	coarse mosaic	11.6
50- 25mm (%)	19.7	fibrous	37.8
25- 15mm (%)	1.0	leaflet	1.1
-15mm (%)	2.5	inert	22.0
Proximate analysis		Reactivity(%)	10
Ash (%, d.)	8.80	Coke strength aftre reaction	
V.M. (%, d.)	0.46	CRI	21.4
F.C. (%, d.)	90.74	CSR	69.9
T.S. (%, d.)	0.76		
Apparent specific gravity(-)	1.07	M.S.I.	34.1
True speific gravity(-)	1.94	Coke strength(Drum indx)	
		DI_{30-15}	94.6
Porosity (%)	45	DI_{150-15}	83.2

Photo 5-3 COKE STRUCTURE OF BOYACA (X 700)

Table 5-17 PROPERTIES OF COKE FROM BOYACA BULK CLEAN COAL

Sample	BOYACA	Sample	BOYACA
Grain size distribution		Anisotropic texture analys is %Vol.	
>125 [illegible]mm %	[illegible]	isotropic	3.5
[illegible] 75mm %	25.8	fine mosaic	24.0
75 [illegible]mm %	45.3	coarse mosaic	11.6
5[illegible] 25mm %	18.7	fibrous	37.8
25 15mm %	[illegible]	leaflet	1.1
15mm %	[illegible]	inert	22.0
Proximate analysis			
Ash %,d.	[illegible]	Reactivity %	10
V.M. %,d.	[illegible]		
F.C. %,d.	[illegible]	Coke strength aftre reaction	
T.S. %,d.	[illegible]	CRI	21.4
		CSR	69.9
Apparent specific gravity	[illegible]	M.S.I.	34.1
True specific gravity	[illegible]	Coke strength Drum indx	
		DI	94.6
Porosity %	[illegible]	DI	83.2

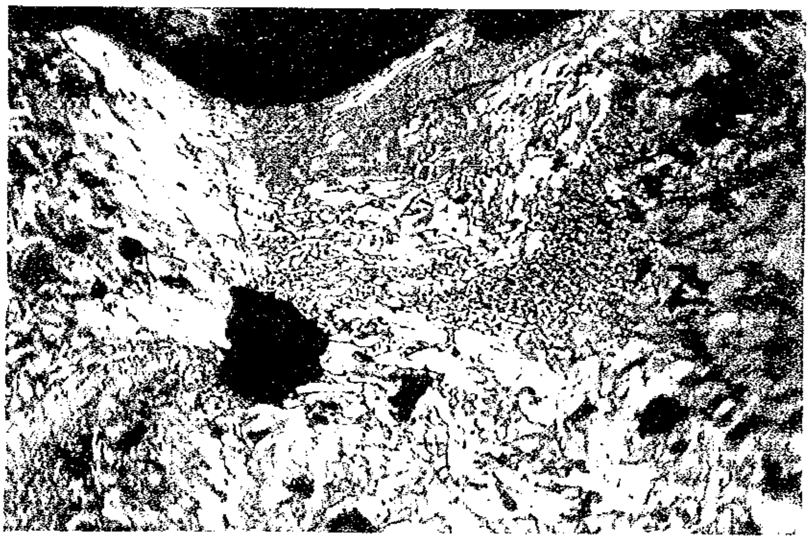


Photo 5-3 COKE STRUCTURE OF BOYACA (X 700)

d) Conclusion

Bulk samples of FNO–LC–30, LAS–LC–(25+30), and Boyaca coals sampled for the coking test show expected properties as shown in Table 5–18; FNO–LC–30 coal as medium volatile matter, heavy coking coal; LAS–LC–(25+30) coal as high volatile matter, weakly coking coal; and Boyaca coal as low volatile matter, heavy coking coal.

Table 5-18 EVALUATION OF BULK SAMPLE COALS AS COKING COALS

Sample	Major Properties		Evaluation
FNO–LC–30	Ash (%, d.)	: 7.25	Heavy coking coal of medium volatile matter
	V.M. (%, d.)	: 23.21	
	Total Sulfur (%, d.)	: 0.85	
	Total Dilation (%)	: 124	
	Maxim Fluididy (logDDPM)	: 2.96	
	Ro (%)	: 1.28	
	CSR	: 70.0	
LAS–LC (25+30)	Ash (%, d.)	: 3.94	Weakly coking coal of high volatile matter
	V.M. (%, d.)	: 37.91	
	Total Sulfur (%, d.)	: 0.59	
	Total Dilation (%)	: 203	
	Maxim Fluididy (logDDPM)	: 4.10	
	Ro (%)	: 0.81	
	CSR	: 41.4	
Boyaca	Ash (%, d.)	: 7.45	Heavy coking coal of low volatile matter
	V.M. (%, d.)	: 21.37	
	Total Sulfur (%, d.)	: 0.95	
	Total Dilation (%)	: 41	
	Maxim Fluididy (logDDPM)	: 1.04	
	Ro (%)	: 1.59	
	CSR	: 69.9	

5.2.5 Properties of Imported Coals

Most of coals produced in Venezuela are high volatile content, with much less low and medium volatile matter, heavy coking coal. To produce blast-furnace coke, Venezuelan and Colombian coals should be blended with low and medium volatile matter heavy coking coal which are imported.

These coals have been selected on the basis of certification of coke quality and that transport distance from coal supplier countries to Venezuela is shorter and shorter.

For the above reasons, the U.S. Pinnacle coal (low volatile matter, heavy coking coal), Blue Creek coal (medium volatile matter, heavy coking coal), and Australian Saraji coal (low volatile, matter, heavy coking coal) have been selected for blending coals.

The results of analysis of the above coking coals are shown and compared in Fig.5-12. Major findings are described in the following.

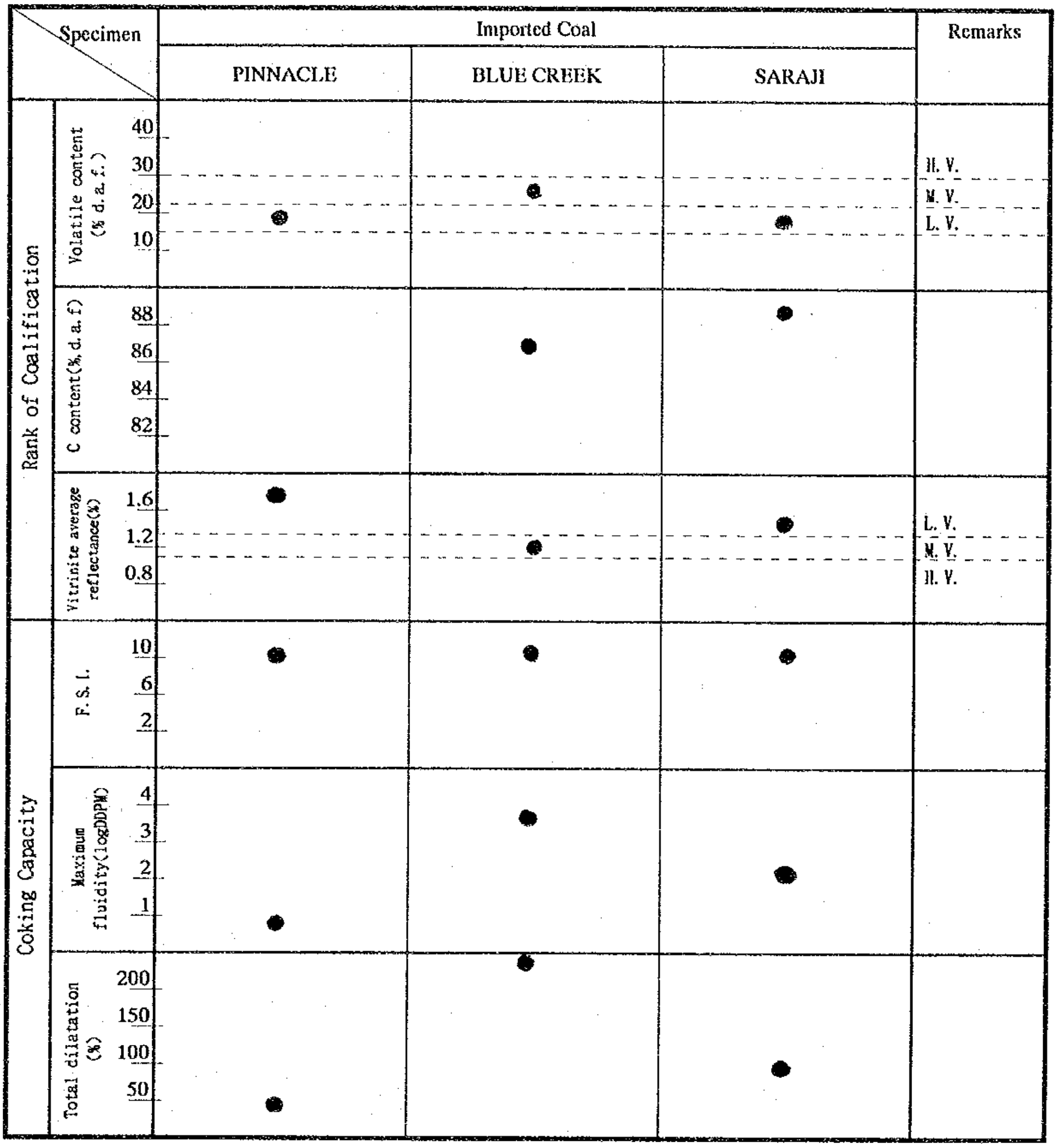
1) Pinnacle coal (Tables 5-19 and 5-20)

   Pinnacle coal has volatile matter of 17.73(%, d.a.f.) on a pure coal substance basis, carbon content of 88.82 (%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 1.73(%, oil), thus is classified as low volatile matter coal. Caking property is sufficiently high, with F.S.I. of 9, M.F. of 0.60, and total dilatation of 42(%).

   Ash content is low at 5.61(%) and sulfur content is 0.76(%, d.), a general level for coking coal.

   Coke produced from Pinnacle coal (Table 5-20) has ash content of 6.01(%, d.), volatile matter of 0.81(%, d.), and total sulfur of 0.67(%, d.). Characteristically, ash content is low. From high coke strength at DI_{150-15}82.5, Pinnacle coal is considered to be low volatile matter heavy coking coal. However, CSR is low at 47.0. From these data, Pinnacle coal, while not contributing to CSR (coke strength after reaction), works to maintain TI_{25} (mechanical strength).

   In conclusion, Pinnacle coal is rated as high quality, low volatile matter, heavy coking coal with low ash content.



Note: Carbon content varies due to maceral composition and weathering of coal and become low in relation to volatile content.

H.V.=High volatile content coal M.V.=Medium volatile content coal

L.V.=Low volatile content coal

Fig.5-12 COMPARISON OF PROPERTIES OF IMPORTED COALS

2) Blue Creek coal (Tables 5-19 and 5-20)

Blue Creek coal is medium volatile matter coal, with volatile matter of 27.93(%, d.a.f.) on a pure coal substance basis, carbon content of 88.13(%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 1.19(%, oil). Caking property is very high, with F.S.I. of 9, M.F. of 3.60, and total dilatation of 239(%).

Ash content is at a low level of 8.91(%, d.) and sulfur content is high as coking coal at 0.85(%, d.)

From Maceral analysis, vitrinite content is characteristically high at 80.9(%, vol), and as a result, CBI is low at 0.63.

Grindability is high at H.G.I.89 to make the coal highly crushable.

Ash composition is generally comparable to ordinary coking coal, except for P_2O_5 which is slightly high at 1.22%.

Coke properties are shown in Table 5-20. Proximate analysis data on coke made from Blue Creek coal are comparable to ordinary coking coal, with ash content of 11.44(%, d.) which is slightly higher, volatile matter (%, d.), and total sulfur of 0.75(%, d.).

From these data, Blue Creek coal is classified as medium volatile matter, heavy coking coal with high caking property.

3) Saraji coal (Tables 5-21 and 5-22)

Saraji coal is low volatile matter coal, with volatile matter of 20.96(%, d.a.f.) on a pure coal substance basis, carbon content of 89.18(%, d.a.f.) in ultimate analysis, and vitrinite's mean reflectance of 1.55(%, oil).

Caking property is sufficiently high for low volatile matter coal, with F.S.I. of 9, M.F. of 1.70, and total dilatation of 62(%).

Ash content is high at 10.48(%, d.) and sulfur content is relatively low for coking coal at 0.57(%, d.).

From Maceral analysis, vitrinite content is a normal level for coking coal at 65.4(%, vol.).

Grindability is high (H.G.I.91) to indicate that the coal is crushable.

Coke properties are shown in Table 5-22. Proximate analysis of coke made from Saraji coal shows that ash content is 12.14(%, d.), volatile matters 0.72(%, d.), and total sulfur 0.52(%, d.), characterized by high ash content and low sulfur content.

Thus, Saraji coal is classified as low volatile matter heavy coking coal to raise coke's CSR.

Table 5-19 PROPERTIES OF PINNACLE AND BLUE CREEK (U.S.) IMPORTED COAL

Sample	Pinnacle	Blue Cr.
Inherent moistuer(%)	1.00	1.28
Proximate analysis		
Ash (%, d.)	5.61	8.91
V.M. (%, d)	16.74	25.44
F.C. (%, d)	77.65	65.65
V.M. (%, d.a.f.)	17.73	27.93
Total sulfur(%, d.)	0.76	0.85
Ultimate analysis		
C (%, d.a.f.)	88.82	88.13
H (%, d.a.f.)	4.58	5.41
N (%, d.a.f.)	1.22	1.84
S (%, d.a.f.)	0.75	0.88
O (%, d.a.f.)	4.63	3.74
F.S.I.	9	9
Giescler plastometer		
I.S.Temp (℃)	475	415
M.F.Temp (℃)	490	459
Solid.Temp.(℃)	500	504
M.F. (LogDDPM)	0.60	3.60
Dilatometer		
I.S.Temp (℃)	427	382
Max. Cont.Tem. (℃)	463	415
Max. Dilat.Tem (℃)	511	426
Percentage Cont.(%)	20	22
Percentage Dila.(%)	22	217
Total Dilatation(%)	42	239
Maceral analysis (%, Vol.)		
Vitrinite	65.0	80.6
Exinite	0.0	1.3
Micrinite	14.5	7.9
Semi fusinite	14.3	4.5
Fusinite	3.0	0.7
Mineral matter	3.2	5.0
Total inerts	30.2	16.6

Sample	Pinnacle	Blue Cr.
Vit. type(%, Vol.)		
V	V_{15}: 1.3	V_{10}: 9.7
V	V_{16}: 19.5	V_{11}: 33.8
V	V_{17}: 32.5	V_{12}: 29.8
V	V_{18}: 11.7	V_{13}: 7.3
V		
Mean Max. Reflect. (%, oil)	1.73	1.19
SI	7.28	4.60
CBI	5.66	0.63
H.G.I.	89	89
Calorific value (cal/g, d.a.f.)	8732	8696
ASH fusibility(℃)		
Softening point	1410	1490
Melting point	1470	1520
Flow point	1550	1570
ASH composition (%)		
SiO_2	47.70	46.80
Al_2O_3	25.85	28.34
Fe_2O_3	10.07	12.12
CaO	2.72	2.89
MgO	1.32	1.36
MnO	0.14	0.06
TiO_2	1.74	1.56
P_2O_6	0.75	1.22
SO_3	0.64	1.40
K_2O	1.27	2.25
Na_2O	0.63	0.84
Grain size distribution (%)		
+6.0mm	14.8	17.7
6.0-3.0mm	12.5	16.6
3.0-1.2mm	21.8	21.7
1.2-0.5mm	20.7	18.4
0.5-0.3mm	9.6	9.8
-0.3mm	20.6	15.8

Table 5-20 PROPERTIES OF COKE FROM PINNACLE AND BLUE CREEK (U.S.) IMPORTED COAL

Sample	Pinnacle	Blue Cr.
Grain size distri.		
125-100mm (%)	4.3	12.3
100- 75mm (%)	15.4	27.2
75- 50mm (%)	48.6	36.4
50- 25mm (%)	26.7	16.8
25- 15mm (%)	1.7	3.4
-15mm (%)	3.3	3.9
Proximate analysis		
Ash (%,d.)	6.01	11.44
V.M. (%,d.)	0.81	0.95
F.C. (%,d.)	93.18	87.61
T.S. (%,d.)	0.67	0.75
Apparent specific gravity (-)	0.96	1.01
True speific gravity (-)	1.96	1.99
Porosity (%)	51	49

Sample	Pinnacle	Blue Cr.
Anisotropic texture anaiysis (%, Vol.)		
isotropic	4.4	0.9
fine mosaic	0.0	20.3
coarse mosaic	6.5	57.1
fibrous	49.6	7.7
leaflet	5.9	0.0
inert	33.6	14.0
Reactivity(%)	28	10
Coke strength aftre reaction		
CRI	33.0	32.6
CSR	47.0	59.7
M.S.I.	34.5	35.8
Coke strength		
DI_{30-15}	93.8	93.0
DI_{150-15}	82.5	80.8

Photo 5-4 COKE STRUCTURE OF PINNACLE (X 700)

Photo 5-5 COKE STRUCTURE OF BLUE CREEK (X 70

Table 5-20 PROPERTIES OF COKE FROM PINNACLE AND BLUE CREEK (U.S.) IMPORTED COAL

Sample	Pinnacle	Blue Cr.	Sample	Pinnacle	Blue Cr.
Grain size distri.			Anisotropic texture analysis (%Vol.)		
125-100mm (%)	4.3	12.3	isotropic	1.1	0.9
100-75mm (%)	15.4	27.2	fine mosaic	3.3	20.3
75-50mm (%)	48.6	33.4	coarse mosaic	6.5	57.1
50-25mm (%)	26.7	16.8	fibrous	49.6	7.7
25-15mm (%)	1.7	3.4	leaflet	5.9	0.0
-15mm (%)	3.3	3.9	inert	33.6	14.0
Proximate analysis					
Ash %d.b.	6.01	11.44	Reactivity (%)	28	10
V.M. %d.b.	0.81	0.95			
F.C. %d.b.	93.18	87.61	Coke strength aftre reaction		
T.S. %d.b.	0.67	0.75			
			CRI	33.0	32.6
Apparent specific gravity	0.96	1.01	CSR	47.0	59.7
			M.S.I.	34.5	35.8
True speific gravity	1.96	1.99	Coke strength		
			DI	93.8	93.0
Porosity (%)	51	49	DI	82.5	80.8

Photo 5-4 COKE STRUCTURE OF PINNACLE (X 700)

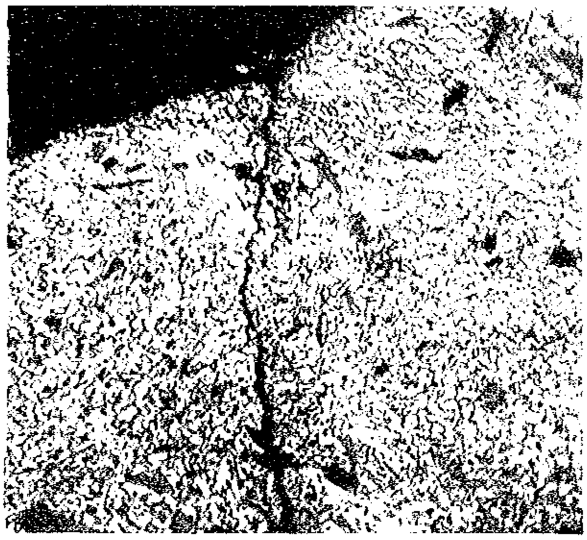


Photo 5-5 COKE STRUCTURE OF BLUE CREEK (X 70

Table 5-21 PROPERTIES OF SARAJI (AUSTRALIA) IMPORTED COAL

Sample	Saraji
Inherent moistuer(%)	1.38
Proximate analysis	
Ash (%, d)	10.48
V.M. (%, d)	18.76
F.C. (%, d)	70.76
V.M. (%, d.a.f.)	20.96
Total sulfur(%, d.)	0.57
Ultimate analysis	
C (%, d.a.f.)	89.18
H (%, d.a.f.)	4.96
N (%, d.a.f.)	1.90
S (%, d.a.f.)	0.63
O (%, d.a.f.)	3.33
F.S.I.	9
Gieseler plastometer	
Initial Softening Temp. (℃)	452
Maximum Fluidity Temp. (℃)	481
Solidificastion Temp. (℃)	503
Maximum Fluidity (LogDDPM)	1.70
Dilatometer	
Initial Softening Temp. (℃)	415
Maximum Contraction Temp. (℃)	454
Maximum Dilatation Temp. (℃)	508
Percentage Contraction (%)	20
Percentage Dilatation (%)	42
Total Dilatation (%)	62
Maceral analysis (%, Vol.)	
Vitrinite	65.4
Exinite	0.0
Micrinite	17.3
Semi fusinite	9.9
Fusinite	1.6
Mineral matter	5.8
Total inerts	31.3

Sample	Saraji
Vitrinite type (%, Vol.)	
V_{13}	3.9
V_{14}	23.5
V_{15}	10.5
V_{16}	22.9
V_{17}	4.6
Mean Maximum Reflectance (%, oil)	1.55
SI	6.93
CBI	3.58
H.G.I.	91
Calorific value (cal/g, d.a.f.)	8668
Ash fusibility	
Softening point(℃)	1590
Melting point (℃)	>1600
Flow point (℃)	>1600
Ash composition (%)	
SiO_2	59.80
Al_2O_3	28.22
Fe_2O_3	5.34
CaO	1.10
MgO	0.57
MnO	0.07
TiO_2	1.37
P_2O_5	0.53
SO_3	0.22
K_2O	1.06
Na_2O	0.56
Grain size distribution (%)	
10.0-6.0mm	34.3
6.0-3.0mm	13.6
3.0-1.2mm	23.2
1.2-0.5mm	18.4
0.5-0.3mm	5.2
-0.3mm	5.3

Table 5-22 PROPERTIES OF COKE FROM SARAJI (AUSTRALIA) IMPORTED COAL

Sample	Saraji
Grain size distribution	
125-100mm (%)	9.9
100- 75mm (%)	30.9
75- 50mm (%)	41.7
50- 25mm (%)	14.2
25- 15mm (%)	1.1
-15mm (%)	2.2
Proximate analysis	
Ash (%, d.)	12.14
V.M.(%, d.)	0.72
F.C.(%, d.)	87.14
T.S.(%, d.)	0.52
Apparent specific gravity(-)	1.11
True speific gravity(-)	1.98
Porosity (%)	44

Sample	Saraji
Anisotropic texture analysis (%, Vol.)	
isotropic	4.7
fine mosaic	5.6
coarse mosaic	14.0
fibrous	46.0
leaflet	1.2
inert	28.5
Reactivity(%)	9
Coke strength aftre reaction	
CRI	17.2
CSR	73.9
M.S.I.	33.0
Coke strength(Drum indx)	
DI_{30-15}	95.0
DI_{150-15}	85.4

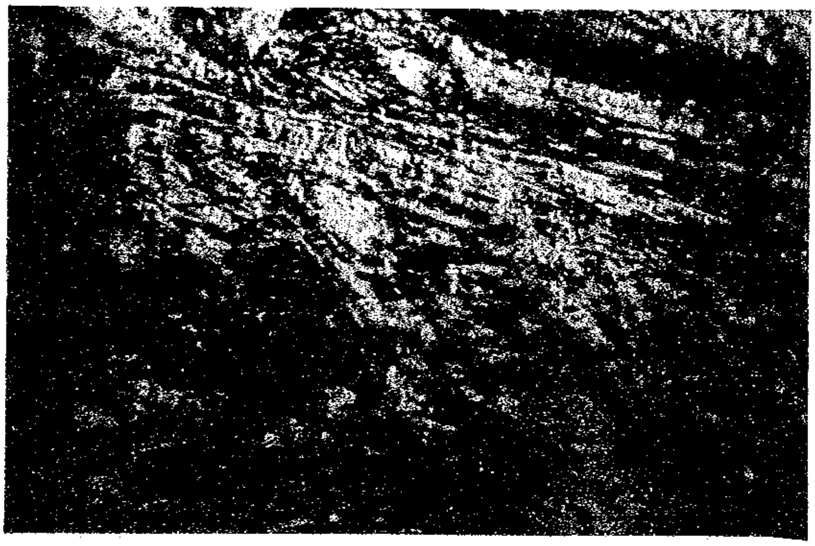


Photo 5-6 COKE STRUCTURE OF SARAJI (X 700)

Table 5-22 PROPERTIES OF COKE FROM SARAJI (AUSTRALIA) IMPORTED COAL

Sample	Saraji	Sample	Saraji
Grain size distribution		Anisotropic texture analys is %Vol.	
125 100mm %	9.9	isotropic	4.7
100 75mm %	30.9	fine mosaic	5.6
75 50mm %	11.7	coarse mosaic	14.0
50 25mm %	14.2	fibrous	46.0
25 15mm %	1.1	leaflet	1.2
15mm %	2.2	inert	28.5
Proximate analysis			
Ash %.d.	12.14	Reactivity %	9
V.M. %.d.	0.72		
F.C. %.d.	87.14	Coke strength aftre reaction	
T.S. %.d.	0.52	CRI	17.2
		CSR	73.9
Apparent specific gravity	1.11	M.S.I.	33.0
True specific gravity	1.98	Coke strength Drum indx	
		DI	95.0
Porosity %	44	DI	85.4

Photo 5-6 COKE STRUCTURE OF SARAJI (X 700)

5.3 Coking Test

5.3.1 Target Quality of Coke for Commercial Production

The target quality of coke is established at a level allowing all cokes to be exported to the U.S. market, as shown in Table 5-23. Note that coke production needs to be conducted by taking into account various variable factors, such as quality of coking coal, blending in the production process of coal preparation, and operation of the coke oven. To examine blending conditions of coking coals, target quality values of coke for commercial production are established, as shown in Table 5-24

There is one characteristic value considered to be very important in the U.S. market, CSR. CSR is the degree of powdering in a blast furnace due to solution loss reaction of coke, which is measured in the laboratory environment. CSR required for blast-furnace coke ranges between 53 and 60, depending upon the size of the blast furnace and its operating conditions. In particular, 58 or more is required for recent PCI operations.

Table 5-23 TARGET QUALITY OF COKE

Standard Quality	
Moisture (%)	4 - 5
Ash (%)	10.5 (Max.)
Volatile matters (%, d.)	1.0 (Max.)
Fixed carbon (%, d.)	88.5 (Min.)
Total sulfur (%, d.)	0.8 (Max)
TI_{25} 59 (Min)	
Coke breeze ratio(-25mm)(%)	5.0 (Max.)
Others important characteristic values	
CSR	53 - 60
P (%, d.)	0.04
K20 + Na20 (%, d.)	0.2 - 0.25
Mean size (inch)	2

Table 5-24 TARGET QUALITY VALUES OF COKE AS A BASIS OF DETERMINING BLENDING CONDITIONS OF COKING COALS

Ash (%, d)	: 10.3	TI25	: 61
Total Sulfur (%,d.)	: 0.76	CSR	: 58

5.3.2 Theoretical Examination of Blending Conditions

(1) Assumptions

Major factors assumed for theoretical examination of blending conditions are coal production, coke production, additional purchase to fill supply gap, and operation of the coke oven, which are established as shown in table 5-25. Calculation of blending coal and coke quality was conducted by applying Mitsui Mining's proprietary method.

Table 5-25 BASIC ASSUMPTIONS FOR THEORETICAL EXAMINATION OF COAL BLENDING CONDITIONS

Coal Production	1) FNO	: 70,000 tons-wet/year (13%)
	2) LAS	: 400,000 tons-wet/year (77%)
	3) Boyaca	: 50,000 tons-wet/year (10%)
	The figure in ( ) designates share of production	
Total Coke Production	1) 1 million ton/year (1,465,000 tons-wet/year)	
	The figure in ( ) designates coal requirements	
Additional Purchase to Fill Supply Gap	A shortage of suitable coal will be met by imports from the U.S. and Australia.	
	1) Blue Creek coal	(medium volatile matter, heavy coking coal to secure production gap previously expected for the FNO coal)
	2) Pinnacle coal	(low volatile matter, heavy coking coal to improve the degree of coalification for blending coals)
	3) Saraji coal	(low volatile matter, heavy coking coal to make up for low CSR)
	( ) - coal quality/intended effect of blending	
Coke production Conditions	1) Coke oven dimantion: High 6.5m, Width 450mm	
	2) Flue temperature	: 1,130°C
	3) Working rate of coke oven battery	: 125%

(2) Properties of coals used

Coals used for blending design are bulk sample coals and imported coals which have properties shown in Table 5-26.

Table 5-26 PROPERTIES OF COALS USED FOR CALCULATION OF COKE QUALITY

Name	Ash Content (%, d.)	Volatile Matter (%, d.)	Total Sulfur (%, d.)	Total Dilatation (%)	Fludity (logD)	SI	CBI	CSR
FNO	7.6	23.2	0.85	124	2.96	5.06	2.39	70
LAS	3.9	37.9	0.59	203	4.10	2.86	0.85	41
Boyaca	7.5	21.4	0.95	41	1.04	6.91	4.91	70
Pinnacle	5.6	16.7	0.76	42	0.60	7.28	5.66	47
Blue Cr.	8.9	25.4	0.85	239	3.60	4.60	0.63	60
Saraji	10.5	18.8	0.57	62	1.70	6.93	3.58	74
Guasare	1.0	39.2	0.41	0	0.48	2.79	0.67	-

(3) Combination of coking coal blending conditions

The following 4 combinations of coking coal blending were examined:

1) Blending of Venezuelan coals only
2) Blending of Venezuelan and Colombian coals
3) Blending of Venezuelan, Colombian, and imported coals
4) Blending using Guasare coal

(4) Calculation of qualities of coal charge and cokes under each blending condition

1) Calculation of coke quality based on blending of Venezuelan coals only

Viability of production of blast-furnace coke by blending FNO coal, which is medium volatile matter heavy coking coal, and LAS coal, which is high volatile matter, weakly coking coal, both produced in Venezuela, was examined.

Coal blending conditions, and calculated qualities of coal charge and cokes are summarized in Table 5-27.

Table 5-27 CALCULATED QUALITIES OF COAL CHARGE AND COKES BY USING VENEZUELAN COAL ONLY

	Blending No.	1	2	3	4	5	6	7
Blending Ratio of Coal(%)	FNO (Venezuela)	15	20	25	30	35	40	50
	LAS (Venezuela)	85	80	75	70	65	60	50
	Boyaca (Colombia)							
Properties of Chargd Coal	Ash (%, d.)	4.5	4.7	4.8	5.0	5.2	5.4	5.8
	Volatile Content (%, d.)	35.7	35.0	34.2	33.5	32.8	32.0	30.6
	Total Sulfure (%, d.)	0.63	0.64	0.66	0.67	0.68	0.69	0.72
	Total Dilatation (%)	192	187	183	179	175	171	164
	Max. Fludity (log DDPM)	3.93	3.87	3.82	3.76	3.70	3.64	3.53
	SI	3.19	3.30	3.41	3.52	3.62	3.74	3.96
	CBI	1.08	1.16	1.24	1.31	1.39	1.47	1.62
	Σ CSR	46	47	49	50	51	53	56
Coke Quality	Ash (%, d.)	8.0	8.1	8.1	8.2	8.3	8.4	8.6
	Toal Sulfure (%, d.)	0.56	0.57	0.58	0.59	0.60	0.61	0.63
	TI25	58	58	58	59	59	60	60
	CSR	55	55	56	57	58	59	59

Blend No.1 in Table 5-27 uses FNO and LAS coals in the ratio based on proportion of production. Coke from Blend No.1 meet target qualities in ash content 8.0(%, d.) and total sulfur 0.56(%, d.), while it falls below target values in coke strength (TI25) and coke strength after reaction with CO_2 (CSR) which are 58 and 55, respectively.

Then, a percentage of FNO coal – medium volatile matter, heavy coking coal – has been gradually increased to 50%. Nevertheless, as Blend No.7 shows, coke strength (TI25) is calculated to be 60, below 61 for the target quality, probably it seems to be caused that volatile matter of coal blend is high, and degree of coalification is insufficient.

2) Calculation of qualities of cokes made from Venezuelan and Colombian coals

As it has become apparent that the blending of FNO coal (medium volatile matter) and LAS coal (high volatile matter) produced in Venezuela does not produce blast-furnace coke, the use of Boyaca coal (low volatile content) produced in Colombia was considered.

Table 5-28 ESTIMATED QUALITIES OF COKES MADE FROM VENEZUELAN AND COLOMBIAN COALS

Coal Blend No.		1	2	3	4	5	6	7
Blending Ratio of Coal(%)	FNO (Venezuela)	13	15	20	25	30	35	40
	LAS (Venezuela)	77	75	70	65	60	55	50
	Boyaca (Colombia)	10	10	10	10	10	10	10
Properties of Coa Charge	Ash (%, d.)	4.8	4.8	5.0	5.2	5.4	5.6	5.7
	Volatile Matter (%, d.)	34.4	34.1	33.3	32.6	31.9	31.1	30.4
	Total Sulfur (%, d.)	0.66	0.67	0.68	0.69	0.70	0.72	0.73
	Total Dilatation (%)	177	175	171	167	163	159	155
	Max. Fluidity (log DDPM)	3.65	3.62	3.57	3.51	3.45	3.40	3.34
	SI	3.55	3.60	3.71	3.82	3.93	4.04	4.15
	CBI	1.46	1.49	1.56	1.64	1.72	1.80	1.87
	Σ CSR	48	49	50	51	53	54	56
Coke Quality	Ash (%, d.)	8.1	8.1	8.2	8.3	8.4	8.4	8.5
	Total Sulfur (%, d.)	0.58	0.59	0.60	0.61	0.62	0.63	0.64
	TI25	59	59	59	60	60	61	61
	CSR	56	56	57	58	59	59	61
Coke Production (ten thousand tons)		32						11

Table 5-28 shows the result of varied blending proportions of FNO and LAS coals, with a proportion of Boyaca coal being held at 10%.

Blend No.1 is based on blending design according to proportion of production at the two fields, shown in Table 5-25. Under this blending condition, annual coke production will total 320,000 tons. In terms of quality, coke strength (TI25) and coke strength after reaction with CO_2 are 59 and 56, respectively, which fall below target values.
Blend No.7 in Table 5-28 is expected to satisfy target quality requirements; FNO coal 40%, LAS 50%, and Boyaca coal 10%.

Table 5-29 shows the result of simulation when a percentage of Boyaca coal is raised to 15% - 20%, and FNO coal is blended 40% to 50%. By blending medium and low volatile matter heavy coking coals 55% - 70% of total, all coke quality requirements will be satisfied. As a result, high quality blast-furnace coke can be produced from Venezuelan and Colombian coals by using high quality low-volatile and medium-volatile coals in large quantities.

Table 5-29 CALCULATED QUALITIES OF COKE MADE FROM VENEZUELAN AND COLOMBIAN COALS (2)

	Coal Blend No.	1	2	3	4	5
Blending Ratio of Coal	FNO (Venezuela)	50	45	40	45	40
	LAS (Venezuela)	30	35	40	40	45
	Boyaca (Colombia)	20	20	20	15	15
Properties of Coal Charge	Ash (%, d.)	6.5	6.3	6.1	6.1	5.9
	Volatile Matter (%, d.)	27.3	28.0	28.7	28.8	29.6
	Total Sulfur (%, d.)	0.79	0.78	0.77	0.76	0.75
	Total Dilatation (%)	131	135	139	143	147
	Max. Fluidity (log DDPM)	2.92	2.98	3.03	3.13	3.19
	SI	4.77	4.66	4.55	4.46	4.35
	CBI	2.43	2.36	2.28	2.15	2.08
	Σ CSR	61	60	59	59	57
Coke Quality	Ash (%, d.)	8.8	8.7	8.7	8.7	8.6
	Total Sulfur (%, d.)	0.69	0.68	0.67	0.67	0.65
	TI25	63	63	63	62	62
	CSR	63	63	62	62	61

3) Calculation of qualities of coke made from Venezuelan, Colombian, and imported coals

As shown in Blend No.7 of Table 5–28, the amount of blast–furnace coke to be produced by blending Venezuelan and Colombian coals will be limited to 110,000 tons annually, due to limited production of FNO coal (medium volatile matter) and Boyaca coal (low volatile matter). The production capacity falls far below critical mass required for the proposed coke oven. To achieve the maximum annual coke production of 1 million tons, therefore, the use of imported coals will become essential.

Then, coal blending conditions to achieve annual production of 1 million tons, and the minimum blending proportion of imported coals to meet coke quality requirements, regardless of coke production capacity, were examined.

For this purpose, U.S. coal was selected in consideration to market proximity and availability, and Australian coal on the merit of improving coke strength after reaction with CO_2.

The result of simulation is shown in Table 5–30. The Table suggests that, to achieve annual production of 1 million tons, a percentage of imported coals should be raised to 65%, as shown in Blend No.6. Coke qualities in this case are calculated to be ash 8.9(%, d.), total sulfur 0.66(%, d.), coke strength (TI25) 63, and coke strength after reaction with CO_2 (CSR) 59.

A lower blending limit for imported coal is 40% as shown in Blend No.3, in which case annual coke production is estimated to be 570,000 tons/year.

On the other hand, the use of Australian (Saraji) coal, when replacing low volatile matter Pinnacle coal by 25% as shown in Blend No.7, will improve coke strength after reaction with CO_2 (CSR) from 59 to 62. Thus, if CSR is to be emphasized, the use of Australian coal will be more beneficial.

Table 5-30 CALCULATION OF MINIMUM BLENDING PROPORTION FOR IMPORTED COAL

	Coal Blend No.	1	2	3	4	5	6	7
Blending Ratio of Coal(%)	FNO (Venezuela)	12	9	8	6	5	5	5
	LAS (Venezuela)	69	54	46	39	31	27	27
	Boyaca (Colombia)	9	7	6	5	4	3	3
	Pinnacle (U.S.)	4	12	16	20	24	25	
	Blue Creek (U.S.)	6	18	24	30	36	40	40
	Saraji (Australia)							25
Properties of Coal Charge	Ash (%, d.)	5.1	5.6	5.9	6.2	6.5	6.6	7.9
	Volatile Matter (%, d.)	33.1	30.6	29.4	28.2	26.9	26.4	26.9
	Total Sulfur (%, d.)	0.68	0.71	0.72	0.74	0.75	0.76	0.71
	Total Dilatation (%)	175	172	170	169	167	168	173
	Max. Fluidity (log DDPM)	3.52	3.27	3.15	3.03	2.90	2.88	3.15
	SI	3.77	4.19	4.40	4.60	4.82	4.84	4.81
	CBI	1.58	1.81	1.93	2.04	2.16	2.16	1.64
	Σ CSR	49	50	51	51	52	52	59
Coke Quality	Ash (%, d.)	8.2	8.4	8.5	8.7	8.8	8.9	10.4
	Total Sulfur (%, d.)	0.60	0.62	0.63	0.65	0.66	0.66	0.63
	TI25	60	61	62	63	63	63	64
	CSR	56	57	58	58	58	59	62
Coke Production (ten thousand tons)		37	48	57	69	88	101	101

4) Calculation of the maximum blending proportion of Guasare coal

Guasare coal contains low ash (1.04%, d.) and low sulfur (0.41%, d.) but it has high volatile matter (39.19%, d.) with very low caking property. Thus, it is classified as high volatile matter non-caking coal, which use for coking coal should be limited in quantity.

In this calculation, based on Blend No.6 in Table 5-31 to achieve 1 million tons of annual coke production, the maximum blending proportion of Guasare coal was calculated by replacing Blue Creek coal (medium volatile matter).

The result of calculation is presented in Table 5-31 From the Table, the maximum blending proportion of Guasare coal is estimated at 5%[1] in consideration to coke strength (TI25) and strength after reaction with CO_2 (CSR).

Table 5-31 CALCULATION OF MAXIMUM BLENDING PROPORTION OF GUASARE COAL (Coke Production - 1 Million Tons)

	Coal Blend No.	1	2	3	4	5	6	7
Blending Ratio of Coal (%)	FNO (Venezuela)	5	5	5	5	5	5	5
	LAS (Venezuela)	27	27	27	27	27	27	27
	Boyaca (Colombia)	3	3	3	3	3	3	3
	Pinnacle (U.S.)	25	25	25	25	25	25	25
	Blue Creek (U.S.)	40	35	30	25	20	15	10
	Guasare (Venezuela)	0	5	10	15	20	25	30
Properties of Coal Charge	Ash (%, d.)	6.6	6.2	5.8	5.4	5.1	4.7	4.3
	Volatile Matter (%, d.)	26.4	27.1	27.8	28.5	29.1	29.8	30.5
	Total Sulfur (%, d.)	0.76	0.74	0.72	0.69	0.67	0.65	0.63
	Total Dilatation (%)	168	156	144	133	121	109	97
	Max. Fluidity (log DDPM)	2.88	2.72	2.56	2.41	2.25	2.10	1.95
	SI	4.89	4.80	4.71	4.62	4.53	4.44	4.35
	CBI	2.16	2.17	2.17	2.17	2.17	2.17	2.18
	Σ CSR	52	51	49	47	46	44	42
Coke Quality	Ash (%, d.)	8.9	8.6	8.2	7.9	7.5	7.2	6.8
	Total Sulfur (%, d.)	0.66	0.65	0.63	0.61	0.59	0.57	0.56
	TI25	63	62	62	61	60	59	58
	CSR	59	58	56	55	54	53	51

1) In January 1994, study team collected sample and analyzed at CICASI. Calculation of maximum blending proportion based on the analytical data is described in detail in Annex-1.

5.3.3 Coking Test by Box Test Method

Major findings from theoretical examination of blending conditions of coking coal are as follows:

1) It is difficult to produce blast-furnace coke from Venezuelan coals alone. (FNO up to 50%)
2) While it is possible to produce blast-furnace coke by blending Venezuelan and Colombian coals, present coal production limits coke production to 110,000 tons/year, far below the minimum level of capacity for the proposed coke oven.
3) The best solution is to blend Venezuelan and Colombian coals with U.S. coals, which will produce high-grade blast furnace coke in commercially viable amounts.

(1) Outline of box test

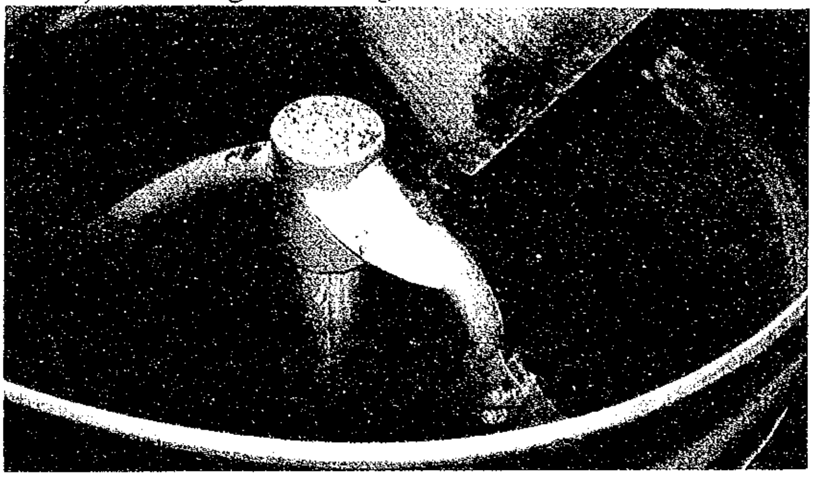
Selected types of coking coals, crushed to 3mm or smaller in grain size, are blended in certain proportions. After adding water to obtain moisture content of 10%, 15kg of the blending coal is put into a 232mm x 232mm x 347mm box made of galvanized iron sheet at a bulk density of 0.8kg/liter. Then, the box is placed in a coke oven in operation for coking.

Major activities involved in the box test show Photos 5-7 and 5-8:

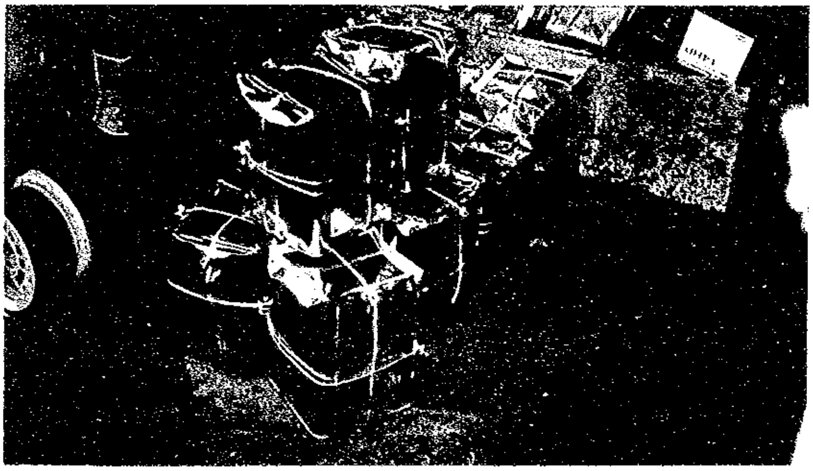
Photo 5-7-1: Blending coking coals
Photo 5-7-2: Coal blend are charged and packed in a box
Photo 5-7-3: The box placed into a coke oven in operation
Photo 5-8-1: The box discharged from the oven
Photo 5-8-2: The box carbonized into a coke
Photo 5-8-3: Coke (FNO coal) removed from the box

Then, the carbonized coke is analyzed at a laboratory to evaluate its quality as blast-furnace coke.

1) Blending and mixing raw coals



2) Blended coals packed in boxes



3) Charging the boxes into a coke oven in operation

Photo 5-7 BOX TEST

1) Boxes removed from the coke oven to the wharf

2) Boxes turns into cokes

3) Cokes removed from the coke oven

Photo 5-8 BOXED AND COKES DISCHARGED FROM THE COKE OVEN

(2) Blending conditions

5 types of coal blend have been established for the box test, as shown in Table 5-32.

Major characteristics of each coal blend are described as follows.

Box 1 : Blending of Venezuelan coals according to proportion of production (Blend No.1 of Table 5-27)

Box 2 : Blending of Venezuelan and Colombian coals according to proportion of production (Blend No.1 of Table 5-28)

Box 3 : Blending of Venezuelan and Colombian coals, at which quality requirements for blast-furnace coke are expected to be satisfied (Blend No.7 of Table 5-28)

Box 4 : Blending of Venezuelan and Colombian coals, added by the minimum required amount of imported coal to meet quality requirements for blast-furnace coke (Blend No.3 of Table 5-30)

Box 5 : Blending required to produce 1 million tons of coke annually (Blend No.6 of Table 5-30)

Table 5-32 BLENDING CONDITIONS FOR THE BOX TEST (%)

	Coal blend No.	Box1	Box2	Box3	Box4	Box5
Blending ratio of coal (%)	FNO (Venezuela)	15	13	40	8	5
	LAS (Venezuela)	85	77	50	46	27
	Boyaca (Colombia)		10	10	6	3
	Pinnacle (U.S.A.)				16	25
	Blue Creek (U.S.A.)				24	40

Boxes 1 and 2 each blend Venezuelan and Colombian coals in different proportions of production. Although these coal blend have been proven not to meet quality requirements, they have been made to cokes in order to check what types of coke are made from them.

Box 3 is designed to confirm technical viability of producing blast-furnace coke by blending Venezuelan and Colombian coals, regardless of their actual production. This is intended to clarify whether blast-furnace coke with sufficient quality can be produced by using these coals, in case that their production increases to a level making coke production a viable option.

Box 4 is designed to determine the minimum amount of imported coal required to produce blast-furnace coke.

Box 5 represents the blending required to produce blast-furnace coke at a rate of 1 million tons per year.

(3) Box test

The box test for the coal blend was conducted in accordance with coke production flow shown in Fig.5-13.

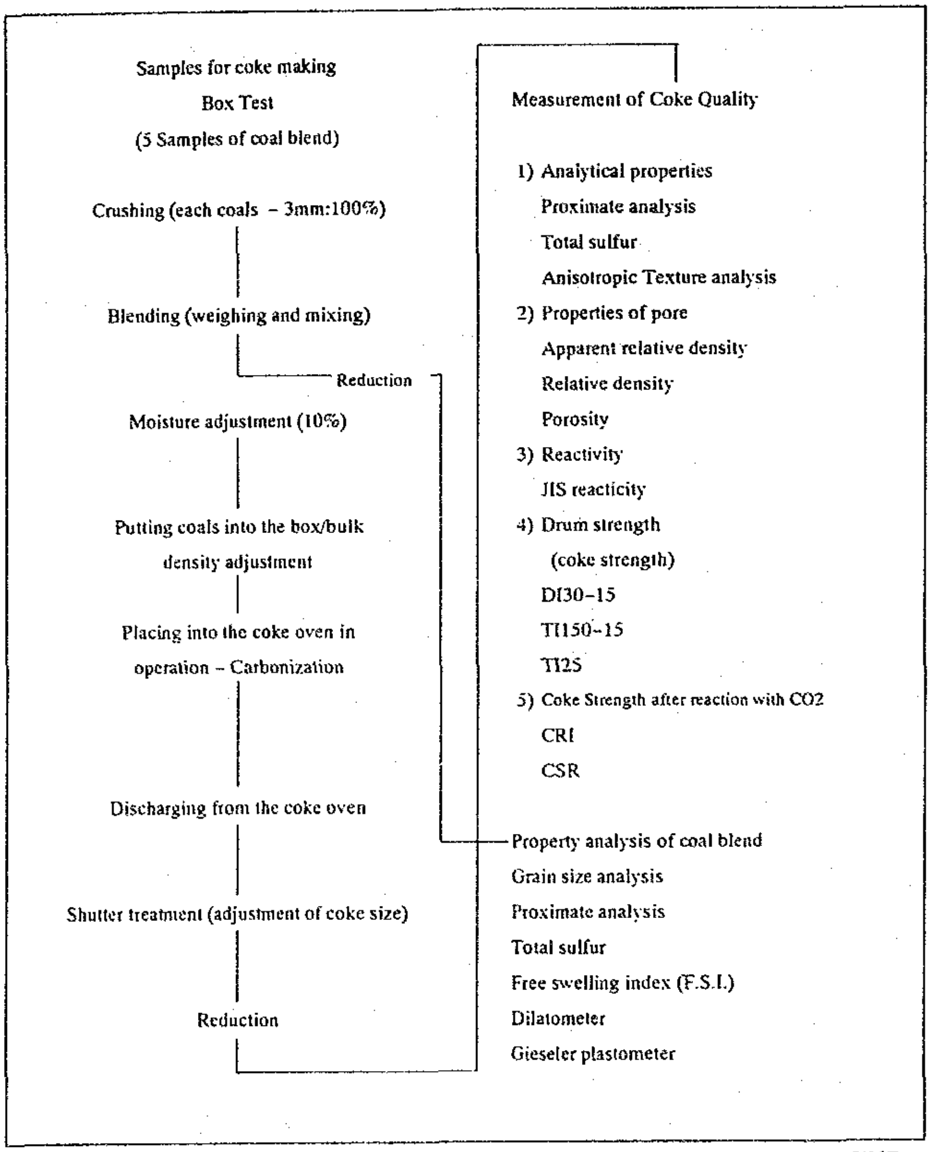


Fig.5-13 COKING TEST FLOW BY BOX TEST METHOD USING COAL BLEND

1) Preparation of the box and coal blend

Coals to be blended, as listed in Table 5-32, are all crushed to 3mm or less in grain size and are mixed in specified proportions, and water is added to 10% moisture content.

15kg prepared and coal blend are put into a box made of galvanized iron sheet at a bulk density of 0.8kg/liter, which is then bound and tightened by steel wires. (Photo 5-7-2) Each type of coal blend was put into 10 boxes.

Properties of the coal blend are shown in Table 5-33 (Grain Size Distribution), Table 5-34 (Proximate Analysis), Table 5-35 (Gieseler Plastometer), and Table 5-36 (Dilatometer).

As shown in Table 5-33, grain size distribution of coal blend is all 3mm or less. Proximate analysis and caking property data are presented in detail in Tables 5-33 through 5-36. Fig.5-14 hilights these data.

Table 5-33 GRAIN SIZE DISTRIBUTION OF COKE FROM COAL BLEND

Box No.	Grain Size Distribution (mm, %)				
	+3.0	3.0-1.2	1.2-0.5	0.5-0.3	-0.3
Box -1	0.0	44.4	38.2	8.4	9.0
Box -2	0.0	39.3	39.7	8.0	13.0
Box -3	0.0	37.0	37.0	11.0	15.0
Box -4	0.0	34.4	32.7	11.8	21.0
Box -5	0.0	27.1	31.4	16.5	25.0

Table 5-34 PROXIMATE ANALYSIS AND TOTAL SULFUR OF COAL BLEND

Box No.	Inherent Moisture (%)	Proximate analysis (%.d) Ash	Volatile matter	Fixed carbon	Volatile matter (%, d.a.f.)	Total (%.d)
Box -1	1.57	4.52	34.98	60.50	36.64	0.63
Box -2	1.46	4.70	34.28	61.02	35.97	0.68
Box -3	1.12	5.73	30.55	63.72	32.41	0.73
Box -4	1.28	5.81	29.85	64.34	31.69	0.70
Box -5	1.34	6.61	26.51	66.88	28.39	0.70

Table 5-35 F.S.I. AND GIESELER PLASTOMETER OF COAL BLEND

Box No.	F.S.I	Gieseler plastometer			
		Initial softening temp. (℃)	Maximum fluidity temp. (℃)	Solidificast. temperature (℃)	Maximum fluidity (Log DDPM)
Box -1	7	404	444	480	3.66
Box -2	8	406	445	482	3.59
Box -3	6 1/2	412	448	487	3.13
Box -4	8 1/2	410	450	490	3.03
Box -5	8 1/2	417	456	492	2.85

Table 5-36 DILATOMETER OF COAL BLEND

Box No.	Initial softening temp. (℃)	Maximum Contract. temp. (℃)	Maximum Dilatat. temp. (℃)	Percent. Contrac. (%)	Percent. Dilatat. (%)	Total Dilatat (%)
Box -1	349	410	472	24	78	102
Box -2	355	414	472	21	83	104
Box -3	373	421	481	23	34	57
Box -4	373	420	481	25	59	84
Box -5	382	427	487	22	44	66

As shown in Fig.5-14, Boxes 1 and 2 which blend Venezuelan and Colombian coals by their proportions of production are characterized by low ash and sulfur contents and are highly suitable for coal blend to produce blast-furnace coke. However, these coal blends show high maximum fluidity and total dilatation to result in excess caking property. Furthermore, the most serious issue of these coal blends is high volatile matter 36(%, d.a.f.) or more, thus a low level of coalification which gives rise to many cracks in coke and reduces coke's mechanical strength.

Box 3 which pursue the best mix of Venezuelan and Colombian coals regardless of their actual production shows a lower volatile matter content 32.4(%, d.a.f.) to offer a higher level of coalification.

Boxes 4 and 5 which blend imported coals with Venezuelan and Colombian coals contain much less volatile matters with more degree of coalification. As for caking property, they show the maximum fluidity of 2.85 - 3.03 (log DDPM) and total dilatation of 66% and 84%, respectively, which are sufficient for coal blends for coke making.

2) Coking

Coking test was conducted by using a large coke oven owned by Mitsui Mining Co., Ltd., as shown in Photo 5-7-3.

3) Evaluation of coke quality

Produced coke was treated in accordance with the coking test flow using the box test method for coal blends, as shown in Fig.5-13. Each box discharged from the oven was broken (Photo 5-8-2) to take out produced cokes (Photo 5-8-3). Cokes were dropped twice by using a shutter testing machine to simulate shocks generally given in the coke oven and to adjust grain sizes. Prepared cokes were reduced in size and various property analysis were conducted.

The results are presented in Tables 5-37 through 5-40, and major properties are shown in Fig.5-15. Among these items, coke strength shows difference between the result of the box test and the actual coke making. To correct the difference, coals actually charged to a coke oven are coked under the same conditions as the box test, and the measured difference in coke strength between cokes made in the actual oven and those made in the box test is determined.

Table 5-41 shows the difference in coke strength between cokes produced in Mitsui Mining's plant and those produced in the box test. It should be noted, however, that, no adjustment has been made for ash content, total sulfur, and CSR as there was no difference between the actual coke oven and the box test.

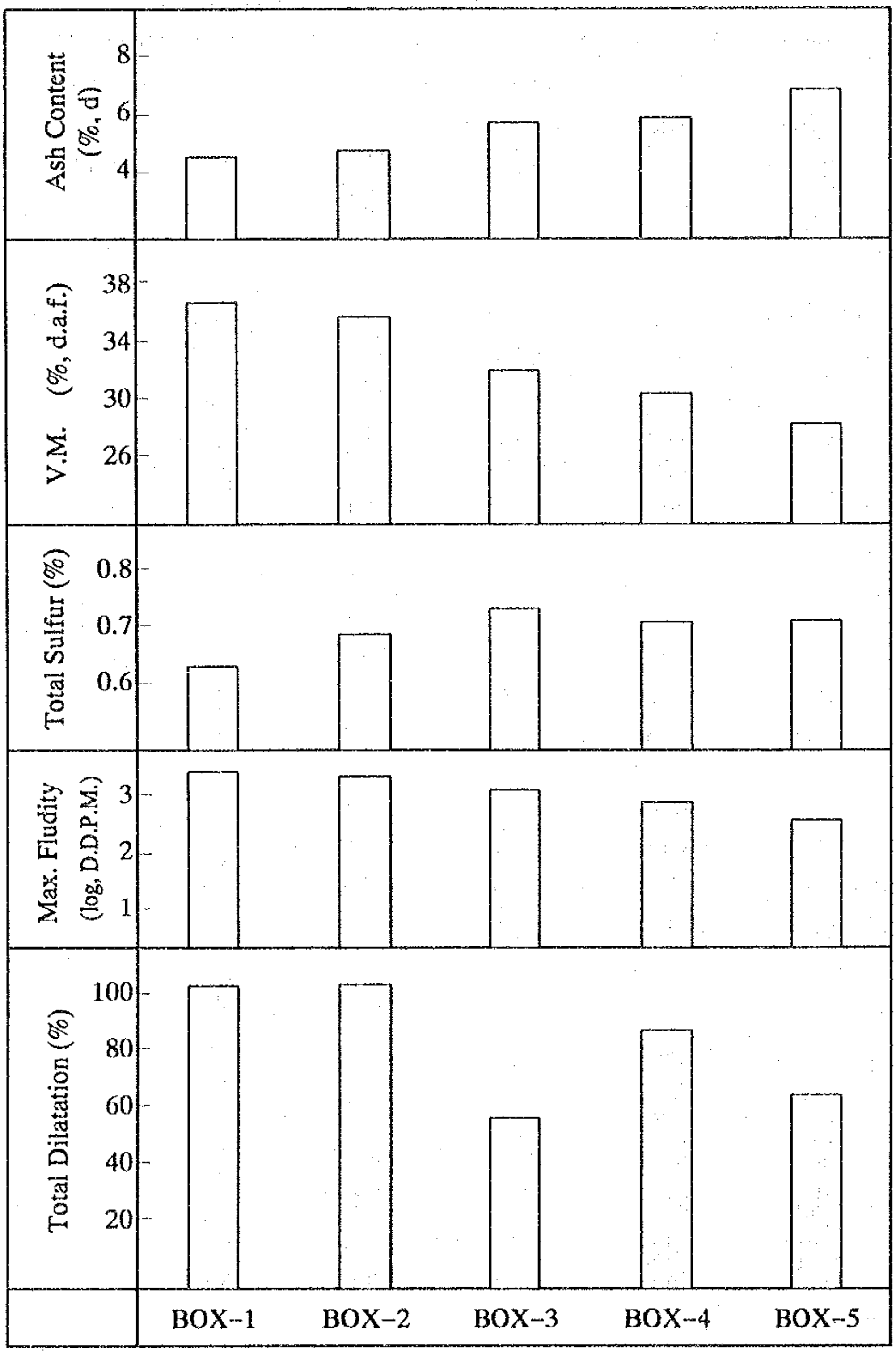


Fig 5-14 COMPARISON OF PROPERTIES OF BLENDED COALS FOR BOX TEST

Table 5-37 GRAIN SIZE DISTRIBUTION OF COKE FROM COAL BLEND

Box No.	Grain size distribution (mm, %)					
	125-100	100-75	75-50	50-25	25-15	-15
Box -1	34.1	23.6	23.5	12.3	2.6	3.9
Box -2	23.3	28.4	27.0	17.2	1.9	2.2
Box -3	36.8	27.9	23.9	9.3	0.8	1.3
Box -4	15.0	19.5	44.8	17.8	1.3	1.6
Box -5	7.4	18.9	40.7	28.8	1.7	2.5

Table 5-38 PROXIMATE ANALYSIS, TOTAL SULFUR AND POROSITY OF COKE FROM COAL BLEND

Box No.	Proximate analysis (%, d)			Total sulfur (%, d)	Apparent gravity (-)	True gravity (-)	Porosity (%)
	Ash	Volatile matter	Fixed carbon				
Box -1	8.01	0.81	91.18	0.57	1.04	1.97	47
Box -2	8.10	0.63	91.27	0.59	1.03	1.95	47
Box -3	8.55	0.83	90.62	0.66	1.06	1.97	46
Box -4	8.26	0.57	91.17	0.58	1.05	1.95	46
Box -5	8.87	0.64	90.49	0.65	1.03	1.98	48

Table 5-39 ANISOTROPIC TEXTURE ANALYSIS OF COKE FROM COAL BLEND

Box No.	isotropic	fine mosaic	coarse mosaic	fibrous	leaflet	inert
Box -1	8.4	65.0	4.5	4.1	0.0	18.0
Box -2	8.1	61.5	2.9	8.6	0.0	18.9
Box -3	6.2	36.1	17.1	14.7	0.2	25.7
Box -4	4.1	51.3	7.5	13.6	1.5	22.0
Box -5	2.3	41.6	13.1	23.5	1.4	18.1

Table 5-40 REACTIVITY AND COKE STRENGTH OF COKE FROM COAL BLEND

Box No.	Coke strength after reaction		Coke strength			
			Drum indx		Tumbler indx	
	CRI	CSR	DI_{30-15}	DI_{150-15}	TI_{25}	TI_{6}
Box -1	34.2	49.5	89.8	78.2	58.3	64.8
Box -2	33.7	51.7	90.1	79.9	59.2	65.2
Box -3	29.4	60.5	95.1	85.5	68.8	70.3
Box -4	27.8	58.1	96.8	86.9	70.9	73.4
Box -5	27.1	59.8	96.5	87.1	71.8	45.5

Table 5-41 COMPARISON OF COKE STRENGTH MADE IN MITSUI MINING'S COKE OVEN AND BOX TEST

Sample	DI_{150-15}	TI_{25}
Cokes made in the box test	84.2	70.3
Cokes made in the coke oven	82.0	61.1
Difference (oven - box)	2.2	9.2

Properties of cokes analyzed in the box test are summarized in Table 5-39 and Fig.5-15. Ash content is 9.0(%, d.) or less in all the samples, which is below the target value for commercial production at 10.3(%, d.). Also, total sulfur is less than the target value of 0.76(%, d.) in all the cases.

CSR clears the target value of 58 in Boxes 3, 4 and 5, ranging between 58.1 and 60.5. On the other hand, it falls below the target in Boxes 1 and 2, 49.5 and 51.5 respectively. As discussed in general description of coal blend in 1), this seems to be attributable to an insufficient level of coalification.

4) Box test summary

Coke strength, as shown in Fig.5-15, satisfies the TI_{25} target value of 61 in Boxes 4 (61.7) and 5 (62.6). On the other hand, Boxes 1 and 2 show significant declines in coke strength to 49.1 and 50.0 respectively. Finally, Box 3 falls slightly short of the target level, with coke strength of 59.6.

Notably, coal blends in Boxes 1, 2 and 3, which did not reach the target level, were supposed to produce highly strong cokes, with coke strength of 58, 59, and 61, respectively.

The difference between the calculated values and the measured one has been reviewed to identify its causes, and as shown in Fig.5-16, it has been revealed that the difference increases with an increase in volatile content of coal blend. This means, an insufficient level of coalification of coal blend has caused between the calculated values and the measured ones.

Major findings from the box test are as follows:

a) The blending of Venezuelan coals according to proportion of production, cannot produce blast-furnace coke.
b) By the same token, the blending of Venezuelan and Colombian coals according to proportion of production cannot produce blast-furnace coke.
c) In the blending of Venezuelan and Colombian coals, not based on actual proportion of production, only TI_{25} is 59.6, very close but slightly above the target value of 61.
d) To produce blast-furnace coke to meet specific quality requirements, imported coals, 40% to 65% of total, should be blended with Venezuelan and Colombian coals.
e) Volatile matter of coal blend to produce blast-furnace coke should be set at below 30.0(%, d.a.f.).

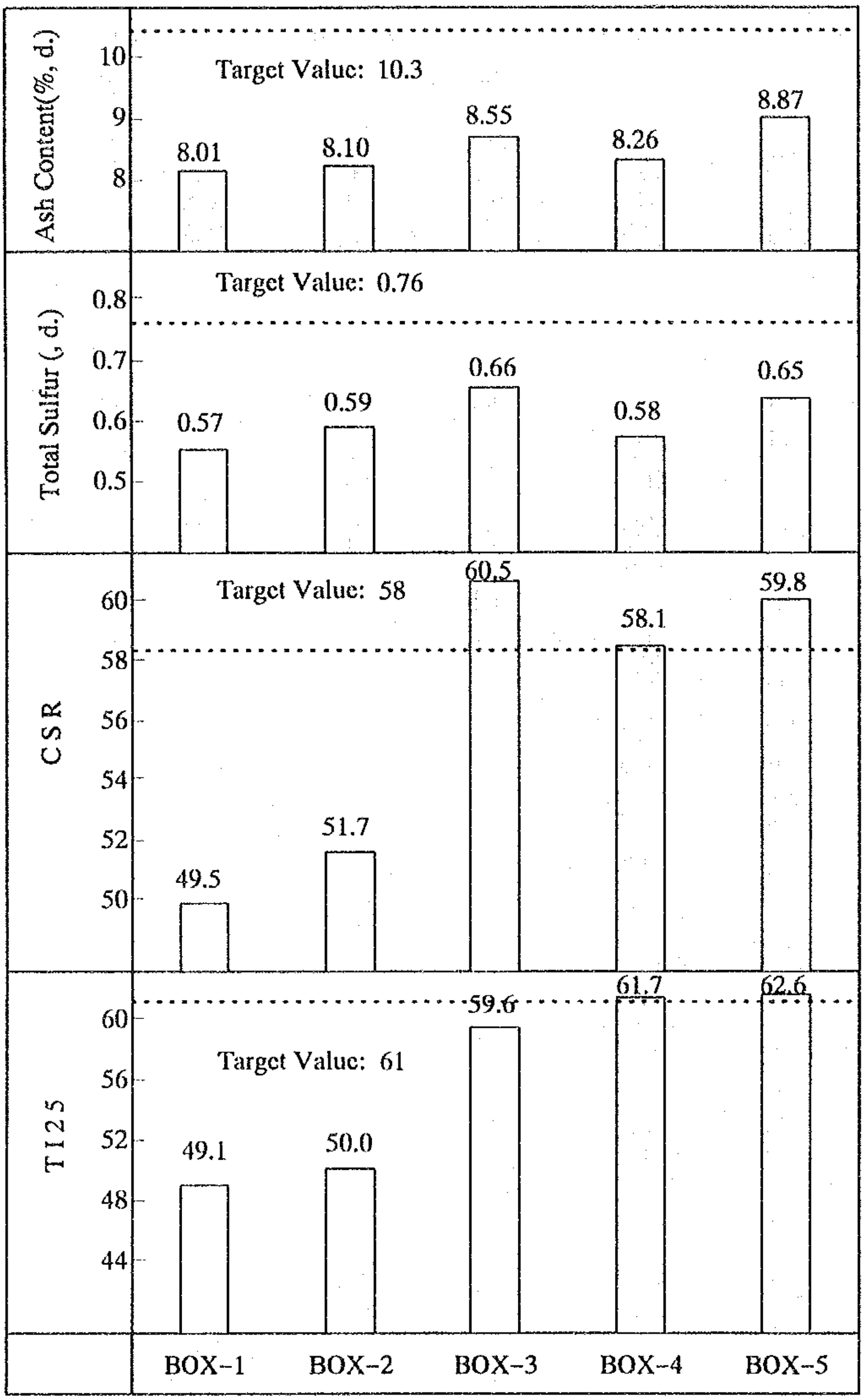


Fig.5-15 COMPARISON OF COKE QUALITIES BY BOX TEST
(ADJUSTED TO THE ACTUAL COKE MAKING CONDITIONS)

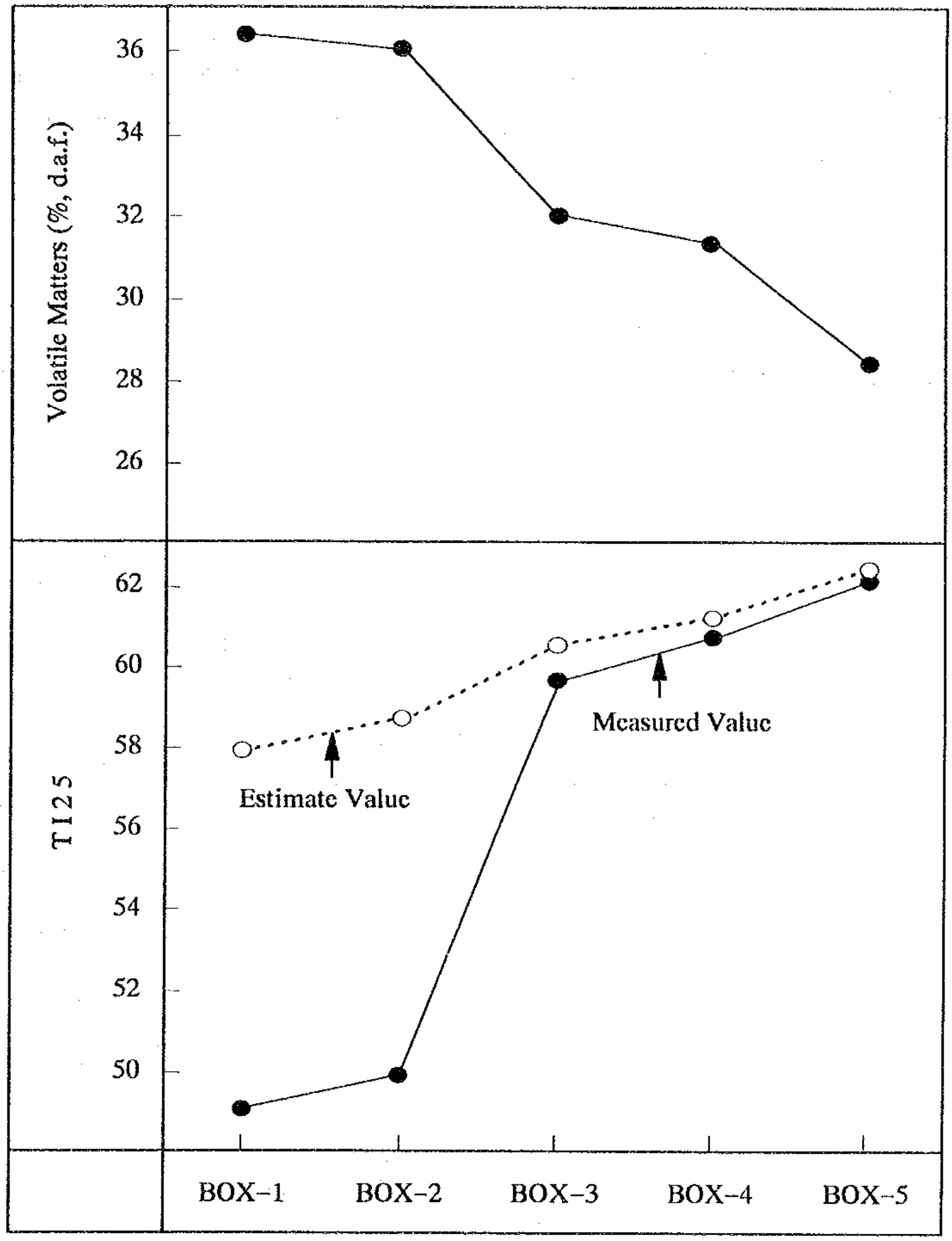


Fig.5-16 COMPARISON OF ACTUAL TI_{25} VALUES OBTAINED FROM BOX TEST AND ESTIMATED VALUES (ADJUSTED TO THE ACTUAL COKE MAKING CONDITIONS)

5.3.4 Coking Test Using the Simulated Coke Oven (SCO)

While the box test is one of low-cost and easy-to-do coking test methods, it sometimes produce data lacking reliability. For this reason, the coking test was conducted for the most important Box-5 coal blend by using high-cost but highly reliable SCO. Note that the coking test using SCO was conducted according to the process flow shown in Fig.5-17.

Samples for coke making
SCO (carbonization)

Crushing (each coals - 3mm:100%)

Blending (weighing and mixing)

Moisture adjustment (8%)

Charging to the SCO/bulk density adjustment

Coking

Discharge from the SCO

Shutter treatment (adjustment of coke size)

Reduction

Measurement of Coke Quality

1) Analytical properties
   Proximate analysis
   Total sulfur
   Anisotoropic texture analysis
2) Properties of pore
   Apparent relative density
   True relative density
   Porosity
3) Reactivity
   JIS reacticity
4) Drum strength
   (coke strength)
   DI150-15
   TI25
5) Coke strength after reaction with CO2
   CRI
   CSR

Fig 5-17 COKING TEST FLOW BY SCO COAL BLEND

(1) Preparation and properties of coal blend

Coal blend was prepared by crushing all the coals to be blended into 3mm or smaller in grain size. Then, FNO-LC-30 coal 5%, LAS-LC-(25+30) coal 27%, Boyaca coal 3%, Pinnacle coal 25%, and Blue Creek coal 40% were blended, and water was added to obtain moisture content of 8%.

Measured property data of the coal blend are shown in Table 5-42 (Grain Size Distribution), Table 5-43 (Proximate Analysis and Total Sulfur), Table 5-44 (F.S.I. and Gieseler Plastometer), and Table 5-45 (Dilatometer).

These data indicate that the coal blend does not show any problem in terms of ash content (6.68%, d.), volatile matter (28.76%, d.a.f.), and total sulfur (0.73%, d.). On the other hand, sufficient caking property is shown in terms of F.S.I. (9), maximum fluidity measured by Gieseler plastometer 2.63 (log DDPM), and total dilatation measured by dilatometer of 70%.

Table 5-42 GRAIN SIZE DISTRIBUTION OF COAL BLEND

Sample No.	Grain size distribution (mm, %)						
	25-10	10-6.0	6.0-3.0	3.0-1.2	1.2-0.5	0.5-0.3	-0.3
SCO test-1	0.0	0.6	3.4	25.1	27.9	14.4	28.6

Table 5-43 PROXIMATE ANALYSIS AND TOTAL SULFUR OF COAL BLEND

Sample No.	Inherent Moisture (%)	Proximate analysis (%.d) Ash	Volatile matter	Fixed carbon	Volatile Matter (%, d.a.f.)	Total Sulfur (%, d)
SCO test-1	1.34	6.68	26.84	66.48	28.76	0.73

Table 5-44 F.S.I. AND GIESELER PLASTOMETER OF COAL BLEND

Sample No.	F.S.I	Gieseler plastometer			
		Initial softening temp. (℃)	Maximum fluidity temp. (℃)	Solidificast. temperature (℃)	Maximum fluidity (Log DDPM)
SCO test-1	9	415	462	495	2.63

Table 5-45 DILATOMETER OF COAL BLEND

Sample No.	Initial softening temp. (℃)	Maximum Contrac. temp. (℃)	Maximum Dilatat. temp. (℃)	Percen. Contra. (%)	Percen. Dilata. (%)	Total Dilata. (%)
SCO test-1	385	429	490	22	48	70

Table 5-46 ASH COMPOSITION ANALYSIS OF COAL BLEND

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	TiO_2	P_2O_5	SO_3	K_2O	Na_2O
SCO test-1	50.38	27.44	10.74	2.32	1.12	0.07	1.53	0.73	0.78	1.55	0.67

(2) Coking by SCO

Coking of coal blend was conducted by using a simulated coke oven (SCO), which is electrically heated and has effective dimensions of 430mm (width), 640mm (length), and 480mm (height).

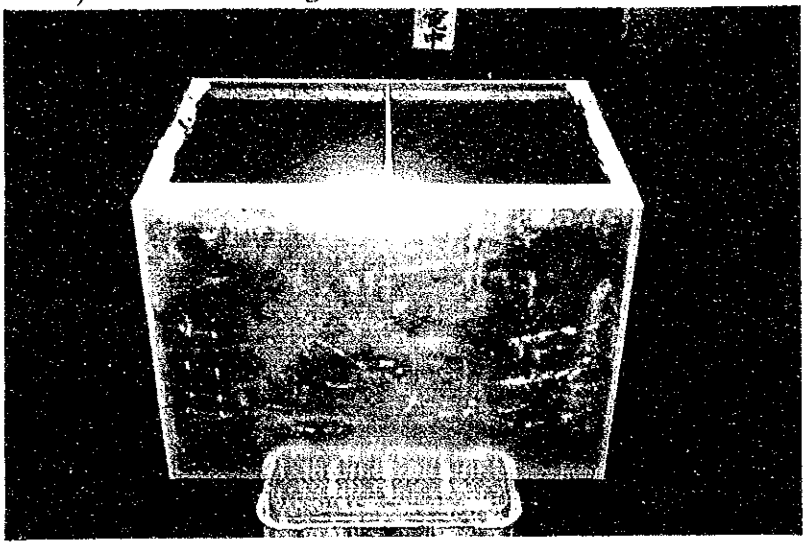
Before charging coal blend into the SCO, it is placed into a charging container (425mm x 420mm x 620mm) made of galvanized iron sheet at a weight of 80kg with bulk density of 0.72kg/liter. Then the container is charged into a carbonization furnace.

Heating conditions for the SCO are summarized as follows:

Charging at 800°C →	800°C →	1050°C →	1100°C →	1100°C →	Discharge
	1 hour	13 hours	5 hours	0.5hours	

Container discharged from the SCO is water cooled and opened. The major SCO and related processes are shown in Photos 5-9 and 5-10.

1) Coal blend charged into the SCO container



2) SCO and cokes removed

Photo 5-9 CHARGING CONTAINER AND SCO