RESULTS OF EXPLORATORY DRILLING FROM FEBRUARY 1992 TO JULY 1992, COAL RESOURCE EXPLORATION AND ASSESSMENT PROGRAM (COALREAP), THAR DESERT, LAKHRA SOUTH, INDUS PLAIN, AND ADJACENT AREAS, SINDH PROVINCE, PAKISTAN

Part I - Text

by

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Open-File Report 94-595

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and the U.S. Geological Survey, under the auspices
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PREFACE

This report was originally one portion of a proprietary administrative report that was prepared by the Geological Survey of Pakistan and the U.S. Geological Survey (USGS) for the U.S. Agency for International Development. As such it received a limited distribution within Pakistan as Geological Survey Project Report (IR)PK-108. Because of it's length, (IR)PK-108 has been divided into five parts for its release to the public by USGS. This part of the report contains introductory text that is meant to accompany the basic borehole data, which are presented in other reports as follows (borehole numbers in parenthesis):

Open-File Report 94-596-A	Indus Plain area (BN-1,KWH-1,KWH-2)
Open-File Report 94-596-B	Lakhra south area (LS-1,LS-2,LS-3,LS-4)
Open-File Report 94-596-C	Meting-Jhimpir extensions (SO-1,SO-2,SO-3,SO-4,SO-5)
Open-File Report 94-596-D	Thar Desert area (TP-1,TP-2,TP-3,TP-4)

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ABSTRACT

The results of drilling, including lithologic and geophysical logs, are presented for 16 coal exploration boreholes drilled in Sindh Province by the Geological Survey of Pakistan as part of a cooperative program with the U.S. Geological Survey and the U.S. Agency for International Development. This program began in 1985 and known as COALREAP. In this phase of exploration, conducted between February and July 1992, four holes were drilled in the southern part of the Lakhra coal field, five holes were drilled in geologic extensions of the Meting-Jhimpir coal field, three holes were drilled in the Indus Plain, and four holes were drilled in the Thar Desert. The Thar Desert holes confirmed the presence of a large coal deposit - by far the largest in Pakistan - that has no surface expression and is of yet undetermined stratigraphy, but whose existence was previously predicted by USGS and GSP investigations of water-well drilling. The coal intercepted in the other areas was thinner and deeper than anticipated prior to drilling, but the data from these holes include significant new stratigraphic information regarding future exploration prospects, notably the presence of coal in a horizon not previously recognized as coal-bearing, the Chilia beds of the Lakhra Formation, as well as important structural implications for the Indus Plain.

Most of the boreholes completed during this phase of drilling were cored from the top, and the core is being retained in Pakistan for further study by GSP. Density, natural gamma, neutron and caliper logs were run for most holes, and 92 samples were submitted for proximate and ultimate analysis, 40 of which were also submitted for trace element and oxide determinations. Interpretive studies including coal-bed correlations, reconciliation of core loss with geophysical logs, and results of laboratory analysis, will be presented in subsequent reports. A few samples were analysed in the field for gas desorption; these yielded very little gas and the data are presented without further analysis. Additional drilling recommendations are also included, and drilling in the Thar Desert to define the extent of the deposit continues.

PART I

SUMMARY OF DRILLING AND RELATED ACTIVITIES

by

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Introduction

Project background

Between August 1985 and June 1993, the United States Geological Survey (USGS) and the Geological Survey of Pakistan (GSP) engaged in a cooperative investigation of the coal resources of Pakistan, known as COALREAP (Coal Resource Assessment and Exploration Program). COALREAP was Component 2A of the joint Government of Pakistan (GOP) and United States Agency for International Development (USAID) Energy Planning and Development Project (EP&D)[1], which is financed by GOP, and by grants from USAID. USGS participation in the project was directed by a Participating Agency Service Agreement[2] (PASA) with USAID.

Coal development in Pakistan is currently limited to small-scale underground mining operations which generally support the brick-making industry. The expressed purpose of the EP&D project is to decrease Pakistan's reliance on imported oil. As such, the first two years of COALREAP exploration activiites were explicitly directed by the PASA to: (1) the delineation of the regional extent of the Lakhra and Sonda coal fields (fig 1),

[1]Project No. 391-0478 [2]PASA No. IPK-0478-P-IC-5068-00

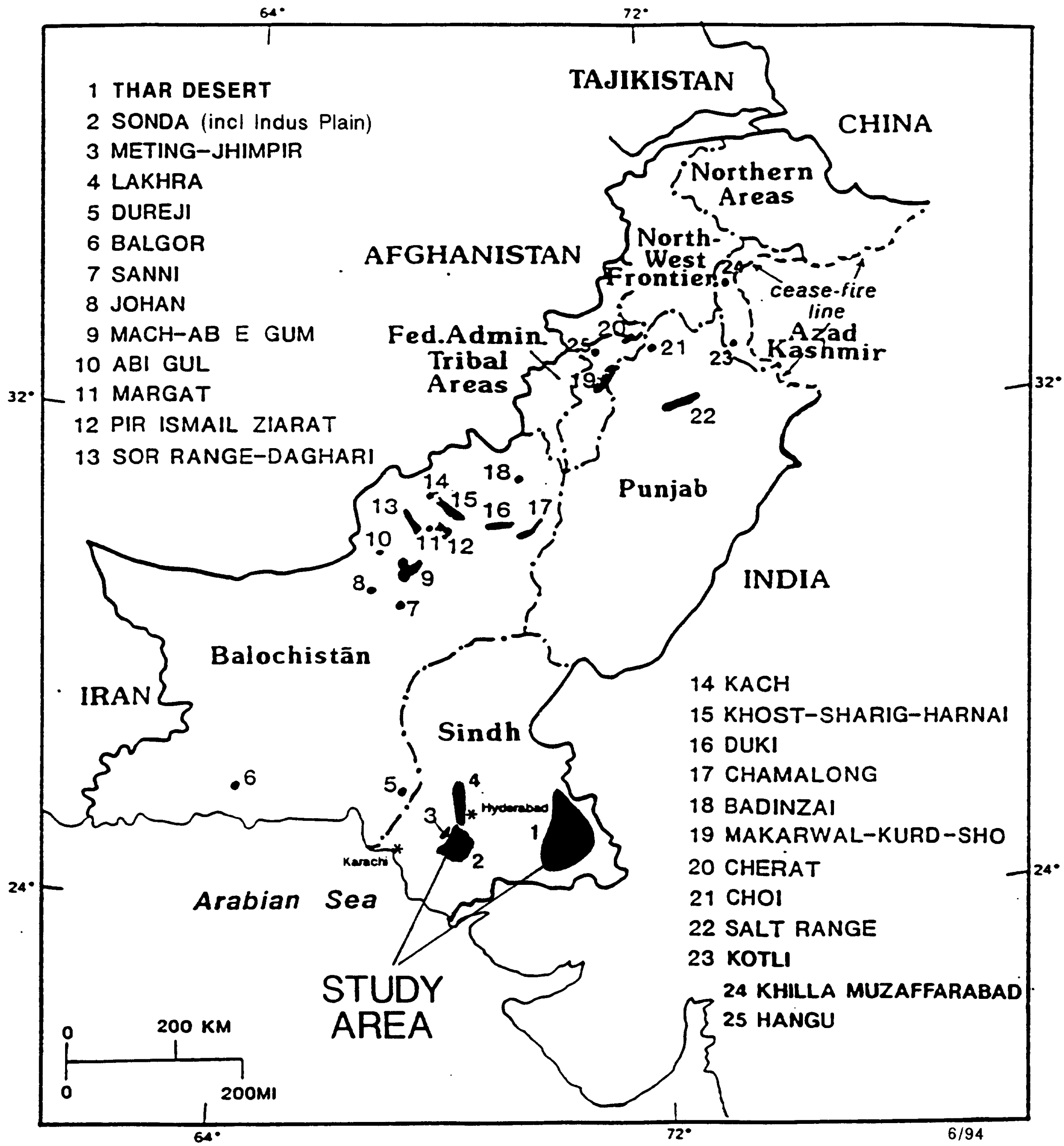

Figure 1. Index map, showing Pakistani coal fields and occurrences.

which were then the focus of considerable interest for expansion to larger-scale development, and (2) the development of a plan for exploration of other coal-bearing areas of Pakistan (the **National Exploration Plan**, Geological Survey of Pakistan and U.S. Geological Survey, 1988).

The generally promising results of the first phase of drilling in the Lakhra-Sonda area between 1985 - 1987 (see Schweinfurth and others, 1988) prompted two additional phases of drilling in the Sonda coal field between 1987 and 1989 (see Thomas and Khan, 1992; SanFilipo and others, 1994). No COALREAP drilling occurred in Sindh Province between February 1989 and January 1992, mostly due to the perception of security risks to field personnel from dacoity (a local term for banditry) and civil unrest. Although the initial exploration program had produced especially favorable results in the northwestern part of the Lakhra coal field, additional drilling there was prevented for the remainder of the project due to the security problem. COALREAP field activities outside of Sindh Province consisted for the most part of regional geologic studies, although USGS provided some advisory input to a few holes drilled by GSP in Punjab and Balochistan.

In March 1989, USGS and GSP began investigating reported occurrences of carbonaceous materials in water wells being drilled by various other agencies in the Thar Desert area of Pakistan (SanFilipo and others, 1992). These preliminary investigations indicated that the Thar Desert probably contained coal resources in quantities that dwarfed those previously discovered in Pakistan, and a modest (six borehole) COALREAP exploration program was proposed. A perception by other investigators that the carbonaceous material recovered from the water wells in Thar was not coal, but in fact modern Indus peat (A.H. Kazmi, oral commun., 1989), plus the perceived security and logistical problems, prevented the drilling program from materializing in 1990 as originally proposed.

By late 1990, the Energy Wing of the GOP Ministry of Planning and Development began expressing repeated concern over the lack of COALREAP drilling activity, and subsequently proposed a COALREAP infill development drilling program (i.e. closely spaced boreholes) in the Sonda coal field. As this plan was a departure from the reconnaissance exploration drilling mandated by the PASA and the National Exploration Plan, a compromise program was eventually negotiated by the concerned parties. The revised drilling plan consisted of: 1) four holes to be drilled in the northwestern part of the Sonda coal field (i.e. the Jherruck area) to determine the feasibility of mining from an engineering standpoint and the prudence of additional COALREAP drilling, 2) four boreholes in the Thar Desert, 3) four to seven boreholes to complete the PASA requirement to determine the extent of coal occurrence in the "zone between" the Lakhra and Sonda coal fields (hereinafter referred to as Lakhra south), as outlined in SanFilipo and others (1988, p. 2-113), and 4) eight to sixteen additional holes to be divided among: a) completion of the remaining recommendations for reconnaissance drilling in the Lakhra and Sonda fields as presented in SanFilipo and others (1988, p. 2-111 to 2-114), in particular those for the northwest Lakhra area, security permitting, b) closely spaced drilling in the Jherruck area, contingent on the results of item (1) above, and c) other areas, if new information so warranted. One shallow hole penetrating the Sohnari coal zone was also initially proposed for the purpose of calibrating recently purchased GSP geophysical equipment before beginning the main drilling program, which generally targeted deeper Bara Formation coals.

The proposed drilling was to be done by GSP between October 1991 and June 1992. The John T. Boyd Co. was retained to supervise and evaluate the Jherruck engineering holes (item 1 above, herinafter referred to as the JTB- holes), which were to be drilled simultaneously with the initial reconnaissance exploration holes supervised by USGS in the south Lakhra area.

Due to funding delays, drilling did not begin until January 5, 1992. For logistical reasons, it was decided to complete the four JTB- holes prior to commencing the COALREAP holes. A USGS geophysicist traveled to Pakistan in January in an attempt to calibrate the logging equipment using the JTB- holes and some nearby water wells which were simultaneously being drilled by the Sindh Arid Zone Development Agency (SAZDA). Several other changes to the proposed drilling plan were made for various reasons to be discussed in detail later in this report. This resulted in fewer holes being drilled in the Lakhra and Sonda coal fields than planned, and more holes being drilled in other areas, notably the Indus Plain and extensions of the Meting-Jhimpir coal field (fig. 1), the latter a Sohnari coal field.

Previous work

Geologic overviews and results of preCOALREAP exploratory drilling in the Lakhra coal field are covered in Ghani and others (1973), Memon and others (1976), Ahmed and others (1984b, 1986), and Boyd, (1986). Results of drilling for the first phases of COALREAP drilling in the Lakhra field are included in Thomas and others (1988) and Schweinfurth and others (1988), with coal resource estimates and an updated geologic summary in the latter.

Geologic overviews and the results of preCOALREAP drilling in the Sonda coal field are included in Ahmed and others (1984a, 1986). The results of the first three phases of COALREAP drilling in the Sonda field are contained in Thomas and others (1988), Landis and others (1988), and SanFilipo and others (1989). Coal resource estimates and updated geology are included in Thomas and others (1992) and SanFilipo and others (1994).

A geologic overview of the Meting-Jhimpir coal field is presented in Ahmed and others (1986), and the results of some COALREAP and preCOALREAP drilling in Meting-Jhimpir are presented in Schweinfurth and others (1988).

Descriptions of coal occurrences in water wells drilled in the Thar Desert and the geology of adjacent areas are discussed in SanFilipo and others (1992). The potential for the occurrence of coal in the Indus Plain is briefly discussed in the National Exploration Plan (GSP, 1988) and SanFilipo and others (1988).

A summary of COALREAP exploration drilling in Sindh Province prior to the holes included in this report is contained in table 1.

Present study

This study includes the results of COALREAP drilling

Table 1. Summary of COALREAP drilling through July 1992, Sindh Province, Pakistan.

Driller	Dates	Field (area)	Series Prefix	Number of holes
GSP*	1985	Lakhra (north)	L-(/85)	4
IVCC	1986 - 1987	Lakhra (north)	UAL-	10
		Sonda (north)	UAS-	9
		Sonda (south)	UAT-	9
		Sonda (east)	UAK-	3
		Meting-Jhimpir	UAJ-	1
IVCC	1987 - 1988	Sonda (east)	UAK-	13
GSP	1988 - 1989	Sonda (north)	JK-	20
GSP**	1992	Sonda (north)	JTB-	4
GSP***	1992	Lakhra (south)	LS-	4
		Meting-Jhimpir (extensions)	SO-	5
		Sonda (Indus Plain)	BN-	1
		(Indus Plain)	KWH-	2
		Thar Desert	TP-	4

GSP = Geological Survey of Pakistan

IVCC = Indus Valley Construction Company, Lahore (contract drillers)

*interim drilling program funded by USAID prior to USGS supervised contractor drilling; 10 GOP funded holes were also drilled by GSP in the northern Sonda field between 1985 and the start of COALREAP contractor drilling in April 1986, some of which were geophysically logged by COALREAP.

**holes drilled under the supervision of John T. Boyd Co.

***this report

completed during PASA year 7 (ending July 31, 1992). Actual drilling activities covered by this report took place between February 19, 1992 and July 5, 1992; the report does not include the results of GSP drilling activities conducted between January 5, 1992 and February 8, 1992 under the supervision of the John T. Boyd Company with non-PASA EP&D component 2A funds.

The report is organized in two parts. Part I contains introductory material and a summary of drilling related activities for the entire drilling program. Part II contains basic lithologic and geophysical data arranged according to the geographic area or the stratigraphic target of the drilling. The subdivisions for Part II are: a) Indus Plain (3 holes), b) Lakhra south (4 holes), c) Meting-Jhimpir extension - Sohnari coals (5 holes), and d) Thar Desert (4 holes).

The number and location of the boreholes actually completed differs somewhat from the drilling plan outlined on p.6 of this report. The primary reasons for the departure from the drilling plan were: 1) The security situation would not permit drilling in northwest Lakhra or the northernmost part of south Lakhra; the difficulty in choosing suitable drilling sites in south Lakhra was exacerbated by the presence of army maneuvers there; 2) non-COALREAP drilling that had been proposed for the Khorewah area of the Indus Plain could not be financed by GSP and was therefore included in COALREAP. This drilling had been planned by GSP based on oil and gas records not available to USGS at the time; 3) Initial indications from the JTB- holes suggested that the tract did not warrant more USAID-financed drilling, especially in light of the favorable results of the first few Thar holes;

and 4) Unforseen logistical problems prevented the original drilling schedule to be followed; these included the inability of the truck mounted Acker rigs to operate in the Thar Desert, and the length of time required to break from drilling activities for various Pakistani holidays, which was unforeseen by USGS. The shallow Sohnari holes, which could be completed in a few days, were drilled in order to keep crews active up to holiday breaks and to utilize the Acker rigs after they failed to operate successfully in Thar.

Purpose and scope of work

The purpose of this report is to present basic lithologic and geophysical data as recorded at the drill site. The data presented in this report are considered preliminary and subject to change. In particular, coal intercepts have not been reconciled with geophysical logs. Where warranted by the drilling results, interpretative reports, including coal geology, coal-bed correlations, coal-quality analysis, and coal-resourcé calculations, will be forthcoming from GSP and/or USGS, subject to the availability of funding.

Acknowledgements and responsibilities

A drilling project of this magnitude requires the coordinated efforts of a large number of people, not all of whom can be individually acknowledged in this space. In particular, the GSP drilling crews and the well-site geologists who endured the heat, dust, and dacoits on a daily basis deserve special recognition. The efforts of Mr. Rauf Gul of USAID and Mr. John Huckey of the

U.S. Consulate in securing armed escorts for the drilling camps and travel to the field were greatly appreciated, as was Mr. Saleem Wahidy, DIG Police, Hyderabad Range, for their provision. The efforts of Major Bajwa, HQ 18 Pakistan army division, in securing permission to drill within the Kotri Firing Range, were also greatly appreciated. The information provided by the Sindh Arid Zone Development Authority (SAZDA), particularly Chief Hydrologist Mr. Abdul Khalique Shaikh, regarding logistics and existing data in the Thar Desert was critical to the major coal discovery there. The staff of the USAID rest house in Hyderabad for their continued support of the project was also greatly appreciated.

USAID funds for this drilling program were provided through a Project Implementation Letter (PIL). This differed from previous USAID-sponsored GSP drilling in that funds were provided for salary and daily living allowances for GSP personnel in the field in addition to the operational funds (generally limited to consumables such as diesel fuel and drilling mud) that prior drilling programs were restricted to. A list of critical USGS GSP project personnel and their responsibilities are shown in tables 2 and 3 respectively.

J.E. Fassett was responsible for coordinating GSP, USAID and USGS activities. Zaki Ahmed was the overall program manager for GSP and was responsible for, among other things, GSP personnel assignments. N.A. Durrani and R. Siddiqui were responsible for administration of the PIL and approval of expenditures. SanFilipo was responsible for selecting borehole locations and drilling depths, with the exception of the Khorewah holes, which

Table 2. USGS project personnel and responsibilities

NAME	RESPONSIBILITY
James E. Fassett	Resident team leader Pre-project planning Drilling oversight (Khorewah)
Nasir A. Durrani	Pre-project planning Administration of PIL expenditures
Mr. Asrarullah	Process PIL approval
John R. SanFilipo	Pre-project planning Field supervisor (except Khoerwah) Report coauthorship
Douglas C. Muller	Geophysical technician

Table 3. GSP personnel and responsibilities.

NAME	RESPONSIBILITY
Zaki Ahmed	Project coordinator
Razi Siddiqui	PIL administration
Rafiq A. Khan	Field supervisor (Thar) Report coauthor
Abbas A. Shah	Field supervisor Report coauthor
Ghazanfar Abbas	Field supervisor (Khorewah)
Altaf H. Chandio	Well-site geologist, report coauthor
Shafique A. Khan	- do -
Mohammad A. Tagar	Well-site geologist
Ghulam Sarwar Lashari	- do -
Abdul Rahim Memon	- do -
Ch. Mohammad Anwar	- do -
Altaf A. Khan	- do -
Zameer M. Khan	- do -
M. Dawood Khan	- do -
M. Riaz Khan	- do -
M.R. Kazmi	Director of drilling operations
Syed A. Ashraf	Senior drilling engineer
Mehtab-ur-Rahman	Geophysicist, Logging equipment operator
Nizamani	- do -
Huda	- do -
Inayat H. Shah	Surveyor
Sarwar M. Shah	-do-

were the responsibilty of Fassett and GSP. Day to day field activities were supervised by SanFilipo, Rafiq A. Khan (through April), and Abbas A. Shah, with the exception of the Khorewah holes, which were supervised by Ghazanfar Abbas. Syed Ashraf coordinated drilling logistics from Karachi, under the supervision of M. R. Kazmi (Quetta). D.C. Muller spent about one month during the JTB- and initial COALREAP drilling assist GSP in setting up the geophysical logging units.

Drilling Summary

Location and access

The project area is located in southern Sindh Province, Pakistan. The areas drilled include portions of the Thar Desert, Lakhra, Sonda and Meting - Jhimpir coal fields, and adjacent areas (fig. 1). Borehole locations are shown in figures 2 - 4.

The LS- series of boreholes were drilled in the in the southern part of the Lakhra coal field, along the axial trace of the Lakhra anticline (fig. 2), for the purpose of filling in the data gap between the producing part of the Lakhra coal field and the already densely drilled Sonda coal field (figs. 2 and 3). The Lakhra south area is located within a few kilometers from Hyderabad and is accessable by well-maintained dirt roads. The rocky flats and isolated mesas that characterize the area make it much more accessible than the more rugged northern part of the Lakhra field, as well as offering less cover for potential dacoit activity. However, much of the area is under military reservation and requires permission for use.

As previously explained, the SO- series of boreholes were

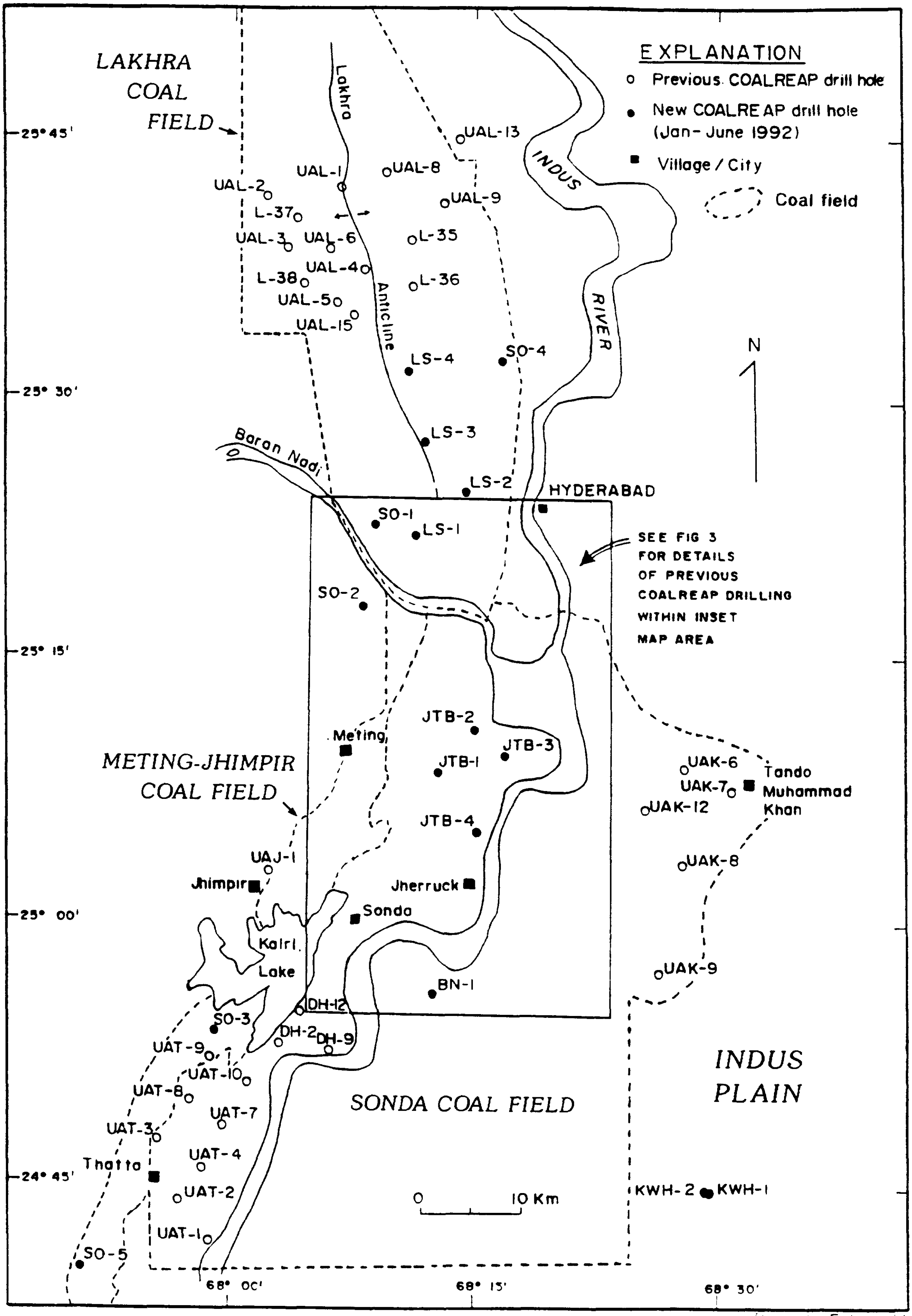

Figure 2. COALREAP borehole locations for the Lakhra, Sonda, and Meting-Jhimpir coal fields and adjacent areas. Coal-field boundaries are from SanFilipo (in prep).

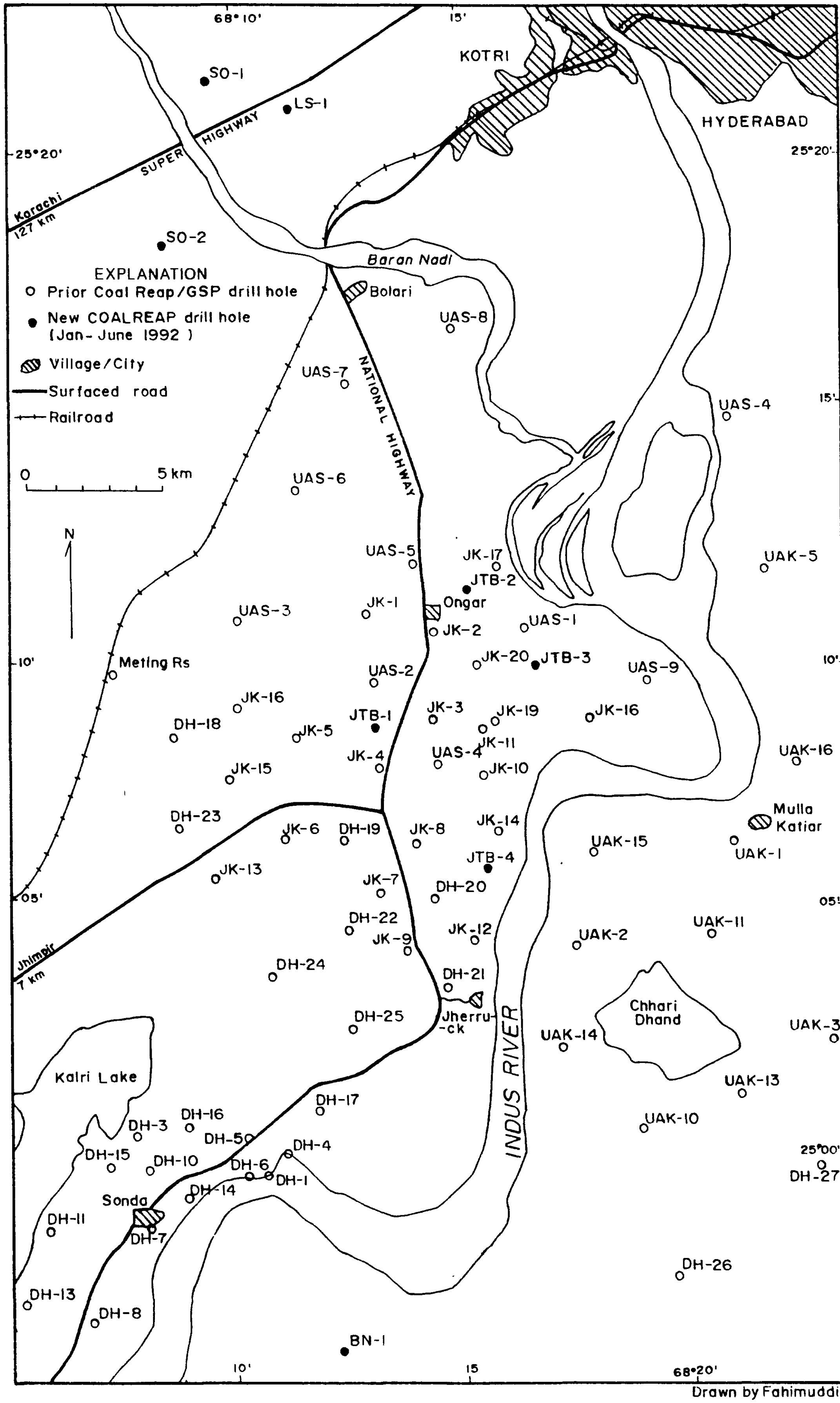

Figure 3. Detailed borehole location map, northern part of the Sonda coal field and vicinity.

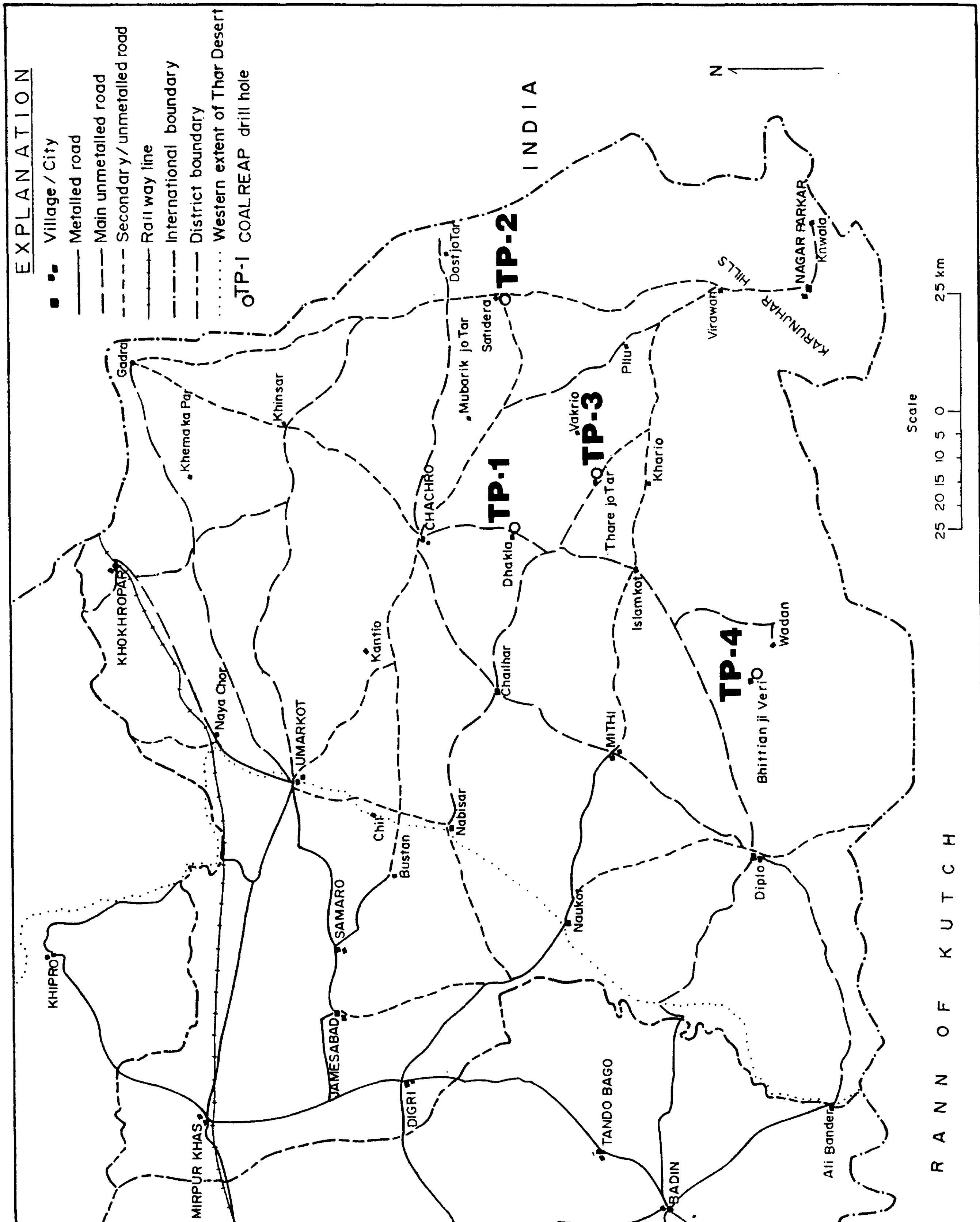

Figure 4. Location of COALREAP boreholes drilled in the Thar Desert between February and July, 1992.

shallow holes testing Sohnari coals, which are generally much thinner and deeper than the Bara Formation coals of the Lakhra-Sonda coal fields. These holes were drilled along the outcrops of Eocene rocks which extend northward and southward from the producing Meting-Jhimpir coal field (fig 2). These areas are characterized by rocky flats and isolated mesas similar in character to the Lakhra south area, and they are generally easily accessible from the National and Super Highways (fig. 2) by well-maintained dirt tracks.

Boreholes KHW-1, KHW-2, and BN-1 were drilled within the irrigated portions of the southern Indus Plain (fig. 2). This area is densely populated and contains numerous well-maintained roads. Although the last few hundred meters of approach to these holes is difficult due to irrigation dikes, they are otherwise easily accessible from metalled (paved) roads. Although well-within the Indus plain, and over 30 km from the nearest Indus River crossing, BN-1 is located within the Sonda coal field as defined by Ahmed and others (1984).

The Thar Desert area is characterized by semi-stable sand dunes typically up to 80 m high. North of Khokhropar (fig. 4) the dune fields are dominated by northeast-southwest trending seifs typically up to 25 km long; south of Khokhropar barchan dunes several kilometers in length dominate. The interdune areas are characterized by playas. The only metalled road in the southern part of Thar extends from Naukot to Mithi (fig. 4). The main dirt tracks are somewhat stabilized by heavy use, but four-wheel drive is required for small-vehicle travel in the desert and all-wheel drive is required for truck-mounted drilling rigs.

Public transportation in the desert is provided by surplus World War II vintage U.S. army trucks. These vehicles can be hired (rented) in the larger villages and can easily transport a skid mounted drilling rig.

Data from the JTB- series drill holes are not included in this report, but the borehole locations are shown in figs. 2 and 3 for completeness. The results of the JTB- drilling are discussed in John T. Boyd Co. (1992), and basic drilling data is available in GSP files.

Drill-hole coordinates in the Survey of Pakistan metric rectangular grid system are shown in table 4, along with collar elevations in meters. Hole locations were surveyed by GSP surveyors using a theodolite to triangulate from control points for which the Survey of Pakistan publishes elevations and relative horizontal distances. Hole coordinates were then computed trigonometrically. The accuracy standards for this level of survey are about +/-5 m horizontally and +/-1 m vertically (Sarwar M. Shah Khan, Sr. Photogrammetrist, GSP, oral communication, 1989), but the numbers in table 4 are recorded to somewhat greater precision, exactly as provided by the surveyors. It should be noted that the surveyed coordinates of some holes, notably SO-3 and BN-1, vary slightly (a few hundred meters) from the locations recorded on topographic sheets during drilling. It is therefore advisable that the locations in table 4 be field checked prior to any additional drilling in immediate areas.

Drilling operations

Drilling was done by GSP crews using GSP-owned equipment.

Table 4. Surveyed drill-hole coordinates and elevations, COALREAP drilling from February through July, 1992. Boreholes drilled under the supervision of the John T. Boyd Co. (JTB- holes) are not shown.

DRILL HOLE	EASTING* (meters)	NORTHING* (meters)	GROUND ELEVATION (meters above MSL)
BN-1	2159103	810189	14.0
KHW-1	2187089	787206	9.6
KHW-2	2186838	787742	10.6
LS-1	2159165	855380	56.0
LS-2	2165211	861810	55.2
LS-3	2161903	867513	57.6
LS-4	2161393	875223	81.0
SO-1	2156334	856676	60.4
SO-2	2154581	850422	56.4
SO-3	2136513	805516	29.3
SO-4	2170344	875422	28.7
SO-5	2122510	781534	34.5
TP-1	2365892	802144	78.0
TP-2	2415787	803082	89.6
TP-3	2376377	781018	73.7
TP-4	2333256	755653	19.8

*Survey of Pakistan rectangular grid system

Two Longyear-44 and one Longyear-38 skid-mounted drilling rigs and two Acker WA III-C truck mounted rigs were employed. The Acker rigs were purchased for GSP by USAID; the Longyear rigs were upgraded by USAID. Drilling was by continuous wireline coring or conventional rotary non-coring methods. For non-coring intervals a tricone roller bit was generally used. Diamond HQ- and NQ-size bits were used for cored intervals. Kwik Thik bentonite and CMC polymer mud was the usual drilling medium, occassionally supplemented by locally purchased additives or Johnson Revert.

Drilling operations were generally conducted around-the-clock in three eight hour shifts, although mid-day operations were generally suspended after May due to extreme temperatures. One senior drilling engineer and one drilling foreman supervised the overall operation of each rig. Each shift was supervised by a junior drilling engineer. A GSP geologist was normally present during drilling operations. SanFilipo visited each site (except TP-1) on an intermittent basis to observe the core and drilling progress and to pick up coal samples for shipment to the U.S., but the day-to-day operations and lithological and geophysical logging were conducted by GSP personnel.

USAID financed "operational" costs of the project. This essentially equates to outlays for consumable drilling supplies; these include petroleum-oil-lubricants (POL) and maintenance for drilling machinery and ancillary vehicles, drilling fluids, mud-pump fittings, cement, core boxes, and consumable "foreign exchange" drilling supplies which must be purchased from abroad, such as core barrels, bits, reaming shells, core lifters, casing shoes and casing. For this project, USAID also financed salary and daily living allowances for GSP personnel in the field. USAID also funded "commodity-related services" incidental to drilling consumables, such as rental of water tankers, pickup trucks and other necessary vehicles not available from GSP, and hire of local laborers for digging mud pits and access roads.

Drilling operations began with a Longyear-44 at TP-1 on February 1, 1992. Other rigs were deployed to this project as they were freed from operations at the JTB- holes in Sonda. Operations with an Acker rig began at LS-1 on 19 Feb 92. The difficulty in obtaining compressors to perform pumping tests at the JTB- holes caused some delay in shifting the rigs. A Longyear 44 began operations at LS-2 on March 1, and the second Acker spudded LS-3 on 14 March. The Longyear 44 remained in Thar for the life of the project and completed 3 holes. The second Longyear 44 was shifted to Thar to complete TP-4 after several attempts to deploy an Acker to the desert failed; the three-axel Ackers do not have power to the front axel and were not able to travel in the sand. After completion of the LS- holes, the Ackers were deployed to drill shallow holes in order to keep them busy for the life of the project.

The Khorewah holes were originally intended to be part of a GSP drilling program distinct from COALREAP. Because GSP could not finance the holes, the USGS Resident Team Leader agreed to include these holes in COALREAP PIL and assume responsibility for their supervision. A Longyear 38 was deployed from Lahore and began drilling KHW-1 on March 7, which was drilled just outside of a fenced gas well that had reported a very thick and shallow coal bed. The first coal intercepted in KHW-1 was much deeper and thinner than that reported in the gas well, so a second hole was drilled less than 1 km from the first, more-or-less on the opposite side of the gas well. When it became clear that both holes were nearly barren, the operation shifted to the Sonda coal field to drill BN-1 under the supervision of SanFilipo. Although not considered a high-priority hole, BN-1 was included in the drilling program because it was the only remaining hole necessary to complete USGS recommended drilling in the Sonda coal field, and was very easily accessible by the rig already deployed in Khorewah.

Drilling operations were scheduled to break for the observence of Eid-ul-Fitr during the last week of March through the first week of April. LS-1 and LS-2 were completed on March 11 and March 17 respectively. It was originally intended that these rigs would shift to northwest Lakhra and set casing before the holiday break, but those plans were abandoned due to the security situation. In order to keep the rigs operating, two unplanned shallow Sohnari tests, SO-1 and SO-2, were drilled in lieu of beginning holes in northwest Lakhra that would be too deep to complete before the break (unfortunately the rig at SO-1 broke down and the hole had to be reentered after the Eid break). The plans to drill north of LS-4 were eventually abandoned altogether due to the security situation (specifically a kidnapping and shootout at one of the operating mines in northwest Lakhra and an armed attack on a USGS field party traveling some 50 km north of the intended drilling area).

Boreholes LS-3 and LS-4 are located within the Kotri Firing Range, which is permanently occuppied by a few personnel of the Pakistan Army for small-arms practice, but is also the site of periodic heavy artillery and tank maneuvers. LS-3 and LS-4 were located on the axial trace of the Lakhra anticline in order to keep drilling depths to a minimum. A misunderstanding between the Army, the USGS supervisor, and the drilling crews resulted in the necessity to suspend drilling at LS-4 from April 26 to May 21 during live-round tank maneuvers. The rig was shifted to drill SO-4 during this period. LS-4 was reentered on May 21 but abandoned 164 m short of the target depth on June 3 for the Eid-ul-Azha celebration. Plans may have been made by GSP to reenter the hole and remove stuck casing and rods and possibly complete the hole to total depth after the formal completion of this project. Drilling at TP-4 also broke for Eid in early June, but was reentered and completed in early July.

Despite the usual presence of eight or ten armed guards at the drill camps, and armed escorts traveling with most vehicles, a number of security incidents worth noting took place. In particular, a rented pickup truck occuppied by three GSP personnel was hijacked by persons armed with automatic weapons while enroute to JTB-4, and a number of firing incidents took place at various drill sites, notably LS-2. In addition to this, several GSP vehicles were confiscated by the Army during the quasi-martial law that was declared in Sindh towards the end of the drilling program. All of these factors, along with the problems at LS-4 and several "strikes" by GSP drivers and drilling crews, extended the drilling project well beyond its anticipated timeframe.

Drilling statistics including depths and core recovery are shown in table 5. With the exception of KHW-1 and KHW-2, SanFilipo had the responsibilty of picking the initial core point and the total depths for this drilling project. Past experience with drilling conditions in Sindh has proven that for this type of diamond drilling, the real costs of coring hardly exceed those of noncoring (see SanFilipo and others, 1989). For this reason, holes spudding in bedrock were cored from at or very near the top of the hole for this phase of drilling. In the Thar Desert, the drillers were instructed to begin coring at 55 m or the first occurrence of bedrock, whichever came sooner, or before that, at the discretion of the driller.

Because the main purpose of the LS- series boreholes was to establish a coal-bed correlation scheme between the Lakhra and Sonda fields, it was imperative that these holes penetrate both the "lower" and "upper" coal zones of SanFilipo and others (1988). These holes are therefore relatively deep, with the exception of LS-4 which was abandoned before reaching the target depth of 400 m. The general target depth in the TP- holes was to penetrate at least 30 m of the thick sand that underlies the main coal zone in SAZDA TH-5 (SanFilipo and others, 1992). This target was met at TP-1, which twinned SAZDA TH-5, and probably met at TP-4, but TP-2 was barren and unexpectedly bottomed in granite, and TP-3 intercepted granite just below the coal. The target depth of the SO- holes was to penetrate a few meters of

Table 5. <u>Drilling statistics</u>

Drill Hole	Total Depth (m)	Non-core drilling (m)	Core drilling				Core recovered				Percent core recovery			
			HQ (m)	NQ (m)	Total (m)	Cumulative total (m)	HQ (m)	NQ (m)	Total (m)	Cumulative total (m)	HQ	NQ	Total	Cumulative total
BN-1	213.96	25.90	188.06	-----	188.06	188.06	108.29	-----	108.29	108.29	58	--	58	58
KWH-1	137.31	3.35	101.93	32.03	133.96	322.02	27.29	12.94	40.23	148.52	27	40	30	46
KWH-2	230.73	1.82	138.38	90.53	228.91	550.93	50.72	17.65	68.37	216.89	37	19	30	39
LS-1	402.64	7.39	234.49	160.76	395.25	946.18	213.78	109.68	323.46	540.35	91	68	82	57
LS-2	372.49	6.10	366.39	-----	366.39	1312.57	322.19	-----	322.19	862.54	88	--	88	66
LS-3	352.37	6.10	346.27	-----	346.27	1658.84	256.01	-----	256.01	1118.55	74	--	74	67
LS-4	236.50	----	236.50	-----	236.50	1895.34	177.46	-----	177.46	1296.01	75	--	75	68
SO-1	108.38	2.13	106.25	-----	106.25	2001.59	102.02	-----	102.28	1398.03	96	--	96	70
SO-2	160.18	6.10	154.71	-----	154.71	2156.30	152.58	-----	152.58	1550.61	99	--	99	72
SO-3	124.15	2.87	121.28	-----	121.28	2277.58	109.08	-----	109.08	1659.69	90	--	90	73
SO-4	123.54	9.14	114.40	-----	114.40	2391.98	112.23	-----	112.23	1771.92	98	--	98	74
SO-5	132.76	1.70	131.06	-----	131.06	2523.04	124.13	-----	124.13	1896.05	95	--	95	75
TP-1	253.13	54.86	198.27	-----	198.27	2721.31	147.66	-----	147.66	2043.71	74	--	74	75
TP-2	196.42	54.86	141.56	-----	141.56	2862.87	108.41	-----	108.41	2152.12	77	--	77	75
TP-3	209.57	22.70	186.87	-----	186.87	3049.74	124.70	-----	124.70	2276.82	67	--	67	75
TP-4	252.60	12.32	240.28	-----	240.28	3290.02	165.00	-----	165.00	2441.82	69	--	69	74
Total	3507.36	217.34	3007.70	283.32	3290.02	3290.02	2301.55	140.27	2441.82	2441.82	77	50	74	74

* intermittent intervals after the first core point were not cored - see individual drill hole logs

the D limestone of the Lakhra Formation (Ahmed and others, 1984a, SanFilipo and others, 1994); the drilling depth required to do this was deeper than anticipated at each of the SO- series holes. BN-1 was terminated at the occurrence of the non coal-bearing middle Bara facies (see SanFilipo and others (1994, p. 33), which occurred much shallower than anticipated.

Fassett and Gazanfar Abbas were responsible for drilling oversight at KWH-1 and KWH-2. KHW-1 was located about 500 m from a gas well where several coal beds had been reported in the mud log (Appendix 1) to occur at depths as shallow as 11 m, including a 20 m thick coal bed at 33 m depth. The decision to stop drilling at KWH-1 was made after no such bed was intercepted by 100 m depth, but drilling continued to 137 m while waiting for the geophysical logger to arrive on site. The rig was shifted to a site selected by Fassett about 600 m northwest of KHW-1, just outside the gas-well fence, and another hole (KWH-2) was drilled. When the main gear box broke at 186 m, just prior to the Eid break, and the hole was essentially barren, SanFilipo ordered the hole geophysically logged, with the hopes of freeing up the rig to speed up the Thar drilling. After the Eid break, however, KWH-2 was reentered on the decision of higher authorities.

The preferred core size for COALREAP drilling is HQ (63.5 mm). HQ is preferred because: 1) core recovery tends to be better than with smaller diameters, 2) enough material is available with HQ to sample each coal bed 30 cm or greater in thickness and obtain all the necessary splits, 3) the most important geophysical tools can easily pass through HQ rods, which permits unstable holes to be logged before collapsing. It has, however, been necessary for some COALREAP drilling to reduce to NQ (47.6 mm) or smaller size, due to adverse drilling conditions such as friable sandstone. The need to maintain HQ size has been exacerbated by the introduction of digital geophysical equipment for this phase of COALREAP drilling. The digital tools are of slightly larger diameter than the analog tools previously used, and can more easily hang up in the NQ drill string. With the exception of LS-1, which was reduced well before TD without prior notification to USGS, HQ was generally maintained for this project.

Drilling statisitcs

Sixteen holes ranging in depth from 108 to 403 m and totaling 3507 m were drilled in this phase of COALREAP (table 5, figures exclude 4 holes totaling 855 drilled under supervision of J.T. Boyd Co.). About 94 percent was cored, and HQ was maintained for 92 percent of the core drilling. More detailed drilling statistics, including cased intervals and drilling records for each borehole, are included in Part II.

The cumulative recovery in cored intervals was about 74 percent for this phase of drilling, which is slightly better than most of the prior phases of COALREAP drilling (see SanFilipo and others, 1988, 1994). Core recovery in individual holes ranged from 30 percent to 99 percent. The overall core recovery was much poorer than average in the deeply alluviated Khorewah and Bano holes and much better than average in the very shallow Sohnari holes. Except for the Khorewah holes, the core recovery in coal beds was also very good. Most of the core loss appears to have occurred in thick-bedded, friable sandstone intervals, which is typical when coring the upper Paleocene series of Sindh. Reconciliation of core-loss intervals with geophysical logs, particularly for coal beds, will be included in subsequent reports, subject to the availability of funds.

Data collection

Rock sampling and descriptions

Two or three GSP geologists were generally assigned to each drill hole. Shifts were scheduled so that at least one geologist would be present during drilling, but logistical problems, notably at TP-1, resulted in some core (including coal) being pulled with no geologist present. The geologist was responsible for insuring that the drillers maintained proper records of drilling depth, collected samples of cuttings at regular intervals during non-core drilling, and properly extracted core from core barrels. Cuttings were usually sampled at 1.52 m (5-foot) intervals. After describing the cuttings, the geologist bagged and labeled a small sample for retention. Core was extracted from the inner core barrel onto a wooden core trough by means of hammering or mud pressure. The mud cake was washed off and the core was described by the geologist. Core was boxed in standard sized wooden boxes and properly labeled by the geologists. The core is currently stored in the GSP core library at Sonda village.

Rock descriptions are included in Part II. The position and presumed lithology of core loss intervals in Part II are as estimated by the geologist at the well site; both are subject to reinterpretation after reconciliation with geophysical logs, and may be revised in subsequent reports.

Coal sampling methods

A list of coal intercepts and field sample numbers is included in Appendix 2. Additional information is provided by the sample forms recorded in the field and provided in Part II. Except as noted, all coal beds 30 cm thick or greater were evenly split by chisel in the field so that samples could be submitted to both USGS and GSP laboratories. Thinner beds were sampled for GSP labs at the site geologist's discretion. Individual coal beds were divided into smaller sample benches at the discretion of the site geologist, depending on the homogeneity and thickness of the coal.

If coal was intercepted during daylight hours, it was immediatly described, bagged and labeled. If coal was cut at night and could not be described by artificial light, it was placed in polyethelene or styrene sleeves and wrapped in wet cloth, or temporarily sealed in PVC pipe until it could be described and sampled in daylight. After description, coal samples were double or triple bagged in plastic, to preserve moisture, and labeled. Immediately after bagging, all samples were placed in air-tight plastic barrels, which were trucked to Karachi after being filled. GSP samples were submitted for grinding and proximate analysis at GSP laboratories in Karachi. The barrels containing USGS samples were shipped to the USGS headquarters in Reston VA by air. Upon arrival in Reston, the barrels were opened and the samples were examined and sent to a contractor lab (Geochemical Testing, Somerset PA) for grinding and a standard coal analysis package (proximate, ultimate, heating value, sulfur forms, equilbibrium moisture, hardgrove grindability, ash fusion temperature and apparent specific gravity). If sufficient sample is available, the contractor returned splits for trace element analysis, petrography, and back up, in the that order of priority. The results of analysis will be presented in future reports.

A sampling problem occurred when only one GSP geologist was assigned to TP-1 and he had to leave the site to get core boxes (normally the responsibility of the drilling crew, and a two-day trip due to the remoteness of the site). Despite the first coal occurrence being within 1 meter of the depth predicted in the predrill report, the coal was apparently boxed for several days before description and sampling, and appears to have dried substantially. There were no barrels available at the site, so the core was wrapped in plastic and shipped to Hyderabad in PVC pipe. Because the coal was oriented, SanFilipo split most of the TP-1 core in Hyderabad and shipped the GSP split to the recently installed petrographic laboratory in Islamabad. The TP-1 splits sent to Islamabad are noted in Appendix 2. Because of the importance of the major coal discovery at Thar, two GSP splits (TP-1-1 and TP-1-2) and one USGS split (TP-1-5A2) were sent for proximate and standard coal analysis respectively immediately after drilling. Sample TP-1-7, which was described as "dirty coal" and not sampled at the well site, was sampled by SanFilipo at the Sonda core library approximately one month after drilling. Rather than having a high ash content as initially described in the field, this sample comes from the top of the main coal bed and appears to possibly be weathered or less mature than the underlying coal, and very much resembles the light-brown coal described for borehole ODA-2 in SanFilipo and others (1992).

The remainder of the oriented TP-1 core was X-radiographed in Reston and benched into microfacies before submittal for the standard coal analysis package. A list of the samples benched by microfacies appears in Appendix 2. These will hopefully be the subject of future petrographic study by USGS. It is assumed that the samples sent to the GSP petrographic laboratory will be resplit and also submitted for proximate analysis at the GSP Karachi laboratory (the purpose of duplicate analysis by USGS and GSP is to calibrate the GSP lab; although this has been attempted several times, the GSP facility has recently moved, and steps to standardize the lab are still necessary). In any case, the ground backup split of the benches that were not submitted to GSP are being retained for eventual GSP analysis.

Due to COALREAP budget restrictions, only 40 of the 92 samples submitted to USGS contractor labs for standard analysis have thus far been submitted for trace element and oxide analysis. These samples are noted in Appendix 2; they include most of the main Thar coal bed at TP-3, and probable bifurcations of the same bed at TP-4. The Thar samples were chosen over samples from the other areas because of their special significance; they represent a major new coal discovery, which is by far the largest in Pakistan to date, and which, unlike the other coal fields of Sindh, has not previously been studied for trace elements (see

Landis and others, 1988, and Finkleman and others, 1994). We chose to spread the sample selection between TP-3 and TP-4 in order to best represent the Thar coal, both vertically and laterally, within the budget constraint of 40 samples. With that in mind, we attempted to chose samples with a wide range of ash yields, which has been shown by Finkleman and others (1994) to be strongly correlated with trace element concentrations for the Sonda coal field, and to eliminate thinner samples (many of which were desorption samples). We chose this sampling scheme rather than combining samples to represent all four TP- holes in order to maintain correlation with the samples submitted for standard analysis. Trace element splits for the remaining samples have been retained for future analysis if needed.

Gas desorption testing

Coal-bed methane is currently being produced in commercial quantities from several basins in the United States. Although the stored gas content for such areas generally increases with the rank of the coal and its depth below the water table (Close and Erwin, 1989), some commercial gas is being produced in the Powder River Basin from low-rank coals that are associated with compaction structures situated well-above the regional water table (Law and others, 1991).

Despite the thermal immaturity of Sindh coals and their general proximity to the water table, a directive to include coal-bed desorption measurements in this phase of drilling was issued by the USGS Resident Team Leader. Measuring coal-gas desorption potential at the drill-site is a very time consuming process that requires specialized equipment. The procedure consists of placing an unsplit core of about 30 cm length in a sealed cannister and measuring the volume of water displaced by escaping methane at periodic intervals. Because most of the coal-bed gas is desorbed shortly after exposure to atmospheric pressure, extreme care must be taken to record the time interval between coal bed penetration and direct gas measurements. To estimate the gas yield, the measured volume of gas desorbed is converted to STP and plotted versus time, and the results extrapolated back to the time of coal bed penetration to make up for "lost gas". These procedures are outlined in detail in Barker (1991), McCulloch and Diamond (1976), and Close and Erwin (1989).

We tested eight samples for desorption potential. The results of the tests are shown in table 6. As expected, the gas yield was small. For most of the samples tested there was insufficient gas generated to make reliable calculations of lost gas. On an empirical basis, the cummulative gas yields of the samples we tested are about two orders of magnitude less than typical commercial wells (see Close and Erwin, 1989), and more than one order of magnitude less than typical desorbtion measurements from the Powder River Basin (see Barker, 1991). We have therefore just presented the raw data in table 6; no conversions to STP, estimates of lost gas, or gas yields per unit mass have been included.

Because of the care that must be taken to handle the samples very quickly, measuring the desorption at the drill site is labor intensive. Given the shortage of GSP geologists available for

Table 6. Results of gas desorption tests. Pressure and temperature are the ambient conditions recorded at the drill site. Time of +1 indicates next day reading. 'Coal intercepted' refers to the time that the top of the coal bed was penetrated. 'Sample top intercepted' refers to the approximate time that the top of the desorption sample was intercepted for beds that were not penetrated in a single run. 'Fishing begins' refers to the time when the core run has been completed and the wireline assembly is latched to the innertube for retrieval from the core barrel through the drill string. No attempt to compute gas lost during drilling and sampling was made for this report. Samples were not weighed; weight of sample can be determined from the sample thickness and core diameter of 63.5 mm, assuming an average specific gravity of 1.30 g/cc. Note that LS-4-1, LS-4-2B, TP-3-2B and TP-3-2X were subsampled for desorption (cannister length = 30cm), but not for other analyses (Appendix 2).

Sample number	Time (hours)	Pressure (mm Hg)	Temp °C	Gas vol. (cc)
LS-4-1	0300..........(coal intercepted @ 172.96)			
	0435..........(fishing begins)			
	0445..........(core reaches surface)			
(depth:	0455..........(coal removed from innertube)			
173.03 m)	0500..........(coal sealed in canister)			
	0510	998	28	35
(thick:	0520	998	28	5
0.30 m)	0530	998	28	few bubbles
	0600	998	29	few bubbles
	0700	1000	32	few bubbles
	0900	1001	36	few bubbles
LS-4-2A	1035..........(coal intercepted @ 190.98)			
	1145..........(fishing begins)			
(depth:	1205..........(core reaches surface)			
190.98 m)	1212..........(coal removed from innertube)			
	1215..........(coal sealed in canister)			
(thick:	1225	1001.5	41	35
0.30 m)	1235	1001.5	42	5
	1245	1001.5	42	few bubbles
	1630	1000.0	40	2
	1245+1	1000.5	43	nil
LS-4-2B	1035..........(coal intercepted @ 190.98)			
	1145..........(fishing begins)			
(depth:	1205..........(core reaches surface)			
191.68 m)	1212..........(coal removed from innertube)			
	1220..........(coal sealed in canister)			
(thick:	1230	1001.5	41	25
0.30 m)	1240	1001.5	42	5
	1250	1001.5	42	few bubbles
	1635	1000.0	40	1
	1255+1	1000.5	43	nil
TP-3-2B2	0956..........(core run began)			
	1140..........(coal intercepted @ 145.96)			
(depth:	1210..........(fishing begins)			
147.44 m)	1214..........(core reaches surface)			
	?? ....(coal removed from innertube)			
(thick:	1226..........(coal sealed in canister)			
0.30 m)	1236	743	41.5	15
	1246	-	-	nil

Sample number	Time (hours)	Pressure (mm Hg)	Temp °C	Gas vol. (cc)
TP-3-2D	1215............(core run began)			
	1245............(sample top intercepted)			
	1425............(fishing begins)			
(depth:	1430............(core reaches surface)			
148.64 m)	?? ....(coal removed from innertube)			
	1445............(coal sealed in canister)			
(thick:	1455	739	42.5	34
0.22 m)	1506	-	-	nil
	1521	739	43.0	15
	1536	-	-	nil
	1608	738	42.5	25
	1623	-	-	nil
	1652	-	-	nil
	1800	-	-	13
	1938	-	-	nil
	2156	-	-	nil
	2245	-	-	nil
TP-3-2K1	1630............(core run began)			
	1630............(sample intercepted)			
	1836............(fishing begins)			
(depth:	1842............(core reaches surface)			
153.92 m)	?? ....(coal removed from innertube)			
	1854............(coal sealed in canister)			
(thick:	1944	741	37	35
0.30 m)	2013	-	-	nil
	2156	-	-	nil
	2245	-	-	nil
	2343	-	-	nil
TP-3-2Xa	2235............(core run began)			
	2325............(sample top intercepted)			
	2345............(fishing begins)			
(depth:	0005+1..........(core reaches surface)			
165.52 m)	?? ....(coal removed from innertube)			
	0016............(coal sealed in canister)			
(thick:	0030	-	-	nil
0.29 m)	0110	-	-	nil
	0134	-	-	nil
	0537	-	-	nil
	1625	741	41	100
	2100	746	33	nil
TP-3-2Xb	2235............(core run began)			
	2325............(sample top intercepted)			
	2345............(fishing begins)			
(depth:	0005+1..........(core reaches surface)			
165.81m)	?? ....(coal removed from innertube)			
	0012............(coal sealed in canister)			
(thick:	0026	746	30.5	1
0.30 m)	0110	-	-	nil
	0149	-	-	nil
	0537	-	-	nil
	1615	741	41	80
	2050	746	33	nil

well-site activities for this project, their diversion from more important well-site functions was probably ill-advised for this phase of the project. The study and in-situ measurement of coalbed methane is at best imprecise however, particularly for low-rank coals, and additional gas desorbtion measurements of Sindh coals under more rigorously controlled conditions are probably warranted. In particular, if the thick coal at Thar extends to the deeper subsurface towards the Indus Basin to the west, the coal-bed methane potential could be considerable, and additional investigations are warranted. This will be discussed further in the section Preliminary conclusions and recommendations.

Geophysical logging

Geophysical logs for each drill hole are included in Part II. All logging for this project was done using GSP unit MT-2, which is one of two identical Mount Sopris digital logging units mounted in Ford panel vans and purchased for GSP by USAID. The other unit (MT-1) was theoretically available for the project, but was never fully operational during this phase of drilling. Downhole tools from MT-2 were occasionally cannabilized to keep MT-1 operating during the project. Prior to this phase of COALREAP drilling, these units had only been operated in a few shallow holes for the purposes of training operators and calibrating the equipment. Previous COALREAP drilling was logged using older, but generally more reliable, analog equipment.

Normal operation with MT-1 and MT-2 usually consists of several passes (e.g. first through drill pipe and then in an open hole) with each two modular probes. The first probe (JLP*) consists of natural gamma, neutron, spontaneous potential (SP), single-point resistivity, and short-normal (40") resistivity. The SP and resistivity tools were not operational during this project. The second probe (XAP*) consists of gamma-gamma-near density (GGFR - more or less equivalent to 4-pi density), natural density (GGNR - more or less equivalent to high resolution density of the analog recorders used previously), gamma-gamma-far gamma, single-arm caliper, and guard (focused) resistivity. The guard log did not properly function during this project, and generally was not run.

A USGS logging technician was sent to Pakistan during the early parts of the JTB- and TP- drilling to try and get both units fully functional, but he was unsuccessful. In addition to the problems with the resistivity and SP probes, a number of other logging problems plagued the project, notably the reluctance of the operators to run the tools through pipe, and the lack of spare parts available for the vans, which were involved in several road accidents, most likely due in part to their left-hand drive (i.e. nonstandard for Pakistan) and lack of side windows. Mitigation of logging problems required an inordinate amount of time and attention by the field supervisors.

Because of the instability typical of holes drilled in the soft coal-bearing strata of Sindh Province, the normal COALREAP logging procedure is to run both tools through the drill rods as

*XAP and JLP are manufacturers designations for these probes and are alphabetized mnemonic devices with no intrinsic meaning (i.e. not acronyms).

soon as total depth is reached. Depending on the position of the coal, the rods and/or casing are then partially pulled back and logs are run below the pipe in the open part of the hole. This is especially important for getting a useful caliper log in the coal intervals (which obviously can't be obtained through the pipe), because once the casing is pulled (even surface casing), the holes tend to collapse. The caliper log is essential to distinguish coal from caved intervals, which are very frequent in these holes. If the hole is clear to a useful depth when the casing is completely pulled, a final logging pass is made in the open hole.

A list of the geophysical logs provided in Part II is shown in table 7. Because GSP was able to maintain HQ size without reduction for most of this drilling phase, most of the holes did not require deep casing, and only two passes with each probe were run. For some very shallow holes (e.g. SO-1, table 7), only the open-hole log was run. Additional information on the condition of the holes and the casing and mud used is provided on the geophysical log headers and the cover sheets of the lithological logs in Part II. Specific logs mentioned in the text that follows will be referred to by their identification number in brackets, and the type of log will generally be referred to by the abbreviation shown on the digital header to each log (i.e. JOH for JLP open-hole, JDP for JLP through drill pipe, XOH for XAP open-hole, XDP or XADP for XAP through pipe, etc.)

The only significant problem from not running supplementary logs with the casing partially pulled back arose in a three-meter interval of core loss and coal at 78 m depth in KWH-1. Based on

Table 7. **List of geophysical logs.** Each letter indicates a single log included in Part II, numbered as shown in brackets.

	Probe type	
Borehole	JLP	XAP
BN-1	R[1],O[2]	R[3],O[4]
KHW-1	C[5]	C[6]
KHW-2	C[7],c[8]	C[9],c[10]
LS-1	C[11]	C[12],RC[13] (from 158 m)
LS-2	R[14],o[15]	R[16],o[17]
LS-3	R[18],O[19]	R[20],O[21]
LS-4	R[22]	R[23]
SO-1	O[24]	O[25]
SO-2	R[26],O[27]	R[28],O[29]
SO-3	R[30],O[31]	R[32],O[33]
SO-4	O[34]	O[35]
SO-5	R[36],o[37]	R[38],o[39]
TP-1	o[40]	r[41],o[42]
TP-2	R[43],O[44]	R[45],O[46]
TP-3	r[47],o[48]	r[49],o[50]
TP-4	R[51]	R[52]

Explanation:

R r = through rods
C c = through casing
RC rc = through rods and casing
O o = open hole (+surface casing)

Upper case indicates approx to TD
Lower case logged short of TD

for most cases:

--------XAP--------
high-resolution den
4-pi density (GGFR)
natural gamma
caliper (open hole)

-----JLP-----
natural gamma
neutron

the XDP density logs [6], the entire interval could be either coal, or, a wash-out. SanFilipo's suggestion of only pulling the casing back to 76 m for the first pass of open-hole logging was ignored by the USGS and GSP Khorewah supervisors, and the hole collapsed before a caliper log could be run. The coal bed in question was not present in KWH-2, less than 600 m to the northwest.

Other problems that arose included the XAP probe getting stuck in NQ rods at 158 m at LS-1, forcing the cable to be cut to retrieve the tool [13]. Although both probes easily pass through NQ rods at the surface, GSP declined to log through NQ after that incident for fear of foreign material dropping in the annulus and jamming the probe in the drill stem. This did not cause any major deficiencies in the suite of logs obtained for this project, but it did exacerbate the importance of not reducing the hole size, which may have slowed drilling progress a bit.

A similar problem arose because of the reluctance of the operator to open the caliper through drill pipe. The GGNR is a sidewall log; without the caliper open the tool swings periodically in the hole, which causes a recording anomaly at regular intervals. This can be easily observed on the LS-1 XOH log [12] above 184 m, where the caliper was partially retracted. It is also possible that the digital logs are showing some casing effects at pipe joints; this will be investigated in future interpretive reports.

Despite a depth shift for the gamma trace on the XAPD log [13] which was stuck at 158 m in LS-1, the log is included in Part II because it shows useful information; in particular it illustrates the difference between the pendulum effect described in the previous paragraph and some of the other anomalous signals (e.g. 195 and 198.4 m on the XOH log [12]) that mimic true coal signatures (e.g. the XAPD log [13] at 201.8 m on the GGNR/GGFR and 205 m on the shifted gamma).

Because of the instability of the hole, TP-3 was logged through the major coal before the hole was completed. After pulling the rods for open-hole logging, the hole partially collapsed. It was redrilled and deepened, but did not intercept much coal below the main bed and was not relogged in order to avoid risking unnecessary desert travel by the sole operating logging unit. Because of access problems, TP-1 was also not logged to TD; the loggers did not reach the hole until several days after completion, and the bottom of the hole collapsed after the drillers pulled the rods back to prevent sticking during the wait. The neutron probe was also not functioning on the JLPO probe at TP-1 [40]. In general subjective terms, the digital JLP log does not seem as useful for hole-to-hole correlations as the older analog gamma-neutron logs used in prior COALREAP drilling, which is their most important purpose for this type of drilling. The single-arm caliper is also not nearly as effective as the 3-arm caliper used previously, which is obviously of major importance in this type of operation.

Although the COALREAP program has formally ended, detailed geophysical log interpretation for all the boreholes included in this report will hopefully be included in subsequent work. At a minimum this should include using the geophysical logs to reconcile the coal intercepts shown in Appendix 2 with the core loss recorded at the drill sites, and correlation of the LS-series boreholes between the Lakhra and Sonda coal fields, which was their primary purpose.

Preliminary conclusions and recommendations

South Lakhra

Based on four widely spaced boreholes, it appears that the southern part of the Lakhra coal field (arbitrarily defined as the area north of Baran Nadi and east of the Indus River on figure 2) contains only thin coal beds which are relatively deep. Although obvious from the topography and surface geology that the coal in the Lakhra south area would be somewhat deeper than in the area of the Lakhra field presently being mined (north of borehole UAL-15, fig 2; see SanFilipo and others, 1988), the degree of deeping is greater than was anticipated. While the precise stratigraphic contacts are yet to be determined, initial indications from the drilling are that the Lakhra Formation, which overlies the coal-bearing Bara Formation, probably thickens depositionally in this general area. The apparent depositional thickening would account for the greater depth to coal than anticipated, and might account for the thinning of the coal if occurring as the result of a lateral facies change at the expense of the Bara Formation.

Part of the rationale for drilling the south Lakhra holes was that earlier COALREAP drilling in the Sonda field had indicated that the Lakhra Formation was generally much thinner than originally reported by Nutall (1932) or Cheema (1977), who proposed that the unit thinned abruptly from the Sonda area to the Lakhra area due to pre-Sohnari erosion. Although the alternative possibility that the Lakhra Formation locally thickened in south Lakhra was discussed in SanFilipo and others (1988 p. 28 - 30), the apparent degree of thickening at LS-3 and LS-4 is greater than was anticipated. The unit as a whole still does not appear to be as thick in south Lakhra as was first reported, but the cores and electric logs need to be studied in more detail and correlated with the earlier drilling in the Lakhra and Sonda fields to determine the precise stratigraphic relationships. However, given the inability to complete the Lakhra drilling program as planned, and the incomplete geophysical records from the holes that were drilled, it may still be difficult to establish a reliable correlation scheme between Lakhra and Sonda from existing data. Two additional boreholes in south Lakhra were drilled by GSP for the Pakistan Mineral Development Corporation several years ago, but we were unable to locate any records from these holes. The search for these records, and the core itself (which may be stored at Sindh Univ. at Jamshoro) should continue, and the information should be integrated into future GSP studies.

Sohnari areas

Preliminary indications are that the Sohnari strata are more variable in thickness and lithology than previously indicated, and have less coal potential than was hoped for (SanFilipo and others, 1988, Wnuk and others, 1991). It was particularly disappointing that SO-1 was barren, because this hole is only a few kilometers south of a quarry that exposes a well-developed unit in the Sohnari (unit 17 of measured section LS-1, Wnuk and others, 1991, p. 46) that is similar to local underclays. It should be noted that the "underclay" is absent in SO-1; a superjacent coal could occur in other areas of the subsurface where the unit may be present, but in any case would probably not be extensive. Boreholes LS-1 and LS-2 also penetrated the Sohnari in the same general area as SO-1. LS-2 was located near Mehran University, where an engineering test hole drilled in 1986 reported coaly material (Appendix 1). A relatively thick carbonaceous Sohnari interval was recorded at LS-2, but Sohnari coal was not present. Borehole SO-3 did confirm that the "Hilaia (Chilia) beds", which have been variously placed in the underlying Lakhra Formation (Nutall, 1932), or the Sohnari (SanFilipo and others, 1988), are in fact coal-bearing, as was first indicated in COALREAP borehole UAJ-1, drilled in 1986. Preliminary field investigations downdip from SO-3 indicate that the area is probably down-faulted to the west. While the potential for Sohnari coal occurrence may increase to the west if the Chilia beds thicken or if the carbonates lying between the Chilia beds and the Sohnari proper pinch out, so will its depth. Additional Sohnari coal drilling is not recommended at this time, although the SAZDA water well drilling in the area should be closely monitored. In addition to this, the Government of Sindh should consider lifting the current moratorium on leasing in the Sonda coal field or modifying it apply to the Bara Formation only, because in its current form it is preventing Sohnari exploration by the private sector (Shahid Ali Beg, General

Manager National Mines, oral commun., 1992), which was not its original intent when imposed at the request of the COALREAP cooperators in 1986.

Indus Plain

Initial indications from oil and gas records (Appendix 1: Union Texas Khorewah-1) that a very thick and very shallow coal deposit exists in the Khorewah area are obviously in error. The general hypothesis that shallow coal deposits overlying fault blocks might occur in this area (Jim Fassett, oral commun., 1992) is also somewhat dubious, because most of the block-faulting in the southern Indus Basin is pre-Tertiary (see Hardy *in* Raza and Sheikh, 1988). While some of these faults were undoubtably reactivated during Indo-Asian plate collision, it is extremely unlikely that soft Bara sediments could have been preserved through modern Indus erosion over these types of structures. The depth to bedrock was over 75 m in both in KWH-1 and KWH-2, as should have been easily predicted from previous COALREAP drilling in the Indus Plain and by an informed examination of the Union Texas mudlog, primarily from the abundance of mica in the upper part of the hole, which is characteristically absent in the Bara Formation but ubiquitous in modern Indus sediments. The cuttings for this gas well, which are stored in the GSP core library in Quetta, were examined by GSP after KWH-2 was drilled, and no coal was evident in the upper part of the hole (Ghazanfar Abbas, oral commun., 1992). While it appears that a moderately thick coal bed may subcrops just below alluvium at 78 m depth in KWH-1, this by no means certain because the most of the core was not recovered, the interval was not properly logged geophysically, and the bed is absent 600 m away at KWH-2. In any case, the presence of coal at that thickness and depth could probably be expected from simple structural projections of the Bara Formation from the Sonda coal field, and is by no means extraordinary. Reports that prior to the Thar discovery this was the "shallowest discovery of coal of this thickness in Sindh" (memorandum from Fassett to S.A. Hassan, USAID, March 24, 1992) are erroneous (shallower coal of comparable thickness is presently being mined from numerous locations in the Lakhra coal field, see SanFilipo and others, 1988). It should also be noted that this hypothetical coal deposit has been erroneously referred to in the literature as the Badin coal field and has had an equally erroneous preliminary resource estimate of 8 billion tonnes made on the basis of the Union Texas hole (Kazmi and others, 1990, Thomas and others, 1992). Bara coals are recorded in the Badin area, but they are considerably deeper (GSP, 1988).

BN-1 was drilled based on the projections of shallower coal updip from the Sonda area (SanFilipo and others, 1994). Initial observations of the data from this hole indicate that the main Sonda coal bed is considerably shallower in the Bano area than was projected, and has been removed by erosion at BN-1. It is therefore likely that the mining potential on the east side of the Indus River immediately south of the UAK- series is limited. BN-1 is useful from a stratigraphic standpoint in that it is one of the few core holes that have penetrated the non-coal bearing middle facies of the Bara Formation (see SanFilpo and others, 1994), and this interval (starting at about 150 m) in BN-1 should be further studied.

Thar Desert

A preliminary drilling plan for the Thar Desert was included in SanFilipo and others (1992, p. 39-42), which was actually compiled in 1989 and released to GSP and USAID in draft form in 1990. Although the specific drilling locations recommended in that document were somewhat altered for the TP- series drilling on the basis of additional oil and gas and water-well drilling collected between 1990 and the commencement of drilling, the basic objectives were not. The first objective was to confirm what was at that time a speculative inference of coal occurrence. This was successfully accomplished at TP-1, which twinned SAZDA TH-5 and confirmed the coal picks of SanFilipo and others (1992, p. 33) quite well, including a 19 m coal bed (with partings) at about 162 m depth. The second priority of establishing the continuity of the coal was successfully accomplished at TP-3, which intercepted a coal bed nearly 30 m thick (including partings) at a depth of about 146 m. Together these two boreholes constitute a major new coal discovery, by far the largest in Pakistan to date. With the exception of the very top of the main coal bed at TP-1 (sample TP-1-7), the coal recovered from the TP- holes appears in hand specimen to be slightly more mature than the samples recovered from water wells and tested by SanFilipo and others (1992). Initial indications are that the coal is of slightly lower rank (probably lignite *B*) than the lignite of probable equivalent age from India (see SanFilipo and others, 1992, p.16).

As indicated in SanFilipo and others (1992, p. 36-38), the major objective of any comprehensive exploration program in Thar should be finding coal that is shallow enough to surface mine, because the coal is far too thick to be efficiently recovered by conventional underground mining methods. With this in mind, TP-2 was located between TP-1 and the Indian border, under the assumption that the coal-bearing rocks would rise towards the Indian shield outcrops in Rajasthan. Granite of presumably Precambrian age was intercepted at 184 m, far shallower than anticipated. The granite is directly overlain by a thin layer of sediments that is similar in appearance to the coal-bearing rocks at TP-1 and TP-3, but containing only carbonaceous shale, with no coal. The possibilty that the section would thin in this area was discussed in SanFilipo and others (1992, p.19), but recently acquired water-well drilling data had indicated otherwise. A hole located a few kilometers east of TP-2 was drilled by the Pakistan Water and Power Development Authority (WAPDA) to a depth of 188 m and did not report granite, and several holes between TP-2 and the Indian border exceeded 200 m depth without reporting igneous rock (one WAPDA hole drilled about 20 km northeast of TP-2 reported basalt at 253 m, which we had assumed was Deccan trap underlying coal-bearing rock, but in fact is probably basement). It now appears that there are a number of basement faults in the area, and the coal-bearing rock can not be simply projected up-dip to the Indian shield. Given the obvious constraint of thick aeolian and fluvial surficial materials that appear to be widespread in the Thar Desert, this hypothesis, if true, would indicate the potential for the occurrence of coal at surface mineable depths in the Pakistani portion of the Thar Desert is somewhat limited.

The location for TP-4 was selected under the assumption that the coal might be shallower towards Kutch, were it is being surface mined in India. The location was moved towards the shield outcrops at Nagar Parkar (fig.4) from the more easily accessible Ali Bander location proposed in SanFilipo and others (1992, p. 41), however, because oil and gas logs acquired from Ali Bander indicated the depth to coal-bearing rocks probably exceeded 500 m. The first coal at TP-4 was at about 181 m depth, and from the fact that 12 relatively thin coal beds were recorded between 181 and 275 m, it appears that the coal-bearing section is splitting and thickening away from the shield and TP-3. We nevertheless believe that the greatest potential for surface mineable coal in the Pakistani side of Thar exists in the general area between boreholes TP-2, TP-3, TP-4, the Rann of Kutch, and Nagar Parkar. Although it appears from satellite imagery (and the seismically located Kutch fault, see SanFilipo and others, 1992) that there is a structural discontinuity along the Rann of Kutch (fig. 4), shallow (81 m) basement is recorded in water wells as far north as Pilu (fig. 1). It is recommended that the geophysical studies suggested in SanFilipo and others (1992, p. 40), which have not as yet been initiated, be completed prior to additional drilling.

The COALREAP program has formally ended with the completion of a 21 hole drilling program in Thar that was drilled under the supervision of Fassett between Oct 1992 and June 1993 (see

Fassett and Durrani, 1994). This program essentially consisted of drilling on a grid between TP-4 and the northmost reported occurrence of coal in water wells at Khokhropar (fig 4), with no holes drilled east of TP-4 due to prohibative depth. USAID funded 13 subsequent holes in Thar, ten of which were infill holes drilled by GSP in the vicinity of TP-3 for the John T. Boyd Co., and 3 of which were in outlying areas to the south (see Fassett and Durrani, 1994). We recommend drilling the following additional areas in Thar, ideally after completing the geophysical studies outlined above:

1) The area of greatest potential for surface mining, as outlined in the preceeding paragraph.
2) The area near Mithi. Although the coal is likely to be relatively deeper here, this can not be determined with certainty until the area is drilled, especially in light of the suspected faulting. This area contains some large "parks" of relatively flat land free of big dunes, and therefore might be more suitable to mining. There is a metalled road to Mithi which will enable access by one of the Acker rigs, which can easily drill a deep hole, but have so-far been inoperable in the desert (despite the large capital investment by USAID to acquire them). If the coal is in fact deep, the hole can serve as a better gas desorption test than those previously run.
3) A deep core hole in the vicinity of Badin, Nabisar, or some other nearby oil and gas hole with good available records. The purpose of this hole would be to firmly establish the relationships between areas of known

stratigraphy with Thar, and to serve as a deep coal desorption test. The oil and gas hole chosen to be twinned should be one that penetrated the Deccan traps (to insure statigraphic position), and should have a reported depth to the top of the Ranikot Group no shallower than 400 m.

It should also be noted that the high priority hole recommended for the Jacobabad high in SanFilipo and others (p. 40-42) was not drilled as part of our program for logistical reasons. An oil and gas and water-well inventory of this area and other areas of Cholistan (as the desert north of Thar is known) is recommended, to possibly be followed by a modest drilling program. Satellite imagery that was not available when the original recommendation was made indicates that there is a structural saddle between Pakistan and India in that area, and coal would probably be deeper than originally projected. Considering the thickness of the coal at TP-1 and TP-3, however, the entire desert area and Indus Basin should be considered for coal potential, and the possibilty of thermogenic or biogenic coal-bed methane from the deeper areas should not be prematurely discounted. Once again it will be emphasized that comprehensive inventories of existing data and preliminary geohysical studies should be completed before far more costly drilling begins.

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Appendices

Appendix 1

Supplemental information

Appendix 1: Mud log, Union Texas Khorewah No. 1

Logging Systems Master Mud Log

INFORMATION SERVICES

Company	UNION TEXAS PAKISTAN
Well	KHOREWAH 1
Field	KHOREWAH
Region	BADIN BLOCK
Location	PAKISTAN
Co-ordinates	24°44'56.05" N 68°29'26.373" E
API No. / Sec. / Twp. / Rge.	
Drilling Contractor	POOL INTAIRDRIL RIG 219
Rig/Type	IDECO RIR MLD KAL UZ 350 AH
Total Depth	6850'
TVD	
Spud Date	9 JUNE 1988
T.D. Date	25 JUNE 1988

ELEVATION AND LOGGING DATA

Permanent Datum	RKB
Elevations	32 ft GL - 50 ft KB (AMSL)
Log Measured From	KB
Logged Depths	35' To
Logged Depths	To
Unit	MWD 140665
Supv. Engineer	P NASH
Logging Engineers	G JOHNSON, M FAREED, P EVANS
Other Services	
Scale	☐ 1:200 ☒ 1:500

HOLE DATA

		To
20"	To	35'
14 3/4"	To	712'
9 7/8"	To	6850'

CASING DATA

		To
20"	To	35'
10 3/4"	To	710'

MUD TYPES DATA

	To
FRESHWATER GEL	712'
BRINE POLYMER	6850'

LITHOLOGY SYMBOLS

Conglomerate, Breccia, Gravel, Sand, Sandstone, Siltstone, Shale, Clay/Mudstone, Volcanics, Marl, Limestone, Dolomite, Anhydrite, Salt, Coal/Lignite, Igneous, Metamorphic

ABBREVIATIONS

DRILLING DATA

NB	New Bit	LAT	Logged
RRB	Rerun Bit	U	Gas U[illegible]
TD	Turbo Drill	BG	Backgr[illegible]
PDCB	Polycrystalline Diamond Compound Bit	TG	Trip Gas
		STG	Short Tr[illegible]
CB	Core Bit	CG	Connect[illegible]
DB	Diamond Bit	DST	Drill Stem
WOB	Weight on Bit	DS	Direction[illegible]
RPM	Revs Per Minute	DC	Depth Co[illegible]
CO	Circulate Out	C	Carbide T[illegible]
PR	Partial Returns	CKF	Check for
NR	No Returns	FLT	Flowline T[illegible]
		BHT	Bottomhol[illegible]

MUD DATA

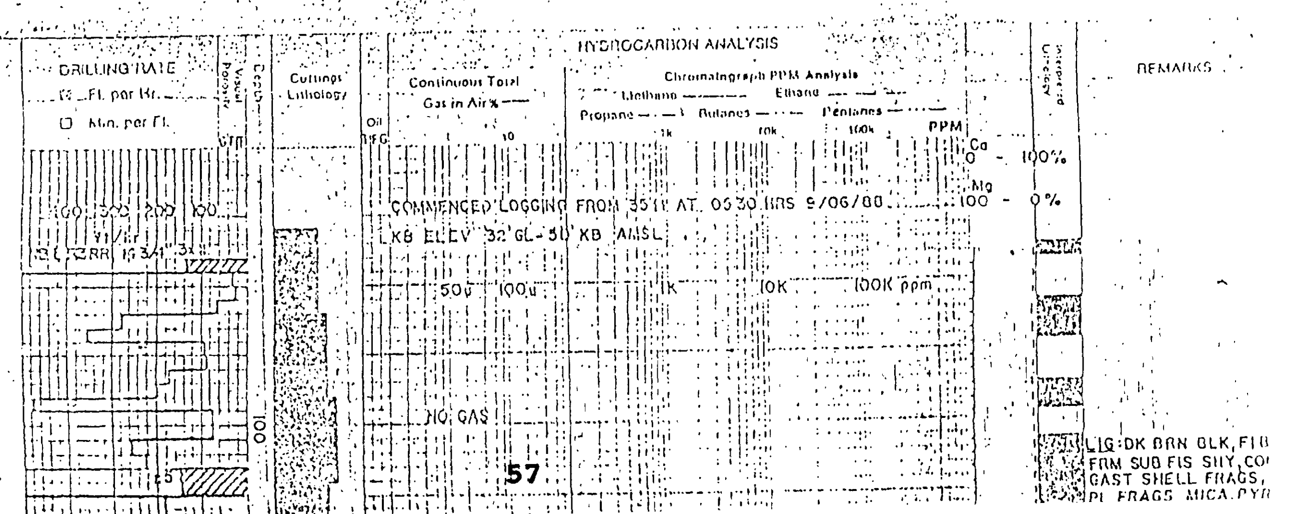
W	Mud Density	PV	Plastic V[illegible]
V	Funnel Viscosity	YP	Yield Poi[illegible]
FL	Filtrate Loss	S	Solids Co[illegible]
FC	Filter Cake	G	Gels
CL	Salinity	RM	Mud Resi[illegible]
PH	Hydrogen Ion Content	RMF	Filtrate Re[illegible]

ENGINEERING DATA

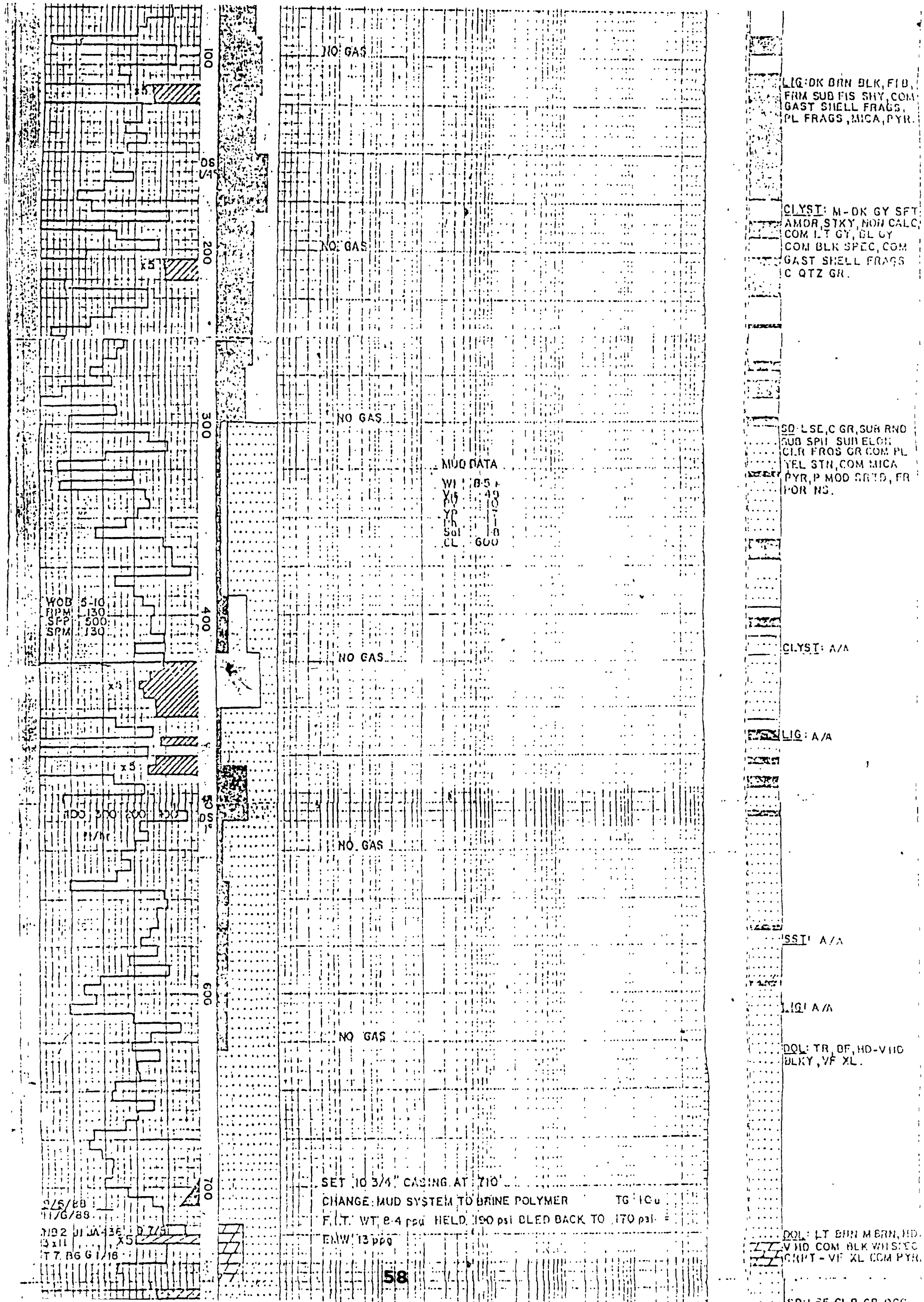
- Ct Core No. 1, recovery
- DST 1 Drill Stem Test No. 1
- Casing Seat
- Sidewall Core
- RFT Interval Tester
- E-LOG Wireline Log Run
- LOT Leakoff Test
- PIT Pressure Integrity Test
- Gas traces
- Gas
- Oil traces
- Oil
- Bitumen
- Water
- Salt Water
- Fresh Water
- Hydrocarbons
- H_2S smell

BIT DATA SHEET KHOREWAH 1

BIT No.	TYPE	SIZE	JETS	DEPTH OUT	DRILLED	HOURS RUN	WOB	RPM	CONDITION	AV ROP	K REVS	RUN No.
1	R3RR	14 3/4"	3x8	712'	712'	3.3	0-10	118		219	20	1
2	J1	9 7/8"	3x11	1391'	679'	7.2	10-20	120	7-6-1/16"	99.3	48	2
3	J55	9 7/8"	3x11	2161'	770'	19.7	40	110	3-2-IN	39.1	129	3
4	J1	"	"	4857'	2696'	53.5	40	120	4-5-1/16"	50.4	396	4
5	J1	"	"	5939'	1081'	42	40-45	125	7-4-1/8"	25.8	302	5
6	J44	"	"	6372'	433'	44.7	45-50	65	4-8-1/8"	9.7	170	6
7	J44	"	"	6850'	478'	55.4	45	65	5-4-1/8"	8.5	200	7



Appendix 1 (Union Texas Khorewah No. 1) continued



Appendix 1 continued: Drillers log, Mehran University Jamshoro test hole located near LS-2

MEHRAN UNIVERSITY OF ENGINEERING AND TECHNOLOGY

(JAM SHORO)

SUBSURFACE EXPLORATION LOG

CONDUCTED BY: CIVIL ENGINEERING DEPARTMENT M·U·E·T JAMSHORO

BORE HOLE NO	1	LOCATION : SITE OF NEW ARCH: BLDG; M	
DEPTH	100 FT	DATE	01 TO 10 DEC 1986
METHOD	ROTARY	GWT*	NOT ENCOUNTERED

DEPTH FT	THICKNESS FT	S·P·T PENETRATION RESISTANCE N	SOIL CLASSIFICATION	LOG	PEN: RESIS 10 30 50
7·0	7·0	29	Yellowish silty sand with stone pieces		
13·6	0·6	50/1	Brownish silty clay medium hard with lime-stone partings in between.		
20·0	0·6	55/1			
25·0 FT	18·0 FT				
74·0 FT	49·0 FT		LIMESTONE		
85·0 FT	11·0 FT		Yellowish Brown silty clayey shale traces of sand and Gypsum		
100·0 FT	15·0 FT		Looks like coal sample is sent to the laboratory for analysis.		

* Ground Water Table

A. MEMON 22/12/86

Appendix 2

Preliminary coal intercepts and sample numbers, COALREAP drilling, February - June 1992.

Depths and thicknesses subject to revision from geophysical logs and results of ash analysis. Brackets indicate single beds divided into benches. Samples submitted for trace element and oxide analysis (as of April 1993) are indicated by the symbol &; oriented samples submitted to the GSP petrographic lab in Islamabad are indicated by the symbol *. The symbol @ denotes gas desorption test was run on the sample; d.coal = dirty coal; aa = as above.

					--Sample number--	
Drill hole	Lithology	From (m)	To (m)	Thickness (m)	USGS	GSP
BN-1	coal	101.74	102.06	0.32	BN-1-1	BN-1-1
	coal	119.67	120.03	0.36	BN-1-2	BN-1-2
	coal	122.85	123.31	0.46	BN-1-3	BN-1-3
KHW-1	coal	78.18	78.38	0.20	----	KHW-1-1A
	loss	78.38	80.42	2.04		
	coal	80.42	80.77	0.35	----	KHW-1-1B
	loss	80.77	81.25	0.48		
KHW-2	coal	120.90	121.25	0.35	----	KHW-2-1A
	coal	121.25	121.55	0.30	----	KHW-2-1B
	coal	121.55	121.85	0.30	----	KHW-2-1C
	coal	124.26	124.56	0.30	----	KWH-2-2
LS-1	coal	201.81	202.61	0.80	LS-1-1	LS-1-1
	d.coal	216.86	217.11	0.25	----	----
	coal	224.11	225.16	1.05	LS-1-2	LS-1-2
	d.coal	362.52	363.02	0.50	----	----
LS-2	coal	153.77	154.13	0.36	LS-2-1	LS-2-1
	coal	169.52	169.90	0.38	LS-2-2	LS-2-2
	coal	181.44	181.51	0.07	----	----
	coal	197.61	197.85	0.24	LS-2-3	LS-2-3
	coal	214.92	215.52	0.60	LS-2-4	LS-2-4
LS-3	coal	204.34	204.61	0.27	----	----
LS-4	coal	172.96	173.36	0.40-	LS-4-1 @	----
	d.coal	173.36	173.46	0.10-	----	----
	coal	190.98	191.28	0.30-	LS-4-2A @	----
	ptg	191.28	191.38	0.10		
	coal	191.38	191.43	0.05	----	----
	d.coal	191.43	191.68	0.25	----	----
	coal	191.68	192.11	0.43-	LS-4-2B @	----
	coal	193.43	193.98	0.55-	LS-4-3	----
	d.coal	193.98	194.08	0.10-	----	----

Appendix 2 cont.

Drill hole	Lithology	From (m)	To (m)	Thickness (m)	USGS	GSP
SO-2		no coal				
SO-3	d.coal	62.71	63.11	0.40	SO-3-1	SO-3-1
SO-4		no coal				
SO-5		no coal				
TP-1	coal	144.08	144.28	0.20	----	
	coal	146.38	147.57	1.19-	TP-1-1.1	TP-1-1
	coal	147.57	147.80	0.23	TP-1-1.2	-aa-
	ptg	?147.80	?148.70	0.90		
	coal	148.70	149.54	0.84	TP-1-2.1	TP-1-2
	coal	149.54	149.64	0.10	TP-1-2.2	-aa-
	coal	149.64	150.22	0.58-	TP-1-2.3	-aa-
	coal	?161.58	?161.78	0.20	------	----
	coal	?162.11	?163.83	1.72-	TP-1-7.1	TP-1-7*
	loss	163.83	164.13	0.30		
	coal	164.13	164.34	0.21	TP-1-3.1	----
	coal	164.34	164.97	0.63	TP-1-3.2	----
	coal	164.97	166.30	1.33	TP-1-3.3	----
	coal	166.30	166.59	0.29	TP-1-3.4	----
	coal	166.59	167.43	1.12	TP-1-3.5	----
	coal	167.43	168.02	0.59	TP-1-3.6	----
	ptg	168.02	169.17	1.15		
	coal	169.17	169.47	0.30	TP-1-4.1	----
	coal	169.47	169.86	0.39	TP-1-4.2	----
	coal	169.86	170.23	0.37	TP-1-4.3	----
	coal	170.23	170.62	0.39	TP-1-4.4	----
	coal	170.62	171.35	0.73	TP-1-4.5	----
	coal	171.35	171.99	0.64	TP-1-4.6	----
	coal	171.99	172.88	0.89	TP-1-4.7	----
	coal	172.88	173.87	0.99	TP-1-4.8	----
	ptg	173.87	177.39	3.52		
	coal	177.39	178.55	1.16	TP-1-5.1	TP-1-5A*
	coal	178.55	178.91	0.36	TP-1-5A2	-aa-
	coal	178.91	180.47	1.56	TP-1-5.2	TP-1-5B*
	ptg	?180.47	?181.02	0.55		
	coal	181.02	181.66	0.64-	------	----
	coal	186.31	186.86	0.55	------	----
	coal	190.47	192.00	1.53-	TP-1-6.1	TP-1-6A*
	coal	192.00	193.50	1.50-	-aa-	TP-1-6B*
TP-2		no coal - granite at 184.45 m				
TP-3	coal	134.87	135.07	0.20	----	----
	coal	136.25	136.36	0.11	----	----
	coal	137.06	137.40	0.34	&TP-3-1	TP-3-1
	coal	143.54	143.83	0.29	----	----

continued

Appendix 2 cont.

Drill hole	Lithology	From (m)	To (m)	Thickness (m)	USGS	GSP
TP-3 cont.	coal	145.96	146.78	0.82-	&TP-3-2A	TP-3-2A
	ptg	146.78	147.19	0.41		
	coal	147.19	147.74	0.55	&TP-3-2B @	TP-3-2B
	loss	147.74	147.82	0.08		
	coal	147.82	148.64	0.82	&TP-3-2C	TP-3-2C
	coal	148.64	148.86	0.22	TP-3-2D @	TP-3-2D
	coal	148.86	149.36	0.50	&TP-3-2E	TP-3-2E
	coal	149.36	150.12	0.76	&TP-3-2F	TP-3-2F
	ptg	150.12	151.17	1.05		
	coal	151.17	151.74	0.57	&TP-3-2G	TP-3-2G
	coal	151.74	152.35	0.61	&TP-3-2H	TP-3-2H
	coal	152.35	153.28	0.93	&TP-3-2I	TP-3-2I
	coal	153.28	153.92	0.64	&TP-3-2J	TP-3-2J
	coal	153.92	154.22	0.30	TP-3-2K1@	TP-3-2K1
	coal	154.22	154.80	0.58	&TP-3-2K2	TP-3-2K2
	ptg	154.80	155.70	0.90		
	coal	155.70	156.72	1.02	&TP-3-2L	TP-3-2L
	coal	156.72	156.97	0.25	TP-3-2M	TP-3-2M
	coal	156.97	157.64	0.67	&TP-3-2N	TP-3-2N
	coal	157.64	158.24	0.60	&TP-3-2O	TP-3-2O
	coal	158.24	158.94	0.70	&TP-3-2P	TP-3-2P
	coal	158.94	160.02	1.08	&TP-3-2Q	TP-3-2Q
	coal	160.02	161.52	1.50	&TP-3-2R	TP-3-2R
	coal	161.52	162.42	0.90	&TP-3-2S	TP-3-2S
	coal	162.42	163.07	0.65	&TP-3-2T	TP-3-2T
	coal	163.07	164.30	1.23	&TP-3-2U	TP-3-2U
	coal	164.30	164.75	0.45	TP-3-2V	TP-3-2V
	coal	164.75	165.52	0.77	&TP-3-2W	TP-3-2W
	coal	165.52	166.11	0.59	TP-3-2X @	TP-3-2X
	coal	166.11	167.66	1.55	TP-3-2Y	TP-3-2Y
	coal	167.66	168.21	0.55	&TP-3-2Z1	TP-3-2Z1
	coal	168.21	169.21	1.00	&TP-3-2Z2	TP-3-2Z2
	coal	169.21	169.90	0.69	&TP-3-2AA	TP-3-2AA
	coal	169.90	170.73	0.83	&TP-3-2AB	TP-3-2AB
	coal	170.73	171.38	0.65	&TP-3-2AC	TP-3-2AC
	coal	171.38	172.26	0.88	&TP-3-2AD	TP-3-2AD
	coal	172.26	172.93	0.67	TP-3-2AE	TP-3-2AE
	coal	172.93	173.83	0.90	&TP-3-2AF	TP-3-2AF
	coal	173.83	175.28	1.45-	&TP-3-2AG	TP-3-2AG
	coal	197.25	198.35	1.10	&TP-3-3	TP-3-3
TP-4	coal	180.91	181.25	0.34-	TP-4-1A	TP-4-1A
	coal	181.25	181.60	0.35	TP-4-1B	TP-4-1B
	coal	181.60	181.95	0.33-	TP-4-1C	TP-4-1C
	coal	192.05	193.02	0.97-	&TP-4-2A	TP-4-2A
	coal	193.02	193.58	0.56	&TP-4-2B	TP-4-2B
	coal	193.58	194.31	0.73	&TP-4-2C	TP-4-2C
	ptg	194.31	194.51	0.20	-----	-----
	coal	194.51	195.16	0.65-	&TP-4-2D	TP-4-2D
	coal	198.03	198.18	0.15	-----	-----
	coal	200.68	201.12	0.44	&TP-4-3	TP-4-3
	coal	203.45	203.75	0.30	TP-4-4	TP-4-4
	coal	205.73	206.08	0.35	&TP-4-5	TP-4-5
	coal	223.78	224.66	0.88	&TP-4-6	TP-4-6
	coal	229.01	229.71	0.70-	&TP-4-7A	TP-4-7A
	coal	229.71	230.18	0.47	&TP-4-7B	TP-4-7B
	coal	230.18	230.73	0.55-	&TP-4-7C	TP-4-7C
	coal	248.22	248.44	0.22	-----	-----
	coal	256.14	257.34	1.20	TP-4-8	TP-4-8
	coal	261.43	262.10	0.67	TP-4-9	TP-4-9
	coal	272.05	273.05	1.00	TP-4-10	TP-4-10
	coal	274.44	274.57	0.13	----	----