GEOLOGICAL EXPLORATION REPORT

ON

THE LUBHOKO COALFIELD DEVELOPMENT PROJECT

IN

THE KINGDOM OF SWAZILAND

DECEMBER [illegible]

JAPAN INTERNATIONAL
COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Kingdom of Swaziland, the Government of Japan decided to conduct a survey on the Lubhuku Coalfield Development Project and entrusted the survey to the Japan International Cooperation Agency (JICA). The JICA sent to the Kingdom of Swaziland a survey team headed by Mr. Hajime Nozaki from November 11, 1980 to March 25, 1981 and from July 18, 1981 to March 4, 1982.

The team exchanged views on the Project with the officials concerned of the Government of Swaziland and conducted a field survey in Lubhuku area. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Kingdom of Swaziland for their close cooperation extended to the team.

Tokyo, December, 1982

Keisuke Arita

President

Japan International Cooperation Agency

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SUMMARY

SUMMARY

1. The Government of the Kingdom of Swaziland has decided to develop coal resources occurring in a deeper part of its coalfield in order to attain self sufficiency in energy resources and to obtain foreign exchange earnings through export of coal. The Swaziland Government requested the Government of Japan for technical cooperation on the execution of the Deep Coal Drilling Project in May, 1979. The Japanese Government complied with the request and the Scope of Work concerning the execution of the exploration work in the Lubhuku coal-field was concluded on March 25, 1980 between the Japan International Cooperation Agency (JICA) and the Geological Survey and Mines Department of Swaziland.

2. The purpose of the investigation is to ascertain geological characteristics of the coal seams occurring in the deeper part of the Lubhuku coalfield and to obtain basic information of them for the future planning of exploration and exploitation of the coalfield.

3. The JICA team was organised to conduct the exploration in cooperation with the Swaziland counterparts and commenced the work in November, 1980. The investigation consisted mainly of drilling with total length of 10,660.84 meters in 28 boreholes, and magnetometry survey, geophysical logging, surface geological survey and laboratory testing were also executed. Fieldwork was executed in the fiscal years 1980 and 1981, and geological study was carried out in the fiscal year 1982.

4. More than twenty coal seams were found in the Lower Coal Zone of the Ecca Series during this drilling investigation, of which three coal seams, Intermediate Marker, Main Seam and Footwall 3, are considered to be minable. The Main Seam occurs most predominantly with coal thickness of more than 1.0 meter in the area, and a maximum thickness of 4.57 meters in the northwestern part. The Intermediate Marker and Footwall 3 are also extensively distributed with coal thickness of 1.0 to 1.9 meters especially in the northern part. General modes of occurrence of these coal seams in the northern part are superior to those in the southern part.

5. Heavy minerals in sandstone and pollen analysis were tested but not found to be useful methods for the correlation of horizons. However, geophysical logging is indicated as a useful method as this shows characteristic log response to specific horizons. Litho-stratigraphic correlation is also useful as in cases some coal seams can be correlated as a group with their general lithofacies.

6. Sills and dykes of the Karoo dolerite extensively intrude into the area, especially in the southern part. The intrusion frequency of the dolerite is generally high in the southern part at 25 to 40 percent, on the contrary, it is fairly low in the northern part at 1 to 25 percent. These intrusions show very complex occurrence and affect the coal seams with replacement and thermal alteration.

7. The Lower Coal Zone shows deltaic plain to alluvial plain facies and an appropriate environment for the deposition of the coal seams was provided in the northern and southern parts of the area. The major coal seams were extensively deposited in stable sedimentary basins during early sedimentary period and these basins became somewhat unstable in the later period. The sedimentary basin in the northern part during early period shows high coal ratio and this basin tends to the north of the investigated area.

8. Most of the major coal seams are classified as semi-anthracite and some of them as anthracite. The quality of these coal compares favorably with that of the Mpaka mine and anthracite from those Natal mines which are in operation at present. This indicates that the Lubhuku coal has the same marketability as those coals have.

9. Total coal reserves of 186 million tons are expected in the area, and of those about 60 percent are in the Main Seam and about 70 percent are in the northern part. These reserves in the northern part are considered to be enough for the development of new coal mine in the future.

10. This investigation reveals that the known coal seams occurring in the shallow part have been ascertained to continue up to the depth of 450 meters and more below the surface in the virgin area of the Swaziland coalfield. Besides, coal seams in the northern part of the Lubhuku area are promising judging from their modes of occurrence and little intrusions of dolerite. These promising coal seams appear to extend north of the investigated area.

11. Therefore, it is strongly recommended to perform further drilling investigation of total length of about 7,400 meters in 20 boreholes at 1 kilometer intervals in the northern part of the area and its northern adjacent part, in order to select the area for further detailed drilling investigation. These drillings will contribute extensively towards the promotion of the development of new coal mine in the future for attaining of self sufficiency in energy resources, which one of the main targets of the Kingdom of Swaziland.

CHAPTER 1. INTRODUCTION

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1.1 Purpose of the Investigation

Attaining of self sufficiency in energy resources is one of the main targets in the Third National Development Plan (1978/79 – 1982/83) established by the Government of the Kingdom of Swaziland, because about 40 percent of the total energy resources consumed in Swaziland have been imported from the Republic of South Africa. Especially, coal in Swaziland is the energy resources with the greatest future potentiality and the Government expects much of developing of the coal resources to dissolve the dependence on the foreign energy resources, to develop further industrial activities and to increase employment opportunity in the country. Furthermore, since Ngwenya iron mine, one of the main foreign exchange earners for over the past fifteen years, was closed in 1978, the Government intends to obtain earnings through export of coal to replace those of the iron mine and to make an effective contribution to the country's economic growth.

Coal resources in Swaziland have been known to exist in the Lowveld of the country for more than a century. Exploration of coal has been performed in many areas of the coalfield by the private sector and the Government (Geological Survey and Mines Department), however, most of the exploration is concentrated in a shallow part of the coalfield. The Swaziland Government took notice of development of the coal resources occurring in a deeper part of the coalfield where very few exploration works have been executed, and prepared Deep Coal Drilling Project (DCDP) to evaluate potentiality of coal resources and to frame a long-term energy policy of the country.

Under the circumstances, the Government of Swaziland had submitted a request to the Government of Japan for technical cooperation on the execution of the Deep Coal Drilling Project in May, 1979. In compliance with this request, the Scope of Work, stated the extent and contents of the works to be performed in the Lubhuku area, was concluded between the Japan International Cooperation Agency (JICA) and the Geological Survey and Mines Department of Swaziland on March 25, 1980. The area is favorably situated and has top priority among five target areas proposed by the Swaziland Government. The JICA team was organized to conduct the exploration work and commenced it in November, 1980.

The purpose of the investigation is to ascertain geological characteristics of coal seams in the Lubhuku area, to obtain basic information on them (coal reserves, depth and thickness of coal seams, etc.) for future study on possibility of the development of the coal resources, and to contribute to preparation of future planning for exploration and exploitation of these coal seams.

The coal seams to be investigated in this project are those in the Middle Ecca Series (Lower Coal Zone) of the Karoo System, especially occurring in the deeper part more than 200 meters below the surface.

1.2 Method, Period and Organization of Exploration Work

The exploration work consisted mainly of the drilling of twenty-eight holes and the magnetometry survey around the planned borehole site, the geophysical logging in the drilled holes, the surface geological survey at the area required and the laboratory tests were also executed. The exploration was conducted in two fiscal years 1980 and 1981. In this report, the former is tentatively called Phase I and the latter, Phase II. Geological study was carried out in the fiscal year 1982.

The exploration of Phase I was commenced in November, 1980, however, the work was delayed due to unexpectedly excessive rain and unseasonable weather and the drilling was ended in March, 1981 with discontinued three holes because of their difficult drilling conditions caused by jamming.

The exploration of Phase II was started from July, 1981 and completed in March, 1982, as planned, including continuation of drilling of the discontinued three holes in the previous year, because the countermeasures for heavy rain and difficult drilling conditions were sufficiently taken.

The geophysical logging (carried out by BPB Instruments, Ltd.) and magnetometry survey were performed by the Swaziland counterparts. The drilling work was carried out by the Rock Grout Construction (Pty) Ltd. – Rock Boring and Drilling (Pty) Ltd., the Republic of South Africa, for Phase I and by Interdrills (Pty) Ltd., South Africa for Phase II.

Drilling Investigation:

Phase I	9 holes	Total	2,825.62 meters
Phase II	22 holes*	Total	7,835.22 meters
Total	28 holes	Total	10,660.84 meters

Note: *Continuation of drilling of three holes discontinued in Phase I is included.

Magnetometry Survey:

Phase I	9 places
Phase II	19 places

Geophysical Logging:

Phase I	6 holes
Phase II	16 holes

Surface Geological Survey:

The surface geological survey at the area required was carried out in parallel with the drilling work.

Each one engineer for geology, geology-drilling and drilling-survey was sent from Japan during fieldwork. On the other hand, a project coordinator, a drilling engineer, one to three geologists and other staffs of the Swaziland Government collaborated with the JICA team as counterparts. The Swaziland authorities extended those conveniences such as transportation of equipment and staffs, stay and inmigration procedures for the JICA team, office for the desk work, office equipment, and the tax exemption procedures for survey instruments. The exploration process and engineers concerned are summarized in Fig. 1. The members of JICA team and Swaziland counterparts are shown in Tables 1-1 and 1-2 respectively.

JICA team fully explained a draft report in detail to the Swaziland Government's authorities concerned in November, 1982 and the report was accepted by the Government.

Figure 1. General View of Exploration Work

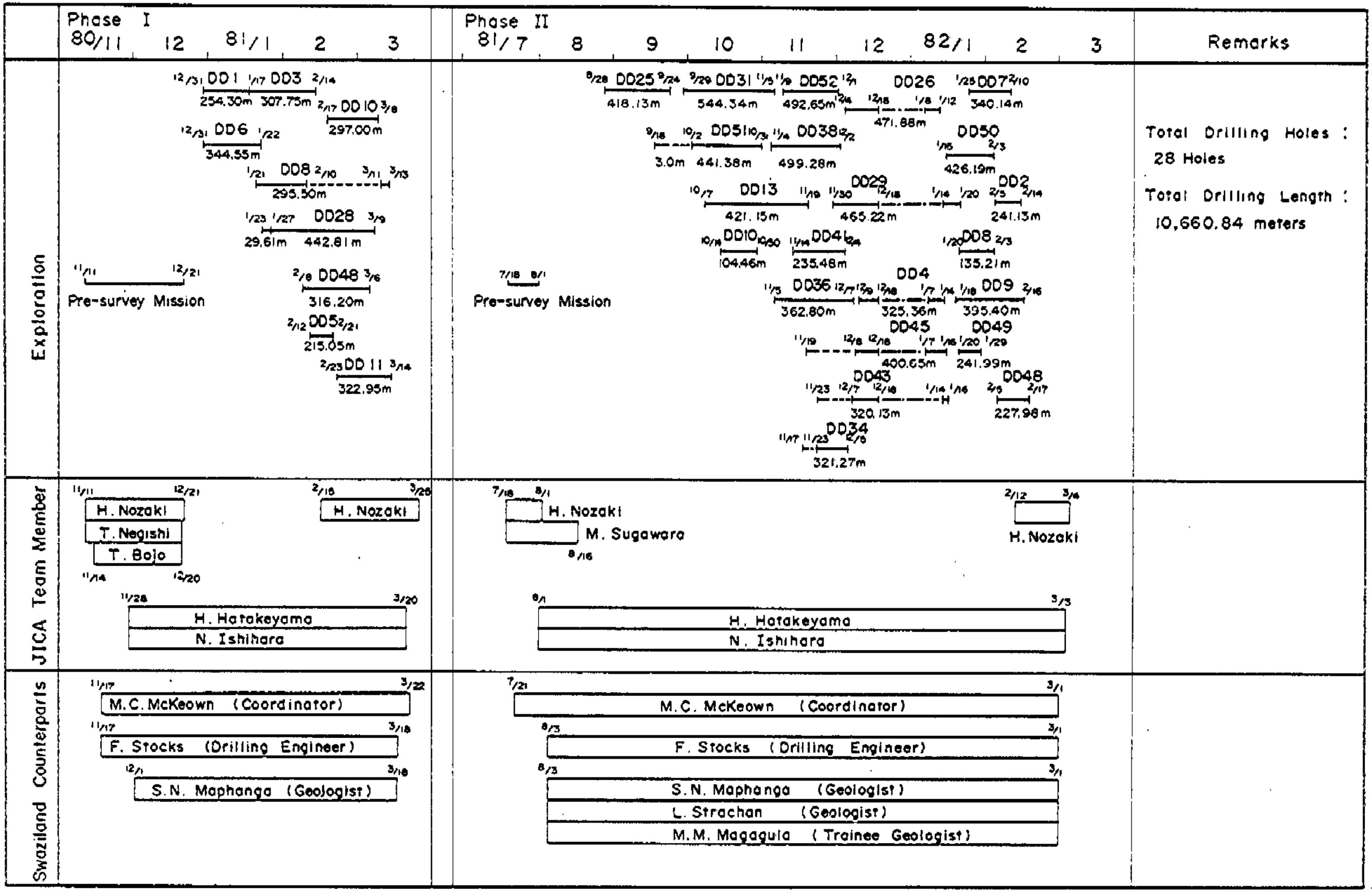

Table 1-1 Members of JICA Team

Name	Charge	Position	Working Period
Hajime Nozaki	Leader, Geology	Chief Geologist, Overseas Coal Development Department, Sumitomo Coal Mining Co., Ltd.	AI,AII, BI,BII, E
Michiyoshi Sugawara	Geology	Chief Geologist, Overseas Coal Development Department, Sumitomo Coal Mining Co., Ltd.	AII,C
Toshio Negishi	Geology	Geologist, Overseas Coal Development Department, Sumitomo Coal Mining Co., Ltd.	AI
Hiroichi Hatakeyama	Drilling, Survey	Mining Engineer, Overseas Coal Development Department, Sumitomo Coal Mining Co., Ltd.	DI,DII
Norio Ishihara	Geology, Drilling	Geologist, Overseas Coal Development Department, Sumitomo Coal Mining Co., Ltd.	DI,DII
Toshiatsu Bojo		Japan International Cooperation Agency	AI
Koichi Yajima		Japan International Cooperation Agency	E

Note:

AI: Preparation (Phase I) November 11, 1980 to December 21, 1980

AII: Preparation (Phase II) July 18, 1981 to August 1, 1981

BI: Final Management (Phase I) February 15, 1981 to March 25, 1981

BII:	Final Management (Phase II)	February 12, 1982 to March 4, 1982
C:	Field Work (Phase II)	August 2, 1981 to August 16, 1981
DI:	Main Field Work (Phase I)	November 28, 1980 to March 20, 1981
DII:	Main Field Work (Phase II)	August 1, 1981 to March 3, 1982
E:	Report Explanation	October 30, 1982 to November 14, 1982

Table 1-2. Members of Swaziland Counterparts

Name	Charge	Position
M.C. McKeown	Coordinator, Geology	Head of Coal Unit, Geological Survey and Mines Department, Ministry of Commerce, Industry, Mines and Tourism (MCIMT)
F. Stocks	Drilling	Drilling Superintendent, Geological Survey and Mines Department, MCIMT
S.N. Maphanga	Geology	Geologist, Geological Survey and Mines Department, MCIMT
L. Strachan	Geology	Geologist, Geological Survey and Mines Department, MCIMT
M.M. Magagula	Drilling, Survey	Trainee Geologist, Geological Survey and Mines Department, MCIMT

CHAPTER 2. GENERAL DESCRIPTION OF THE LUBHUKU AREA

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2.1 Location and Access

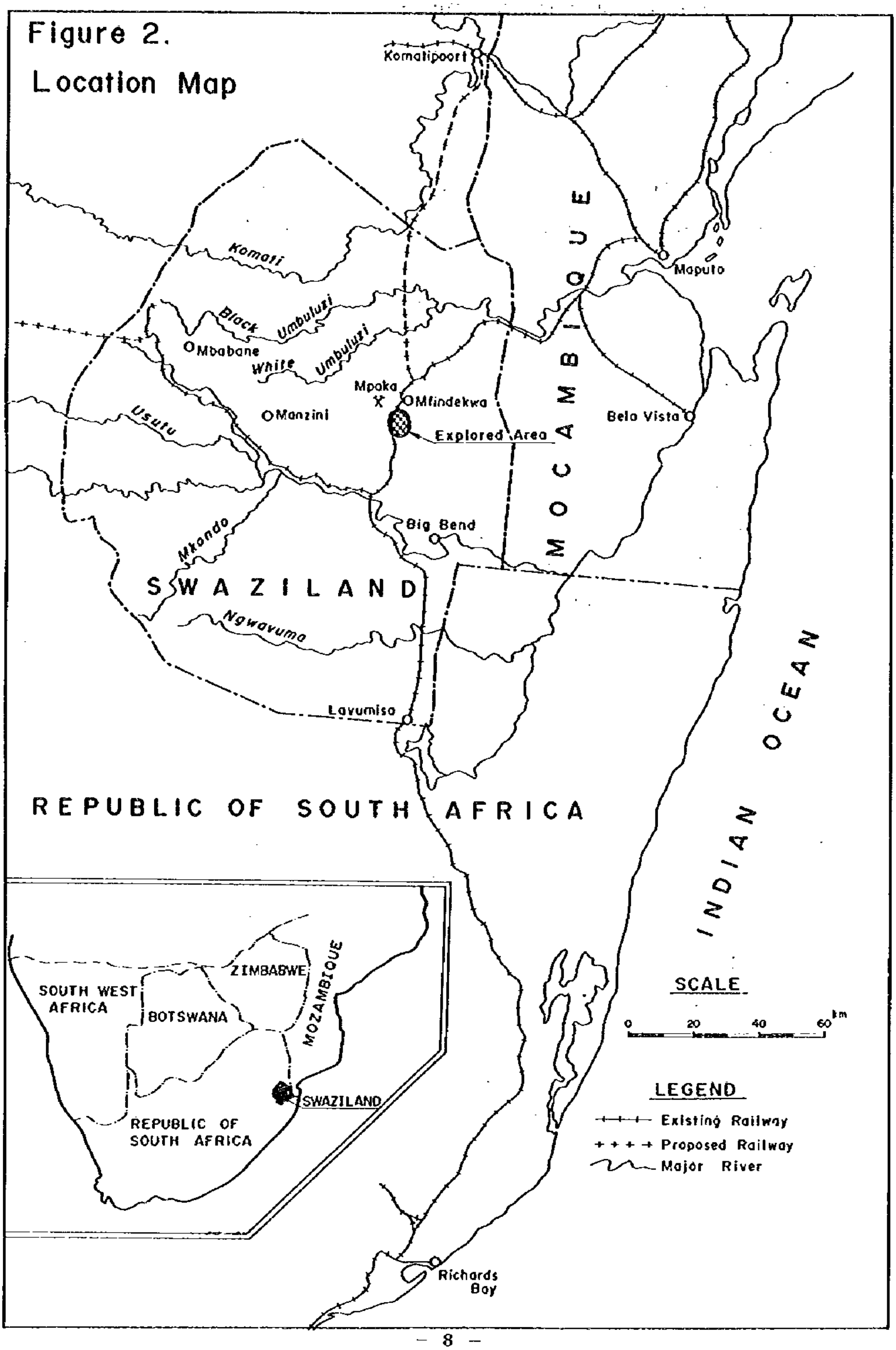
Lubhuku Area is situated in the Lubombo District, east side of the central part of the Kingdom of Swaziland, and is about 70 km east-southeast of the capital city, Mbabane, about 40 km east of the commercial city, Manzini, and about 20 km west-southwest of Siteki, the District Headquarters. It is located around longitude 31°50'E and latitude 26°30'S (Fig. 2). A paved road, leading to Siteki from Mbabane via Manzini, runs about 5 km north of the northern end of this area and a side-road branched from it runs towards the south through this area.

Another off-road runs through the southeastern part of this area to Siteki. It takes about one and half hours from Mbabane to the area or about 30 minutes from Siteki by car. A railroad, leading to the ports of Maputo, Mozambique and Richards Bay, South Africa and being used mainly for freight transportation, runs from north to south across the central part of this area, and Lubhuku station is located near the center of this area. Access to this area is very convenient.

2.2 Topography

The topography of Swaziland is mainly divided into four zones elongating north and south based on the altitude. They are called the Highveld (average altitude: 1,200 m), Middleveld (average altitude: 700 m), Lowveld (altitude: 120 to 370 m), and Lubombo (altitude: 370 to 770 m) from the west (Fig. 3). The Lubhuku area belongs to the Lowveld and is a gently undulating flat low land with the altitude of 250 to 350 m. Some tributaries (Lubugu, Mtindekwa, etc) flowing into the Great Usutu River to the south run through the area, but most of them are wadis flowing only in the rainy season. The area is covered with dense bushes and some of them are 3 to 4 m high. The climate of the Lowveld is tropical, and the annual rainfall is 500 to 900 mm, but the humidity is generally high. The rainy season is from October to March and rainfall is especially concentrated from December to February.

Figure 2.
Location Map



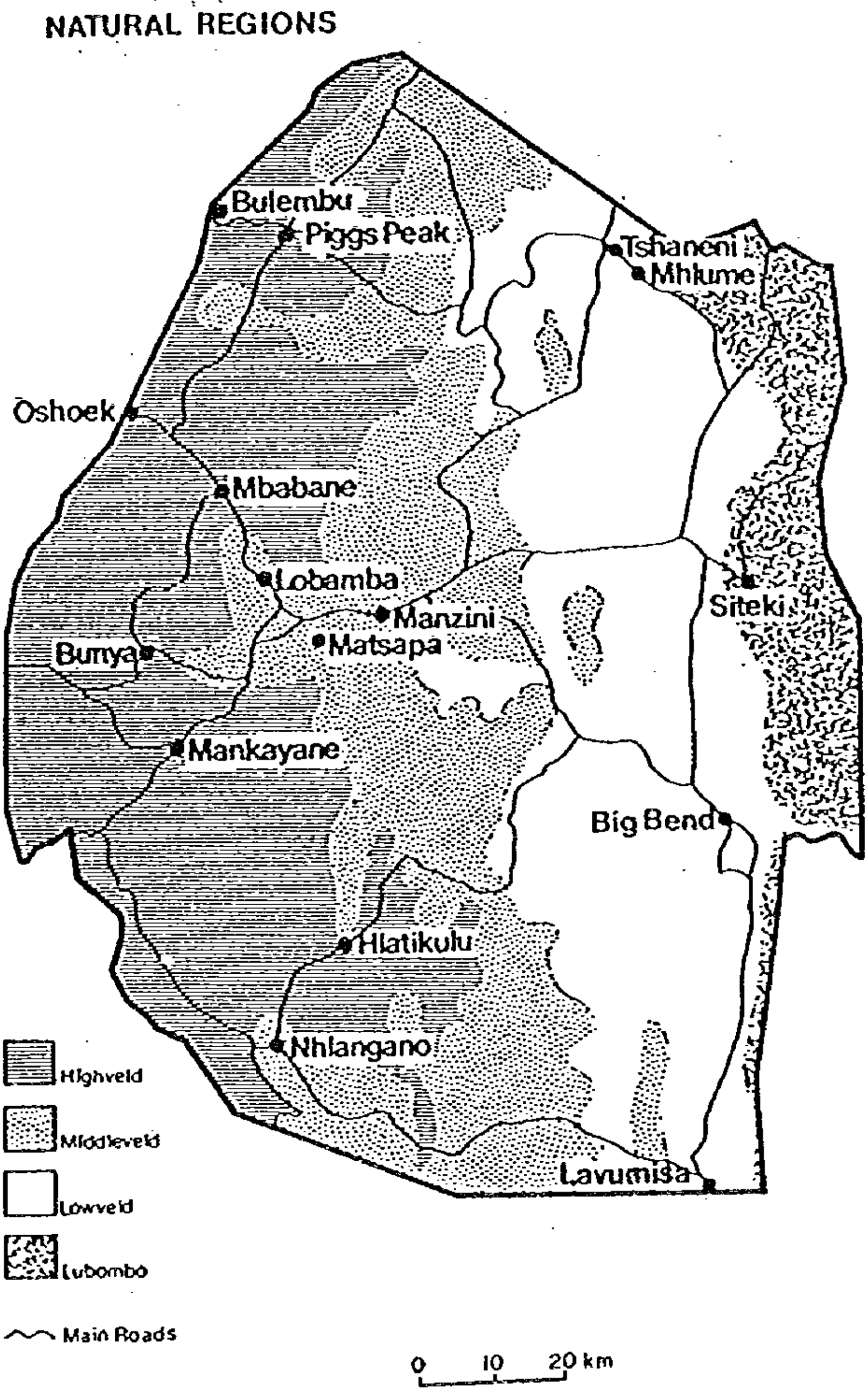


Figure 3. Morphologic Region Map

2.3 Investigated Area

The investigated area (Lubhuku area) covers about 14 km in north-south direction and about 10 km in east-west. Coal seams occur in shallow part in the west at less than 200 m below the surface, and the mining licence area of SUMCOR Ltd., formerly Swazi Coal Corporation Ltd., (3 km x 2.5 km) is located near the center of this part. The Geological Survey and Mines Department is now independently carrying out drilling exploration to the north of this concession.

Therefore, the investigation was carried out in an area of about 80 km^2, about 14 km north-south and about 5 to 6 km east-west, in the central and eastern part of the Lubhuku area where coal seams occur more than 200 m below the surface.

Mpaka coal mine of Swaziland Collieries Ltd. is located just north of the investigated area and now produces about 180,000 tons of coal annually.

In these areas, exploration works have been previously carried out where the Lower Coal Zone occurred at the shallow depths. Shell Coal Swaziland (Pty) Ltd. had executed drilling exploration for the Upper Coal Zone to the east of the Lubhuku area. However, no prior investigation was carried out in the Lubhuku area except geological mapping, 1:50,000 in scale, by the Geological Survey and Mines Department.

Plates 1 and 2 show landscape of the investigated area and execution of the magnetometry survey and drilling work.

Plate 1. Photographs of Investigated Area

1. Landscape of Lubhuku Area

   A distant view of Lubhuku area from Lebombo Mountains.

2. View of Lubhuku Area

   Cutting line in east-west direction through bush at the center and Lebombo Mountains at background.

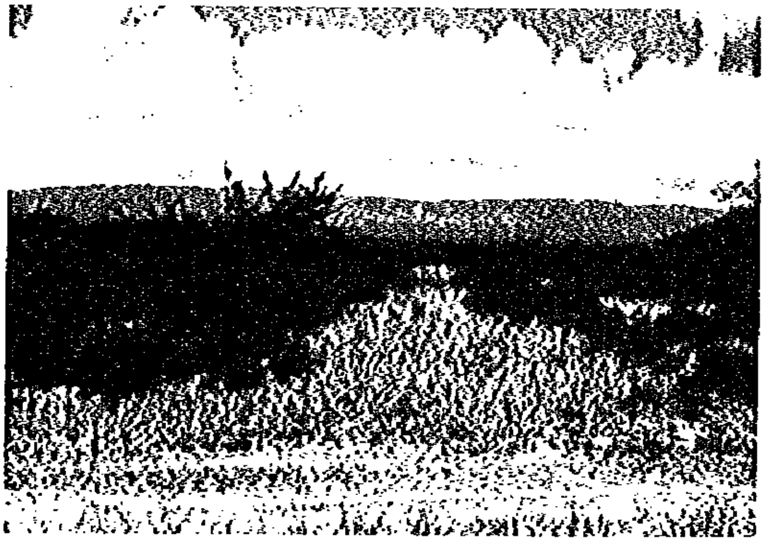
3. Magnetometry Survey

   Magnetometry survey around planned drilling site.

Plate 2. Photographs of Drilling Work

1. Assembling of Drill Rig at the Site
2. Drill Rig under Operation
3. Recovering of Core from Core Barrel

1.

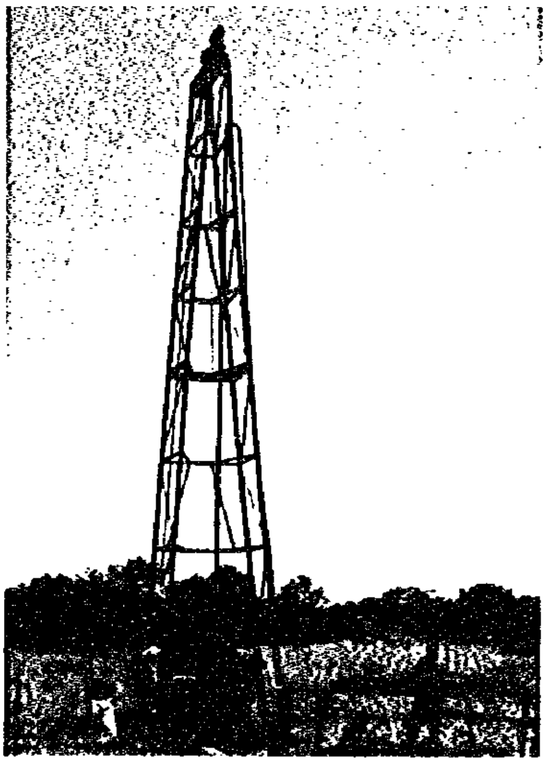


2.

3.

Plate 2.

1.



2.

3.

CHAPTER 3. DRILLING WORK

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3.1 Outline of Drilling Work

The drilling in Phases I and II was carried out at 2 km intervals in principle in the investigated area except the southeastern and southwestern parts as predominant intrusion of dolerite is expected in these parts. Drilling at 1 km intervals was executed along two east-west lines in the central and northern parts of the area because coal seams are expected to occur stably in these parts.

Fig. 4 shows the location of boreholes executed in Phases I and II.

The number of boreholes drilled in Phases I and II are 9 and 22 (the latter including the continuation of drilling of 3 holes discontinued in Phase I) respectively. In Phase I, drilling of three boreholes (DD 8, 10, and 48) was not able to continue because of jamming trouble, caused by fractured dolerite encountered in the holes, within the duration of the work.

Consequently, upon consultation with the Government of Swaziland, it is decided that drilling of these three holes should be continued in Phase II after taking counter-measures to overcome these troubles, because geological information obtained from these holes will be important for the geological study of the Lubhuku area. In Phase II, these three holes were successfully drilled to the planned depth, namely, DD 8 and 48 holes were drilled after wedging past the problematical position and DD 10 hole was drilled at BQ size after inserting NQ casing to the depth bored in Phase I.

In Phase I, two machines were initially used for drilling and one machine was added later. Since the work was delayed due to unexpectedly concentrated and heavy rain from January to February, 1981, one additional drilling machine was employed as a counter-measure to accelerate the work bringing the total to four. Only one of the four drilling machines used the wire-line method.

In Phase II, four drilling machines were initially used and two machines were added in the middle of the period to accelerate the work. Of the six machines, five machines used the wire-line method and the remaining one was used for non-core drilling of weathered zone.

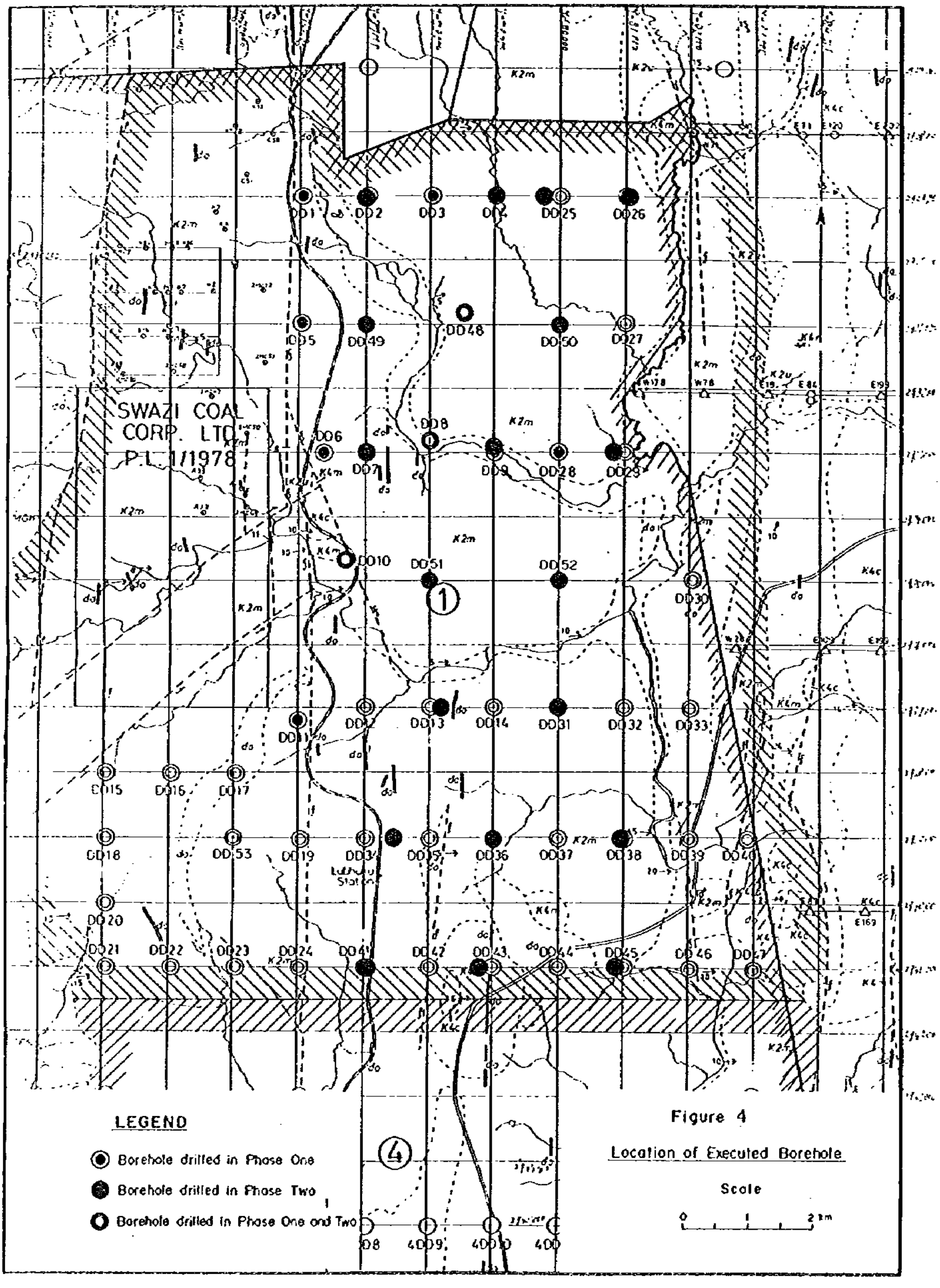


Figure 4
Location of Executed Borehole

Table 2 shows types of drilling machines and methods in each hole.

Casing of 89 or 110 mm in diameter was used to protect against collapse of the hole because the rock in the investigated area has been weathered to a depth of between 10 to 40 meters below the surface.

In Phase I, the weathered zone was drilled using NXC diamond bits (ϕ = 90 mm), but non-core drilling of the weathered zone was carried out by the air flush method to improve the overall efficiency of drilling in Phase II.

For drilling below the setting depth of the casing, NX diamond bits or NQ diamond bits were employed in Phase I, while mainly NQ diamond bits and occasionally TNW bits were used in Phase II.

The core recovery was very high, over 97 percent in Phase I and around 99 percent in Phase II. The drilling mud was prepared by mixing JAGUAR (the same kind as C.M.C.) with fresh water. In case of collapse heavy oil was added to the mud water in order to prevent the drilling rods from sticking.

Interruptions of the work were minimized in Phase II as sufficient countermeasures were taken. Tractors were used in Phase II to overcome any trouble in the transportation of the drilling water during heavy rain which was the major cause of the delay of the work in Phase I. In addition, the drilling operation was changed from one shift a day (sometimes two shifts a day) in Phase I to two shifts a day in Phase II to complete the work within the allotted period.

3.2 Performance of Drilling Work

The drilling work in Phase I was commenced on December 31, 1980, and ended on March 14, 1981 with a total length of 2,825.62 meters drilled in 9 boreholes. The work in Phase II started on August 28, 1981, and was completed on February 17, 1982 with total length of 7,835.22 meters drilled in 22 boreholes (including the continuation of the drilling of the 3 boreholes discontinued in Phase I).

Table 2 Drilling Machine and Method

Phase I			Phase II		
Hole No.	Drilling Machine	Drilling Method	Hole No.	Drilling Machine	Drilling Method
DD1	TOHO D4	Conventional method	DD2	JOY SULLIVAN D26	Wire-line method
DD3	JOY SULLIVAN 22	-ditto-	DD4	JOY SULLIVAN D26	-ditto-
DD5	TOHO D4	-ditto -	DD25	SECO 50	-ditto-
DD6	TOHO D4	Conventional method and wire-line method (225.80-344.55m)	DD26	JOY SULLIVAN D26	-ditto-
DD8	TOHO D4	Conventional method and wire-line method (259.00-295.50m)	DD49	TONE TGM	-ditto-
DD10	JOY SULLIVAN 22	Conventional method (0-297.00m)	DD50	JOY SULLIVAN D26	-ditto-
DD11	TOHO D4	Conventional method	DD7	SECO 50	-ditto-
DD28	TOHO D4	Wire-line method	DD9	JOY SULLIVAN D26	-ditto-
DD48	JOY SULLIVAN 22	Conventional method (0-316.20m)	DD29	SECO 50	-ditto-
			DD51	JOY SULLIVAN D26	-ditto-
			DD52	SECO 50	-ditto-
			DD13	JOY SULLIVAN D26	Conventional method and wire-line method (317.20-421.15m)
			DD31	SECO 50	Wire-line mehtod
			DD34	JOY SULLIVAN D26	-ditto-
			DD36	JOY SULLIVAN D26	-ditto-
			DD38	JOY SULLIVAN D26	-ditto-
			DD41	TONE TGM	-ditto-
			DD43	TONE TGM	-ditto-
			DD45	JOY SULLIVAN D26	-ditto-
			DD48	JOY SULLIVAN D26	-ditto- (175.00-402.98m)
			DD8	JOY SULLIVAN D26	-ditto- (212.39-347.60m)
			DD10	JOY SULLIVAN D26	-ditto- (297.00-401.46m)

The total drilled length sums up to 10,660.84 meters in 28 boreholes. Fig. 5 shows the drilling results of each machine used and Table 3 shows the drilling record of each borehole. The actual drilling rate in Phase I and Phase II was 15.3 m/day and 20.7 m/day respectively.

The drilling troubles and their countermeasures in DD 8, DD10, and DD 48 holes during Phases I and II are outlined below.

DD 8 – Jamming accident occurred upon encountering a fractured zone in dolerite at the depth of about 248 m. It was decided to discontinue the work temporarily and to restart it later using the wire-line method as the machine on-site used only conventional equipment, and its core barrel and bit would be severely damaged if the drilling was continued. Jamming accident recurred for about 36 m after the restart of the drilling.

A drilling rod was accidentally broken during the overcoming work and the drilling had to be stopped at the depth of 290.50 m with the remains of a core barrel and five rods in the hole (Phase I). In Phase II, the pulling out of these rods and the core barrel from the hole was not successful in spite of many attempts, and therefore the hole was drilled after wedging past the problem. The wedge was set at the depth from 212.39 to 216.54 m and coring was begun from 212.59 m. The wedging angle was 1°05′.

DD 10 – Jamming accident occurred upon encountering a fractured zone in dolerite at the depth of about 297 m. It was not possible to overcome the trouble and the drilling was discontinued at the depth of 297.0 m (Phase I). In Phase II, NQ casing was set to 297.0 m after removing with some difficulty the slimes which had accumulated at the bottom of the hole and the drilling was successfully continued using BQ bit.

DD 48 – The work was discontinued at the depth of 316.20 m because the drilling was not able to continue upon encountering a fractured zone in dolerite near the bottom of the hole (Phase I). In Phase II, a drilling rod broke due to jamming trouble during removal of slimes from the bottom of the hole, and 22 rods and a core barrel were left in the hole. It was not possible to pull out these remains

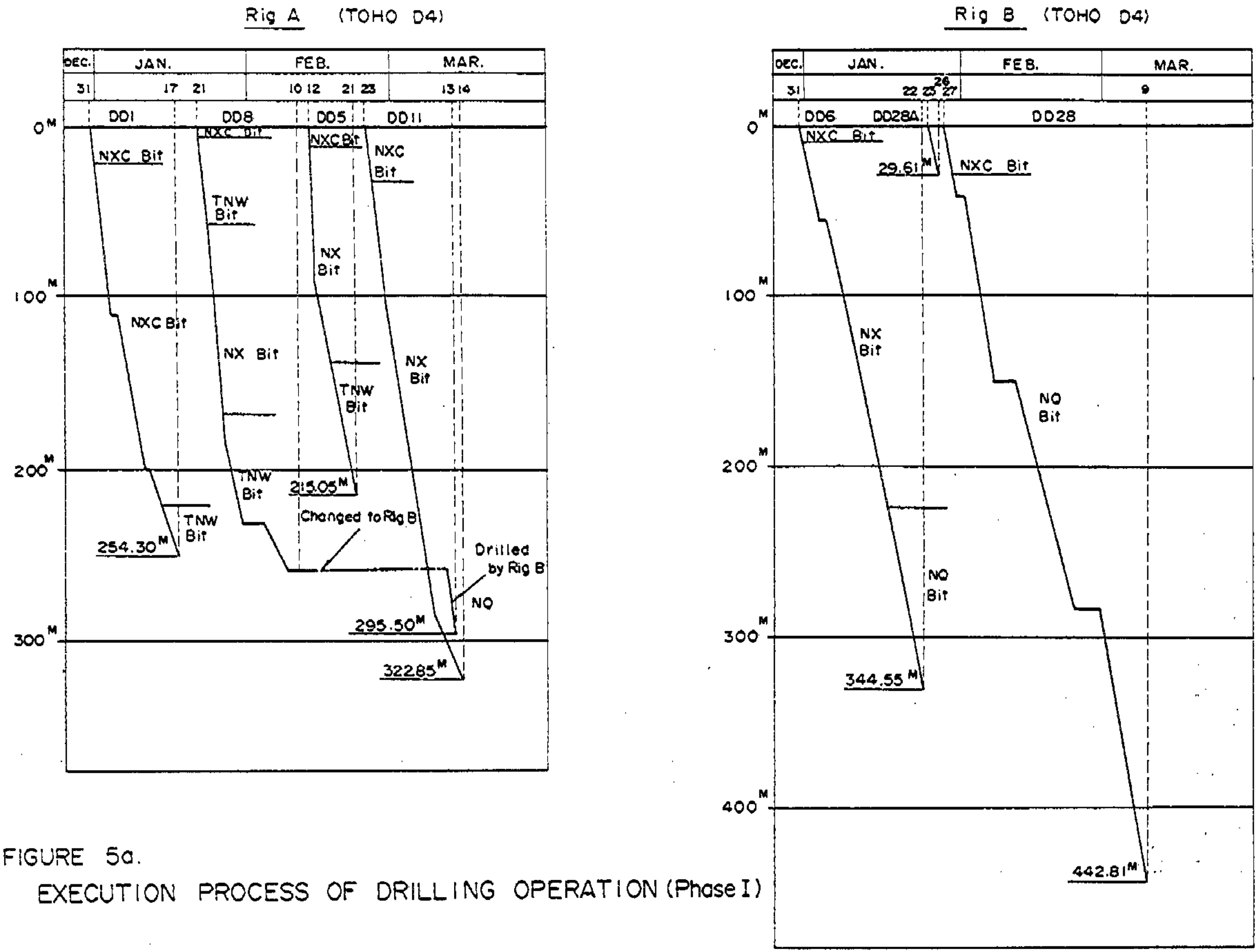


FIGURE 5a.
EXECUTION PROCESS OF DRILLING OPERATION (Phase I)

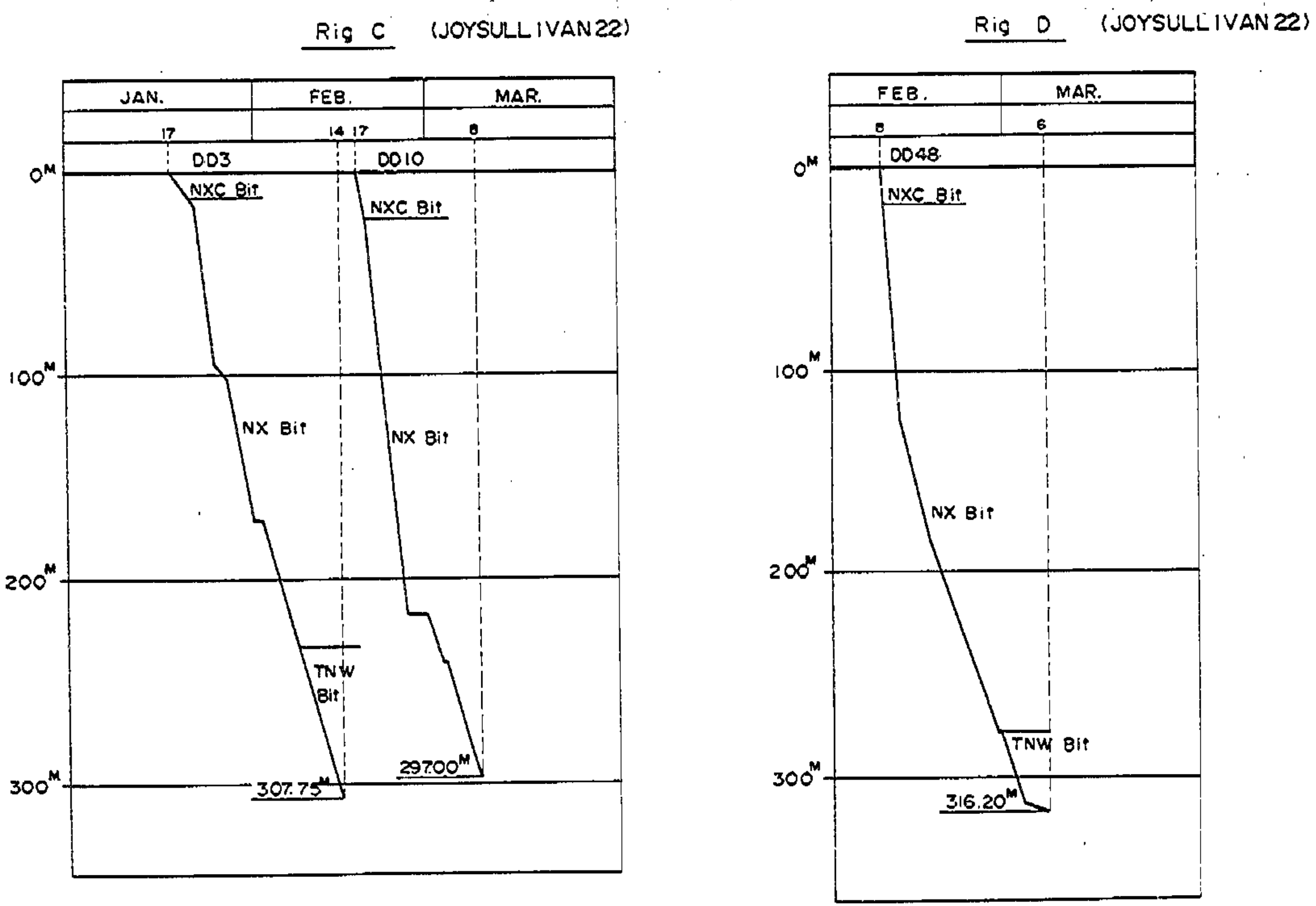


FIGURE 5b. EXECUTION PROCESS OF DRILLING OPERATION (Phase I)

RIG E (SECO 50)

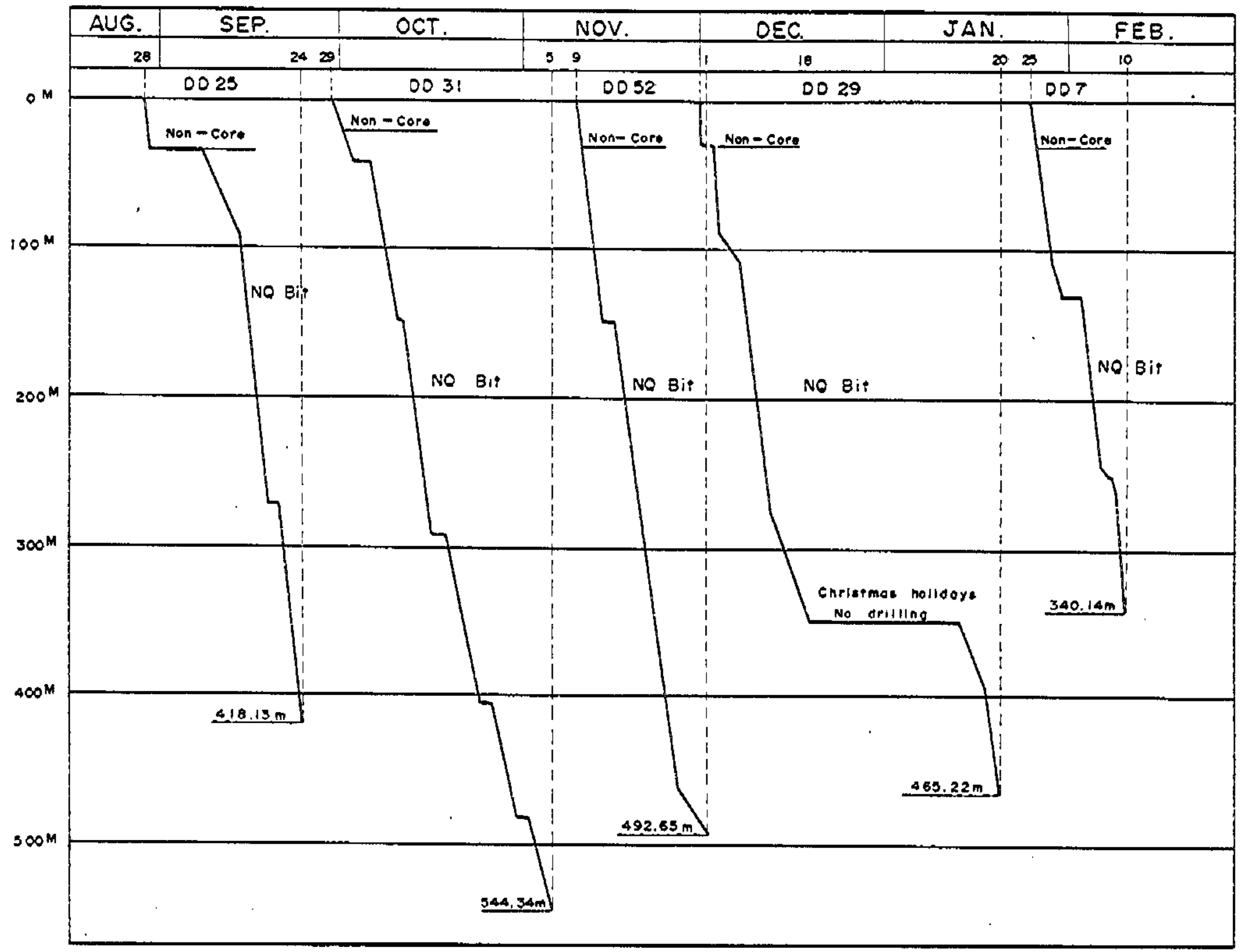


Figure 5c. Execution Process of Drilling Operation (Phase II)

RIG F (JOY SULLIVAN D26)

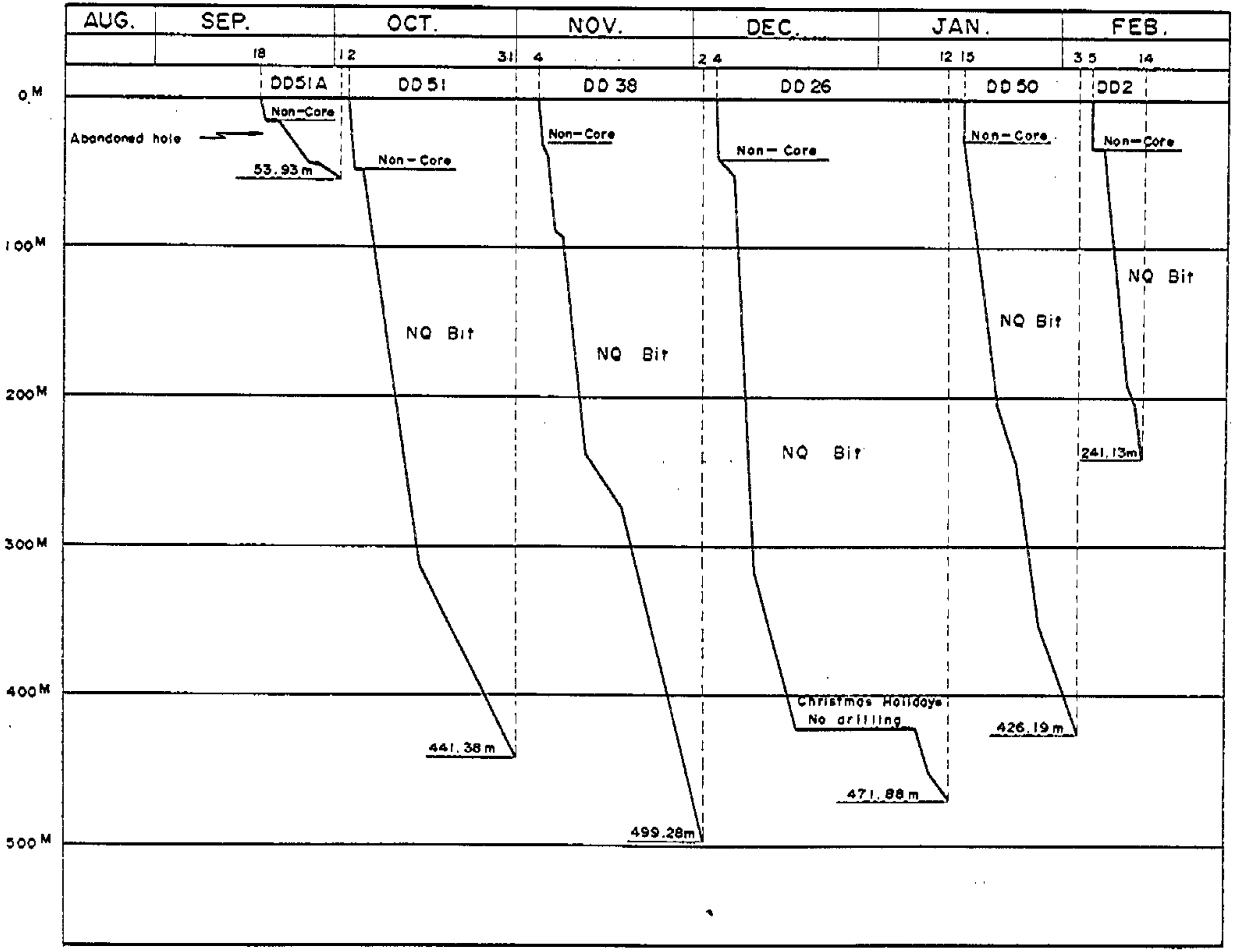


Figure 5d. Execution Process of Drilling Operation (Phase II)

RIG G (JOYSULLIVAN D26)

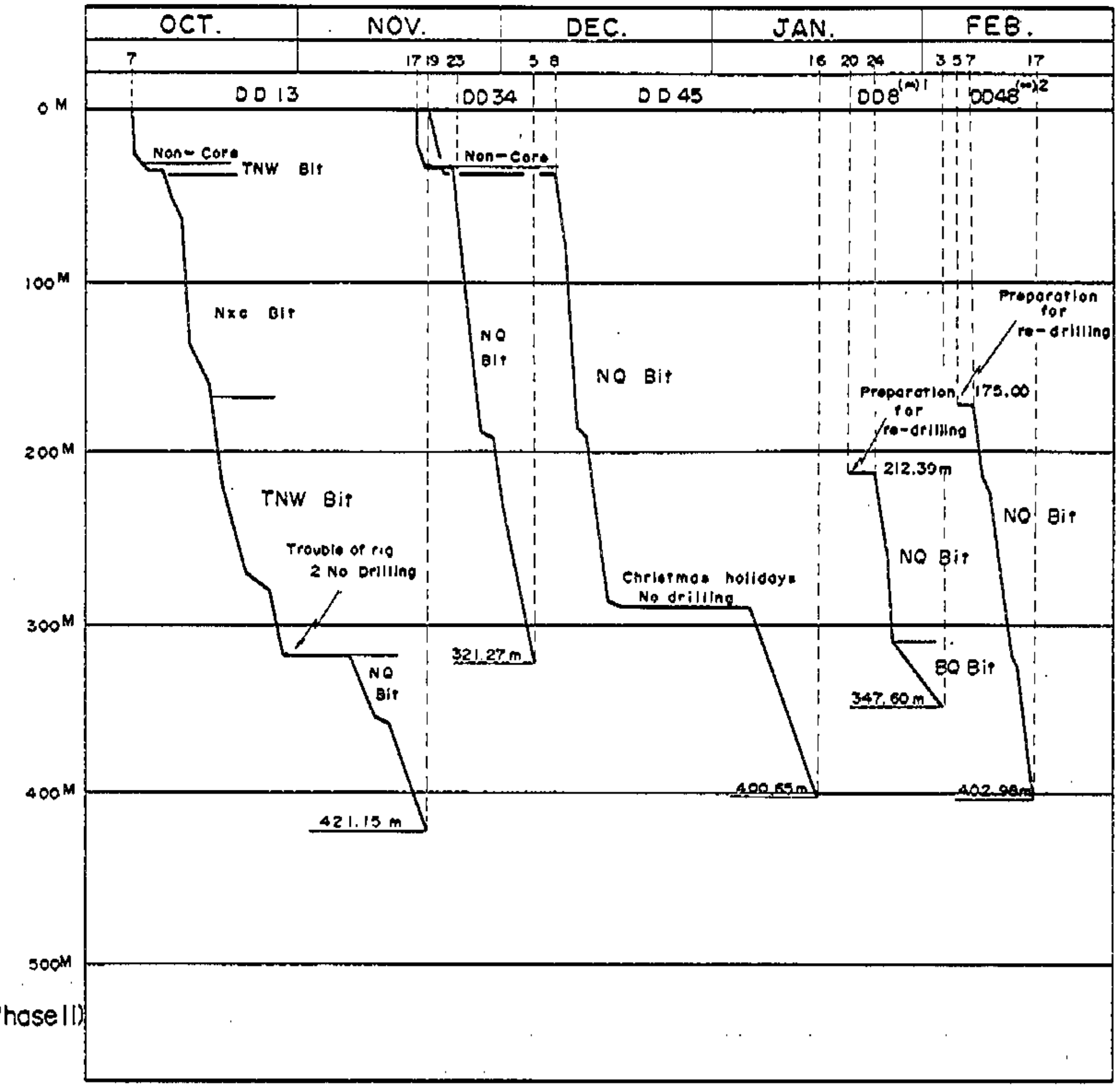


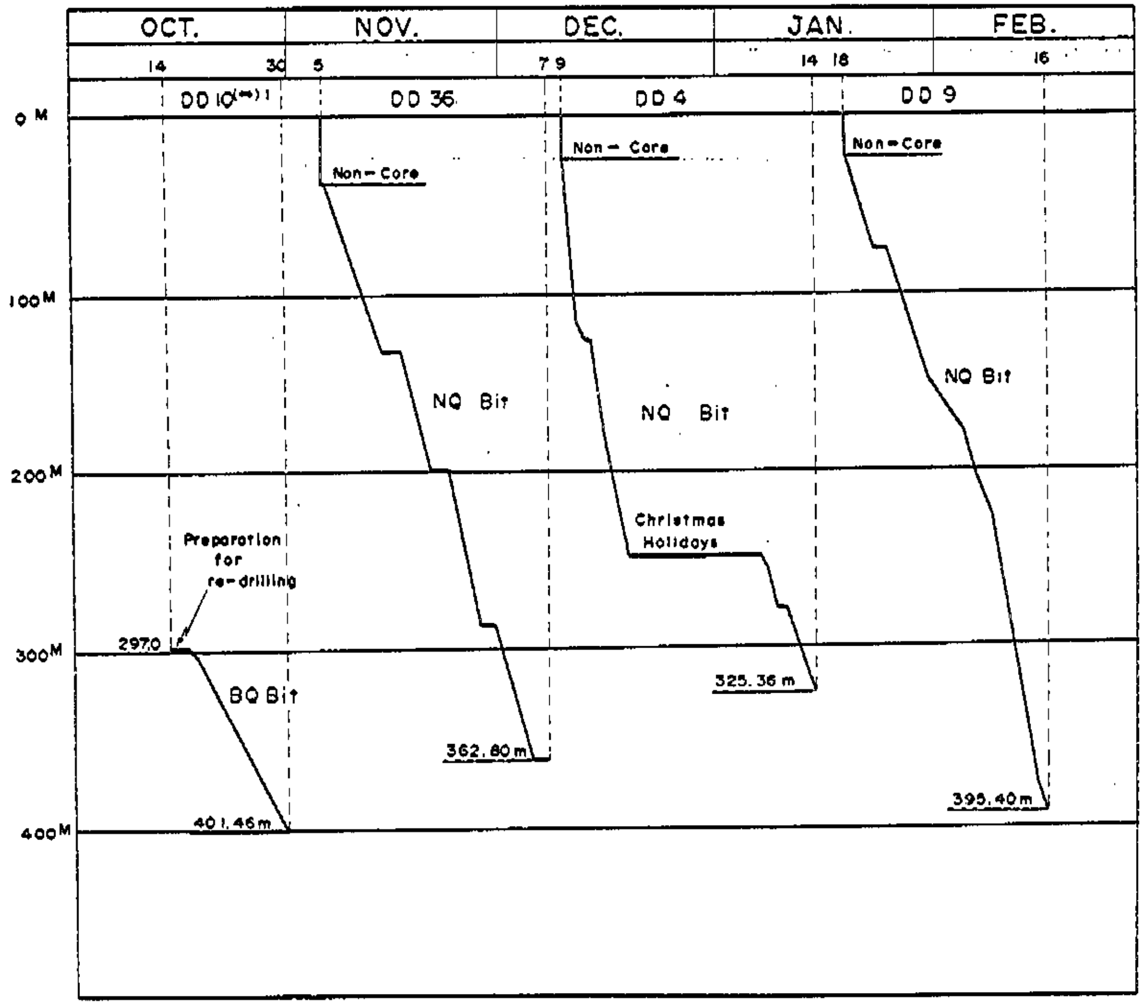
Figure 5e.

Execution Process of Drilling Operation (Phase II)

(*)1 DD8 hole had been discontinued in Phase I at the depth of 295.50 M, and was re-drilled in Phase II from the depth of 212.39 M using a wedge.

(*)2 DD48 hole had also been discontinued in Phase I at the depth of 316.20 M, and was re-drilled in Phase II from the depth of 175.00 m using a wedge.

RIG H (JOYSULLIVAN D26)



(*) 1. DD 10 hole had been discontinued in Phase I at the depth of 297.00 M and was continued to drill from the depth of 297.00 M in Phase II.

Figure 5f. Execution Process of Drilling Operation (Phase II)

RIG I (TONE TGM)

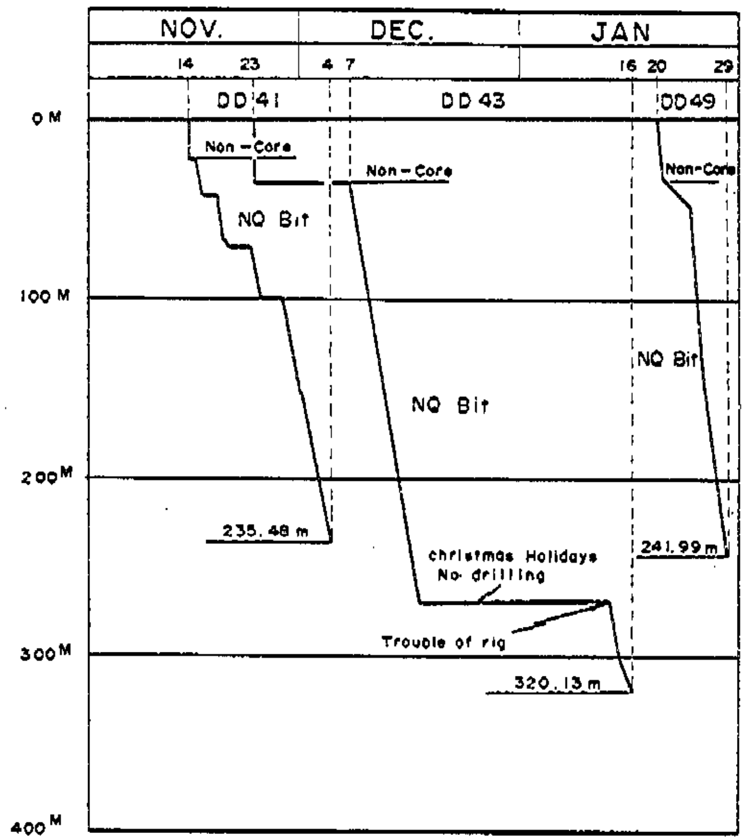


Figure 5g. Execution Process of Drilling Operation (Phase II)

Table 3a. Drilling Record

	DD1	DD6	DD3	DD8	DD28	DD48	DD5	DD10	DD11
Operating Period	31/12,1980 ~ 17/1,1981	31/12,1980	17/1~14/2, 1981	21/1~13/3, 1981	27/1~9/3, 1981	3/2~6/3, 1981	12/2~21/2, 1981	17/2~8/3, 1981	23/2~14/3, 1981
Actual Operating days	16	22	25	17	31	26	9	17	20
Coordinate X	+2,929,000	+2,933,000	+2,929,047	+2,932,800	+2,933,000	+2,930,841	+2,931,000	+2,934,650	+2,937,220
Coordinate Y	−75,920	−76,400	−77,914	−78,000	−80,000	−78,541	−76,000	−76,720	−76,040
Elevation (m)	+ 281.8	+ 282.5	+ 292.2	+ 252.8	+ 254.5	+ 275.3	+ 290.9	+ 266.2	+ 274.2
Final Drilling Length (m)	254.30	344.55	307.75	295.50	442.81	316.20	215.05	297.00	322.85
Planned Drilling Length (m)	300.00	335.00	370.00	370.00	435.00	380.00	315.00	345.00	315.00
Coring interval (m)	21.0~254.30	9.0~344.55	13.25~307.75	9.15~295.50	28.00~442.81	17.92~316.20	11.75~215.05	22.55~297.00	33.00~322.85
Core recovery (%)	98	98	99	97	98	98	98	99	99
Remarks				*1	*2	*3		*4	

*1 : Drilling work was discontinued in the fracture zone of dolerite . This hole was continued to drill in the Phase II

*2 : The first borehole was abandoned at the depth of 29.61 m because of caving.

*3 : Drilling work was discontinued in the fracture zone of dolerite. This hole was continued to drill in the Phase II.

*4 : — ditto —

Table 3b. Drilling Record

	DD25	DD51	DD31	DD13	DD38	DD36	DD52	DD41	DD34	DD29	DD26
Operating Period	28/8 1981 ~ 24/9 1981	2/10 1981 ~ 31/10 1981	29/9,1981 ~ 5/11,1981	7/10,1981 ~ 19/11,1981	4/11,1981 ~ 2/12,1981	5/11,1981 ~ 7/12,1981	9/11,1981 ~ 1/12,1981	4/11,1981 ~ 4/12,1981	18/11~17/11 1981 23/11,1981 ~ 5/12,1981	30/11,1981 3/12,1981 ~ 20/1,1982	4/12,1981 ~ 12/1,1982
Actual operating days	16	25	27	29	23	26	19	12	14	21	18
Coordinate X	+2,929,000	+2,935,000	+2,937,000	+2,937,000	+2,939,000	+2,939,000	+2,935,000	+2,941,000	+2,939,000	+2,933,000	+2,929,000
Coordinate Y	− 79,754	− 78,001	− 80,000	− 78,200	− 80,950	− 79,000	− 80,000	− 77,070	− 77,450	− 80,810	− 81,050
Elevation( )	+271.3	+266.0	+250.0	+248.7	+232.0	+250.0	+261.8	+272.3	+276.9	+238.0	+260.5
Final drilling length(m)	418.13	441.38	544.34	421.15	499.28	362.80	492.65	235.48	321.27	465.22	471.88
Planned drilling length(m)	400	455	490	395	445	350	520	130	265	460	475
Coring interval( )	35.19 ~418.13	14.60 ~441.38	21.00 ~544.34	31.64 ~421.15	29.08 ~499.28	36.00 ~362.80	29.30 ~492.65	41.70 ~235.48	34.00 ~321.27	28.82 ~465.22	38.59 ~471.88
Core recovery(%)	100	99	99	100	100	100	99	100	100	100	99
Remarks		※1									

※1. The first hole was abandoned at the depth of 53.93 M because of hole bending

Table 3c. Drilling Record

	DD43	DD45	DD4	DD50	DD9	DD49	DD7	DD2	DD10	DD8	DD48
Operating Period	23/11 1981 7/12 1981 ~ 16/1 1982	19/11~20/11, 1981 8/12, 1981 ~ 16/1, 1982	9/12 1981 ~ 14/1 1982	15/1 1982 ~ 3/2 1982	18/1 1982 ~ 16/2 1982	20/1 1982 ~ 29/1 1982	25/1 1982 ~ 10/2 1982	3/2 1982 ~ 14/2 1982	14/10 1981 ~ 30/10 1981	21/1 1982 ~ 3/2 1982	8/2 1982 ~ 17/2 1982
Actual operating days	13	18	16	17	24	9	13	8	12	9	10
Coordinate X	+2,941,000	+2,941,000	+2,929,000	+2,931,000	+2,932,900	+2,931,000	+2,933,000	+2,929,020	+2,934,650	+2,932,800	+2,930,841
Coordinate Y	− 78,790	− 80,860	− 79,000	− 80,000	− 79,000	− 77,000	− 77,000	− 76,983	− 76,720	− 78,000	− 78,541
Elevation(m)	+280.2	+249.1	+260.6	+251.4	+248.9	+277.0	+270.0	+292.5	+266.2	+252.8	+275.3
Final drilling length(m)	320.13	400.65	325.36	426.19	395.40	241.99	340.14	241.13	401.46	347.60	402.98
Planned drilling length(m)	275	370	320	300	385	290	370	205	397	365	406
Coring interval(m)	35.00 ~ 320.13	34.00 ~ 400.65	23.43 ~ 325.36	26.73 ~ 426.19	23.20 ~ 395.40	34.81 ~ 241.99	28.55 ~ 340.14	33.10 ~ 241.13	22.55 ~ 401.46	9.15 ~ 347.60	17.92 ~ 402.98
Core recovery(%)	99	100	100	99	100	99	99	99	94	99	100
Remarks									＊1	＊2	＊3

＊ 1. : This hole had been discontinued at the depth of 297.00 m in the Phase Ⅰ and was continued to drill from the depth of 297.00 m in the Phase Ⅱ.

＊ 2. : This hole had been discontinued at the depth of 295.50 m in the Phase Ⅰ. In the Phase Ⅱ, this hole was re-opened from the depth of 212.39 m using a wedge.

＊ 3 : This hole had been discontinued at the depth of 316.20 m in the Phase Ⅰ. In the Phase Ⅱ, this hole was re-opened from the depth of 175.00 m using a wedge.

from the hole and the work was temporarily stopped. The hole was eventually drilled by the wedging method past the problem. The wedge was set from 175.00 to 179.20 m and coring was begun from 177.70 m. The wedging angle was 1°05′.

As mentioned above, drilling of the three discontinued holes, which has provided important information for geological study, was successfully continued in Phase II despite the difficult strata conditions which had to be overcome.

CHAPTER 4. GEOLOGY

CHAPTER 4. GEOLOGY

4.1 General Description

The following data were mainly used for the geological study in addition to the results of this investigation.

Topographical map	:	1/50,000 Topographical maps
		2631BC, 2631BD, 2631DA and 2631DB
		1/10,000 Topographical maps
		75/2926, 75/2932 and 75/2938
Geological map	:	1/250,000 Geological map
		1/50,000 Geological maps
		2631BC, 2631BD, 2631DA and 2631BD
Drilling data	:	Shell Coal Swaziland (Pty) Limited
		Quarterly Report, 1976

4.2 General Geology and Stratigraphy

The Kingdom of Swaziland is underlain chiefly by metamorphic, granitic, sedimentary, volcanic and ultrabasic rocks of Precambrian age, sedimentary and volcanic rocks of Palaeozoic and Mesozoic ages, and dolerite intruded into the above rocks. The stratigraphy of these rocks is shown in Table 4.

4.2.1 Basement Rocks

The basement rocks of the coal field in Swaziland are composed of metamorphic, granitic, volcanic and sedimentary rocks of the Archaean, and are extensively distributed mainly in the Highveld and Middleveld, occupying about 70 percent of the country.

The Swaziland Supergroup, lowermost member of the basement, is divided into the Onverwacht Group composed mainly of mafic volcanic rocks, the Fig Tree Group mainly composed of fine-grained sediments and the Moodies Group mainly of coarse-grained siliceous sediments in ascending order. The Swaziland Supergroup underwent orogeny and

Table 4. Geological Formations of Swaziland

Geological Age	Sedimentary Rocks		Igneous and Metamorphic Rocks
Quarternary	Alluvium		
Jurassic - Cretaceous			Karoo Dolerite
Triassic - Jurassic	Stormberg Series	Karoo System	
Triassic	Beaufort Series	Karoo System	
Permian	Ecca Series	Karoo System	
Carboniferous	Dwyka Series	Karoo System	
Archaean			Granites
Archaean			Usushwana Complex
Archaean			Granites
Archaean	Mozaan Group	Pongola Sequence	
Archaean	Nsuze Group	Pongola Sequence	
Archaean			Granites and Gneisses
Archaean	Moodies Group	Swaziland Supergroup	
Archaean	Fig Tree Group	Swaziland Supergroup	
Archaean	Onverwacht Group	Swaziland Supergroup	

regional metamorphism and metamorphic rocks and granites (synkinematic granite) were emplaced.

The Pongola Sequence is younger than the Swaziland Supergroup, gneisses and most granites, and consists of the Nsuze Group of volcanic and sedimentary rocks and the Mozaan Group of sedimentary rocks (mostly quartzites) in ascending order. Late kinematic granites occurred after the deposition of the Pongola Sequence and post-kinematic granites intrude into younger rocks after the intrusion of the Usushwana Complex of ultrabasic rocks.

The metamorphic grade of the Swaziland Supergroup is low, and the texture of the original rocks are well preserved, and the Pongola Sequence is hardly metamorphosed, although strongly deformed.

4.2.2 Karoo Sequence in Swaziland

The Karoo Sequence is extensively distributed in the inland area of the southern part of Africa, and is the characteristic formation being composed mainly of continental sediments. These rocks are exposed in a wide area measuring 1,400 km x 650 km, called the great Karoo Basin in the Republic of South Africa. The Karoo Sequence extends towards the north through Swaziland along the Lebombo Graben which forms a belt zone of about 50 km in width elongated from the eastern end of the Basin. The Karoo Sequence in Swaziland is mainly distributed in the Lowveld and Lebombo in the eastern part of the country and occupies about 30 percent of the surface area of the country. The Sequence unconformably overlies the Precambrian basement, but is also partially in fault contact with the basement.

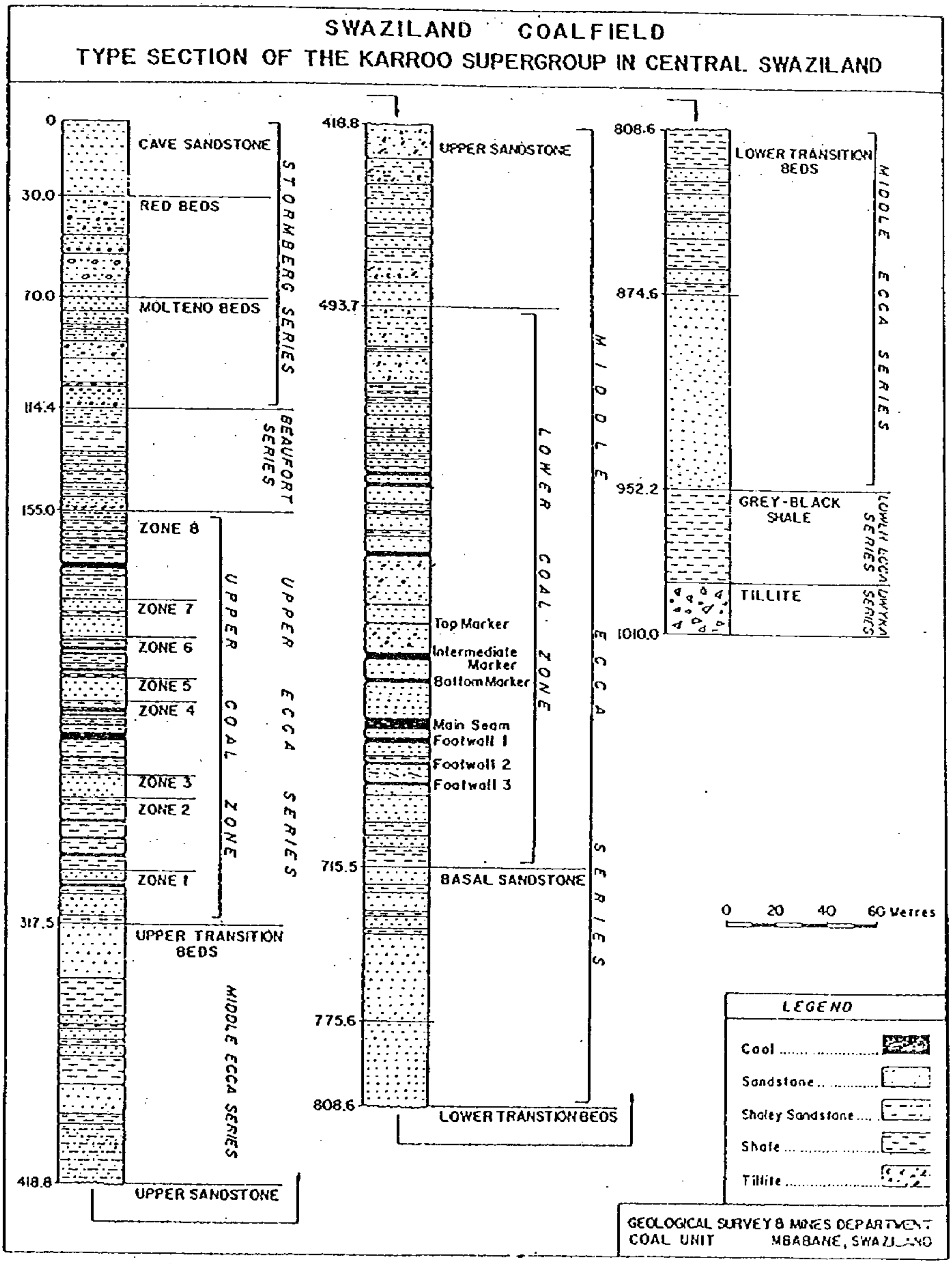
The lithofacies of the Sequence indicate a glacial stage at the lower part, a sedimentary stage at the middle and a volcanic activity stage at the upper. In Swaziland the Sequence strikes generally N-S and dips 5 – 10°E but dips in the eastern part become slightly greater at 10 – 20°E.

Table 5 and Fig. 6 show the general stratigraphy of the Karoo Sequence in Swaziland. It is understood that the terminology of this stratigraphy is now being compared with that recently described for the Karoo Sequence in South Africa (L.E. Kent, 1980) and will probably be amended accordingly.

Table 5. Karoo Sequence Stratigraphy in Swaziland

Series	Stage	Lithology	Thickness in meters
Stormberg	Lebombo	Rhyolite, dacite, ignimbrite, tuff, tuffaceous sandstone	at least 6,100
	Drakensberg	Basalt, tuff, tuffaceous sandstone	
	Cave Sandstone	Sandstone	60 - 90
	Red Beds	Shale, mudstone	30 - 35
	Molteno Beds	Sandstone, quartzite, shale	45 - 60
Beaufort		Arenaceous shale, sandstone	30 - 35
Ecca	Upper Ecca	Carbonaceous shale, sandstone, coal	105 - 135
	Middle Ecca	Sandstone, coal, carbonaceous shale	455 - 610
	Lower Ecca	Shale, mudstone	45 - 90
Dwyka		Tillite, sandstone, shale	0 - 45

FIGURE 6.


SWAZILAND COALFIELD
TYPE SECTION OF THE KARROO SUPERGROUP IN CENTRAL SWAZILAND
0
CAVE SANDSTONE
30.0
RED BEDS
70.0
MOLTENO BEDS
STORMBERG SERIES
114.4
BEAUFORT SERIES
155.0
ZONE 8
ZONE 7
ZONE 6
ZONE 5
ZONE 4
ZONE 3
ZONE 2
ZONE 1
UPPER COAL ZONE
UPPER ECCA SERIES
317.5
UPPER TRANSITION BEDS
MIDDLE ECCA SERIES
418.8
UPPER SANDSTONE
418.8
UPPER SANDSTONE
493.7
Top Marker
Intermediate Marker
Bottom Marker
Main Seam
Footwall 1
Footwall 2
Footwall 3
LOWER COAL ZONE
MIDDLE ECCA SERIES
715.5
BASAL SANDSTONE
775.6
808.6
LOWER TRANSTION BEDS
808.6
LOWER TRANSITION BEDS
874.6
MIDDLE ECCA SERIES
952.2
GREY-BLACK SHALE
LOWER ECCA SERIES
TILLITE
DWYKA SERIES
1010.0
0 20 40 60 Metres
LEGEND
Coal
Sandstone
Shaley Sandstone
Shale
Tillite
GEOLOGICAL SURVEY & MINES DEPARTMENT
COAL UNIT MBABANE, SWAZILAND

(1) Dwyka Series

The Dwyka Series, the lowest unit in the Karoo Sequence, is considered to be of Late Carboniferous age, and has variable distribution in Swaziland.

The Dwyka is composed of hard tillite containing glacially derived rock fragments such as granite, pegmatite, gneiss and quartzite, with intercalated thin beds of sandstone, siltstone and shale. The thickness of the formation is about 45 m in the thicker part, although 300 m thickness has been observed west of the coalfield.

(2) Ecca Series

The Ecca Series is considered to be of the Permian and is divided into three subunits.

The coal-bearing formation occurs in the Upper and Middle Ecca. The coal seams in the Upper Ecca are generally called the Upper Coal Zone and those in the Middle Ecca are the Lower Coal Zone.

The lower Ecca is composed of nonfossiliferous grayish black shale which conformably overlies the Dwyka Series and ranges in thickness from 45 to 90 m.

The Middle Ecca ranges in thickness from 455 to 610 m, and is divided into five parts, namely, the Lower Transition Beds, Basal Sandstone, Lower Coal Zone, Upper Sandstone, and Upper Transition Beds in ascending order. The subunit is composed mainly of sandstone and shale containing muscovite, with intercalated carbonaceous shale and coal.

The thick arenaceous beds generally exhibit cross-bedding and small fragments and flakes of carbonaceous matter are often found in the sandstone above the upper part of the Basal Sandstone.

Glossopteris browniana, G. indica have been occasionally reported from the Middle Ecca in the southern part of Swaziland.

The Upper Ecca is composed of alternating cycles of sandstone zone and carbonaceous shale-coal zone, and the sandstone generally contains small fragments of carbonaceous matter. The thickness of the subunit ranges from 105 to 135 m.

(3) Beaufort Series

The Beaufort Series conformably overlies the Upper Ecca and is composed of grayish blue micaceous shale and siltstone. The bed is generally arenaceous and partially grades into very fine-grained argillaceous sandstone.

The Series ranges in thickness from 30 to 35 m and is considered to be of the Triassic.

(4) Stormberg Series

The Stormberg Series conformably overlies the Beaufort Series. The Series is divided into a lower part of sedimentary rocks, and an upper part of volcanic rocks, and are considered to be Triassic to Jurassic in age. The sedimentary rocks are divided into the Molteno Beds, composed of feldspathic sandstone containing very little mica, with occasional intercalations of shale and quartzitic sandstone, the Red Beds, composing of red to reddish purple mudstone and shale with gray sandstone in the middle, and the Cave Sandstone, composing of light gray massive quartzose sandstone. The thickness of the sedimentary rocks ranges from 135 to 185 m.

Thick volcanic rocks overlie these sedimentary rocks. The lower part of which is the Drakensberg Formation of basaltic facies (basalt, basaltic tuff, tuffaceous sandstone), whilst the rhyolite facies (rhyolite, dacite, rhyolitic and rhyodacitic ignimbrite, tuff and tuffaceous sandstone) in the upper part is the Lebombo Formation which forms the Lebombo Mountains. The whole thickness of the volcanic rocks, although the upper zone of the rocks is not found in Swaziland, is considered to be more than 6,100 m.

These volcanic rocks are considered to be resulted from the eruption through fissures during Jurassic time.

4.2.3 Karoo Dolerite

Dark greenish gray basic igneous rocks extensively intruded into the Precambrian rocks and Karoo Sequence are called Karoo dolerite.

The dolerite intrudes into almost all areas where the Karoo System is distributed, however, only local intrusions of the dolerite are found in the Precambrian rocks except southern part of the country. Dolerite dykes are a predominant in the volcanic rocks of the Drakensberg Series in the eastern part, but sills predominate in other rocks.

The dykes generally strike N-S, but some of them deviate from general trend.

The intrusions are of different types, from fine-textured basalt to coarse-textured dolerite, including gabbro. The main constituents are pyroxene, plagioclase and olivine.

The Karoo dolerite is similar in composition to the basalt of the Drakensberg stage, and its intrusion is considered to have started during Jurassic time and continued into early Cretaceous time. A narrow indurated zone is partially observed in the Karoo sandstone and shale along the contact of dolerite intrusions, and coal seams can be also thermally affected for a width up to the thickness of the intrusion.

4.3 Geology of the Ecca Series

The stratigraphy of the Ecca Series, coal-bearing formation, is shown in Table 6. The Lubhuku area is underlain by both Upper and Middle Ecca Series. The drilling was begun in the horizon ranging from lower part of the Upper Ecca to the upper part of the Lower Coal Zone of the Middle Ecca, and terminated at lowest part of the Lower Coal Zone or uppermost part of the Basal Sandstone.

The Ecca Series is distributed in a north-south trending narrow belt about 150 km long and 6 to 22 km wide in the Lowveld, continuing northwards into Transvaal and southwards into Natal in the Republic of South Africa. Small outcrops of the Series are also found along the southwestern border of Swaziland. The Ecca Series distributed in the Lubhuku area is described in detail in the following (see Drawing 1 – 6). A revision of the position of the boundaries in the area between the Upper Sandstone and the Lower Coal Zone and between the Lower Coal Zone and the Basal Sandstone, which were indefinite in previous reports, are defined in this report.

4.3.1 Basal Sandstone

According to previous reports, the formation is generally composed of fine- to medium-grained homogeneous white sandstone in the lower part and medium- to coarse-grained sandstone or grit with scattered carbonaceous fragments and micaceous mudstone in the upper part, and coal seams are not present in the formation.

The base of mudstone at a horizon of about 30 m below the Footwall 3 Seam has previously been taken as the boundary between the Basal Sandstone and overlying Lower Coal Zone. The upper and lower parts of the formation are about 55 and 31 m in thickness respectively.

Table 6. Ecca Series Stratigraphy in Central Swaziland

Formation	Member	Lithology	Average thickness in meters
Upper Ecca	Zone 8	Carbonaceous shales and coals	34
	Zone 7	Sandstone with shale parting	15
	Zone 6	Carbonaceous shales and coals	17
	Zone 5	Sandstone	9
	Zone 4	Carbonaceous shales and coal seams up to 6 meters thick	29
	Zone 3	Sandstone	8
	Zone 2	Carbonaceous shales and coals Dolomitic inclusions	29
	Zone 1	Sandstones with carbonaceous shale and coal	21
Middle Ecca	Upper Transition Beds	Alternation of gray shales and sandstones with intercalations of narrow limestone bands	101
	Upper Sandstone	Gray sandstones, sandstones with carbonaceous shale partings. Characterized with irregular carbonaceous wisps	75
	Coal Zone	Sandstones, grits, gritty sandstones with mudstones, carbonaceous shales and coal seams	222
	Basal Sandstone	Upper: Sandstones and grits with mudstone Lower: White homogeneous sandstone	93
	Lower Transition Beds	Upper: Alternation of shale and sandstone Lower: Sandstones but no carbonaceous matter	143
Lower Ecca		Gray - black shales	36

However, a thin coal seam of 3 cm thick interbedded in coarse-grained sandstone was confirmed in DD 10 and DD 51 holes during this drilling investigation. The coal seam exists around 60 and 35 m respectively below the Footwall 3 Seam, i.e. in the horizon equivalent to the upper part of the Basal Sandstone in previous reports. This indicates difference from the previous definition that no coal seam occurs in the Basal Sandstone.

Furthermore, megascopical and physical difference cannot be observed between the mudstone-shale at the base of the Lower Coal Zone and just underlying mudstone-shale at the uppermost part of the Basal Sandstone, as both are carbonaceous.

Therefore, since the base of the mudstone-shale at the lowermost part of the Lower Coal Zone forms an indefinite boundary to both beds, it is recommended that the boundary between the Lower Coal Zone and Basal Sandstone is redefined to the base of thin mudstone or medium- to fine-grained sandstone lying about 12 to 13 m below the said thin coal seam encountered in DD 10 and DD 51 boreholes in this report (Drawing 3).

Besides DD 10 and DD 51 holes, DD 31 and DD 45 holes were drilled through the uppermost horizon of the Basal Sandstone, however, the thin coal occurring at the lowermost part of the Lower Coal Zone encountered in the former holes is considered to be thinned out in the latter. Rocks in the uppermost part of the Basal Sandstone encountered in these four holes are coarse-grained sandstone or coarse-grained sandstone with intercalations of medium-grained sandstone.

4.3.2 Lower Coal Zone

The formation is generally characterized by the predominance of coarse-grained or gritty sandstone with intercalations of alternating beds of fine-grained micaceous sandstone and carbonaceous shale.

Especially, the formation is interbedded with about 20 coal seams and minable thicker coal seams are also found among them. This formation is about 200 m thick. The boundary between the Lower Coal Zone and Upper Sandstone is described in the next paragraph. Most of the horizon of the Lower Coal Zone has been drilled in this investigation except in some holes.

An apparent key or marker beds have not been observed in this formation except for the coal seams.

Although several coal seams are embedded in the upper part of the Lower Coal Zone, these seams appear to be restricted within small extent as they are generally thin and partially thinned out. Many extensive thick coal seams exist in the middle and lower parts of the formation.

Relatively accurate correlation of different parts of the Lower Coal Zone revealed between these widely spaced boreholes can be achieved by subdividing the coal seams into several groups and correlating these groups.

Major coal seams in the middle and lower parts of the formation are the Footwall 4, Footwall 3, Footwall 2, Footwall 1, Footwall 0 (the seam frequently converges with overlying Main Seam), Main Seam, Bottom Marker, Intermediate Marker, Top Marker, and Upper Coal in ascending order. These coal seams are described in detail in the paragraph "4.6 Coal Seams".

Intervals between the Top Marker and Intermediate Marker, Intermediate Marker and Bottom Marker, and Bottom Marker and Main Seam are nearly constant in all boreholes.

The interval between the Top Marker and Intermediate Marker is about 6 m and the rock facies is gray to yellowish gray feldspathic coarse-grained sandstone. That between the Intermediate Marker and Bottom Marker ranges from 6 to 7 m and the rock is gray to yellowish gray feldspathic coarse-grained sandstone. And the interval between the Bottom Marker and Main Seam ranges from 14 to 18 m, but it thickens in DD 6 and DD 7 holes about 25 m. The rock in this interval is gray to yellowish gray feldspathic coarse-grained sandstone or very coarse-grained sandstone with frequent subangular pebbles.

The intervals between coal seams in the horizon from the Footwall 1 to Footwall 4 below the Main Seam, are not very constant and the thickness of coal itself is extremely variable.

The Main Seam generally intercalates carbonaceous shale of 40 to 70 cm thickness in the upper part. The thickness of the coal seam above this shale parting varies from 10 to 50 cm. In most cases, the roof of the Main Seam is coarse-grained sandstone or shale and the floor is shale. The roofs of the Intermediate Marker and Footwall 3 are generally coarse-grained sandstone and the floors of these are shale.

The following problems on the thickness of the Lower Coal Zone were posed during this drilling investigation. That is, when a dolerite sill intrudes into the sedimentary rocks, it is necessary to distinguish whether the sill intrudes along weak zone of the sedimentary rocks and raises the strata above, or the sedimentary rocks are replaced by the dolerite itself.

Therefore, in case of determination of true thickness of the sedimentary rocks, the thickness of the dolerite must be excluded in the former, but in the latter that of the dolerite must be included.

The mode of intrusion of the dolerite in the Lubhuku area is described in detail in the paragraph "4.5 Dolerite", but it is hard to distinguish them definitely. In case of DD 8, the dolerite intrudes between the Intermediate Marker and Main Seam and the interval between both coal seams is larger than that in general interval, which indicates that the strata above the sill are raised by the intrusion. Conversely, the dolerite intrudes into the horizon of the Main Seam and replaces the coal seams in DD 52.

The dolerite intrusions in this area have not occurred under simple conditions, for besides the above mentioned mode of intrusion, the dolerite frequently intrudes into the sedimentary rocks, raising the strata above and simultaneously replacing the rocks in some places.

As only several boreholes were drilled up to the horizon of the Basal Sandstone in this drilling investigation, the thickness of the Lower Coal Zone, which is represented by that from the upper boundary to the Footwall 4, tends to thicken towards the eastern part of this area and attains a maximum of about 240 m near DD 29 hole. The thickness near DD 51 and DD52 in the central part of this area is relatively thin, about 180 m. It attains a minimum of about 150 m near DD 11 and DD 43 south of DD 10 and DD 51.

4.3.3 Upper Sandstone

The formation is generally characterized by its fine- to medium-grained gray sandstone with occasional particles of grit, remarkable carbonaceous fragments and some intercalations of gray shale. The thickness of the formation is about 70 m. The formation has been distinguished from underlying Lower Coal Zone based on the above characteristics, however, coarse-grained sandstone occurring in the Lower Coal Zone is also found in this formation and the carbonaceous fragments characterizing this formation were also remarkably found in the Lower Coal Zone during this drilling investigation.

Therefore, when determined on the basis of the previous definition, the boundary between the Upper Sandstone and Lower Coal Zone is very indefinite and may lack uniformity. In order to make it clear, the base of the Upper Sandstone is defined as follows in this study.

The base of the Upper Sandstone is assigned to the top of the thin coal seam which is the uppermost one among the thin coal seams occurred in the beds below the Upper Transition Beds. In the case when this thin coal seam thins out, the base of the Upper Sandstone is assigned to the corresponding horizon determined by the lithofacies correlation (Drawing 3). In this investigation the formation was penetrated in all boreholes except DD 5 and DD 41. The thickness of the formation tends to increase towards the east in the Lubhuku area similar to the Lower Coal Zone and attains a maximum of about 89 m near DD 29.

4.3.4 Upper Transition Beds

The formation is generally characterized by its alternation of sandstone and grayish blue shale. Especially, the lowermost shale contains thin banded fine-grained sandstone and can be a useful key bed. The maximum thickness of the formation is about 95 m. Although the formation was penetrated in all boreholes except five holes (DD 1, 2, 5, 41 and 49), all the sequence was drilled in eight holes (DD 25, 26, 50, 28, 29, 38, 13 and 31). The thickness of the formation is relatively thin (50 to 60 m) near DD 25 and DD 26, and attains to 95 m and 88 m in DD 28 and DD 38 respectively. Thin intercalations of calcareous bed are occasionally found in the formation, however, these intercalations are drilled in only three holes (DD 28, 50 and 52) in the lower part of the formation during this investigation.

4.3.5 Upper Coal Zone

The formation is composed of shale, coal and sandstone, and is divided into eight zones consisting of shale zones with intercalated coal seams and sandstone zones.

As shown in Table 6, the odd numbered members are sandstone zones and the even numbered members indicate the shale zones with coal. Exceptionally, Zone 1 also intercalates coal and shale. The thickness of this formation is about 160 m. The formation was penetrated in eight holes (DD 25, 26, 50, 28, 29, 38, 13 and 31), however, coal seams were drilled in only three holes of DD 26, DD 29 and DD 50, and the other holes were started from the lowermost part of the Zone 2 or the horizon of Zone 1.

DD 26 and DD 50 holes, which encountered coal seams, were drilled from the lower part of the Zone 3 and penetrated thin coal seams of the Zone 2 and Zone 1. The Zone 2 is subdivided into about three thin coal seams, and these coal seams contain much intercalated shale and are very thin, with a maximum thickness of 67 cm. DD 29 was drilled from Zone 1 and a thin coal seam (40 cm) was penetrated. According to the geologic map of Swaziland (scale: 1/50,000), this formation is distributed at the surface in north-south direction and its width ranges from 300 to 500 m at about 1.5 km east of DD 26.

However, the present geological study shows instead that the boundary between the Upper Coal Zone and Upper Transition Beds should be redrawn to the west of DD 25 and DD 28, because the drilling was started at the Zone 2 of the Upper Coal Zone in DD 25 and at the Zone 1 in DD 28. The upper boundary of this formation was determined on the basis of the data of shallow drilling executed by Shell Coal (Pty) Ltd. in the region east of the Lubhuku area for the purpose of exploration of the Upper Coal Zone. The study reveals that the upper boundary of this formation should be revised to about 400 m east of that defined in the existing geologic map. This study therefore indicates that the Upper Coal Zone is distributed over a more extensive area than that shown in the previous reports (See Drawing 1).

4.3.6 Microscopic Examination of Sandstone

The microscopic examination of sandstones occurring from the lower part of the Upper Sandstone to the lower part of the Lower Coal Zone shows that the main constituents are quartz with subordinate orthoclase, plagioclase, and microcline. Minor amounts of muscovite and biotite, bent or deformed by the pressure of adjacent grains, occupy the interstices of grains of quartz and feldspar. In addition, calcite, chlorite and sericite occasionally occur in the irregular interstices of the grains.

The grain size of these minerals is generally from 0.3 to 1.0 mm in diameter and most of them are of subangular to subround grains (roundness from 0.15 to 0.40) whilst round grains (roundness from 0.40 to 0.60) are occasionally found.

The sandstone is generally moderately ill-sorted and occasionally moderately well-sorted. Only very few grains of heavy minerals such as garnet, zircon, apatite and magnetite were found, therefore no heavy minerals may prove to be useful for stratigraphic correlation.

Typical photomicrographs of the sandstone are shown in Plate 3.

Constituent minerals, roundness of grains and sorting of grains of the sandstone are fairly similar throughout the sequence. The sandstone is subarkose to arkose of continental sediment origin derived from granite and gneiss.

4.4 Geologic Structure

N-S trend geologic structure is predominant in the Karoo Sequence province in Swaziland. N-S trending faults predominate and oblique faulting is occasionally observed. Most of the dolerite dykes also trend N-S and these N-S trending structures are considered to be related to the growth of the same trend in the Lebombo Graben.

A major fault with a N-S trend runs along the railroad in the western part of the Lubhuku area and is tentatively called "Lubhuku fault", because it is the most predominant fault in this area. This fault has previously been regarded as running to the west of DD 1 and DD 5 and to be offset by NE-SW trend faults to the south of DD 6 and to continue southwards passing through the east of DD 11. However, since discontinuity of the strata has now been found between DD 1 and DD 2 and not to the east of DD 11 during this drilling investigation, this fault is considered to run east of DD 1 and west of DD 11 (Drawing 1).

Furthermore, the Molteno Beds and Cave Sandstone have previously been regarded as being present in a graben-like area formed by the Lubhuku fault and the subsidiary NNW-SSE trending fault near DD 6 and DD 10. However, it is now considered that this structure does not exist because the Upper Transition Beds was penetrated near the surface in DD 10 and discontinuity of the surrounding strata was not found.

From the results of drilling, the existence of some N-S and NNE-SSW trending faults nearly parallel with the Lubhuku fault is expected within this area, but these faults are expected to be small in scale. The faults occurred in the area are generally normal fault dipping westward and their throws are considered to be ranged from 10 to 50 m (Drawings 2a and 2b).

The strike of the strata in this area varies from N-S in the north, NNE-SSW, and NNW-SSE in the south, and a syncline plunging very gently to the east is found near DD 11 to DD 31. In addition, an anticline nearly parallel with the above syncline is found near DD 51 to DD 52. Dips of the strata are generally less than 10°E and most of them are within 5°E in the western part, and are slightly steeper at 10 – 20°E in the eastern part.

The geologic map of 1/50,000 in scale shows a basin structure on a small scale near DD 43 and occurrence of the Molteno Beds and Cave Sandstone, however, it is considered that this structure is not exist because the Upper Transition Beds was penetrated near the surface in DD 43.

Further detailed investigation about the effects of the intrusions of dolerite sill on the geologic structure is required because of a lack of sufficient data for this study. So far the present investigation reveals that displacement of the strata is found above intruded dolerite sills which is caused by the raising of the overlying strata by the intrusion of the inclined sill. Strike and dip of the sediments also vary in part due to the intrusion of dolerite sill, and it is considered that the syncline occurring around DD 11 to DD 31 was partially caused by the intrusion of the dolerite sills "A" and "B" in the northern part and sills "C" and "D" in the south.

Plate 3. Photomicrographs of Sandstone

1. Arkose sandstone
   Upper Sandstone, Middle Ecca Series
   DD 3, 75.0 m, crossed nicol, ×40

2. Arkose sandstone
   Lower Coal Zone, Middle Ecca Series
   DD 3, 191.0 m, crossed nicol, ×85

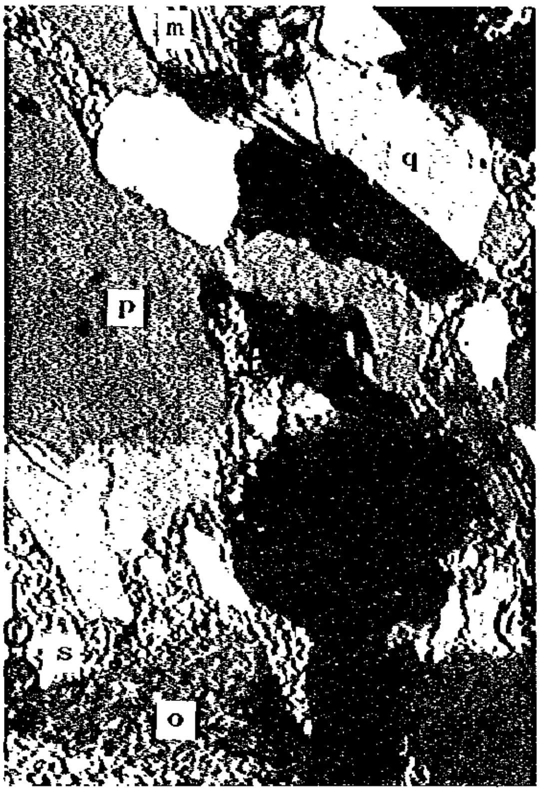
3. Subarkose sandstone
   Lower Coal Zone, Middle Ecca Series
   DD 3, 307.0 m, crossed nicol, ×40

4. Subarkose sandstone
   Upper Sandstone, Middle Ecca Series
   Dolerite fragments in sandstone
   DD 43, 119.2 m, crossed nicol, ×40

Remarks: q: quartz o: orthoclase P: plagioclase
b: biotite m: muscovite s: sericite

Plate 3.

1.



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4.5 Karoo Dolerite

4.5.1 Mode of Occurrence

Various kinds of Karoo dolerites ranging in thickness from 1 cm to more than 100 m were encountered in all the boreholes drilled in the Lubhuku area. These dolerite intrusions are divided into three types, concordant sill, inclined (discordant) sill, and dyke based upon their mode of occurrence.

The concordant sill intrudes almost parallel to the bedding of the surrounding strata and the inclined sill intrudes into the strata, cross-cutting the bedding, and dips of the inclined sills are generally between 15 to 50 degrees.

The strike and dip of each sill differ for each intrusion and can also vary even within the same body and the sill occasionally branches off. Most of the sills are the inclined one. The investigation performed to date shows that no specific horizon is susceptible to the intrusion of the sills and that the sills intrude extensively over all horizons of the Karoo Sequence. Generally, the strata above are found to have been raised separating from those below a sill intrusion. In the case of the intrusion of the thicker sills, it seems that some of them partially replace the invaded strata.

The dykes strike nearly N-S and dip nearly vertical and widths are generally up to about 10 m, but rarely reaches 50 m (DD 45). Some dykes intrude along faults. It has been considered that the dykes may partially merge with a sill or intrude it, and fine- to very fine-grained dolerite of 1 to 3 m in width has been observed in the medium- to coarse-grained dolerite sills in DD 9, DD 41, DD 51 and DD 52.

Small fragments of sandstone, shale and coal are sometimes found in the dolerite and small breccias of dolerite have been occasionally found in the invaded strata. Contamination phenomena of dolerite and the invaded rocks have been noted in DD 29 and DD 43.

The dolerite is considered to have several intrusion periods and more than one intrusion period is indicated in this area as contacts of different intrusive rock facies are found in some places for example in DD 34 and small dolerite breccias with different facies are found in the sill in DD 51. The dyke cuts the sill mentioned above, proving a slightly later age of the dyke intrusion.

Frequency of dolerite intrusion (i.e. dolerite percentage in the hole) observed in the boreholes shows 1 to 25 percent in the northern part of this area, increasing to the relatively high figure of 25 to 40 percent in the central and southern parts except in some places (Fig. 7). Especially, the percentage of dolerite is extremely high in DD 9 and DD 34 at more than 70 percent.

Considering the mode of occurrence of the sills, it is considered that four major sill-like bodies have been found in this area, namely, sills "A" and "B" are distributed from the central part to the south of the northern part of the area and sills "C" and "D" in the southern part (Fig. 8). The distribution range and maximum thickness of the sill are as follows:

	Distribution range	Maximum thickness
Sill "A"	about 30 km^2	more than 200 m (DD 9)
Sill "B"	about 17 km^2	about 70 m (DD 9)
Sill "C"	about 28 km^2	about 100 m (DD 38)
Sill "D"	about 8 km^2	about 140 m (DD 34)

These sills show variations in thickness, strike and dip, complexities in their mode of occurrence such as gently inclined basin or dome structures in part, and occasionally branching into subsidiary bodies or thinning out (Drawing 7).

4.5.2 Petrographic Characters

The dolerite is generally massive, compact and dark greenish gray, and partially light greenish gray to light gray when altered. When faulted or jointed the brittle dolerite rock can be extensively fractured and even pulverized.

Petrographic studies reveal that the dykes and thin sills consist of dolerite or basalt in the central part and grade into basalt of finer texture at the margin, whilst the thick sills consist of dolerite or gabbroic or pyroxenitic rocks in the central part which grade into basalt at the margin. Narrow chilled margins generally occur at the contact with the country rock.

The main constituents of the typical dolerites are plagioclase (usually labradorite

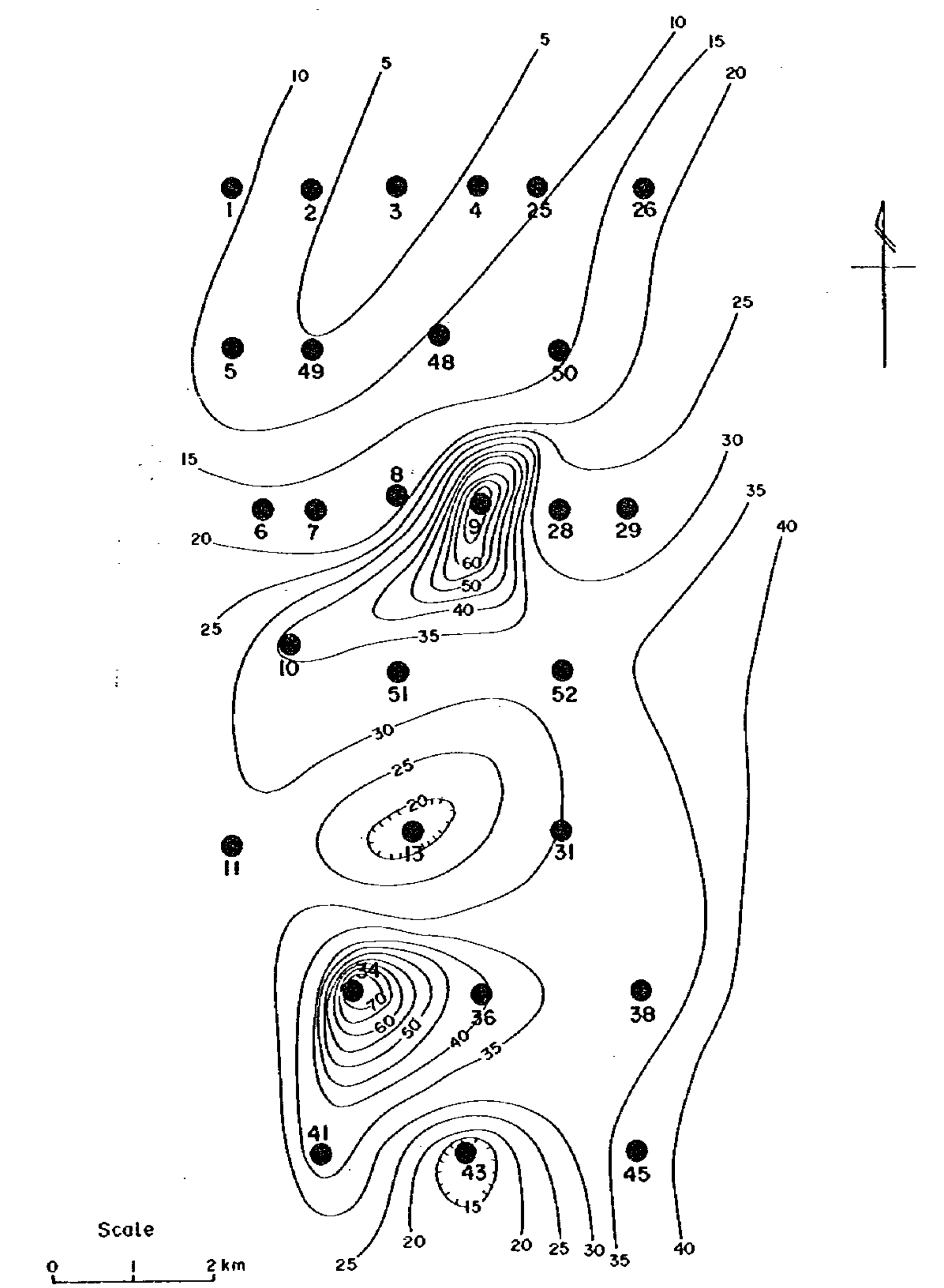

Figure 7. Dolerite Incidence Map
(Showing percentage of dolerite in borehole)

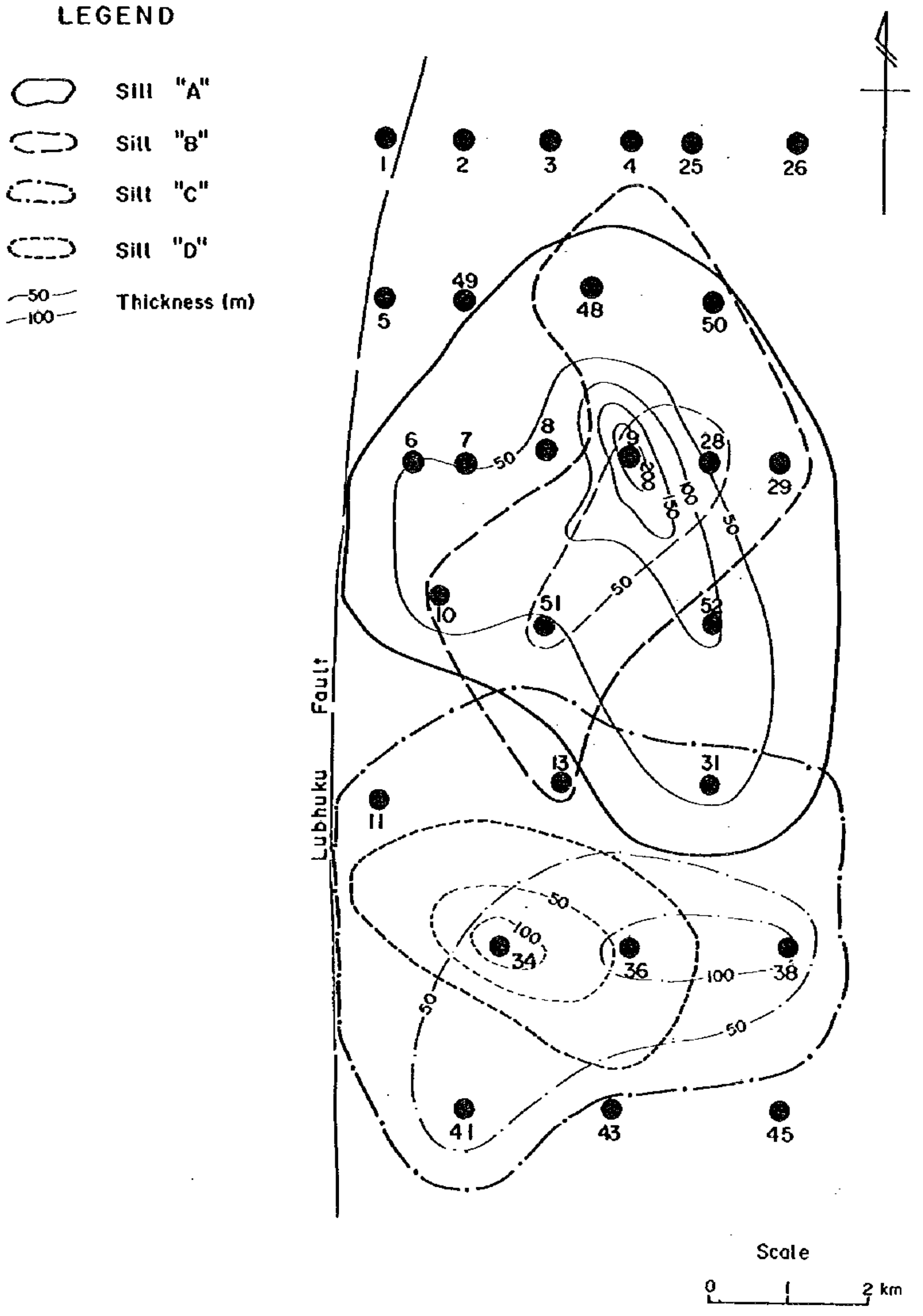

Figure 8. Distribution of Major Dolerite Sill

to bytownite) and augite, and a small amounts of olivine, orthopyroxene, pigeonite, amphibole, and biotite and occasionally found.

Small grains of titaniferous magnetite and ilmenite are dispersed throughout the rocks as accessory minerals and apatite and natrolite are also found.

Trace amounts of quartz and alkali feldspar are occasionally found in the thick sill. Chlorite, epidote, calcite, sericite and serpentine are found as alteration products.

Table 7 shows the petrographic characters of the dolerite observed in thin section.

Table 7. Petrographic Characters of Dolerite

Occurrence	Portion	Texture	Constituent Minerals
Thinner Sills, Dykes	Contact	Glassy	Narrow blackish brown zone (3 to 5 mm) of tachylite.
	Margin	Porphyritic or basaltic	Phenocrysts of olivine and augite in a fine-grained groundmass or mesostasis of pyroxene and plagioclass microlites, sometimes with a little brownish glass.
	Center	Ophitic or basaltic	Crystals of augite and olivine in a groundmass of pyroxene granules and plagioclase laths.
Thicker Sills	Contact	Glassy	Chilled margin (4 to 6 mm) consists of small crystals of plagioclase and augite in glassy groundmass. Very narrow black band (0.1 mm) of iron oxides at very contact.
	Margin	Basaltic	Phenocrysts of augite, olivine and plagioclase in a groundmass of plagioclase (labradorite) laths and small granules of augite.
	Center	Ophitic or holocrystalline	Plagioclase (bytownite-labradorite) laths disposed within large crystals of olivine and augite. Large crystals of olivine, augite, orthopyroxene and plagioclase with little groundmass of plagioclase laths.

In addition to the typical dolerite, its associates such as gabbro, pyroxenite, basalt and fine textured basaltic facies are also found in the Karoo dolerite occurring in the area. The combination of mafic minerals is olivine-augite, augite-orthopyroxene, augite-pigeonite, augite and augite-biotite, and slightly acid facies is occasionally found. These intrusive rocks are typical of tholeiitic basalts occurring in the continental region.

Typical photomicrographs of the dolerite are shown in Plates 4, 5 and 6.

4.5.3 Effect on the Coal Seams

All of the coal in Swaziland is semi-anthracite and anthracite, and these semi-anthracitic and anthracitic conditions are considered to result from thermal effect of extensive volcanism of the Stormberg volcanics and Karoo dolerite after sedimentation of the coal.

The direct effect of the dolerite on the coal seams is replacement of coal seams and a change of the coal quality. All major coal seams in DD 9 and DD 34 are considered to be replaced by the intrusion of the dolerite sill (Drawings 5a and 5b), and the Main Seam in DD 26 and DD 52 is replaced by the sill. Some major coal seams are also replaced by the sill in several boreholes. The Main Seam is partially replaced by the sill in DD 2, DD 8, DD 10 and DD 13.

It is considered that the thermally affected distance by the intrusion of the dolerite is generally about equal to the thickness of the sill and about equal to the width of the dyke on either side. However, the coal seam appears to be actually subjected to thermal effect of the intrusion such as burned-out and coked by the dyke than the sill in general case.

In the case of the thick sills, coal seams are burned out within a distance of 5 to 20 m on either side of the sill "C" (thickness is 100 m) but are hardly affected at a distance more than 30 m (DD 38). Coal seams just below the sill "A" (65 m) are burned out, but those of about 3 m below the sill are partially affected and no effects are found in those of about 16 m below the sill (DD 8). Even no effects are found in some coal seams just below the thick sill.

The burned-out is rather commonly found in the coal seams just in contact with the thin sill, but in this case fairly many coal seams are hardly affected by the intrusion.

The effects on the coal seams by the dolerite dyke are difficult to observe in the drilling investigation, but the coal seam in the Mpaka coal mine is affected by the dyke within its width on either side.

Plate 4. Photomicrographs of Dolerite

1. Contact between dolerite dyke and sandstone
   Blackish brown zone of tachylite along the contact.
   DD 10, 167.7 m, open nicol, ×85

2. Marginal part of the dyke
   Porphyritic olivine-basalt. 17 mm apart from the contact.
   DD 10, 167.7 m, open nicol, ×40

3. Central part of the dyke
   Olivine-basalt, coarse-grained.
   DD 10, 161.6 m, crossed nicol, ×40

4. Contact between different facies of dolerite
   Cracks occur in basaltic rock along the contact of altered dolerite.
   DD 9, 121.8 m, open nicol, ×40

Plate 5. Photomicrographs of Dolerite

1. Contact between dolerite sill "A" and sandstone. Chilled margine, very narrow black band along the contact.
   DD 6, 108.9 m, open nicol, ×85

2. Marginal part of the sill "A"
   Basalt
   DD 6, 143.4 m, open nicol, ×85

3. Central part of the sill "A"
   Dolerite, partly gabbroic.
   DD 6, 128.3 m, crossed nicol, ×40

4. Dolerite enclosing quartz fragments
   DD 6, 119.0 m, open nicol, ×40

Plate 6. Photomicrographs of Dolerite

1. Dolerite sill "C"
   Pyroxenite.
   DD 41, 181.2 m, open nicol, ×40

2. Dolerite sill "C"
   Dolerite.
   DD 38, 352.0 m, crossed nicol, ×40

3. Contact between sill and coal seam
   Basalt, altered
   DD 51, 354.3 m, open nicol, ×40

Remarks: o: olivine a: augite r: orthopyroxene pi: pigeonite
p: plagioclase q: quartz c: chlorite g: garnet

Plate 4.

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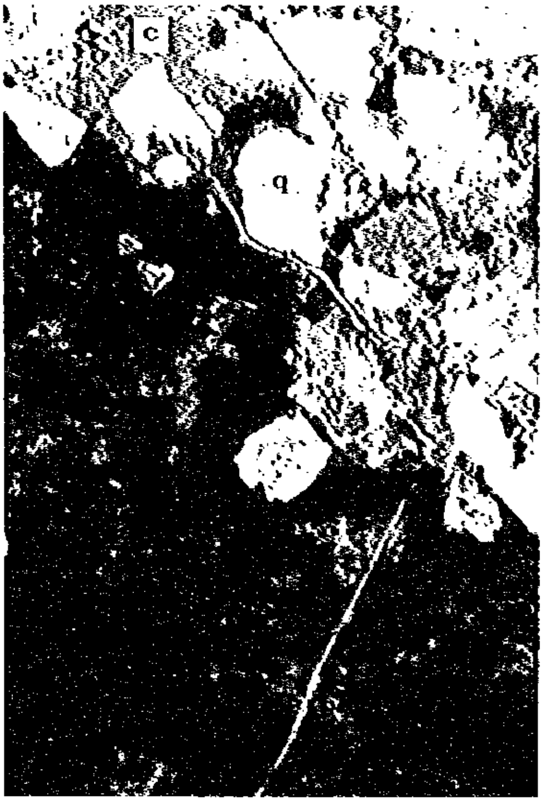

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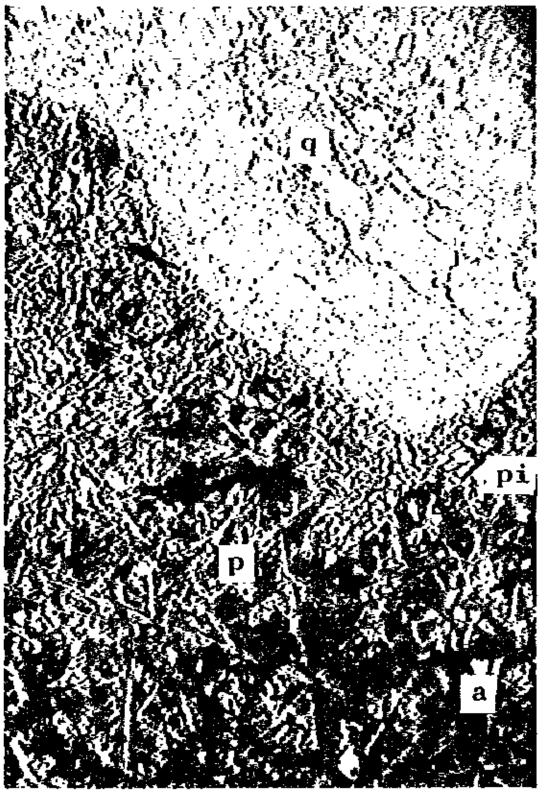

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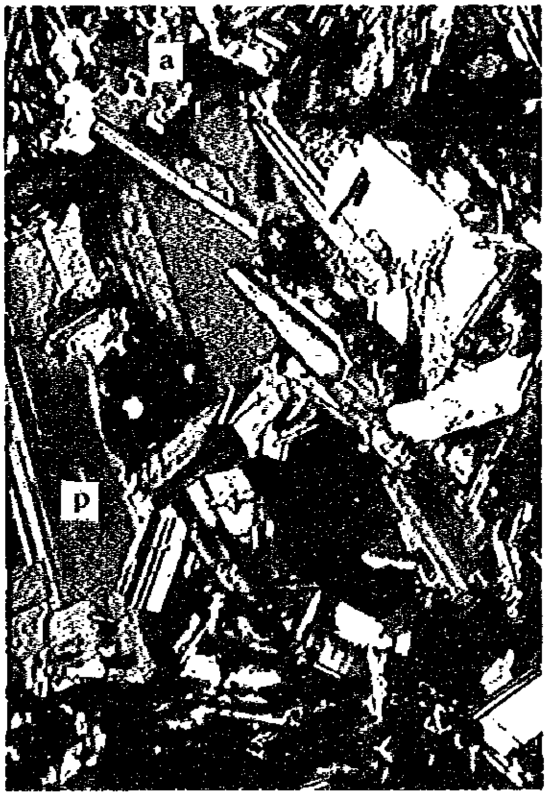

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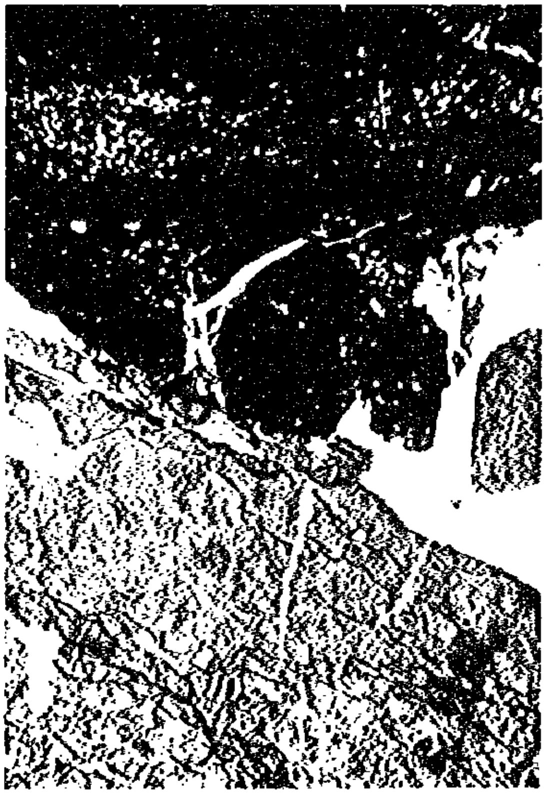

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The effects of the dolerite such as burned-out or coked on the Main Seam are found in DD 1, DD 8, DD 11, DD 13 and DD 51 holes.

4.6 Coal Seams

4.6.1 Outline of Occurrence

The coal-bearing formations in the Lubhuku area consist of the Upper Coal Zone composed of thin coal seams and the Lower Coal Zone lying at the horizon of about 180 m below the Upper Coal Zone, of which the Lower Coal Zone is the subject of this investigation. The Lower Coal Zone contains three major coal seams, the Intermediate Marker, Main Seam and Footwall 3 in descending order, which are all minable.

In addition to these seams, a maximum of about twenty thin coal seams are found in this drilling investigation, however, these seams are considered to be unworkable (Drawing 8).

Since coarse-grained sandstone predominates in the Lower Coal Zone, lateral lithofacies of the formation shows remarkable variation and thin coal seams in the upper part partially thins out. On the contrary, coal seams in the lower part show fairly good continuity though some variations of thickness and parting are found. Consequently, correlation of the horizon can be done by correlating the Top Marker, Intermediate Marker and Main Seam as one group.

On the other hand, the Footwall 1 to 3 below the Main Seam vary markedly in their thickness and distance between the coal seams.

The intrusion of dolerite sills and dykes extremely affects the coal seams in this area, resulting in the replacement of coal seam or anthracitization. These effects are remarkable especially in the southern part.

The coal seams strike NE-SW in the northern part and turn to NW-SE in the central and southern parts. The seams gently dip at 5 to 10°E. The depth of coal seams is considerably shallow near DD 52 in the central part of this area resulted from anticlinal structure (Drawing 9).

An outline of the major coal seams in each hole is shown in Table 8.

4.6.2 Intermediate Marker Seam

In this drilling investigation, the Intermediate Marker was penetrated in 19 holes out of 28. In the other 9 holes, replacement of the seam by the dolerite intrusion is found in 6 holes (DD 1, 9, 10, 34, 45 and 51) and no seam is encountered in 3 holes (DD 36, 43 and 48) because of faults. The seam has a maximum thickness of 2.06 m (coal thickness is 1.83 m) in DD 5 hole and a minimum of 0.40 m in DD 31 among the holes (Drawing 10a). Although a satisfactory interpretation of the tendency of mode of occurrence of this seam cannot be worked out as the available data for the southern part are insufficient, the seam is considered to occur in good state in the northern part, especially on the western side, as compared with those in the southern part.

Generally, the roof of the seam is coarse-grained sandstone and the floor is shale, and the seam has hardly any intercalated partings.

The Intermediate Marker is considered to be not presented in the following areas owing to the dolerite intrusions;

(1) Area with length of 3 km in the north-south direction and about 300 m in width around DD 9.
(2) Area with length of 1.5 km in the south-southeast direction from DD 51 and about 500 m wide.
(3) Area of 1.2 km x 1.5 km around DD 34.
(4) Area with length of about 1.8 km in the south-southwest direction and 300 m wide around a place 1 km southwest of DD 38.
(5) Area with length of about 1 km in the south-southwest direction and 350 m wide around DD 45.

4.6.3 Main Seam

The Main Seam is the thickest seam in the coal-bearing formation in the investigated area. This seam has been mined in the Mpaka coal mine, a single working coal mine in

Table 8-a Thickness of Coal Seams

		DD1	DD2	DD3	DD4	DD25	DD26	DD5	DD49	DD48	DD50	DD6
	Height of Collar (m)	+281.8	+292.5	+292.2	+260.6	+271.3	+260.5	+290.9	+277.0	+275.3	+251.4	+282.5
TOP MARKER	Depth to Seam (m)		157.76	199.54	231.88	334.62	381.23	132.25	156.86	316.78	352.67	243.45
	Seam Thickness	—	0.42	0.32	0.33	0.36	0.24	0.45	0.39	0.04	0.35	1.05
	Coal Thickness		0.42	0.30	0.18	0.36	0.24	0.45	0.39	0.04	0.22	0.60
INTERMEDIATE MARKER	Depth to Seam (m)		164.33	206.89	239.34	341.87	388.15	139.29	164.97		359.72	251.16
	Seam Thickness	—	1.58	1.30	1.54	1.53	1.08	2.06	1.73	—	1.35	1.66
	Coal Thickness		1.58	1.28	1.54	1.53	0.83	1.83	1.73		1.35	1.55
BOTTOM MARKER	Depth to Seam (m)		172.80	216.32	247.95	351.55		147.15	173.19		366.61	258.95
	Seam Thickness	—	0.55	0.51	0.41	0.42	—	0.70	0.50	—	0.43	0.37
	Coal Thickness		0.55	0.48	0.41	0.42		0.58	0.50		0.43	0.35
MAIN SEAM	Depth to Seam (m)	212.16	202.43	231.54	266.58	364.45		162.97	190.22	319.50	386.54	284.25
	Seam Thickness	1.69	1.67	4.14	4.70	3.87	—	4.99	4.65	1.36	3.83	4.26
	Coal Thickness	1.51	1.03	2.42	3.72	3.36		4.57	4.30	1.07	2.81	3.81
FOOTWALL 3 SEAM	Depth to Seam (m)	238.54	216.78	261.15	289.33	387.83		194.27	219.07	344.20		306.55
	Seam Thickness	2.20	1.14	1.07	1.07	0.69	—	1.48	1.23	1.24	—	1.11
	Coal Thickness	1.96	1.10	1.07	0.97	0.69		1.38	1.08	1.10		0.96

Table 8-b Thickness of Coal Seams

		DD7	DD8	DD9	DD28	DD29	DD10	DD51	DD52	DD11	DD13	DD31
	Height of Collar (m)	+270.0	+252.8	+248.9	+254.50	+238.0	+266.2	+266.0	+261.8	+274.2	+248.7	+250.0
TOP MARKER	Depth to Seam (m)	256.18	223.08		364.14	385.90		264.60	279.82	191.90	305.20	344.90
	Seam Thickness	0.55	0.40	—	0.23	0.20	—	0.11	0.50	0.40	0.65	0.12
	Coal Thickness	0.55	0.40		0.23	0.20		0.11	0.40	0.20	0.57	0.02
INTERMEDIATE MARKER	Depth to Seam (m)	262.45	229.62		372.17	391.40			287.19	199.17	319.87	367.85
	Seam Thickness	1.25	1.43	—	1.53	1.37	—	—	0.96	1.43	0.52	0.40
	Coal Thickness	1.25	1.43		1.42	0.50			0.73	1.43	0.52	0.40
BOTTOM MARKER	Depth to Seam (m)	271.50			379.35	398.45				207.40	324.96	378.48
	Seam Thickness	0.51	—	—	0.27	0.35	—	—	—	0.80	0.10	0.02
	Coal Thickness	0.18			0.27	0.35				0.80	0.10	0.02
MAIN SEAM	Depth to Seam (m)	294.94	302.70		396.55	412.69	294.40	353.92		219.30	334.21	
	Seam Thickness	2.84	2.11	—	2.35	3.93	2.20	3.79	—	3.16	2.09	—
	Coal Thickness	2.34	2.11		1.88	2.15	2.20	2.76		2.96	1.95	
FOOTWALL 3 SEAM	Depth to Seam (m)	318.53	324.23		428.52	452.62	314.07	381.97	360.99	290.77	384.69	
	Seam Thickness	1.09	1.10	—	0.79	1.38	1.47	1.68	0.45	0.83	1.04	—
	Coal Thickness	0.62	1.05		0.41	0.97	1.47	1.29	0.03	0.81	0.95	

Table 8-c Thickness of Coal Seams

		DD34	DD36	DD38	DD41	DD43	DD45
	Height of Collar (m)	+276.9	+250.0	+232.0	+272.3	+280.2	+249.1
TOP MARKER	Depth to Seam (m)		250.17	411.94	98.94	231.70	
	Seam Thickness	—	0.19	0.57	0.73	0.58	—
	Coal Thickness		0.06	0.24	0.34	0.20	
INTERMEDIATE MARKER	Depth to Seam (m)			418.31			
	Seam Thickness	—	—	1.18	—	—	—
	Coal Thickness			1.18			
BOTTOM MARKER	Depth to Seam (m)			424.16			
	Seam Thickness	—	—	0.20	—	—	—
	Coal Thickness			0.20			
MAIN SEAM	Depth to Seam (m)			439.37	109.87	238.30	
	Seam Thickness	—	—	1.99	1.15	1.20	—
	Coal Thickness			1.75	0.63	1.16	
FOOTWALL 3 SEAM	Depth to Seam (m)				134.67	268.41	
	Seam Thickness	—	—	—	0.97	0.74	—
	Coal Thickness				0.83	0.64	

Swaziland. The seam generally consists of two coal seams with an intercalation of shale or sandy shale of 40 to 70 cm in thickness. The coal seam above this parting is thin with thickness from 10 to 50 cm. The roof of the Main Seam is shale and occasionally coarse-grained sandstone, and the floor is sandy shale or shale.

The seam was penetrated in 21 holes out of 28. In the remaining 7 holes, replacement of the seam by the dolerite intrusion is found in 5 holes (DD 9, 26, 34, 45 and 52) and no seam is encountered in 2 holes (DD 31 and 36) because of faults. The seam has a maximum thickness of 4.99 m (coal thickness is 4.57 m) in DD 5, and a minimum of 1.15 m (coal thickness is 0.63 m) in DD 41 among the holes (Drawing 10b).

The Main Seam splits over about 5.3 m in thickness in DD 11 and this is considered to be caused by the intrusion of dolerite (thickness of 2.1 m). The seam generally tends to thicken in the west of this area and to thin eastwards.

The seam predominantly occurs in the area north of the northern side of DD 51 – 52 line in comparison with the southern part. Two different sedimentary basins are considered to exist in the northern and southern parts separated by this line during the deposition of the coal seams.

The seam attains a maximum in thickness near DD 5 and DD 49 in the northern part and thins towards the north, south and east.

Considering sand-shale ratio of this horizon, the ratio of sandstone is highest in DD 48, corresponding to the center of the northern part, compared with that in the surrounding area, and conversely the thickness of the Main Seam is a minimum (seam thickness is 1.36 m and coal thickness 1.07 m) at this part.

The seam splits into a couple of seams interbedded with shale or sandstone in DD 28 and DD29 at the eastern end. On the other hand, though the occurrence of the seam in the southern part is not so clear because the Main Seam was encountered in a few holes in this part, the seam attains a maximum thickness in DD 11 (seam thickness is 3.1 m and coal thickness is 2.96 m) and thins towards the south, north and east.

The effects of dolerite intrusion on the coal seams are as stated above and the Main Seam is also affected in its mode of occurrence and quality. In DD 2, DD 8, DD 10, DD 11, DD 13, DD 48 and DD 51, the seam is partially replaced by the intrusion of the dolerite.

The Main Seam is considered not to be present in the following areas owing to the dolerite intrusions;

(1) Area with length of 4 km in the north-south direction and about 1 km in width from about 500 m south of DD 48.
(2) Area with length of about 2 km in the SSW to SE direction and 200 to 300 m in width from 500 m south of DD 29.
(3) Area with length of 1.3 km in the north-south direction and 200 to 600 m in width around DD 34.
(4) Area with length of 1.9 km in the north-south direction and 300 m in width from the middle of DD 36 and DD 38.
(5) Area with length of about 1 km in the SW-NE direction and 400 m in width around DD 45.

4.6.4 Footwall 3 Seam

The Footwall 3 Seam generally occurs at the horizon about 20 m below the Main Seam and its thickness is about 1 m.

The roof of the seam is coarse-grained or medium-grained sandstone and the floor is sandy shale or shale.

The seam was penetrated in 20 holes out of 28, and most of them were concentrated in the northern part of the investigated area. In the remaining 8 holes (DD 26, 50, 9, 31, 34, 36, 38 and 45), the seam is replaced by the intrusion of the dolerite.

Distance between the seam and overlying Main Seam is not very constant and ranges from 12 m to a maximum of 36 m.

The thickness of the seam markedly varies and attains a maximum of 2.20 m (coal thickness is 1.96 m) in DD 1 and a minimum of 0.45 m (coal thickness is 0.03 m) in DD 52 (Drawing 10c). Although the occurrence of the seam in the southern part is not so clear because of poor data available, the seam is considered to thicken on the western side of the northern part, the same as the Main Seam.

4.7 Sedimentary Environment

4.7.1 Sedimentary Environment of the Ecca Series

Regarding sedimentary environment of the Ecca Series, the Lower Ecca Series is composed of well-sorted very fine-grained shale, and the Middle Ecca Series predominates sandstone, but argillaceous facies partially predominates in the Lower and Upper Transition Beds.

The sandstone of the Middle Ecca Series is composed mainly of feldspar, quartz and muscovite derived from granite and gneiss and it is considered that the source of supply was relatively close to the sedimentary basin judging from the sorting of constituent particles and the roundness of the quartz grains. As the feldspar is almost fresh, the climate had been continuously cold from the glacial stage of the Dwyka epoch. On the other hand, the cross-lamination and cross-bedding are extensively found in many of the sandstone, and the water stream played an important role at the deposition of the beds and the formation is of fresh-water fluviatile to deltaic origin.

The thin calcareous beds occassionally occur in the Upper Transition Beds and this indicates transgression for very short period.

Large scale upward-coarsening sedimentation, which is characteristic of prograding delta formation, is found in the lower Ecca Series, Lower Transition Beds and Basal Sandstone, and these beds are considered to correspond to delta shelf facies, prodelta facies and delta-front facies respectively.

Sedimentation of thick formation showing small scale upward-fining depositional cycles is found in the Lower Coal Zone and this represents structurally stable delta plain and alluvial plain facies, and many coal seams occur in this formation.

As progradation proceeded, large scale upward-coarsening sedimentation is also found in the Upper Sandstone and Upper Transition Beds, and these strata represent the delta-front facies and prodelta facies respectively. Since upward-fining depositional cycles are found again in the Upper Coal Zone (Upper Ecca Series) and argillaceous facies is predominant in the strata, this indicates that they are stable lacustrine or swamp sediments.

It is considered that continuous faulting, forming the Lebombo Graben, well preserved the whole sequence of the Karoo Sequence in Swaziland from erosion.

4.7.2 Sand-Shale Ratio of the Middle Ecca Series

The following characteristics of the sedimentary environment based on the sand-shale ratio are found in the Lower Coal Zone, Upper Sandstone and Upper Transition Beds.

The sand ratio is fairly high and constant at 85 to 95 percent in the lower part of the Lower Coal Zone (Top Marker to the lower boundary) and 75 to 85 percent in the upper part (the upper boundary to the Top Marker). Stable sedimentary units (sedimentary basins) are discernible both in the southern and northern parts bordered near the DD 51 to DD 52 line. The units represent a structurally stable delta plain and alluvial plain and provided a suitable place for the deposition of the coal seams (Fig. 9 and 10).

The sedimentary units became somewhat unstable during deposition of the upper part of the Lower Coal Zone and the units disappeared during the deposition of the Upper Sandstone and Upper Transition Beds. Underwater channels extensively occurred during the deposition of the Upper Sandstone and Upper Transition Beds, and the sand ratio decreased gradually because of the relative increase of shale, which resulted in the occasional marked variation in the sand-shale ratio and no sedimentary basin for the coal deposition is found in these stages.

The sand ratios of the Upper Sandstone and Upper Transition Beds are 60 to 90% and 35 to 85% respectively (Fig. 11 and 12). Near to the supply channel of the sediments, disorder of sedementation caused by slumping or contemporaneous erosion is sometimes found in the upper part of the Lower Coal Zone (DD 29 and DD 43) and the Upper Sandstone (DD 3, DD 8 and DD 43).

The supply direction of the sediments, judging from the sand-shale ratio, shows towards the east or southeast at all stages and the source of supply is considered to be the Swaziland Highland (basement rocks of Precambrian age) in the west.

Regarding coal ratio (ratio of coal to the sedimentary bed), in the lower part of the Lower Coal Zone, the northern sedimentary unit has high ratio at 5.0 to 9.5 percent, and higher part of the coal ratio is distributed surrounding DD 48 (sand ratio is 95%) where channel sandstone is predominant. The coal ratio is the highest near DD 4 and DD 49, west of DD 48, and this higher part extends to farther north. The coal ratio of the southern sedimentary unit is relatively low at 4.0 to 6.5 percent, and this is in good agreement with

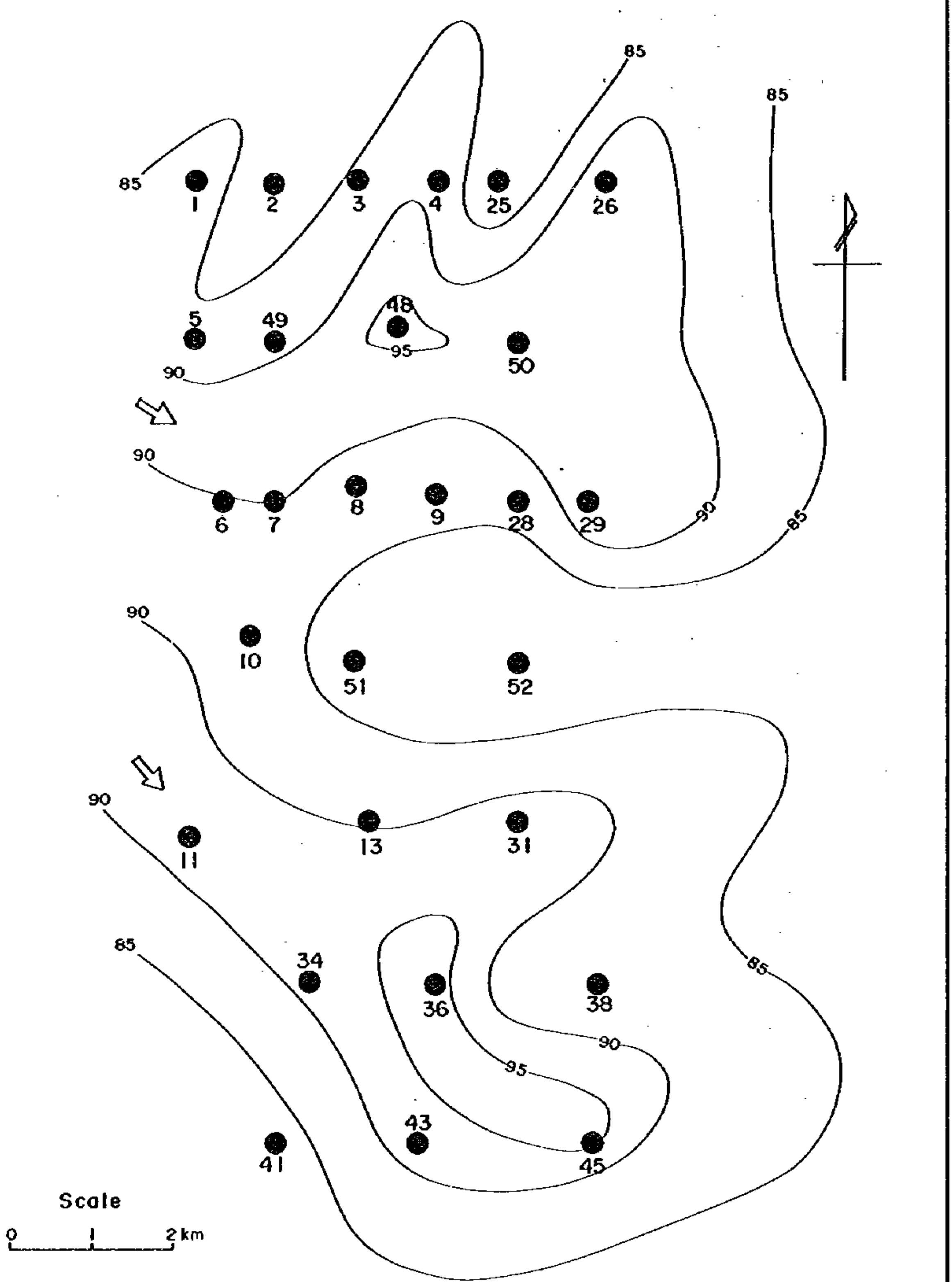


Figure 9. Sand-Shale Ratio, Lower Part of Lower Coal Zone, Middle Ecca.
(Showing sandstone ratio in percent)

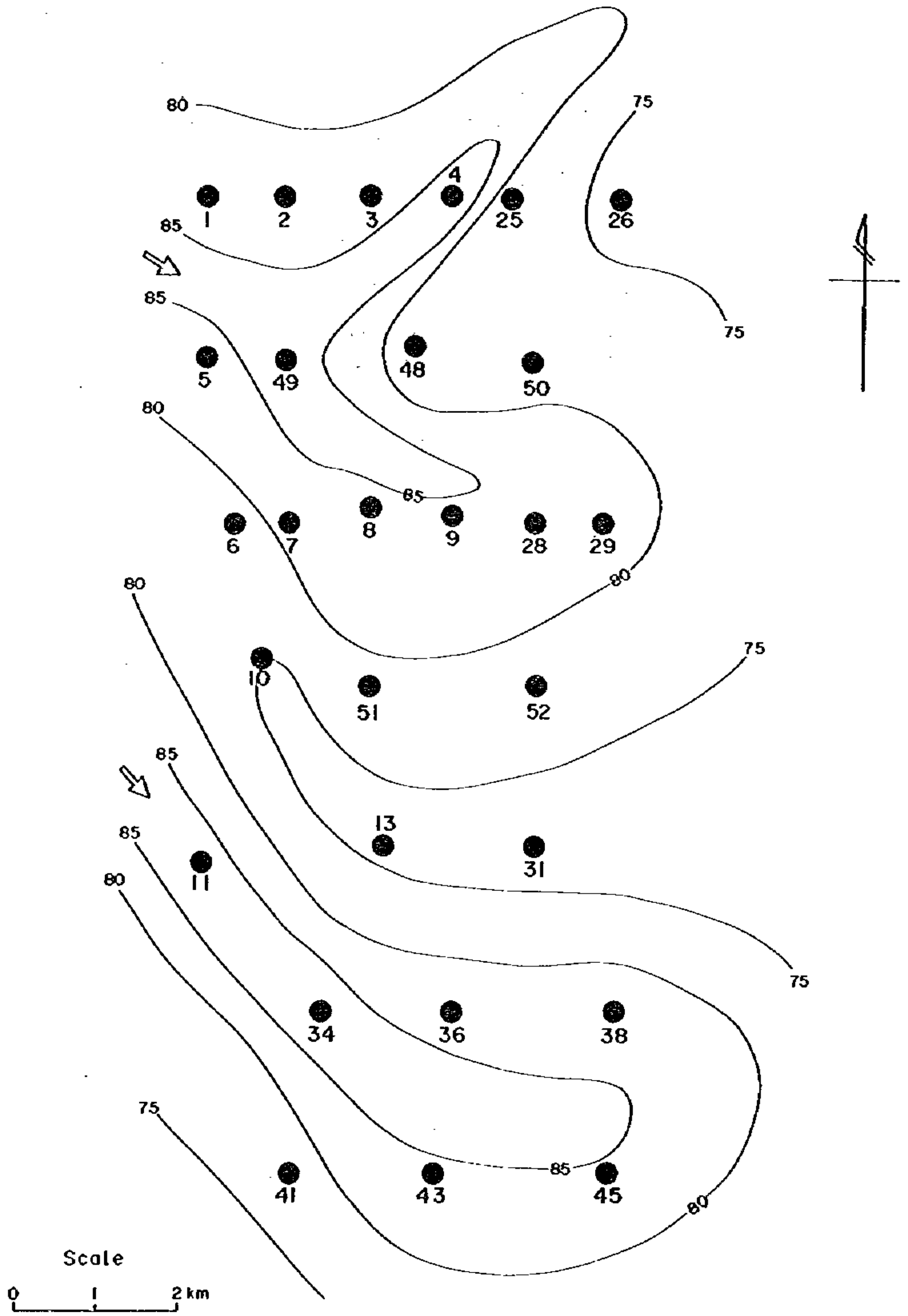


Figure 10. Sand-Shale Ratio, Upper Part of Lower Coal Zone, Middle Ecca.

(Showing sandstone ratio in percent)

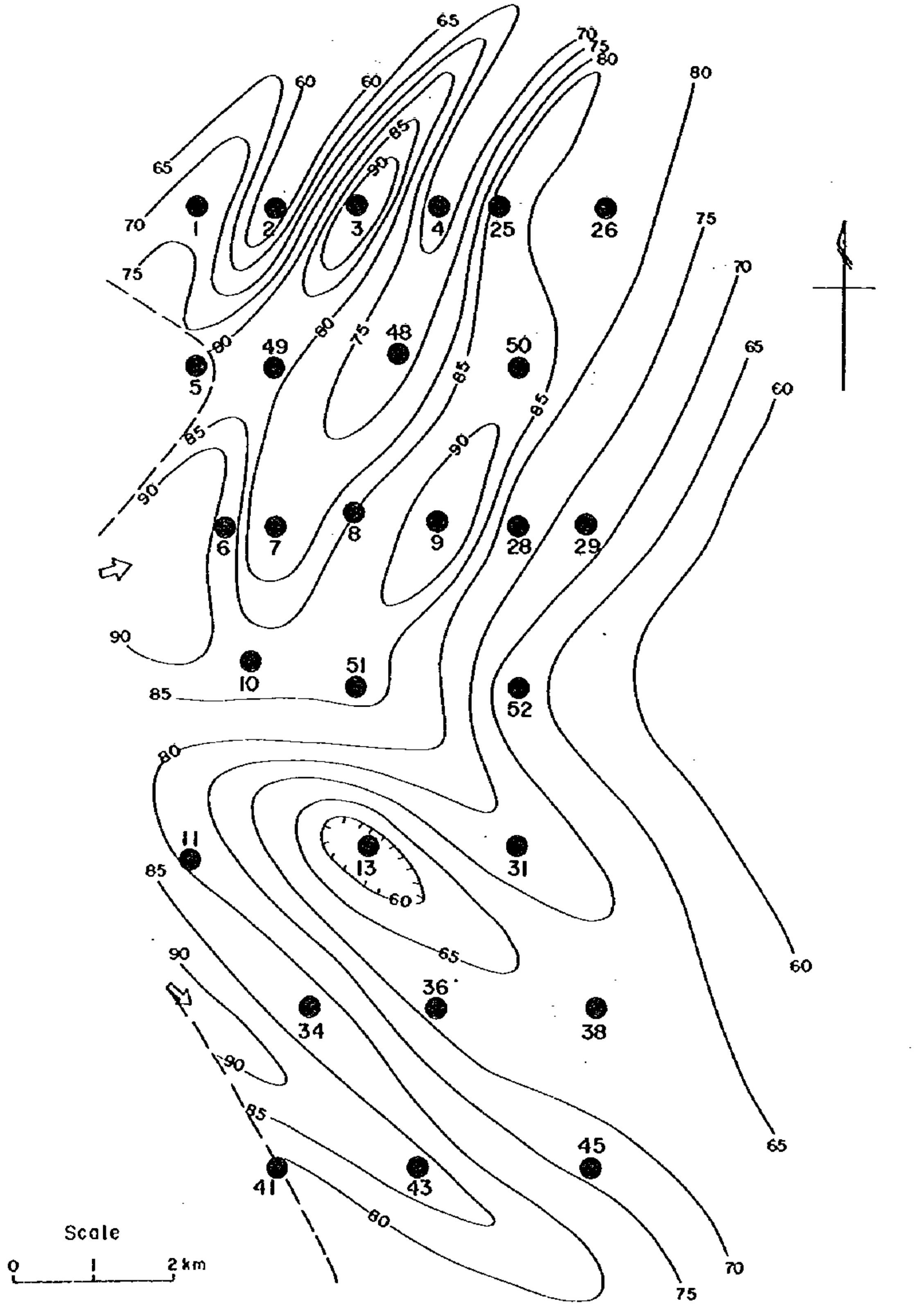


Figure 11. Sand-Shale Ratio, Upper Sandstone, Middle Ecca
(Showing sandstone ratio in percent)

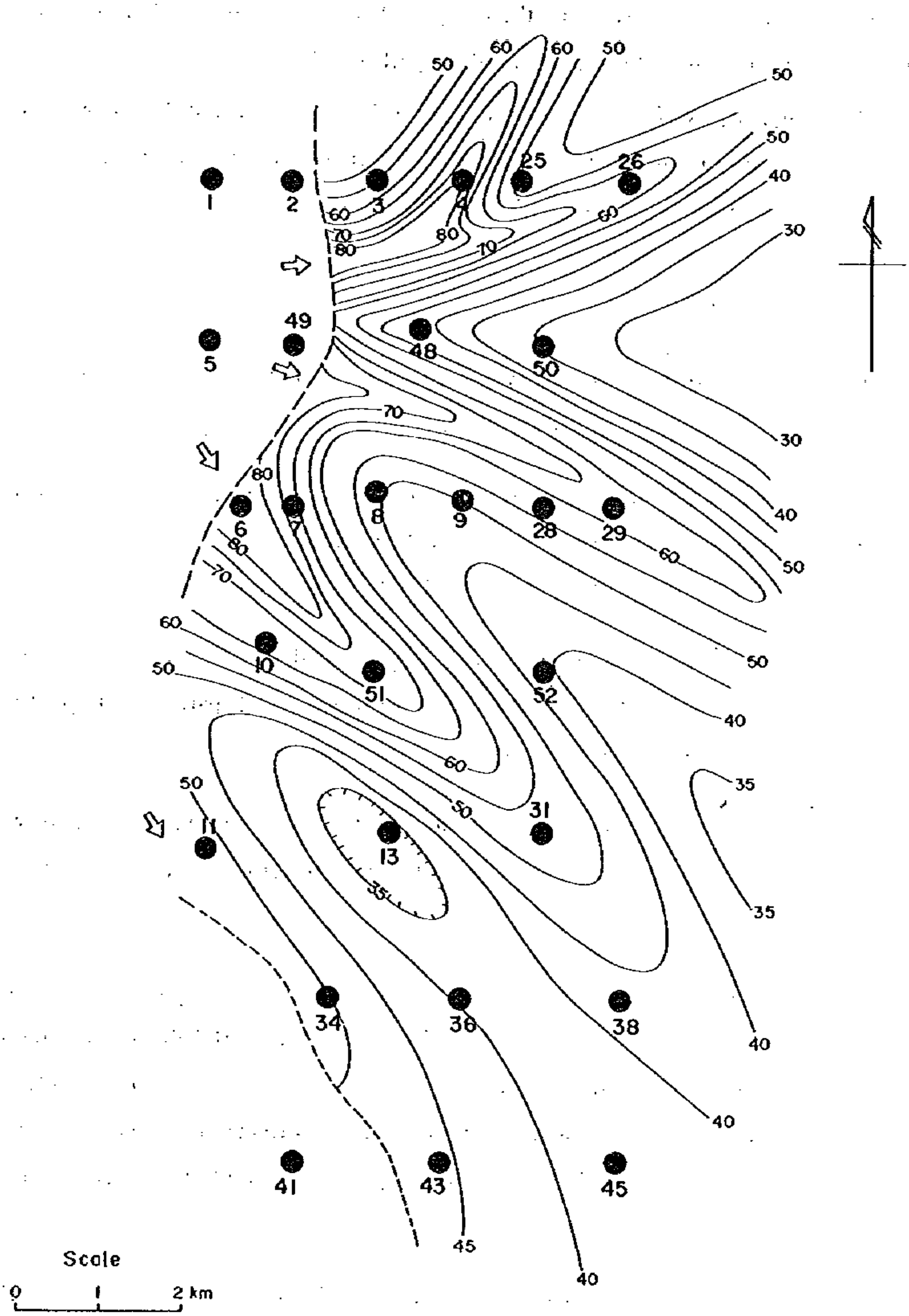


Figure 12. Sand-Shale Ratio, Upper Transition Beds, Middle Ecca.
(Showing sandstone ratio in percent)

the tendency for the occurrence of the major coal seams such as the Main Seam in the southern part is inferior to those in the northern part (Fig. 13).

In the upper part of the Lower Coal Zone, both sedimentary units have low coal ratio at 1.5 to 5.0 percent caused by unstable conditions of the sedimentary units and the coal seams occur less extensively in both units (Fig. 14).

4.8 Palynological Analysis

Only fragments of *Glossopteris* have been reported from the Ecca Series in Swaziland, however, these are sparse and poorly preserved.

Although palynological correlation of the lower Karoo Sequence has been successfully carried out in the southern part of Africa from the South Africa to Zambia, no palynological study has previously been attempted in Swaziland.

As the first attempt in Swaziland, a palynological analysis of coaly shale taken from DD 3 (from the lower part of the Lower Coal Zone to the middle part of the Upper Sandstone) was carried out in this investigation.

Samples were treated by ordinary Schultze method, but no pollen and spore were obtained and the residue was almost carbonized matter, therefore, samples were retreated by HCl-HF method.

As a result, a very few spores may be regarded as non-striate disaccate *(Pityosporites)* were recognized from the central part of the Upper Sandstone. Detailed identification is impossible because they were ill-preserved, but this spore has been reported in the Permian and younger formation. A few spores may be regarded as triletes and monosaccate were also existed, but no details are known because they are carbonized. Plate 7 shows microphotographs of disaccate.

Lack of pollen and spore in the samples may be due either to melting of vegetable materials caused by thermal effects of volcanic activities or that the pollen and spore were present originally in very small amounts.

The Karoo Sequence in Swaziland has been generally subjected to the thermal effects of the volcanic activities and palynological correlation is considered to be difficult.

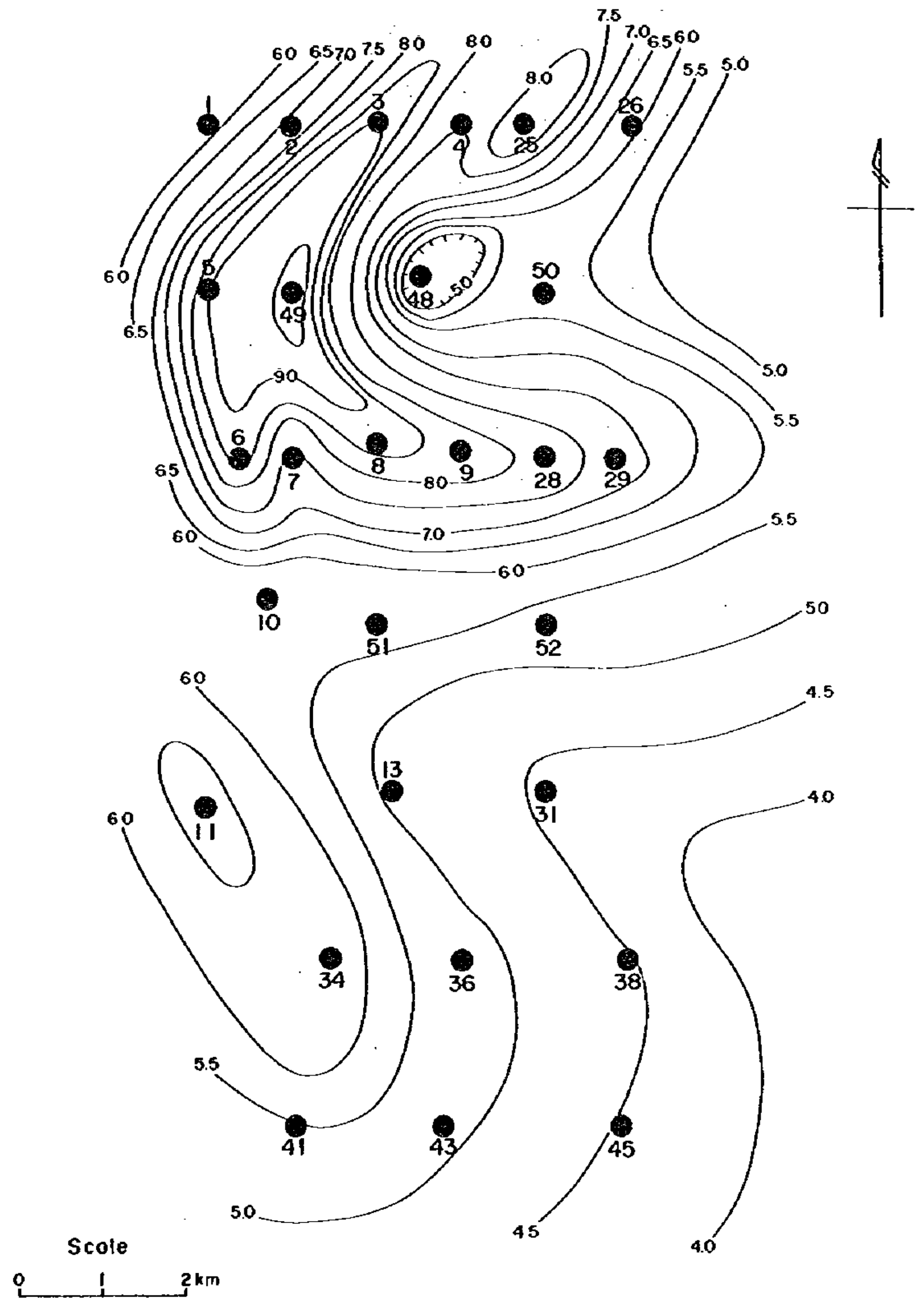


Figure 13. Coal Ratio, Lower Part of Lower Coal Zone, Middle Ecca.
(Showing coal ratio in percent)

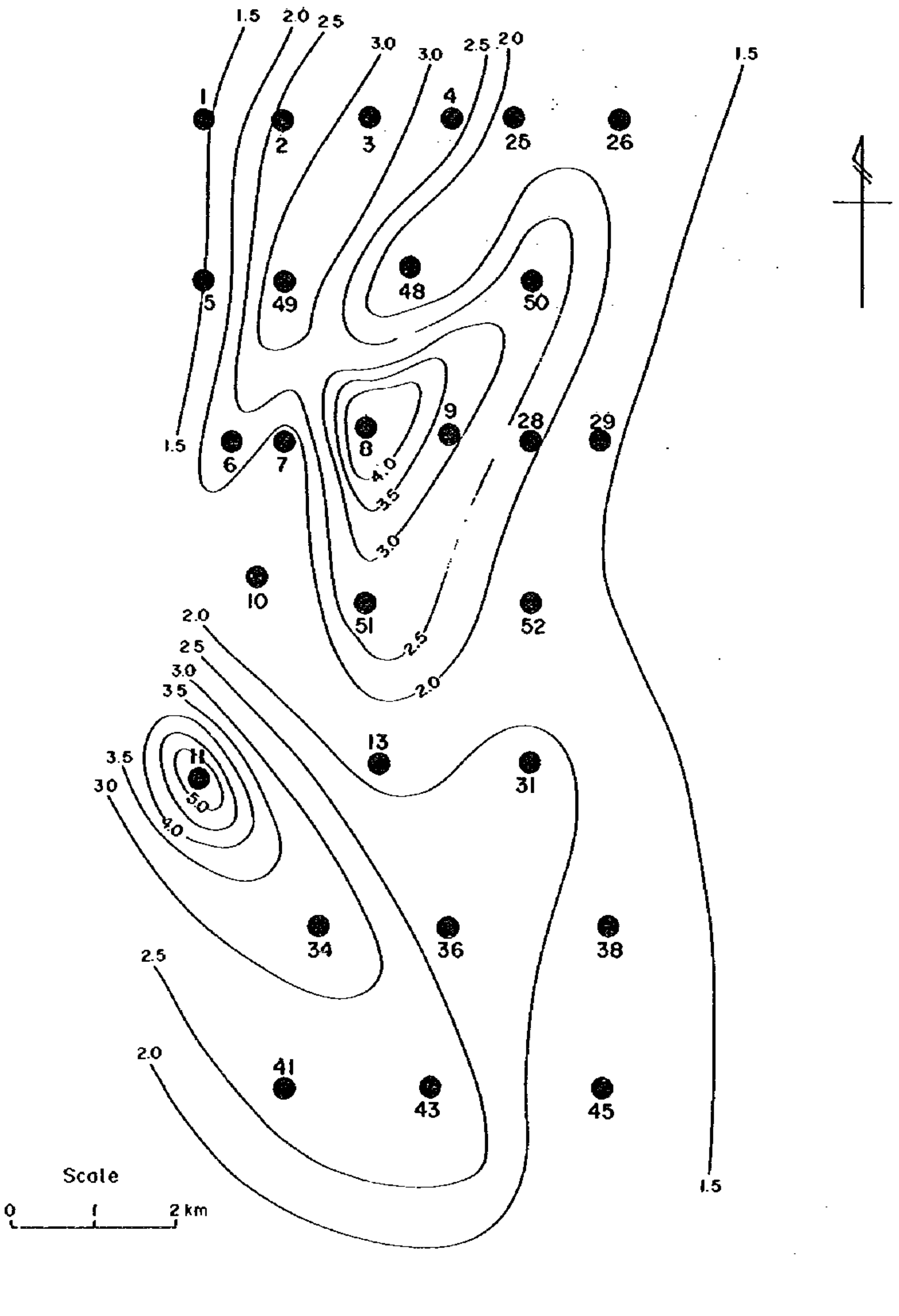


Figure 14. Coal Ratio, Upper Part of Lower Coal Zone, Middle Ecca. (Showing coal ratio in percent)

Plate 7. Photomicrographs of Palynomorphs

1. Part of Spore (Disaccate).
DD3, 65.0m, ×700.

2. Spore (Disaccate?)
DD3, 65.0m, ×700.

3. Spore (Disaccate?)
DD3, 65.0m, ×700.

1.

2.

3.

CHAPTER 5. MAGNETOMETRY SURVEY AND GEOPHYSICAL LOGGING

CHAPTER 5. MAGNETOMETRY SURVEY AND GEOPHYSICAL LOGGING

5.1 Magnetometry Survey

The magnetic intensity was measured by Chemtron G3 proton magnetometer at 5 or 10 m intervals along both north-south and east-west base lines crossed at the planned borehole site within the extent of 200 m. In case magnetic anomalies had been found around the planned site further magnetometry survey was done along lines 50 m apart from the base lines. On the basis of the data, the actual drilling site was determined in order to drill the minimum amount of dolerite.

As a dolerite dyke dipping eastwards was expected just west of the planned site of DD 26, actual drilling was carried out at 50 m east of the planned site where no magnetic anomaly was observed. As a result, no dolerite occurred up to the depth of 220 m, but a thick sill was encountered at the depth of 424 m (Fig. 15). In DD 11, distribution of three parallel dykes were expected and the drilling site was shifted to the location where drilling of these dykes was considered to be minimized, but a sill of 29 m in thickness was encountered at the depth of 7 m (Fig. 16). In DD 50, no magnetic anomaly was observed at the planned site, but the sill "B" (thickness is 22 m) appeared at the depth of 109 m (Fig. 17).

As mentioned above, though interpretation of conformation of the dolerite sill and intrusions at the deep part is difficult from the results of the magnetometry survey, but it is possible to identify the dyke near the surface. However, a systematic survey to cover all the investigation area is necessary to interpret the distribution of the dyke exactly.

5.2 Geophysical Logging

The geophysical logging of each hole was carried out after the drilling was finished (by BPB Instruments Limited).

Following five logs were recorded;

1. Gamma Ray
2. Neutron-Neutron
3. Caliper
4. Long Space Density (LSD)
5. Bed Resolution Density (BRD)

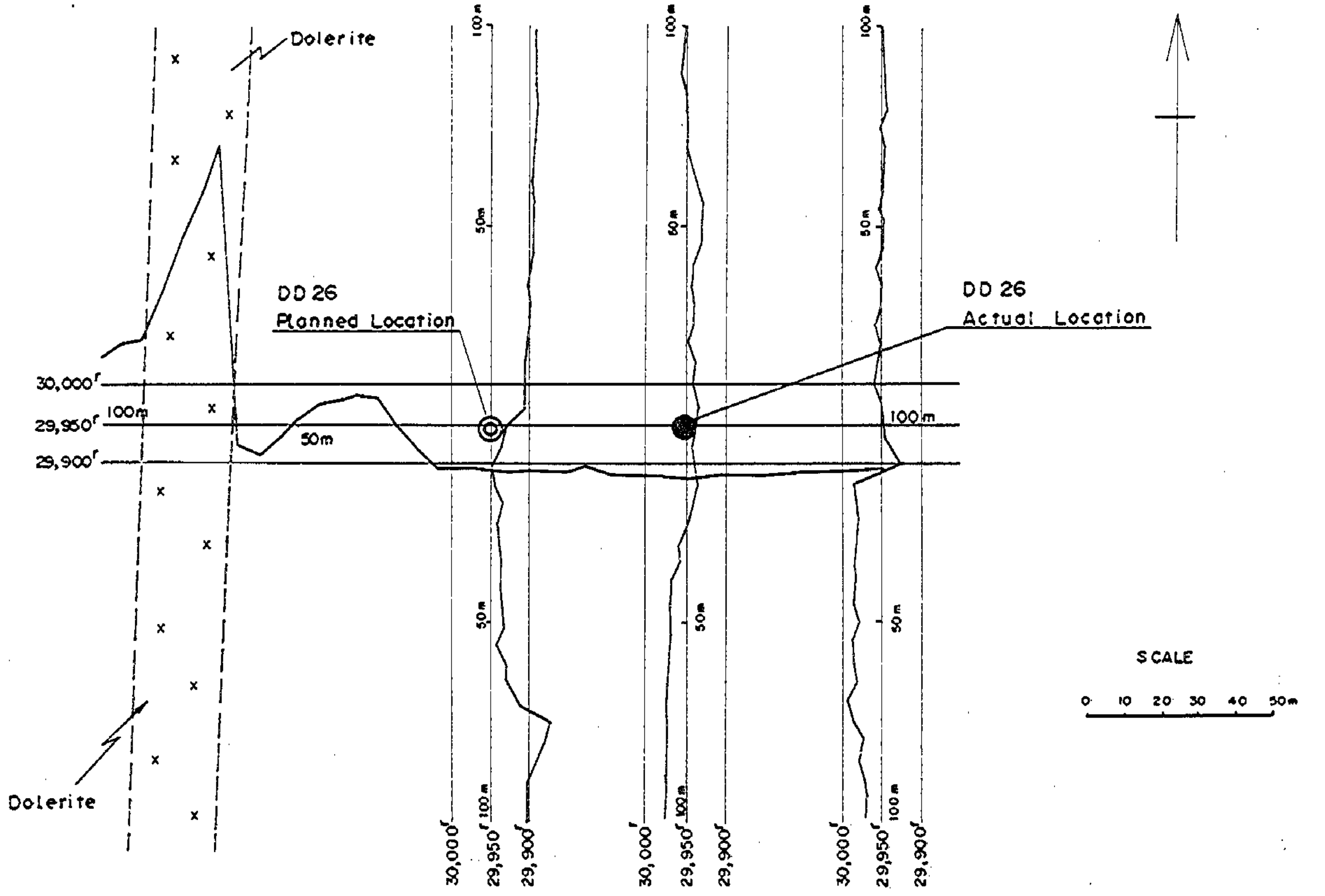
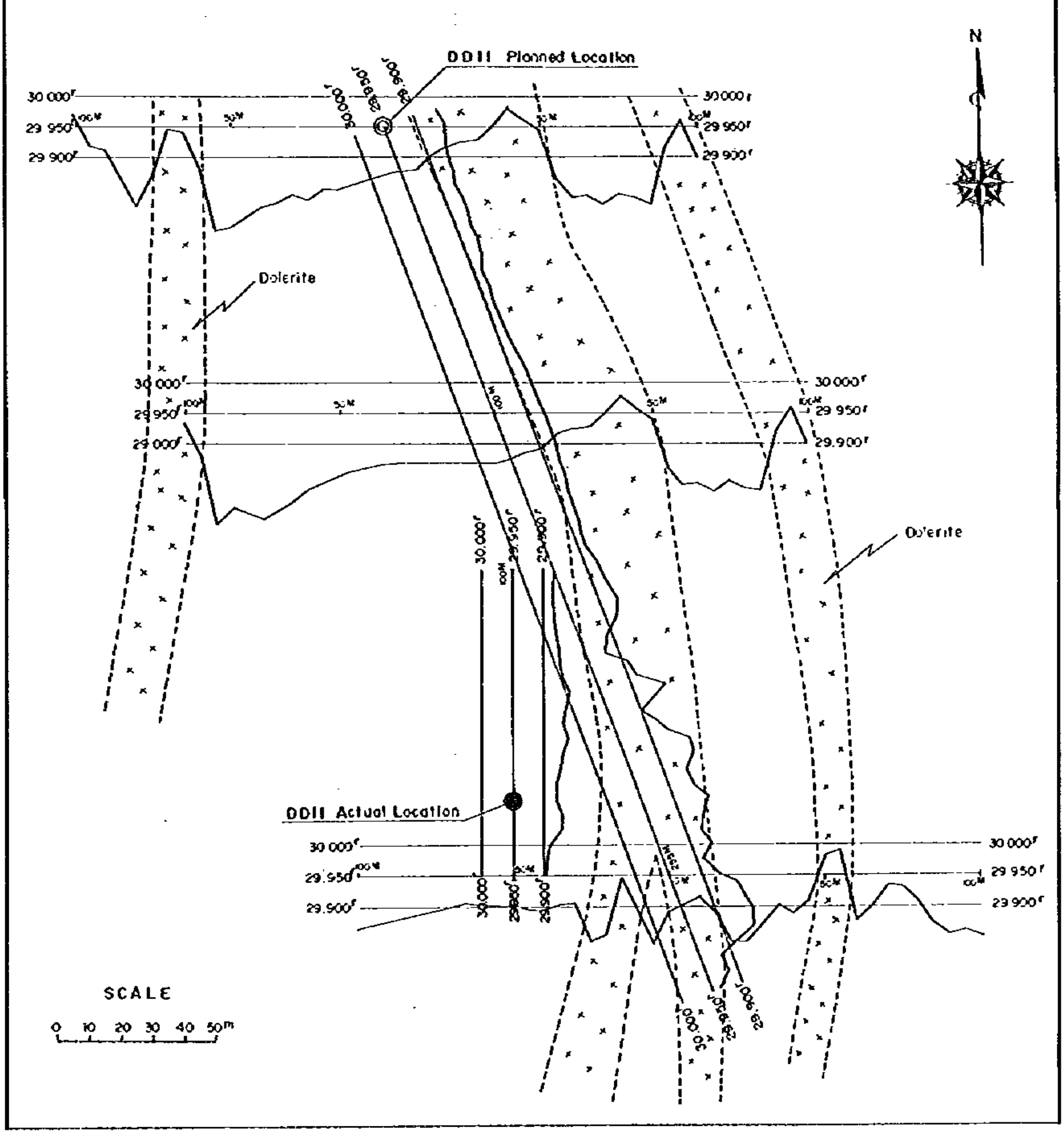


Figure 15 Magnetometry Survey at the site of DD26

Figure 16. Magnetometry Survey at the site of DD 11



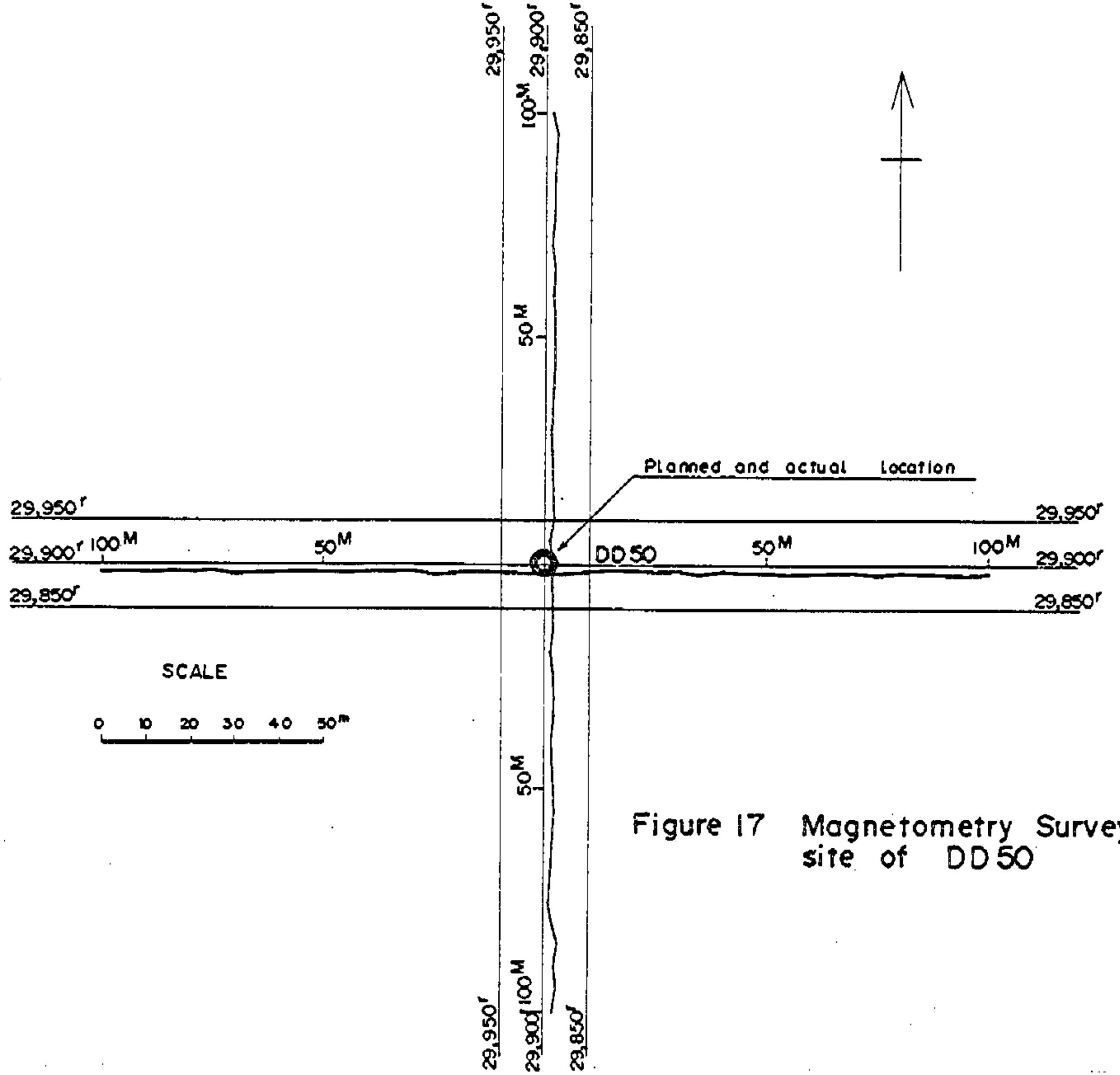


Figure 17 Magnetometry Survey at the site of DD50

Characteristic log responses for coal seam and dolerite are summarized as follows.

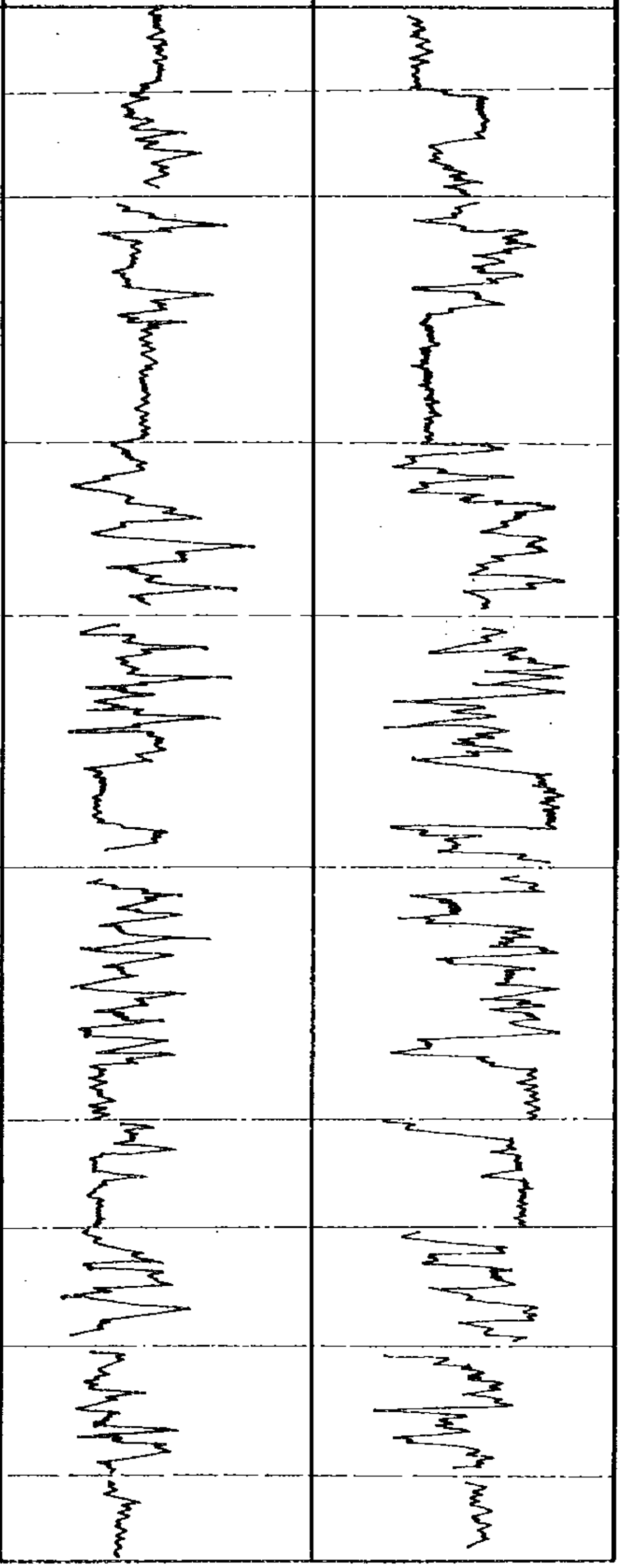
Coal Seam	Gamma ray :	very low radioactivity
	Density :	very low bulk density in both LSD and BRD, generally below 1.7 g/cm^3
	Neutron :	very low counts (high porosity)
Dolerite	Gamma ray :	very low radioactivity
	Density :	fairly high bulk density in both LSD and BRD, generally above 2.8 g/cm^3
	Neutron :	stable moderate to moderately high counts (low porosity)

Furthermore, the composite logs of the gamma ray and neutron-neutron show the following characteristic responses at specific horizons in the Upper and Middle Ecca Series (Fig. 18).

Horizon	Log Response
Upper Ecca Series Sandstone Zone (Zone 1, 3)	Neutron: Stable fairly high counts
Upper Ecca Series Shale Zone (Zone 2)	Gamma ray: Stable fairly high counts
	Neutron: Stable low counts
Upper Transition Beds uppermost sandstone formation	Gamma ray: Stable moderate counts

Figure 18. Schematic Profile of Geophysical Logging

Formation	Lithology	Gamma Ray API* (0 120 240)	Neutron-Neutron SNU (2h 3h 4h 5h)
Upper Coal Zone	Carbonaceous Shales and Coals Zone		
	Sandstone Zone		
Upper Transition Beds	Sandstone and Shale		
	Shale, Sandy Shale		
Upper Sandstone	Sandstone with Sandy Shale and Shale		
Lower Coal Zone	Sandstone, Sandy Shale and Shale		
	(Sandstone, coarse-grained)		
Upper Coal	Sandstone, Sandy Shale and Shale.		
	(Sandstone, coarse-grained)		
Intermediate Marker	(Sandstone, coarse-grained)		
Main Seam	Sandstone and Shale		
Footwall 3	Sandstone, Sandy Shale and Shale		
Basal Sandstone	Sandstone		



Remarks : * Hole Size Corrected

Horizon	Log Response
Upper Transition Beds lowermost shale formation	Gamma ray: Stable fairly high counts Neutron: Stable moderate counts
Above Upper Coal (sandstone formation)	Gamma ray: Stable moderate counts Neutron: Stable fairly high counts
Just above the Intermediate Marker (sandstone formation)	Gamma ray: Stable moderate counts Neutron: Stable fairly high counts
Just above the Main Seam (sandstone formation)	Gamma ray: Stable moderate counts Neutron: Stable fairly high counts
Basal Sandstone uppermost sandstone formation	Gamma ray: Stable moderate counts Neutron: Stable fairly high counts

As mentioned above, the geophysical logging is effective in distinguishing coal seams and dolerites. It also showed that geophysical logging can be employed as a useful means for the correlation of the beds in the Upper and Middle Ecca Series.

Drawing 11 shows the type profile of the geophysical logging in the Upper and Middle Ecca Series. Regarding the effects of the dolerite intrusions on the coal seams, the gradual burned-out of coal seam caused by the intrusion of the sill "A" in DD 8 is relatively well reflected in the density, gamma ray and neutron logs (Fig. 19) of that borehole.

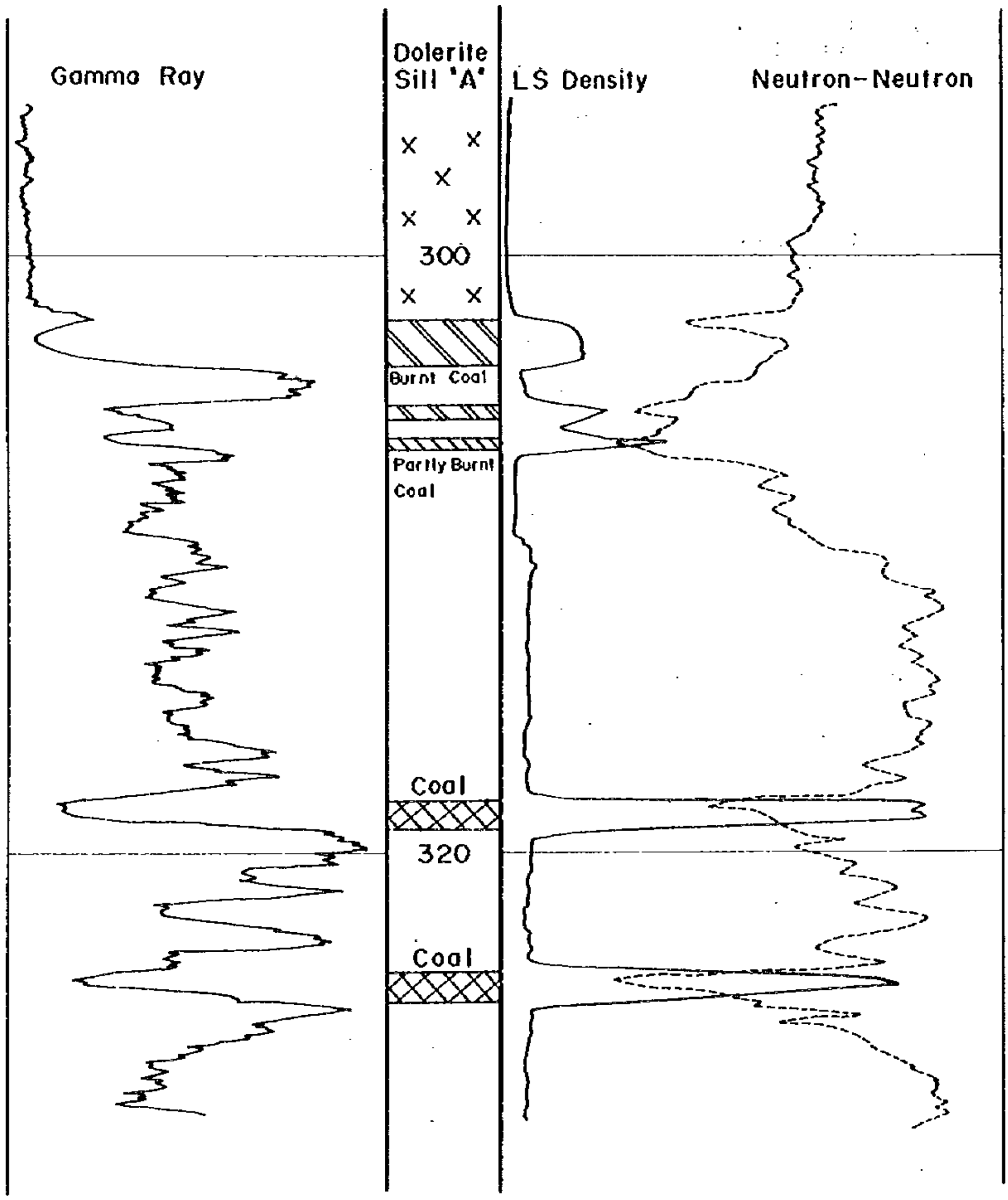


Figure 19. Geophysical Log Response over Coal Seams Metamorphosed by Intrusion (DD8, 296~329m)
Coal seams (Main Seam, Foot wall No.1, No.2 and No.3) progressively less metamorphosed by dolerite sill 'A'.

CHAPTER 6. COAL QUALITY

CHAPTER 6. QUALITY OF COAL

6.1 General Description

Coal seams of one meter and over in thickness were sampled for coal analyses. Almost all of the samples were analyzed in Swaziland (analyzed by Fuel Research Institute of South Africa), and some of them were halved and analyzed in Japan for cross-checking purposes. Total numbers of coal samples analyzed in Swaziland and Japan are 68 and 24 respectively.

At the time of sampling of coal seams, core samples were halved by core-splitter and one of them is served to the analysis. In case of thick coal seams, samples were obtained by dividing the seam into two or three parts.

Items of coal analyses and testing executed in Swaziland are as follows:

- Proximate analysis, Calorific value, Total sulfur and C.S.N. — for all samples
- Float and sink tests — for almost all of the Main Seam and some of the Intermediate Marker and Footwall 3 seam samples
- HGI, Ash fusion point, Petrographic analysis, Ultimate analysis — for seven samples of the Main Seam, five of the Intermediate Marker and four of the Footwall 3 seams

The results of these analyses are shown in Drawing 12a to 12c. In addition, the results obtained in Japan are shown in Table 9a – 9d.

6.2 Proximate Analysis, Calorific Value and Total Sulfur

Mean coal qualities on a dry-ash-free basis of the Intermediate Marker, Main Seam, and Footwall 3 seams obtained from 47 samples are calculated as follows:

Coal Seam	C.V. (kcal/kg) (, MJ/kg))	F.C. (%)	V.M. (%)	No. of samples
Intermediate Marker	8,321 (34.8)	90.4	9.6	10
Main Seam	7,949 (33.3)	90.9	9.1	24
Footwall 3	8,298 (34.7)	89.5	10.5	13

Table 9a. Results of Coal Analysis and Testing (tested in Japan)

	Hole Number	DD3	DD5				DD6	
	Coal Seam	Footwall 3	Intermediate Marker	Main Seam (1)	Main Seam (2)	Main Seam (3)	Main Seam (1)	Main Seam (2)
	Depth	261.15~263.03	139.29~141.35	162.97~164.92	164.92~166.91	166.91~167.96	284.77~286.18	286.18~288.50
Proximate Analysis (%)	Total Moisture	1.4	2.2	2.5	2.2	2.4	1.2	1.3
	Inherent Moisture	1.1	1.2	1.4	1.2	1.2	1.2	1.3
	Ash	35.3	19.4	45.1	15.9	10.7	22.0	11.2
	Volatile Matter	9.8	10.0	8.3	11.1	11.1	11.6	12.7
	Fixed Carbon	53.8	69.4	45.2	71.8	77.0	65.2	74.8
	Total Sulfur	3.6	0.5	0.2	0.4	0.5	0.4	0.4
Calorific Value (cal/g)		5,200	6,640	4,370	6,970	7,530	6,470	7,460
〃 〃 (MJ/kg)		21.8	27.8	18.3	29.2	31.5	27.1	31.2
Specific Gravity		1.75	1.55	1.79	1.49	1.46	1.55	1.47
Hardgrove Grindability Index		63	65	70	62	62	70	73
Ultimate Analysis (%)	C	56.5	73.4	49.1	75.8	80.6	70.0	80.6
	H	2.4	3.1	2.3	3.2	3.8	3.3	3.6
	N	1.3	1.6	1.3	1.8	2.0	1.7	2.0
	O	0.8	1.9	1.3	2.9	2.4	2.6	2.2
	Mineral Matter	35.6	19.6	45.8	16.1	10.8	22.2	11.4
	Combustible Sulfur	3.4	0.4	0.2	0.2	0.4	0.2	0.2
Ash (℃) fusion point	Deformation	1,280	1,250	1,380	1,290	1,300	1,400	1,290
	Hemisphere	1,410	1,290	1,450+	1,340	1,340	1,450+	1,330
	Flow	1,420	1,310	1,450+	1,360	1,390	1,450+	1,400
Ash Analyses (%)	SiO_2	44.66	59.96	64.04	51.33	47.89	59.17	45.26
	TiO_2	1.15	0.95	1.15	1.03	1.25	1.66	0.97
	Al_2O_3	24.58	19.13	24.72	26.16	26.16	27.05	21.52
	Fe_2O_3	19.16	7.62	2.25	6.69	7.41	3.23	14.14
	MgO	0.93	2.03	0.97	1.93	2.33	0.79	2.29
	CaO	2.83	6.11	1.55	7.63	9.36	4.86	9.80
	Na_2O	0.47	0.32	0.45	0.74	0.70	0.37	0.23
	K_2O	4.20	3.05	3.95	2.22	2.19	0.67	0.42
	P_2O_5	0.07	0.11	0.08	0.06	0.06	0.09	0.07
	SO_3	1.56	0.67	0.41	1.84	2.25	1.86	5.20

* Analysed on air dry basis

* Analysed by Tokyo Coal and Mineral Research Institute

Table 9b. Results of Coal Analysis and Testing

Hole Number		DD4		DD25				DD49
Coal Seam		Main Seam (1)	Main Seam (2)	Intermediate Marker	Main Seam (1)	Main Seam (2)	Footwall 3	Intermediate Marker
Depth		267.80-269.20	269.20-271.28	341.87-343.40	364.45-366.32	366.32-368.32	396.89-398.14	164.97-166.70
Proximate analysis (%)	Inherent Moisture	1.9	1.8	1.5	1.5	1.5	1.4	1.6
	Ash	21.5	12.6	21.0	14.0	19.7	22.0	18.0
	Volatile Matter	6.7	7.7	9.0	8.2	8.5	8.7	9.5
	Fixed Carbon	69.9	77.9	68.5	76.3	70.3	67.9	70.9
Total Sulfur		0.34	0.46	0.63	0.44	0.38	0.60	0.47
Calorific Value (cal/g)		6,360	7,220	6,450	7,150	6,560	6,380	6,780
〃 〃 (MJ/kg)		26.6	30.2	27.0	29.9	27.5	26.7	0
Specific Gravity		1.60	1.51	1.59	1.51	1.60	1.59	1.54
Hardgrove Grindability Index		47	43	56	56	65	59	63
Ultimate analysis (%)	C	71.5	80.7	71.9	79.2	73.1	69.3	74.6
	H	3.0	3.0	3.1	3.3	3.2	3.2	3.1
	N	1.3	1.6	1.3	1.7	1.4	1.5	1.5
	O	2.1	1.6	2.0	1.5	2.3	3.3	2.2
	Mineral Matter	21.9	12.8	21.3	14.2	19.9	22.3	18.3
	Combustible Sulfur	0.2	0.3	0.4	0.1	0.1	0.4	0.3
Ash fusion point (°C)	Deformation	1,320	1,320	1,250	1,240	1,220	1,450+	1,280
	Hemisphere	1,410	1,390	1,370	1,450+	1,380	1,450+	1,380
	Flow	1,450+	1,430	1,420	1,450+	1,430	1,450+	1,450
Ash analysis (%)	SiO_2	53.68	45.26	54.50	49.61	49.17	55.70	59.13
	TiO_2	0.87	1.02	0.91	1.00	0.67	1.28	1.00
	Al_2O_3	25.06	24.23	15.60	25.67	21.72	26.93	18.73
	Fe_2O_3	3.83	7.26	14.06	5.39	12.02	7.91	4.03
	MgO	1.20	1.81	1.69	1.78	2.22	0.93	1.33
	CaO	6.70	10.76	6.22	3.52	6.42	2.96	9.24
	Na_2O	2.68	2.96	0.25	0.39	0.26	0.52	0.21
	K_2O	3.52	2.68	3.05	1.65	2.96	1.36	3.73
	P_2O_5	0.09	0.09	0.07	0.08	0.08	0.07	0.06
	SO_3	1.71	3.32	3.16	5.44	3.83	1.96	2.00

Table 9c. Results of Coal Analysis and Testing

Hole Number		DD50		DD29		DD51		DD13	
Coal Seam		Main Seam (1)	Main Seam (2)	Main Seam (1)	Main Seam (2)	Main Seam (1)	Main Seam (2)	Main Seam	Footwall 3
Depth		387.35-388.60	388.95-390.37	413.25-414.70	415.42-416.62	353.92-355.11	355.83-357.71	334.21-336.30	384.69-385.73
Proximate analysis (%)	Inherent Moisture	2.2	1.8	1.7	1.7	6.6	3.0	4.3	1.1
	Ash	22.2	18.2	20.5	15.8	31.5	18.4	32.8	15.5
	Volatile Matter	8.5	7.4	7.6	6.6	5.6	7.3	4.5	10.6
	Fixed Carbon	67.1	72.6	70.2	75.9	56.3	71.3	58.4	72.8
Total Sulfur		0.38	0.52	0.48	0.50	0.02	0.26	0.02	0.63
Calorific Value (cal/g)		6,300	6,760	6,510	6,990	4,560	6,310	4,720	7,060
〃 〃 (MJ/kg)		26.4	28.3	27.2	29.3	19.1	26.4	19.8	29.6
Specific Gravity		1.61	1.53	1.59	1.53	2.16	1.70	2.15	1.53
Hardgrove Grindability Index		61	57	55	54	43	74	42	71
Ultimate analysis (%)	C	70.5	75.1	72.6	78.2	61.5	74.4	61.5	75.8
	H	3.0	2.9	2.9	2.9	0.9	2.0	0.9	3.6
	N	1.4	1.5	1.3	1.3	0.4	1.4	0.2	1.5
	O	2.2	1.5	2.1	1.2	3.4	3.1	3.2	3.0
	Mineral Matter	22.7	18.5	20.8	16.0	33.8	19.0	34.2	15.7
	Combustible Sulfur	0.2	0.5	0.3	0.4	0.1⁻	0.1	0.1⁻	0.4
Ash fusion point (°C)	Deformation	1,330	1,310	1,360	1,310	1,260	1,230	1,260	1,410
	Hemisphere	1,450⁺	1,450⁺	1,430	1,420	1,290	1,310	1,360	1,450⁺
	Flow	1,450⁺	1,450⁺	1,450⁺	1,450⁺	1,420	1,400	1,450⁺	1,450⁺
Ash analysis (%)	SiO_2	52.77	61.16	55.44	62.88	52.16	49.04	57.21	50.89
	TiO_2	0.98	1.07	0.91	1.15	0.53	0.72	1.00	1.08
	Al_2O_3	26.42	24.83	23.69	20.21	14.80	16.10	20.05	29.23
	Fe_2O_3	3.79	3.16	2.58	2.37	8.10	4.59	3.65	7.77
	MgO	2.67	1.71	1.72	1.28	7.97	4.09	2.38	0.96
	CaO	5.86	2.22	8.44	4.96	12.00	18.45	8.68	5.66
	Na_2O	1.08	0.56	0.27	0.25	3.10	1.94	3.21	0.26
	K_2O	3.31	3.52	3.66	3.75	0.50	1.66	3.03	0.57
	P_2O_5	0.08	0.09	0.07	0.07	0.09	0.08	0.10	0.15
	SO_3	2.35	0.95	2.47	2.38	0.10	2.65	0.19	3.09

Table 9d. Results of Coal Analysis and Testing

Hole Number		DD38	
Coal Seam		Intermediate Marker	Main Seam
Depth		418.31-419.49	439.37-441.42
Proximate analysis (%)	Inherent Moisture	2.3	1.6
	Ash	26.9	24.7
	Volatile Matter	7.9	8.9
	Fixed Carbon	62.9	64.8
Total Sulfur		1.12	1.25
Calorific Value (cal/g)		5,850	6,150
〃 〃 (MJ/kg)		24.5	25.7
Specific Gravity		1.69	1.63
Hardgrove Grindability Index		42	56
Ultimate analysis (%)	C	66.5	67.8
	H	2.2	3.1
	N	1.3	1.4
	O	1.5	1.5
	Mineral Matter	27.6	25.1
	Combustible Sulfur	0.9	1.1
Ash fusion point (°C)	Deformation	1,320	1,310
	Hemisphere	1,420	1,380
	Flow	1,450+	1,420
Ash analysis (%)	SiO_2	55.68	53.65
	TiO_2	0.96	0.77
	Al_2O_3	21.97	19.49
	Fe_2O_3	8.61	12.69
	MgO	1.61	1.56
	CaO	5.48	6.82
	Na_2O	0.78	0.36
	K_2O	2.39	2.01
	P_2O_5	0.08	0.07
	SO_3	1.99	2.21