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COAL RESOURCE ASSESSMENT OF THE JHERRUCK AREA, SONDA COAL FIELD, SINDH PROVINCE, PAKISTAN

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ABSTRACT

Between 1985 and 1989, the Geological Survey of Pakistan, in cooperation with the U.S. Agency for International Development and the U. S. Geological Survey, drilled 55 exploratory boreholes in the northern part of the Sonda coal field. The latest program of 20 holes drilled on 3 km centers has enabled individual coal beds to be correlated, and has led to the identification of a contiguous area of about 500 sq km where at least one coal bed exceeds 1 m in thickness.

Seven coal zones containing multiple coal beds have been identified in the upper part of the Paleocene Bara Formation at Jherruck. The thickest and most persistent coal bed occurs in the Sonda zone, and lies at depths of 80 to 400 m in the 530 sq km study area, where it ranges in thickness from 0 up to 6 m. Total in-place coal resources for this bed, considering a minimum thickness of 30 cm and a maximum dry ash yield of less than 50 percent, are estimated to be 900 million tonnes, 40 percent of which is in the demonstrated category. The average thickness of the main Sonda bed within the study area is 1.3 m, but 53 percent of the total resources estimated for this bed occurs within a 150 sq km subarea where the coal is thicker than 1.5 m and less than 300 m deep. The area is relatively undeformed structurally, but mining could be constrained by other factors such as poor roof conditions, potential mine flooding, and limits to acceptable subsidence in irrigated areas which overlie some of the thickest coal. The coal is subbituminous C in rank. Analyses of 66 samples from the main Sonda bed yield thickness-weighted averages of 8 percent ash and 1.4 percent sulfur, which compare favorably with most Pakistani coals, but the average heating value is a relatively low 7933 BTU/lb and the average moisture content is a relatively high 32 percent. Relative to typical U.S. coals of equivalent rank, the Sonda coals appear to be enriched in chlorine, bromine, strontium, and some heavy metals.

The uppermost part of the Bara Formation contains numerous marine faunal and glauconitic zones and appears to intertongue with the overlying shallow marine Lakhra Formation. Coal-bed geometries suggest that a variety of coal-forming environments were present in a generally oscillatory paralic depositional setting, and that the main bed of the Sonda zone probably formed in a raised peat swamp.

INTRODUCTION

Project backround

Since 1985, the United States Geological Survey (USGS) has been assisting the Geological Survey of Pakistan (GSP) in a cooperative investigation of the coal resources of Pakistan; this program is referred to as COALREAP (Coal Resource Exploration and Assessment Program). COALREAP is Component 2A of the joint Government of Pakistan (GOP) and United States Agency for International Development (USAID) Energy Planning and Development Project[1], which is financed by GOP and by grants from USAID. USGS participation in the project is directed by a Participating Agency Service Agreement[2] (PASA) with USAID.

Because the coal deposits of Sindh Province are larger and generally less structurally deformed than other coal deposits of Pakistan, COALREAP drilling has generally been confined to Sindh Province (fig. 1). A few GOP-financed boreholes utilizing equipment purchased under COALREAP have been drilled in other provinces, with USGS serving in a limited advisory capacity, but most of the COALREAP activity in other provinces has consisted of regional geologic studies. Regional geologic studies have only been a minor component of COALREAP activities in Sindh because of the emphasis on drilling, and the presence of security problems in remote field areas. Between 1986 and 1992, USGS maintained an office in Hyderabad (fig. 1) to support COALREAP activities in Sindh; in July 1992 the USGS Sindh office was moved to Karachi.

COALREAP drilling in Sindh Province has taken place in the

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

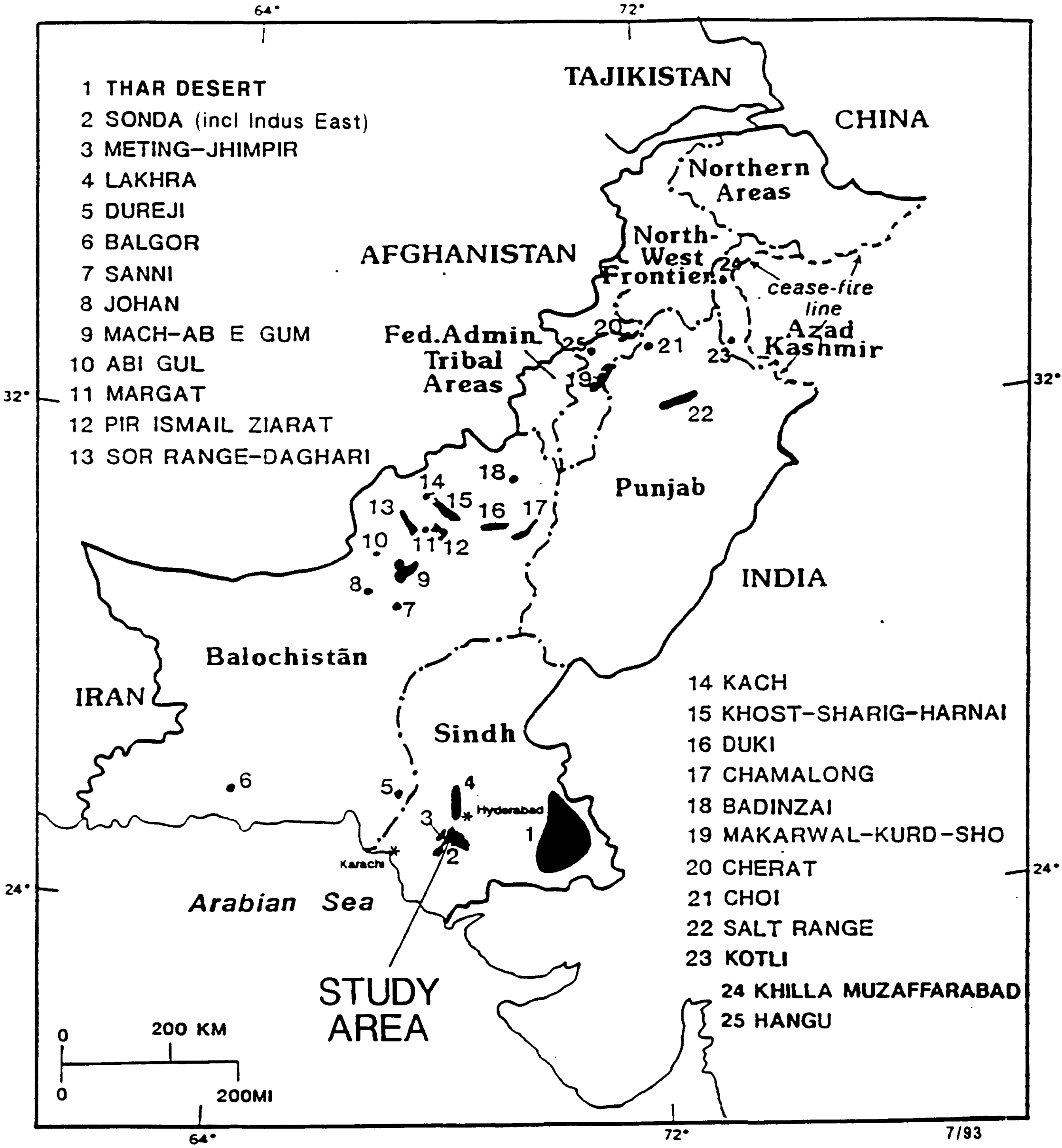

Figure 1. Index map, showing study area and location of Pakistani coal fields and occurrences.

Lakhra, Sonda, Meting-Jhimpir and Thar Desert coal fields (fig. 1), mostly at reconnaissance scales of about 3-mile (4.8 km) spacing between drill-hole centers. Drilling operations have been conducted by both private-sector contractors and GSP drilling crews. Previous reports on the results of COALREAP drilling in Sindh Province include Schweinfurth and Husain (1988), Landis, Thomas, and others (1988), Thomas and others (1988, 1992), and SanFilipo and others (1989, 1990).

The results of pre-COALREAP reconnaissance drilling by GSP in 1985 (Ahmed and others, 1986, Husain, 1986), and the first phase of COALREAP drilling in 1986 (Schweinfurth and Husain, 1988), prompted GSP to propose pre-development infill drilling in the northern part of the Sonda coal field. In April 1987, GSP submitted a proposal (Appendix 1) to USAID for partial financing of a 20-hole, 5000-meter drilling program in a 325 sq mi (850 sq km) area of the Sonda coal field, just north of the town of Jherruck. The Jherruck drilling was to be done utilizing GSP crews and equipment, with USAID financing all consumable items and USGS providing technical assistance, and was to occur simultaneously with USGS-proposed reconnaissance drilling by private-sector contactors on the opposite (eastern) side of the Indus river. The "Indus East" contractor-drilling program began in September 1987 and was completed in February 1988, but funding problems delayed commencing the Jherruck drilling until January 1988, and operational delays extended completion of the drilling program until February 1989.

Purpose and scope

The main purpose of this report is to assess the coal resources in the northwestern part of the Sonda coal field, generally referred to as the Jherruck Area. The report is an update of an earlier report assessing the Sonda coal field (Schweinfurth and Husain, 1988), incorporating drilling done since the completion of the first report. This is an interpretive report; the basic borehole data from Jherruck and surrounding areas, such as lithologic and geophysical logs, are presented in Schweinfurth and Husain (1988), Thomas and others (1988), Landis, Thomas, and others (1988), and SanFilipo and others (1989), and will only be summarized herein.

Completion of this report also served as the primary training tool in the execution of the stated COALREAP PASA objective of training the GSP in modern coal resource assessment methods. Although COALREAP has produced two other comprehensive coal resource assessments (Schweinfurth and Husain, 1988; Thomas and others, 1992), neither proved adequate as training tools; the former relied on computerized technology that was not amenable to transfer to GSP on a sustainable basis, and for the latter there was insufficient GSP counterpart availability to be an effective training tool.

The original intent of the Jherruck proposal (Appendix 1) included GSP's assumption of the primary responsibility for submission of the final Jherruck resource assessment to USAID (Dr. Edwin Noble, USGS, personal communication). A summary report was presented by GSP at a USAID-sponsored workshop in Karachi in 1990 (Kazmi and others, 1990), but a report completed to internationally accepted standards and in sufficient detail to permit mining prefeasability studies was not forthcoming as planned, hence the preparation of this report. The senior author of this report, who did not participate in most of the drilling activities within the study area, agreed to participate in the report writing with the understanding that: 1) GSP would provide two counterparts who would contribute to the report from start to finish, 2) all work would be completed in Pakistan or with counterpart participation in the U.S., and 3) GSP would provide drafting support in Hyderabad, and map processing support utilizing the GSP map publication facilities installed in Quetta through COALREAP. Attempting to fulfill these conditions resulted in severe delays to the completion of this report, and much of the work, particularly map processing, was ultimately done by the senior author in Reston.

This report is primarily based on borehole data generated by COALREAP and other GSP drilling completed from 1981 to February 1989 (fig. 2). The area on the west side of the Indus River in figure 2 has been variously referred to as Sonda North, Indus West, and Sonda West in prior reports, while the area on the east side has been referred to as Indus East or Sonda East. Various configurations of the area between Ongar and Jherruck villages, where the thickest coal is located, have been referred to by GOP as the "Jherruck block", with the intent of defining a mineable unit. For the purposes of this report, we will refer to the general area of figure 2 as the "map area" or "study area" (more precisely the area covered by Plate 1). A restricted area located between Bolari village, Jherruck, the Indus River, and the railroad (fig. 2) will be referred to as the "resource area"

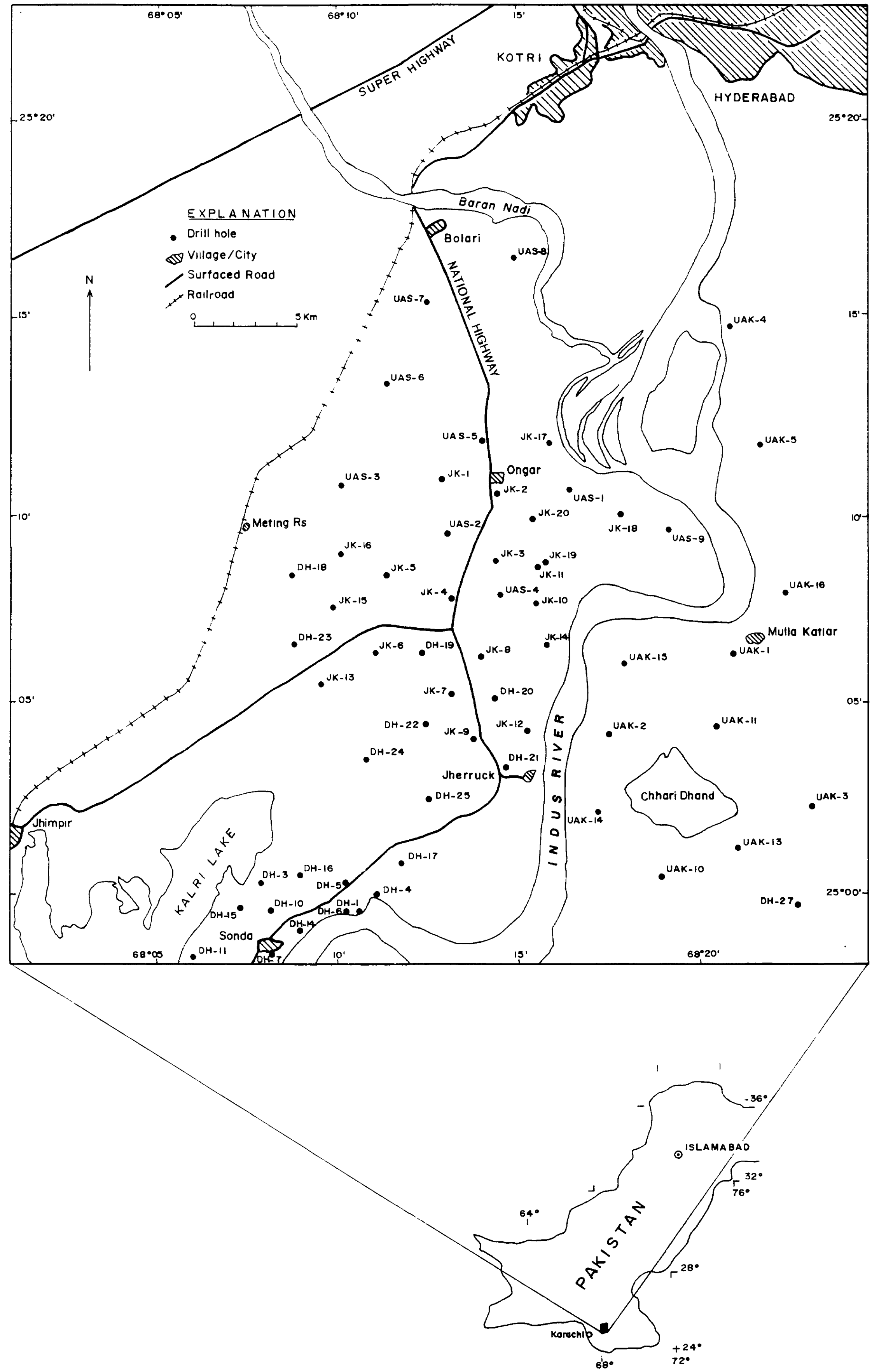

Figure 2. Drill hole locations, Jherruck area and vicinity. Note that the location of JK-18 has been revised from that shown in SanFilipo and others (1989, fig. 2).

(defined precisely on p. 63 and Plate 14). We have calculated coal resources within the "resource area" only, but we have used information from the entire map area to construct our coal-bed models. Coal resources on the east side of the river have been calculated by Thomas and others (1992).

A few outcrop and mine shaft observations were used to supplement the drilling data for this report, mostly for stuctural control (nb: as yet there has been no mining in the Sonda coal field; coal mine data from the adjacent, but stratigraphically higher, Meting Jhimpir coalfield were somewhat useful for structural projections, however, and these mine locations are shown on the Plates included in this report). Only the southern half of the study area has been geologically mapped at a scale of less than 1:250,000 (Ahmed and others, 1984), and this mapping is rudimentary. Despite recommendations by the senior author to the contrary, formal geologic mapping was considered beyond the scope of this project. Because of the large number of unmapped faults in the project area, however, extensive use of aerial photographs was necessary to complete the structure contour and overburden maps.

<u>Responsibilities and acknowledgements</u>

The results of this study represent the culmination of several years of data acquisition and analysis by a large number of individuals, all of whom contributed in one way or another. Drilling operations in the study area took place in four phases, which are summarized in table 1. The responsibilites for drilling-related activities that were assigned to various project personnel are discussed in detail in Schweinfurth and Husain (1988), Landis,

Table 1. Summary of drilling activities through 1989*, Jherruck area and vicinity, northern Sonda coal field, Sindh Province, Pakistan.

Program	Dates	Prefix	Total drilled	This report Map area	This report Resource area
GSP	1981 - 1986	DH-	27**	16	8
COALREAP (IVCC)	1986 - 1987	UAS-	9	9	9
COALREAP (IVCC)	1987 - 1988	UAK-	16	11	-
COALREAP (GSP)	1988 - 1989	JK-	20	20	20

GSP = Geological Survey of Pakistan

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

* four USAID-funded holes were drilled in the study area by GSP in 1992 for the John T. Boyd Co.; these holes were completed during the preparation of this report are not utilized herein.

**17 holes were drilled in the central part of the Sonda coal field between 1981-1983 and 10 holes were drilled in the northern part between 1985 and 1986.

Thomas, and others (1988), and SanFilipo and others (1989), and will be discussed only briefly herein.

In summary, GSP was responsible for borehole site selection for the first and last phases of Jherruck drilling (DH- and JK- series, table 1). USGS was responsible for selecting borehole locations for the second and third phases of drilling (UAS- and UAK- series, table 1). Travel restrictions imposed by the U.S. Consulate in Karachi (due to a security incident at a COALREAP drill site in the Lakhra field) prevented USGS personnel from visiting the field until the final stages of the UAS- program, however, and supervision of most of the UAS- drilling operations, including in some cases determining drilling depths, became the responsibility of GSP. USGS had limited oversight responsibility for the first half of the JK- drilling, but USGS personnel were not on-site for the last ten JK- holes.

The USGS author of this report spent a total of only eight days in the field during actual drilling operations within the study area, and was not responsible for site-selection or drilling depths for any of the DH-, JK-, or UAK- holes, with the exception of staking UAK-1 and UAK-2. The USGS personnel who did have drilling-related responsibilites during the UAK- and JK- programs are noted in the aforementioned reports. The GSP authors of this report performed well-site duties for several of the UAS-, UAK-, and JK- boreholes, including core description and coal sampling, but were not responsible for determination of borehole locations or drilling depth, which was left to more senior personnel.

SanFilipo traveled to Pakistan in February 1989 to compile the basic borehole data (e.g. lithologic and geophysical logs) from the JK- series drilling into a report for public release, and to begin work on the interpretive report. Several subsequent trips to Pakistan were made by SanFilipo to complete this report. The trips are outlined in table 2, along with several delays due to unavoidable circumstances. Throughout the project, progress was delayed by civil unrest in Sindh Province and lack of GSP operating funds. Because the training component of this study required that the GSP counterparts be present for each sequential step in coal resource evaluation, SanFilipo worked on other COALREAP activities during periods when GSP personnel were not permitted to travel to Hyderabad for security reasons or lack of travel funds. The project was also delayed in 1990 when the Ministry of Petroleum and Natural Resources inexplicably cancelled training in the U.S. for SanFilipo's GSP counterparts; the two GSP author's eventually visited the U.S. in 1991 for training in coal resource assessment and to observe several large-scale and unconventional mining operations.

Preliminary coal resource estimates and coal quality statistics were presented by the authors at the First South Asia Geological Congress in Islamabad in February 1992. SanFilipo was required to supervise a large new drilling project in other areas of Sindh Province in 1992, and GSP was unable to meet earlier commitments to provide sufficient additional geologists to allow at least one GSP author to continue work on the report during drilling activities. As a result, only intermittent progress was

Table 2. Schedule of report preparation activities and foreign temporary duty (TDY) travel assignments. Except as noted, most work was performed in the USGS Hyderabad office.

Traveler*	Dates	Activity
SanFilipo	8 Jan 89 - 30 Apr 89	(other COALREAP activities)
	1 May 89 - 29 May 89	Compiling basic drilling data, JK- series. Draft report (IR)PK-85 submitted to USAID 29 May 89.
SanFilipo	Oct - Dec 89	TDY cancelled due to civil unrest in Sindh
SanFilipo	14 Jan 90 - 9 Apr 90	(other COALREAP activities)
	10 Apr 90 - 29 May 90	Data interpretation. Evacuated Hyderabad 23 May due to civil unrest.
Shafique/Chandio	July - Aug 90	U.S. training cancelled by GOP.
SanFilipo	Sep - Oct 90	TDY delayed by GOP elections.
	28 Oct 90 - 15 Dec 90	Data interpretation.
SanFilipo	Jan - May 91	TDY delayed by Gulf war.
	9 May 91 - 13 Jul 91	Data interpretation and map preparation.
Shafique/Chandio	14 Jul - 17 Aug 91	U.S. training
SanFilipo	20 Oct 91 - 14 Dec 91	Data interpretation and map preparation
SanFilipo	17 Jan 92 - 27 Feb 92	Resource calculation and map preparation. Preliminary results presented at GEOSAS Congress, Islamabad, 23 -27 Feb, with coauthors.
	28 Feb 92 - 11 Jun 92	(other COALREAP activities; intermittent map and report preparation during drilling breaks).
	12 Jun 92 - 14 Jul 92	Report and map preparation.
	16 Jul 92 - 22 Jul 92	Med-evaced to Karachi.
	23 Jul 92	Med-evaced to U.S.
	Nov - Dec 92	Report materials arrive in U.S.
	Dec 92 - Oct 93	Report compilation/writing in U.S.

*During SanFilipo's travel to Pakistan, Mssrs. Shafique, Chandio, and Fahimuddin were temporarily assigned to Hyderabad (security, funding, and other commitments permitting).

made in early 1992. SanFilipo had to leave Pakistan for medical reasons in July of 1992. By that time, most of the statistical calculations and maps had been prepared, but the text and final compilation had to be completed in the U.S., after a considerable delay in the receipt of required materials from Pakistan.

Most of the statistics and resource calculations in this report were calculated by the GSP authors of the report under the supervision of the USGS author. All calculations with the exception of the inorganic coal quality parameters were done by hand-held calculator rather than digital computer, so that each GSP trainee would become familiar with all steps in the process. Because of the volume of the data, the inorganic constiuents were reported utilizing USGS computers in Reston Virginia, with the help of Charles Oman of the USGS.

The authors would like to thank Mr. Fahimuddin, GSP Karachi, for the excellent drafting support that he provided in Hyderabad throughout the life of the project. The many GSP geologists who contributed at the drill sites over the course of GSP activities in Jherruck are also duely noted. The staff of the USAID guest house in Hyderabad, who also maintained a USGS office for the course of the entire project, are gratfully acknowledged, as is the help of Mr. John Hucke, Regional Security Officer, U.S. Consulate, Karachi, and Mr. Rauf Gul, Program Specialist, USAID Karachi, in arranging armed escorts to the field. Overall project supervision and the responsibility for coordinating USGS/GSP/USAID activities rested with USGS Resident Team Leaders Edwin Noble (through 7/90) and James Fassett (post 7/90).

Geographic setting

Location, access, and infrastructure

The area studied is located in southern Sindh Province, about 125 km east-northeast of Karachi and 30 km east of Hyderabad (fig. 1). Karachi, a sprawling metropolitan center with a population of over 8 million, is the largest city and the financial center of Pakistan, as well as the capital of Sindh Province. The study area is accessible from Karachi via a poorly maintained metalled road known as the National (or Indus) Highway, which roughly bisects the study area (fig. 2). The main Karachi - Hyderabad trunk, known as the "Superhighway", passes about 25 km north of the center of the study area. It is a well-maintained divided highway up to about halfway between Karachi and Hyderabad, and work on completing the second lane to Hyderabad is in progress. Hyderabad is located on the Indus River, and is an historically important trading and cultural center, with a present population of nearly one million people. The Indus River feeds the world's largest irrigation system, and Hyderabad is one of the agricultural centers of Sindh, as well as a light-manufacturing and textile center.

Most freight in Pakistan is moved by truck, and all roads are severely overutilized. The Indus River is no longer navigable by heavy shipping due to irrigation withdrawal, and thus would not support coal transport by ship. A narrow-guage rail system which connects Karachi and Hyderabad borders the study area on the west, but is currently supporting passenger traffic only. The large canal system (Plate 1) which passes through the study area to supply Indus River water to Karachi for drinking purposes would need to be considerably upgraded to support even light barge traffic.

Coal is currently being mined from small underground workings in the Lakhra and Meting Jhimpir fields of Sindh (fig. 1) and shipped by truck to brick-making centers, mostly in Punjab Province. Most of the mining companies operating in Lakhra and Meting-Jhimpir maintain offices in Hyderabad.

Pakistan suffers from a severe shortage of indigenous energy supplies and lacks the hard currency to sustain energy growth by importing fuels. Electrical loadshedding and brownouts are common in Hyderabad and most other cities, and many rural areas are not yet electrified. The study area lies only a few kilometers from the major north-south electrical grid system in Pakistan. Several feasability studies to develope mine-mouth power plants in the Lakhra coal field to connect to this grid system have been completed (Japan Industrial Cooperation Agency [JICA], 1981, Boyd, 1986). Most of these studies have failed to attract sufficient financing, but three small (50mw) fluidized-bed units are currently under construction by the Pakistan Water and Power Development Authority (WAPDA) at Khanot, just east of the Lakhra field. The ability to use some heavy coal-mining equipment, such as shearers, could be impeded by the chronic voltage problems in the existing electical grid. (B. Rohrer, J. T. Boyd Co., oral commun., 1992).

It should be noted that while the generic restrictions on travel within Sindh Province that have been issued by GOP and USAID due to civil unrest and banditry have been a severe impediment to work in both the Hyderabad office and the field throughout much of COALREAP, the study area itself is generally more peaceful than other areas of Sindh. We are in fact aware of only one serious security incident involving project personnel (an armed hijacking of a GSP vehicle) that has occurred within the Sonda coal field proper during the life of the project.

Topography

The study area lies on the juncture of the foothills to the central mountain ranges of Pakistan and the Indus alluvial plain. Most of the area east of the National Highway (fig. 2) is heavily irrigated farmland with almost no topographic relief. Mining in this area could be constrained by seasonal flooding, perennial waterlogging, depth of alluvium, numerous small villages, and competing agricultural values. The area between the National Highway and the Pakistan Railway Line (fig. 2) consists mostly of rocky plains and small (< 25 ha) mesas with typically less than 30 m relief, and a few larger mesas. Most of this area would be easily accessible with only minor roadwork, and other than increased overburden, there are no topographic obstacles to mining. The regional dip of the rocky areas is gently to the west, however, and hydrologic connectivity with waterlogged areas along the Indus is likely.

The area to the west of the railroad (fig. 2) is characterized by heavily dissected broad mesas and hills of up to 80 m relief, and is a topographic and overburden barrier to coal development.

The topsoils and bedrock which comprise most of the surface in the vicinity of the Sindh coalfields are generally calcareous, and would probably mitigate (or even benefit from) the effects of potentially acidic stack emissions from mine-mouth generating facilities.

Field operations

Field operations during the exploration phases of the Jherruck area have been covered in detail in previous GSP and COALREAP publications (citations to follow), and will only be mentioned briefly here. Borehole locations in Survey of Pakistan rectangular coordinates and hole elevations in meters are shown in table 3. Locations and elevations were surveyed by GSP surveyors triangulating by theodolite from published Survey of Pakistan control points.

The DH- and JK- series boreholes were drilled by GSP using Longyear model 34, 38 or 44 diamond drilling rigs. The DH- and JK- series were generally continuously cored by wireline from the top of the hole. Results of the DH- series drilling were summarized in Ahmed and others (1986), and lithologic logs were released in Khan (1988). Unfortunately no record of core size, noncore intervals, or core recovery is available for the DH- series. DH- cores examined by the authors are of HQ (63.5 mm) and NQ (47.6 mm) size. Four of the DH- series holes (DH-20,21,22, and 27) were geophysically logged during simutaneous USAID programs; the logs are included in Khan and others (1988). Detailed drilling statistics, lithologic logs, and geophysical logs for the JK- series boreholes are included in SanFilipo and others (1989).

The UAS- and UAK- series holes were drilled by the Indus Valley Construction Co. (IVCC), utilizing Atlas-Cupco B-50, Wirth

Table 3. Surveyed drill hole locations and elevations, Jherruck area of the Sonda coal field.

DRILL HOLE	EASTING[1] (meters)	NORTHING[1] (meters)	GROUND ELEVATION (meters above MSL)
JK-1	2161340.2	836583.0	49.40
JK-2	2163660.4	835863.0	17.90
JK-3	2163561.9	832738.3	17.41
JK-4	2161553.6	830913.4	19.81
JK-5	2158454.1	832200.5	32.50
JK-6	2157764.2	828467.3	30.80
JK-7	2161279.5	826607.3	24.47
JK-8	2162688.2	828219.0	18.65
JK-9	2162136.8	824463.6	20.29
JK-10	2165296.3	830597.7	18.04
JK-11	2165674.2	832205.3	15.11
JK-12	2164776.2	824569.8	14.75
JK-13	2155072.4	827132.4	31.39
JK-14	2165826.8	828676.6	15.78
JK-15	2155958.9	830932.5	33.74
JK-16	2156117.4	833411.0	39.71
JK-17	2166273.6	838264.9	20.48
JK-18	2169546.5	834513.1	15.91
JK-19	2165971.1	832495.9	17.86
JK-20	2165508.5	834676.5	15.48
UAS-1	2167167	835853	18.9
UAS-2	2161440	834086	36.0
UAS-3	2156351	836515	78.6
UAS-4	2163655	830964	16.2
UAS-5	2163161	838329	23.5
UAS-6	2158782	841261	45.4
UAS-7	2160849	845115	32.0
UAS-8	2165005	847037	30.8
UAS-9	2171727	833764	18.6
UAK-4	2175092	843281	18.0
UAK-5	2176470	837643	20.4
UAK-6	2185023	830970	13.1
UAK-7	2191315	828194	12.5
UAK-8	2184931	821607	11.6
UAK-9	2182335	811921	11.3
UAK-10	2170796	817186	14.6
UAK-11	2173676	824471	14.3
UAK-12	2181498	826905	12.5
UAK-13	2174299	818421	12.8
UAK-14	2167709	820335	13.1
UAK-15	2169200	827604	15.5
UAK-16	2177140	830634	12.5
DH-1	2156320	816100	13.5
DH-2	2143052	803949	16.8
DH-3	2151712	817783	15.9
DH-4	2157062	816866	9.6
DH-5	2155841	817570	28.9
DH-6	2155677	816176	20.7
DH-7	2152156	814549	9.3
DH-8	2149961	811053	13.4
DH-9	2148148	802964	6.8
DH-10	2152139	816495	21.4
DH-11	2148333	814479	11.1
DH-12	2146165	807848	9.6
DH-13	2147466	811660	10.5
DH-14	2153520	815444	14.2
DH-15	2150761	816685	13.1
DH-16	2153667	818087	28.7
DH-17	2158514	818401	13.8
DH-18	2153881	832352	52.7
DH-19	2159921	828501	32.6
DH-20	2163245	826195	17.2
DH-21	2163601	822910	25.6
DH-22	2159952	825208	28.4
DH-23	2153880	829095	39.6
DH-24	2157029	823594	30.5
DH-25	2159957	821617	24.7
DH-26	2171515	811522	11.6
DH-27	2177222	814946	10.7

[1]Survey of Pakistan rectangular grid system; precision as reported.

B-O, or Longyear 44 rigs. Drilling was generally by noncore rotary methods through the marine rocks overlying the coal-bearing zones, and by wireline coring through coal-bearing intervals. HQ was the preferred core size in order to insure sufficient coal sample for retention of backup and petrographic splits, but reduction to NQ was necessary under some drilling conditions. Detailed drilling statistics, rock descriptions, and geophysical logs for the UAS- and UAK- series holes are presented in Thomas and others (1988), Schweinfurth and Husain (1988, part III.1), and Landis, Thomas, and others (1988).

Rock core is currently stored in wooden boxes in the GSP core library in Sonda. Most of the cored coal was shipped to the U.S. for analysis, but some coal samples from the latter part of the program were split in the field and analysed by both GSP and USGS labs. Coal sampling procedures are discussed in detail in previous COALREAP reports and summarized in the COAL QUALITY section of this report.

COALREAP holes (and DH-20,21,22, and 27) were geophysically logged using two analog recorders purchased by USAID from Geoscience Inc., Boulder Colorado. A Geoscience Inc. operator was present to train GSP and WAPDA operators during the early phases of COALREAP drilling, but he could not travel to the field during most of the UAS- series drilling due to security restricions; consequently, most of the holes in the Jherruck area were logged by GSP operators. Boreholes were generally logged through drill rods with a natural-gamma/neutron tool and a gamma-gamma (4-pi) density tool in order to insure a good log before the holes collapsed. Then the rods and/or casing was pulled (or partially pulled to expose coal) and the holes were relogged with the gamma-neutron-resistivity and 4-pi tools, and logged with 3-arm caliper and high resolution density (HRD) tools. In many cases, the hole collapsed or the resistivity and/or HRD tools were inoperable, and only gamma-neutron and 4-pi logs through rods are available.

The coal-bearing interval of the Sonda coalfield contains a large percentage of friable sand that caused a number of drilling problems, including stuck rods and casing, appreciable core loss (table 4), and holes caving prior to geophysical logging. While the overall core recovery of the IVCC holes within the resource area was comparable to the GSP holes, the holes drilled by GSP were far more stable than the IVCC holes. HQ size was maintained for most of the JK- holes, and the overall condition of the core is much better than the IVCC core; much of the sand recovered in the IVCC holes was probably wash that was recovered out of place (e.g. the interval from 210.35 - 215.65 in UAS-2; see Schweinfurth and Husain, 1988, part III.1). More importantly, the JK- holes were far less rugose than the IVCC holes, and consequently produced much more useful geophysical logs. In any case, the drilling difficulties in the Sonda coal field (and elsewhere in Sindh) underscore the necessity of keeping good records of core recovery and obtaining geophysical logs of good quality. The fact that the loose sands tend to inject themselves several meters or tens of meters up the drill rods after the innerbarrels are pulled implies that these sands are under significant hydrostatic pressure which may act as a

Table 4. Summary of core loss statistics, COALREAP drilling in the Sonda coal field; see Schweinfurth and Husain (1988), Thomas and others (1988), Landis, Thomas, and others (1988), and SanFilipo and others (1989) for details of individual boreholes.

	------Percent core recovery------		
Borehole Series	Total	In coal	Main Sonda bed
UAS-	79	93	98
JK-	70	91	95
Resource area total*	72	92	96
**UAK-	52	75	91
Map area total*	65	88	95

*excluding DH- series; no data available

**within map area only; does not include UAK-6,7,8,9 and 12 severe impediment to mining.

As previously noted, most of the interpretive work in creating this report was done in the USGS office in Hyderabad after a significant amount time had elapsed since the completion of drilling. Field activities during this period were generally restricted to checking faults located by aerial photographs, and verifying published core descriptions and borehole locations where there were correlation problems.

GEOLOGY OF THE SONDA COAL FIELD

The geology of the Sonda coal field has been covered in detail in SanFilipo and others (1988) and will only be briefly discussed herein.

Geologic setting

The Sonda coal field is located in the Kirthar geologic province of the Lower Indus Basin of Shah (1977), and the Thar slope platform tectonic zone of Quadri and Shaib (1986). The Kirthar province (fig. 3) is characterized by two distinct sedimentary facies. The first consists of more than 9000 m of Triassic through middle Miocene-age platform carbonates with subordinate shale and sandstone. These generally shallow-marine rocks were deposited along the northwestern edge of the Indo-Australian plate as it migrated towards the Eurasian plate during the closing of the Neotethyan seaway. The second facies consists of about 3000 m of middle Miocene to recent coarse-clastic molasse sediments that were derived from the folded mountains uplifted to the north and west after the collision of the plates, which began in the middle to late Eocene. The study area lies on the Lakhra structural arch (Hyderabad high) of Kazmi and Rana

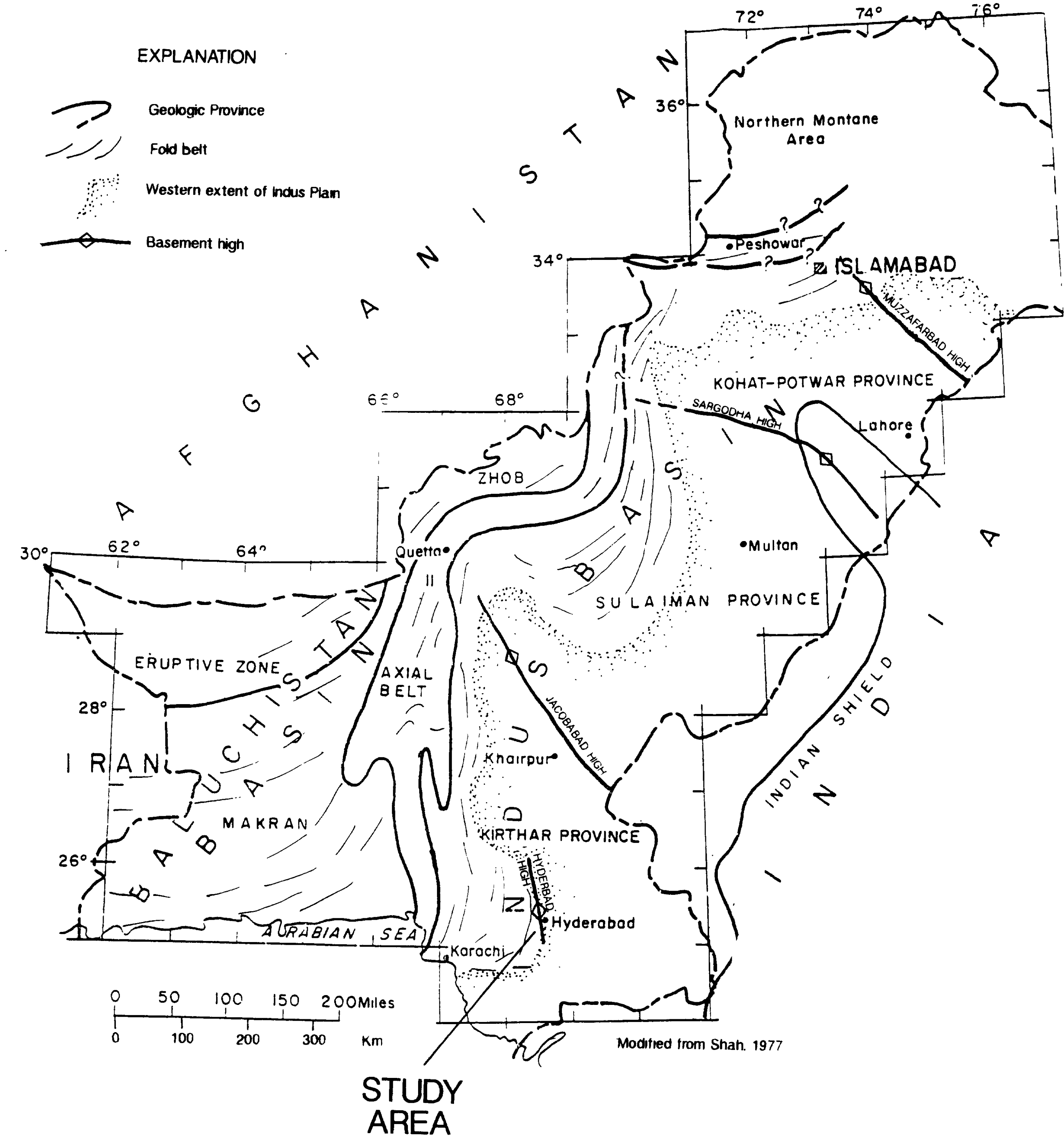

Figure 3. Tectonic setting and major geologic provinces of Pakistan.

(1982), which is the southeasternmost exposed structure of the fold and thrust belt that essentially follows the plate suture (axial belt of fig. 3).

Coal formation in the Kirthar geologic province was restricted to brief periods of emergence within the generally marine precollisional facies. It is unclear from the work done to date whether the primary mechanism for emergence is eustatic, uplift associated with collisional tectonics, or some other process. The recent discovery of early Tertiary age coal nearly superjacent to basement rocks in the Thar Desert (SanFilipo and others, 1992) suggests that previous models for coal deposition in Pakistan, such as local uplift (Ahmed and others, 1986), need to be reevaluated.

Stratigraphy

The generalized stratigraphy of the study area to the depths drilled by COALREAP is shown in figure 4, and a generalized geologic map of the study area and surrounding areas is shown in figure. 5. The stratigraphically highest bedrock unit shown in figure. 4, the Manchar Formation, is the postcollisional Siwalik equivalent in Sindh, and consists of coarse clastics and subordinate claystone of Miocene to Pleistocene age. This unit is over 900 m ft thick at Manchar Lake, about 130 km north of the study area (Farshori, unpub. manuscript), but south of Baran Nadi (fig. 5), the Manchar Formation is limited to a few isolated outcrops. Manchar Formation is mapped (quadrangle 40C/3, unpub., GSP files) within a small part of the study area just west of Bolari (figs. 2, 5), but Manchar has been mapped incorrectly over much of Sindh (SanFilipo and others, 1988), and these rocks may

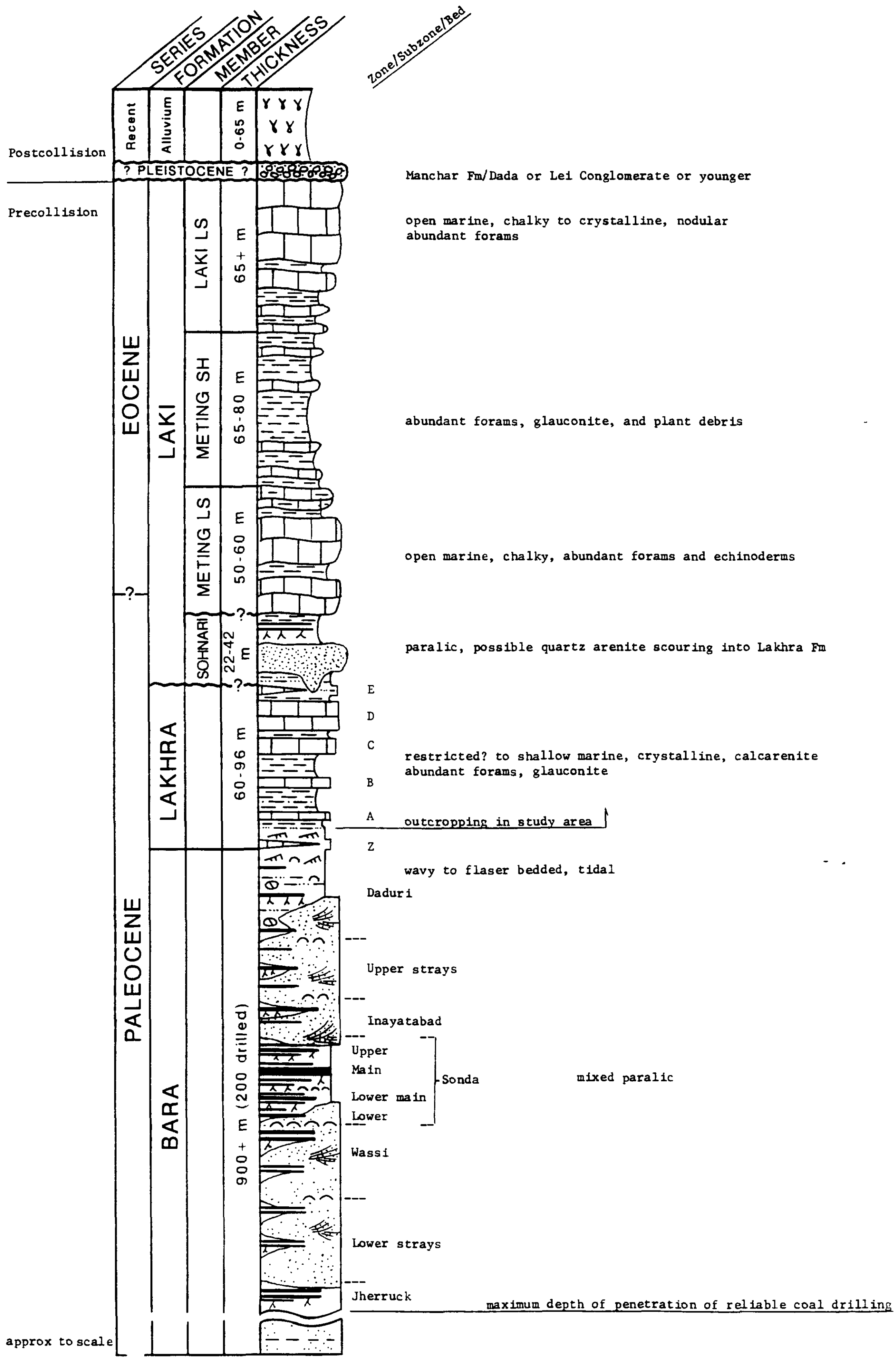

Figure 4. Generalized stratigraphic column, northwestern Sonda coal field. See figure 6 for explanation of symbols.

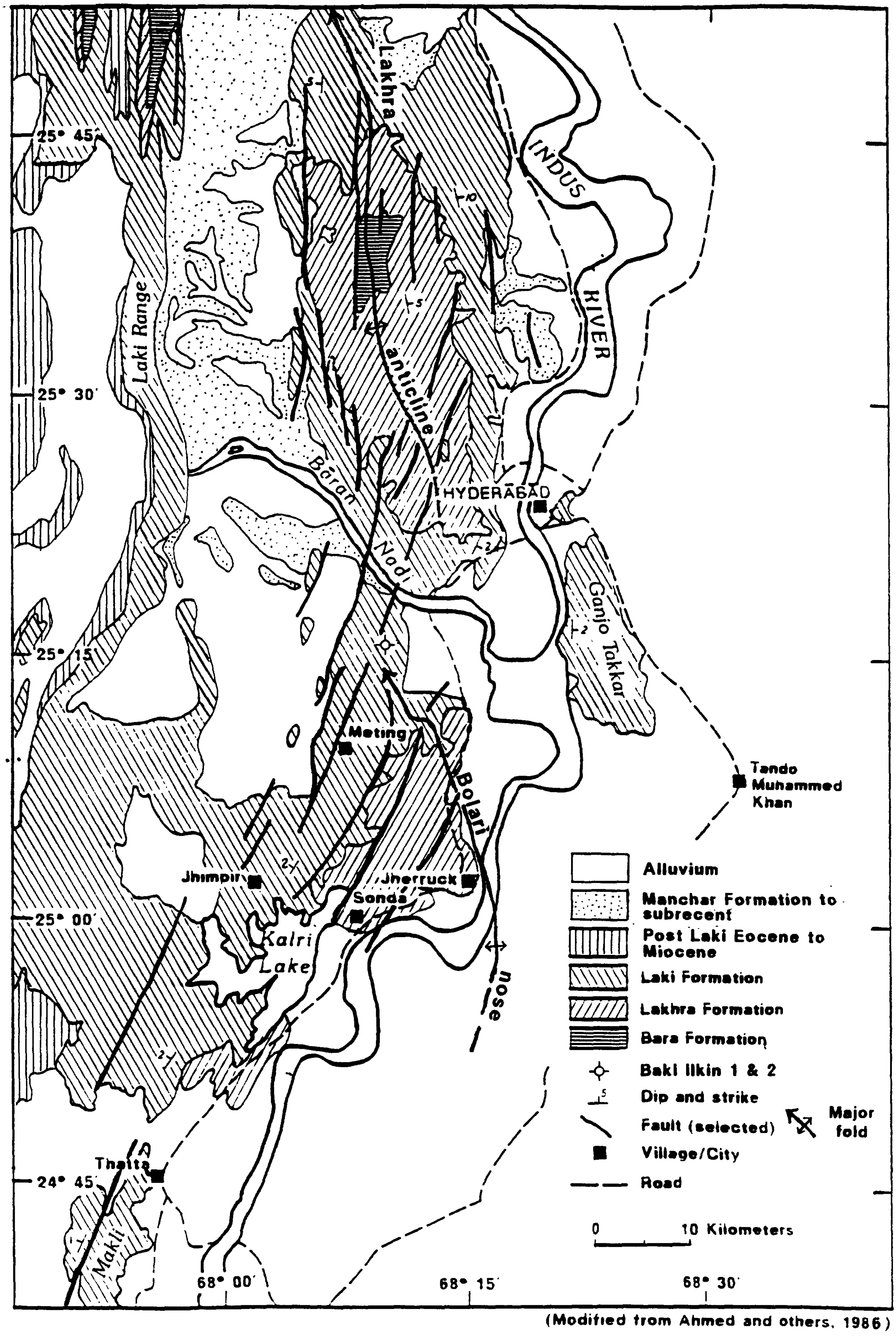

Figure 5. Generalized geologic map of the Lakhra and Sonda coal fields and vicinity.

actually be younger than true Manchar. Although postcollisional rocks are sparse within the study area proper, they are important to regional coal exploration because more than 2000 m of precollisional rocks which overlie the Laki Limestone in most of the Kirthar geologic province (e.g. west side of fig. 5) were probably removed from the study area by pre-Manchar to recent erosion.

The Laki Formation consists of nodular to thinly bedded limestone with subordinate beds of highly glauconitic greenish-brown shale. The limestone is generally a coarse-grained calcarenite composed of foraminifera and echinoderm fragments in a sparry matrix, but in places it is chalky or micritic. Both the Meting Limestone and the Laki Limestone Members form conspicuous steep white cliffs. The two units are difficult to distinguish in hand-specimen, but the Laki is notably brighter and has a conspicuous angular morphology on aerial photos. The Laki Formation is recognized as Eocene by GSP (Kazmi and others, 1990), but Usmani (1983) has indicated that, on the basis of planktic foraminifera, the lower part of the Laki Formation is Paleocene. COALREAP drilling was generally spudded below the base of the Meting Limestone, because the depth to Bara Formation coal would otherwise have been prohibitive.

The Sohnari Member of the Laki Formation (Sonhari Formation of Outerbridge and others, 1991), consists of coal-bearing ferruginous sandstone and claystone. It weathers to a deep red ironstone and has traditionally been described as a fossil laterite marking the base of a regional unconformity (Nutall

1925), but many writers since Ghani and others (1973) have pointed out that the coloring is a modern surficial phenomena. Rather than a fossil laterite, we believe that the Sohnari is probably a tongue of the Bara Formation, as first suggested by SanFilipo and others, (1988). Very conspicuous coarse orthoquartzite lenses that appear to be Sohnari paleochannels scouring the top of the Lakhra Formation have been observed by the authors in outcrops to the north and south of the study area, however, and these suggest that an intra-Sohnari unconformity may in fact exist. Coarse Sohnari sands which possibly represent these channels in the subsurface were penetrated by several COALREAP holes, notably UAS-8 and UAK-5 (see Plates 6 and 8).

The Lakhra Formation is the upper (marine) part of the Ranikot Group of Hunting (1960) and earlier workers. In the study area this unit consists of resistent limestone beds intercalated with dark-brown to greenish brown shale. In the subsurface, the limestone is typically a fossil hash composed of mollusc and foraminifera debris enclosed in a generally soft matrix of glauconitic marl (nb: although molluscs are common in the Lakhra Formation, much of the shell debris described as "pelecypod" or "bivalve" in COALREAP core descriptions was probably in reality the large benthic foraminifera *Discocyclina*, especially near the top of the formation). At the surface the matrix is usually recrystallized and quite hard, and the limestone beds form conspicuous strike ridges or rocky flats surrounding isolated mesas, and these landforms dominate the landscape of most of the study area. In the subsurface towards the north end of the study area, the limestone beds merge at the expense of the shale interbeds, and the unit as a whole becomes more sparry. Going further north to the Lakhra coal field, the unit splits up again and becomes more sandy.

GSP recognizes five key limestone beds in the Lakhra Formation in the Sonda area (Ahmed and others, 1984), named from bottom to top A,B,C,D, and E (fig. 4). We recognize a lower unit, described herin as the "Z" limestone, which pinches out laterally towards the south and east. The "lowest limestone bed" of the Lakhra Formation is frequently used as a datum to correlate coal and other rock units in Sindh (e.g. Ahmed and others, 1984). In the opinion of the authors, the failure to recognize the existence of the "Z" limestone and the gradational nature of the Lakhra/Bara contact (described below) has resulted in erroneous coal bed correlations and unsupportable regional geologic concepts in many prior studies, notably Ahmed and others (1984), SanFilipo and others (1988), Kazmi and others (1990), Outerbridge and others (1991) and Thomas and others (1992).

The contact between the Lakhra and underlying Bara Formation is gradational and intertongueing. There is, in fact, a transitional facies between the two units where shelly, glauconitic claystone which resembles typical interbeds of the Lakhra Formation passes gradually into wavy-bedded tidal siltstone and fine-grained sandstone, which in turn grades downwards into siderite-dominated dark mudstone typical of the uppermost Bara Formation.

The Bara Formation is the main coal-bearing unit in Sindh. The upper part of the Bara Formation is dominated by clean quartzose sandstone interbedded with subordinate mudstone or pale-gray claystone. The mudstone is typically chocolate colored and often contains small, well-preserved gastropod shells which appear to be composed of original aragonite. The claystone is dense, rooted, and contains conspicuous matrix-supported grains which are tentatively identified as authigenic quartz. These claystones are often seatrocks for the Bara coal beds, but coal is also found superjacent to massive sandstone beds.

Coal exploration generally does not penetrate more than the upper 200 m of the Bara Formation. In a test hole which penetrated 550 m of Bara Formation, drilled by the Pakistan mineral Development Corporation (PMDC) in the Lakhra coal field, the upper Bara facies was about 320 m thick, but consisted of mostly non-coalbearing sandstone below the top 200 m. The Bara Formation is reported to be 857 m thick in the Baki Ilkin-2 test well, drilled by the Pakistan Oil and Gas Development Corporation (OGDC) in the north end of the study area (fig. 5).

Baki-Ilkin 2 bottomed in the Chiltan Formation (Jurassic) at a depth of 4,346 m (OGDC, 1990). The geology of the rock units of Sindh Province that are not shown in figure 4 are covered in detail in Hunting (1960), Farshori (unpub. manuscript), and SanFilipo and others (1988).

All of the rock types shown in figure 4 have distinct signatures on natural-gamma/neutron downhole geophysical logs, which are the most useful correlation tools for this type of study. A gamma-neutron log for a typical COALREAP borehole, with the major lithostratigraphic units and facies indicated, is shown in figure 6.

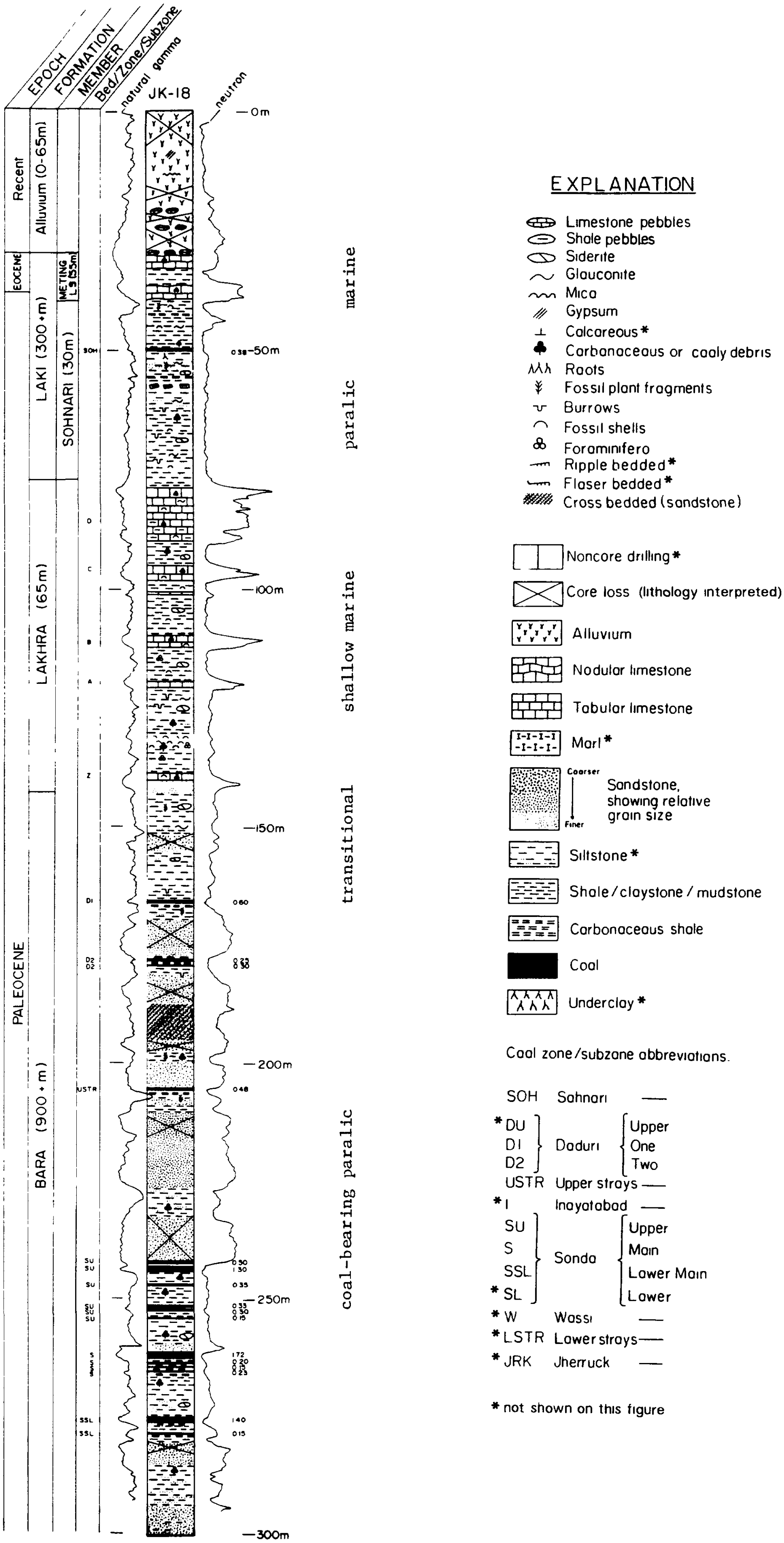

Figure 6. Typical borehole lithologies and gamma-neutron log, Jherruck area and vicinity.

Depositional Environments

Analysis of depositional environments in more detail than the major facies shown in figures 4 and 6 is generally beyond the scope of this report, and is in any case difficult due to lack of available information. In particular, many of the Bara Formation sandstone beds are almost completely lost when cored, and what is recovered is usually commixed to the point that bedforms are unrecognizable. Good exposures of the Bara Formation, which does not outcrop in the study area*, are confined to the Laki Range (fig. 5), where travel is usually restricted due to activity by dacoits (bandits). The authors made a few brief reconnaissance visits to these areas in 1989 and 1990 (Wnuk, SanFilipo, Chandio, and Fatmi, 1993), but in the short time available we were unable to determine if the coal-bearing upper facies is present there. Our study of the upper Bara sandbodies, which are the key to reconstruction of the coal-forming environments, is thus limited to geophysical logs and incomplete core.

The Bara Formation has usually been described as fluviatile (Hunting, 1960, Cheema, 1977), but COALREAP drilling has demonstrated that there is considerable marine influence on at least the upper 200 m (SanFilipo and others, 1988). A few thin marine-fossil hash beds occur in the upper Bara, and the tops of the coal beds are sometimes burrowed and filled with foraminiferal debris and glauconite. In addition, the lack of

*Ahmed and others (1984) mapped about 5 m of wavy bedded siltstone and sandstone along the banks of the Indus River near Sonda as Bara Fm (fig. 5); we believe these beds are above the Z limestone and thus more properly placed in the transitional basal Lakhra Fm, or possibly, a Bara tongue (see DH-1 Plate 8).

matrix material and accessory mica, and the presence of glauconite, shell debris, and *Scolithos* to *Cruziana* ichnofacies, indicates various "marine shelf" (Selly, 1985, p.18, 26) environments of deposition for the major upper Bara sands.

Based on observations at the reference areas and the PMDC deep test hole, Wnuk and others (1992), Wnuk, SanFilipo, Chandio, and Fatmi (1993), and Wnuk, SanFilipo, Fatmi and others (1993) characterized the upper Bara as sequences of inner-shelf tidal sand ridges which shallow and fine upwards to coal-bearing facies. Gamma-neutron logs (e.g. fig 6) indicate both coarsening and fining upward sequences in the upper Bara, however, and we believe that characterization of upper Bara depositional environments more precisely than "mixed paralic" is premature without additional information on sandstone bedforms and geometry. Coal bed isopachs and sulfur and ash isopleths, to be introduced further on in this report, indicate that the thicker Bara coals formed in raised peat swamps.

The middle part of the Bara Formation, which is characterized by unfossiliferous, non coal-bearing, variegated mudstone and interbedded glauconitic sandstone, was penetrated in the PMDC deep test, and possibly a few COALREAP boreholes in the Indus East area (e.g. UAK-9, Landis, Thomas, and others, 1988; Thomas and others, 1992). Wnuk and others (1992) attribute this facies to middle-shelf deposition; we believe, however, that the lack of fossils in these claystones indicates more upland deposition than the coal-bearing Bara facies, and that the glauconite may be transported or the result of episodic marine flooding. The upward transition from nonmarine middle Bara to the mixed-paralic upper Bara and shallow-marine Lakhra facies shown in figure 6 thus appears to be a regional transgressive sequence subject to minor oscillations.

Structure

The Lakhra Arch is a gently dipping anticlinorium that extends at least 150 km from south of Thatta to the north end of the Lakhra anticline (fig. 5). The Lakhra arch is composed of two large en echelon folds: the Lakhra anticline, and a previously unnamed structure, herein referred to as the Bolari nose. The Lakhra anticline is a roughly symmetrical fold with limbs that dip a few degrees, and a number of north-south trending normal faults along the crest (fig. 5); these are presumably tensional and related to the main folding. The Bolari nose is flanked by the eastward dipping Ganjo Takkar cuesta and gently westward dipping rocks of the study area (fig. 5). OGDC drilled the two Baki Ilkin test holes on this structure (located seismically) in ?1989 and 1990. The Bolari structure is poorly defined at the surface because it is breached by the Indus River and most of the eastern limb is covered by modern alluvium. The Makli hills south of Thatta (figure 5.) might be an expression of closure of this structure to the south (SanFilipo and others, 1988).

Kazmi and Rana (1982) considered the Lakhra arch to be an early Himalayan structure, uplifted from Late Eocene through Middle Oligocene time, with subsequent episodes of Miocene and Pleistocene deformation. Outerbridge (1989) suggests that uplift began in the latest Pleistocene and continues today. Since geologic mapping was not a part of our study, no systematic attempt was made to determine the deformation history of the study area. There are, however, some useful generalizations about the structural history of the area that can be made from the structure contour mapping that we did (primarily for the purpose of constructing an overburden map) and the few brief field observations that we made.

Geologic mapping by Hunting (1960) and Ahmed and others (1984) show the study area as relatively undeformed. Our work, based primarily on subsurface data and aerial photo interpretation, shows considerably more structure than has been mapped. A structure contour map (Plate 2) drawn on the top of the main coal bed, shows three structural grains to the area: 1) a regional dip of 1/2 to 2 degrees to the northwest and northeast off the Bolari nose, 2) a series of northeast-southwest trending faults, and 3) a few, presumably normal, faults trending northwest-southeast.

Three structure sections were drawn for this report; the lines of section are shown on figure 7 and Plate 2. Structure section A-A′(Plate 3) is approximately strike and fault normal (i.e. showing the most deformation); section B-B′ (Plate 4) is approximately along the axis of the Bolari nose; section C-C′ (Plate 5) is parallel to the strike of the east limb of the nose (i.e. showing the least deformation) approximately as far as the hinge, and then bends at UAS-6 to become strike and fault normal. All of the structure sections were drawn to pass through the area of thickest coal, near borehole UAS-4.

Only a few of the faults observed on aerial photos and shown on Plates 2 - 5 were actually field checked as part of this study. The fault planes are seldom exposed, but abrupt changes in local dip are usually observable. Care must be taken in the

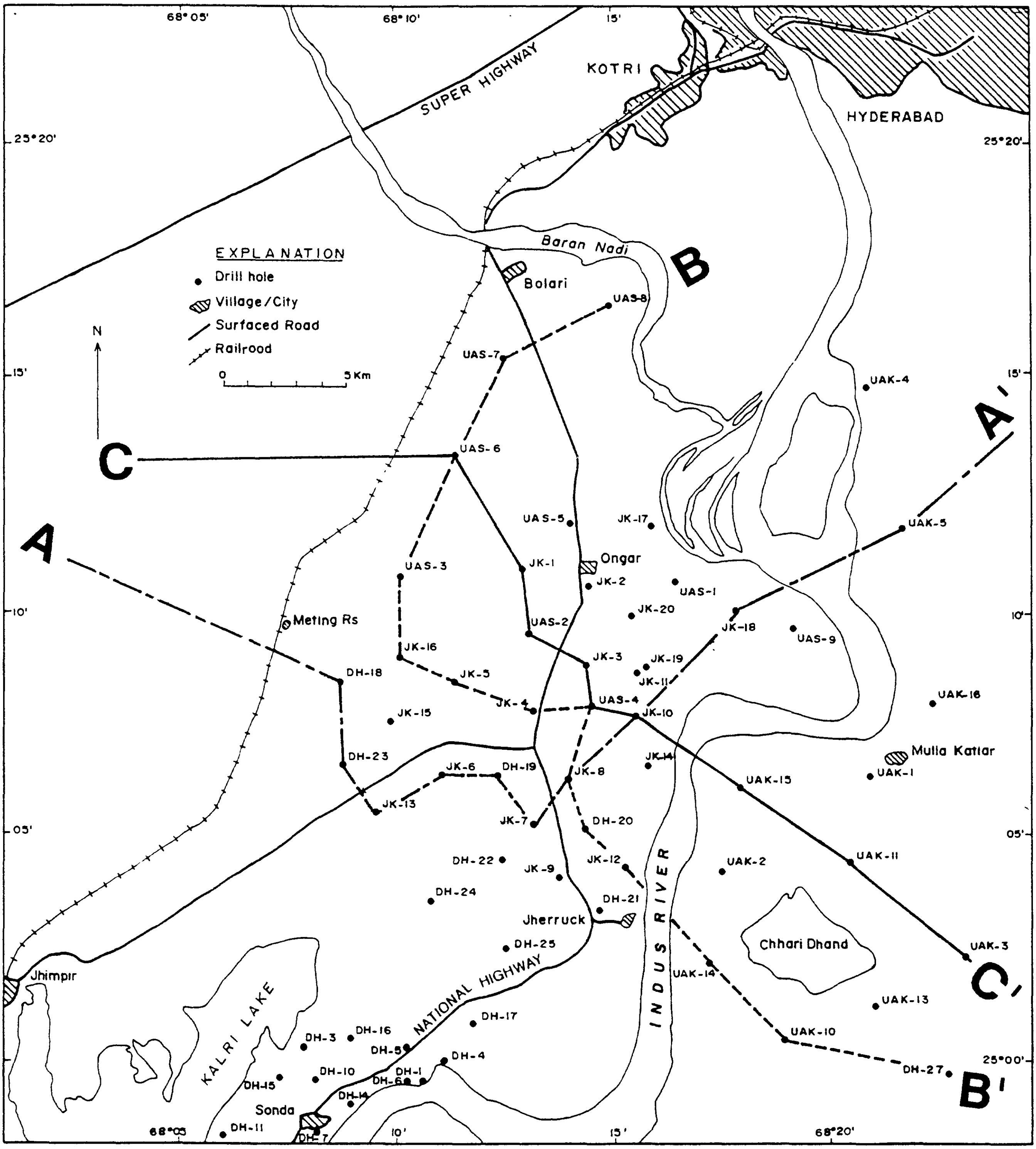

Figure 7. Index map, structure sections. See Plates 3 through 5.

field to avoid mistaking limestone blocks slumping over soft shale for faults, particularly in the southern part of the study area. Most of the fault dips shown on Plates 2 - 5 are inferred.

The limbs of the Bolari nose are clearly shown on Plate 2 and the plunge is clearly shown on Plate 4. To the east of the high cliffs of Jannat (Plate 3) and Teleji (Plate 5), the northeast-southwest faults bound a series of tilt blocks or horsts and grabens, generally with only a few meters displacement, and in some cases, a rotational component. Some of these faults continue across the structural saddle occupied by the intermittent stream Baran Nadi (fig. 5 and Plate 2), and cross-cut the southern part of the Lakhra anticline, where they disrupt Manchar or younger rocks, and are thus presumed to be younger than the Lakhra arch. Towards the northern end of the study area and in the southern part of the Lakhra anticline these faults are typically bounded on one side by a syncline.

Based on their stratigraphic position and a series of very tight drag folds bounding them, the northeast-southwest faults to the west of the Teliji-Jannat scarp (Plates 3 and 5) appear to be low-angle reverse faults. The configuration of opposing low-angle reverse faults as shown in Plates 3 and 5 is similar to that of a "triangle zone" (Jones, 1982), which is a common feature of foreland thrusted terrains, and suggests that these western-most faults of the study area are possibly listric and connected to a decollement at depth (fig 8). The presence of such faults is not particularly significant to the mining potential of Bara coal in the study area; the main purpose of

Compare with the extreme west side of Plates 3 and 5

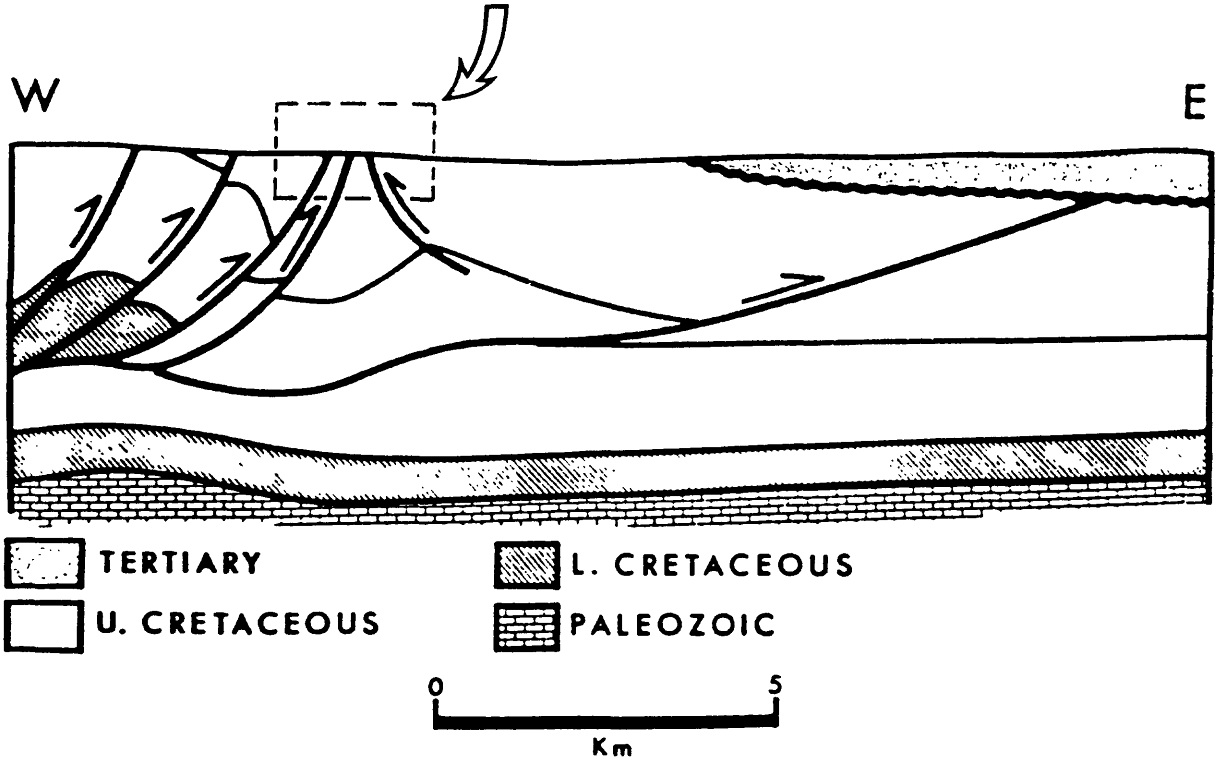

Figure 8. Example of "triangle zone" geometry in a foreland setting, the Canadian Rocky Mountains; modified from Jones (1982). Compare small box with the west side of Plates 3 and 5.

investigating these faults was to determine the potential for shallow Sohnari coal to the west of Teliji-Jannat, which appears to be very low if our structural interpretation is correct. These fault systems may be very significant from a regional geologic perspective. They could, for instance, be related to the occurrence of anomalously shallow coal in the northwest Lakhra coal field (SanFilipo and others, 1988), and they should be examined further.

The first COALREAP report on the Sonda coalfield (SanFilipo and others, 1988, Plates SNH-8,24, and 25) postulated a large fault system seperating the Lakhra anticline from the Bolari nose along the Baran Nadi saddle (Plate 2), and passing between boreholes UAS-7 and UAS-8. This idea was based on primarily on the difficulty in correlating UAS-7 (which was not cored) with other drill holes, including a possible repeat of section in the upper part of the hole, based on the gamma-neutron log. The cuttings from UAS-7 have been reexamined for this report; no repeat in section is evident, and no fault could be located on the ground, so it has been omitted from Plates 2 and 5. In light of the possibilities for blind thrusting as outlined in the proceeding paragraph, and considering the difficulty in correlating UAS-7 with surrounding holes, the possibilty of an undetected major fault in the area remains, however.

The northwest-southeast trending faults are parallel to the pre-Tertiary extensional fault system that is the trapping mechanism for the oil and gas fields of the lower Indus Basin to the east of the study area (Raza and Sheikh, 1988), and they may be the result of reactivation of such structures . The graben shown in the large Indus alluvial meander opposite Wassi village on Plate 2 is a highly stylized best fit to the top of coal at JK-18. The exact location and nature of faulting in the alluvium can not be determined from existing information, but there is clearly some structural component to this meander, as evidenced by the presence of Meting Limestone in JK-18 well below the nearby outcrops of Ganjo Takkar (Plate 3) and Ongar ridge (Plate 5). We investigated the possibility of extending this structure to the northwest towards UAS-7 to solve the correlation problem there, but could find no field evidence to support a connection.

In a relatively undeformed area such as the Sonda coal field, differential compaction in soft sediments like the Bara Formation can easily account for as much apparent "structure" as true structural relief. For example, the apparent depression around JK-9 on Plate 2, is actually stratigraphic (or possibly the result of miscorrelation). Another area of Plate 2 that warrents specific comment is the discordant graben inferred from the main Sonda structure top at UAK-14. Changing the correlation of the thickest coal bed at UAK-14 from an upper stray bed to the main Sonda bed (see Plate 7) would simplify the structure contours and eliminate the need for the graben, but this interpretation is inconsistent with the expected stratigraphic separation between the Sonda coal zone and the base of the Lakhra Formation. The stratigraphic separation problem could be due to an undetected fault intersecting UAK-14 below the base of the Lakhra Formation; the cuttings and core were briefly reexamined for this report, and no evidence of faulting was detected, but additional examination is warranted. Plate 2 should eventually be revised with the information from the new JTB- holes to help resolve this and other structural problems. It should also be noted that the fault at DH-15 has been shifted slightly east of its true location relative to published topographic contours in order to account for an apparent error in either the surveyed location of DH-15 or the registry of topographic sheet 40D/1.

The areas of thickest coal accumulation are relatively undeformed (Plates 4 and 5), and the faults are not expected to be a significant direct impediment to coal mining. These faults do appear to increase the possibilty of hydraulic connectivity to the Indus River, Kalri Lake, and the irrigation canals and waterlogged areas, however, and thus may indirectly impact the feasibility of development of this tract. This will be discussed further in the section CONSTRAINTS ON MINING.

Coal Geology

Coal zone nomenclature

Seven major coal zones in the Bara Formation and one Sohnari coal zone are recognized for this report (fig 4). The Sonda zone and the Daduri zone are further divided into four and three subzones respectively. This coal zone nomenclature follows the format developed by Ahmed and others (1986) and expanded upon by SanFilipo and others (1988). The basis for the coal zone nomenclature used herein is to follow the historical precedents (with the exception of Kazmi and others, 1990, who recognized 29 beds/subzones in the Jherruck area) as much as possible, while maintaining major coal zones that are bounded by more or less discrete stratigraphic units (generally thick sandstones). In reality, the major zones and subzones tend to merge as the sandstones pinch out. The results of this study should be integrated with the four holes recently drilled in the Jherruck area by GSP for USAID and the John T. Boyd Co., to see if a more efficient nomenclature scheme can be developed; in particular, the beds currently assigned to the Wassi zone might better be placed in other zones and the Wassi nomenclature dropped.

Coal bed correlation

Three correlation diagrams, hung on the base of the main coal bed of the Sonda zone, are shown in Plates 6 - 8. Each passes through borehole UAS-4, where this bed is thickest. Correlation diagram A-A′ (Plate 6) is a fence diagram approximately normal to depositional strike on each of three legs; diagram B-B′ (Plate 7) is a fence diagram constucted along depositional strike on two legs, and diagram C-C′ (Plate 8) is a north-south section extending from just south of the Lakhra coal field to the first phase of GSP drilling in the area of Sonda village (fig. 9.). Gamma-neutron logs were the principal correlation tool used to construct these sections; the lithologies and accessories shown are from core descriptions, in a few cases modified by geophysical logs.

Correlation was done by matching gamma-neutron signatures as best as possible, with a few subsequent modifications made to "smooth" the coal-bed isopachs. In general, a gross hole-to-hole correlation was made by using the Z or A limestone as a datum (fig. 10). With the major coal zones thus correlated, individual beds were matched by working from the bottom up (i.e. as the

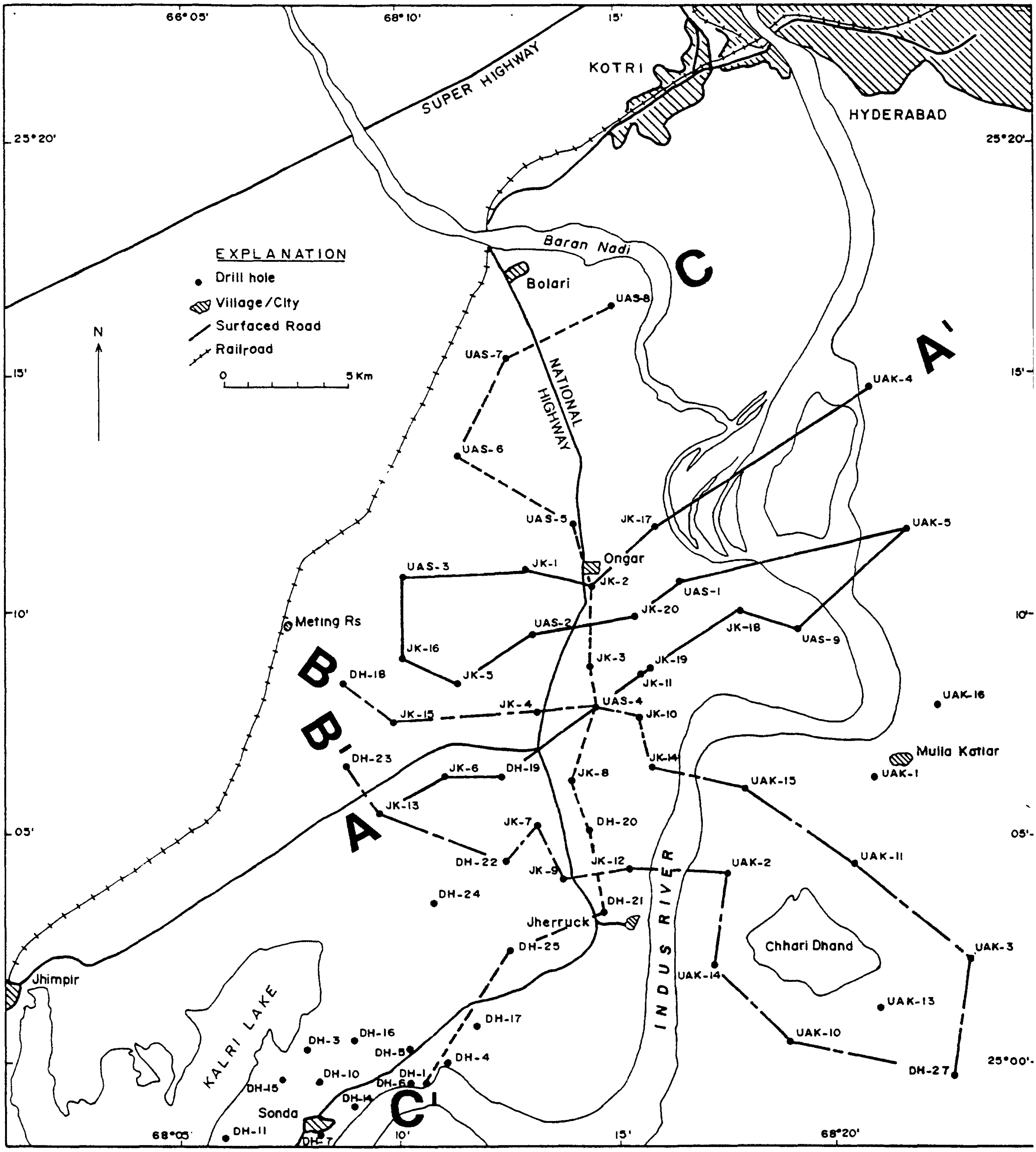

Figure 9. Index map, stratigraphic sections. See Plates 6 through 8

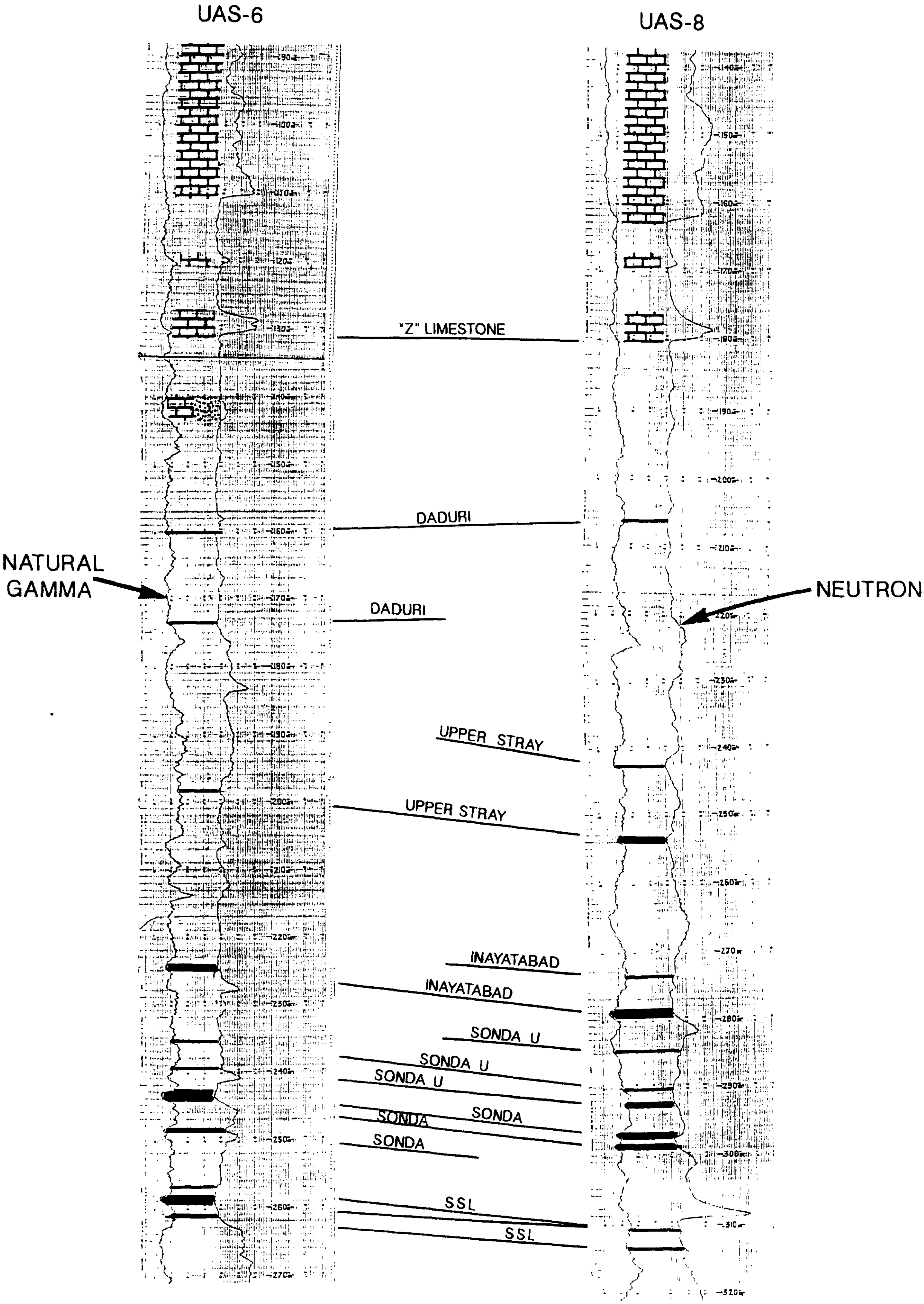

Figure 10. Example of coal-bed correlation with gamma-neutron logs, using the "lowest" limestone of the Lakhra Formation as a datum. Modified from SanFilipo and others (1988).

strata were deposited), with emphasis placed on sandstone interbeds. A few key beds (e.g. the shell hash bed overlying the Wassi zone at UAS-6 and UAS-5, Plate 8) were also used for correlation. Gamma-neutron correlations were done from each drill hole to the surrounding holes in all possible azmiths, (i.e. were not limited to the lines of section shown on Plates 6 - 8). In order to establish edge control for isopach and other derivative maps, our correlations extend beyond the area for which resources were calculated, to some of the UAK- series holes drilled in the "Sonda East" area (a.k.a. "Indus East" area) of Thomas and others (1992). Because the core recovery and the quality of the geophysical logs for the UAK- holes was poor, coal-bed correlation for the Indus East area is dubious at best. We have nevertheless substantially revised the correlations of Thomas and others (1992), because we believe that the method of correlating coal beds by matching 4-pi density responses between drill holes as used therein is of minimal utility in the Sonda coal field, where most of the beds are of similar ash percentage and thickness and therefore have similar 4-pi responses, and because the effects of differential compaction, such as coal bed drapes over thick sandstones, can not be directly observed on density logs. In addition, the extreme rugosity of the UAK-series holes makes the 4-pi logs almost unusable.

A table of coal intercepts is shown in Appendix 2. The addition of 20 new boreholes, and the new approach to correlating the UAK- holes, has resulted in a number of correlation changes from previous COALREAP reports, as noted in Appendix 2. Only minor revisions were made to the correlation of the main Sonda bed, however, and these are not very significant from the standpoint of coal resource estimates. A number of potentially significant correlation problems remain, however, mostly because far too many holes did not completely penetrate the Sonda coal zone (e.g. Plate 6: JK-13, UAS-1, JK-20, JK-17, UAK-4; Plate 7: JK-14, JK-12, JK-13). Correlation of the DH- series holes that were not geophysically logged (all except DH-20,21,22, and 27) is also very dubious.

The most difficult correlation problems are the anomalously thick (?)Sonda coal zone in JK-18 (Plate 6), the anomalously thin (?)Sonda zone in DH-19 (Plate 6) and JK-7 (Plate 7), and the previously mentioned problems with UAS-7. In addition, we believe that the Jherruck zone defined by Ahmed and others (1986) from boreholes DH-18 an DH-19 has actually only been penetrated by one hole to date, DH-18; as previously stated, however, correlation of DH-19 is problematic.

Most of the DH- holes that were not geophysically logged are not in the area of resource calculation for this report. The DH-series correlations have nevertheless been completely revised and are included in Appendix 2 for completeness. Without geophysical logs and good records of core loss, however, correlation of the DH- holes is essentially guesswork.

Coal bed descriptions

Bara Formation coal is generally composed of dull brownish-black attritus with some development of previtrain bands. It is generally soft and shows poorly developed cleat in core, although cleat faces are obvious in the mines in the Lakhra field (all of which are unmechanized). No systematic attempt has been made to measure the cleat spacing for our study, but based on brief examination of spoil piles in Lakhra, it appears to be several centimeters. Bara coal contains abundant pyrite and resin, both of which tend to occur in blebs or along partings. Most of the ash is disseminated, although thin noncoal partings do occur. One conspicuous clay parting occurs near the top of the main Sonda bed in the vicinity of UAS-4 (Plates 6 - 8). Bands of secondary gypsum several centimeters thick commonly occur along bedding plane partings in the mines at Lakhra.

Where the seatrock is a claystone, the coal tends to grade downwards to carbonaceous shale; roof contacts and contacts with coarser-grained floors tend to be somewhat sharper. Marine influences are exhibited by rocks that are intercalated with each of the coal zones, but are most pronounced in the Daduri and upper stray zones. In some cases (e.g. the Daduri 2 subzone in borehole UAS-6, see Plate 8), marine rocks are interlaminated with coal.

The model for the coal bed geometry as shown in the correlation diagrams is one of essentially stacked domal coal beds with only incidental splitting of the beds at the peripheries of the domes. One exception is a major split between the S and SU beds between UAS-4, JK-19 and JK-18 (Plate 6). Given the uncertainties in correlation, it is possible that there is more splitting and joining of coal beds than has been indicated on the correlation diagrams, particularly in the vicinity of JK-18. The most likely alternative correlation to the one shown in Plate 6 would be to move the position of UAS-9 up relative to JK-18, so that the SSL bed of UAS-9 becomes S, S becomes SU, etc.

It is assumed from this model that the peat swamps preceeding coal formation in the Sonda coal field were generally raised swamps proximal to shorelines, and that the main control on peat formation was distance from shoreline. It should be noted that the correlation diagrams could have instead been hung on the top of the main Sonda bed, which would produce a configuration more reflective of basin filling than domed peat. Other evidence introduced later in this report, such as sulfur and ash isopleths, favors the domed peat model, but a sophisticated reconstruction of coal-forming environments, such as decompaction of the strata to original thickness, would require efforts that are beyond the scope of this report.

COAL RESOURCES

Definitions

Coal resources are those occurrences of coal that are currently or potentially economically extractable; the portions of the resource that are currently profitable to recover are reserves. The standards used by the USGS for quantification of coal resources are given in the Coal Resource Classification System of the U.S. Geological Survey (Wood and others, 1983; herinafter referred to as "Wood").

Coal resources were calculated for this report by use of a modified version of the "extrapolated bed method" of Wood (p.37). The extrapolated bed method essentially involves estimating the volume of coal for a given bed within areas of interest (such as overburden limits) from coal isopach maps, and multiplying the volume times the density of the coal.

Because a coal "bed" can be thought of in several different contexts (e.g. as a lithic unit, as a stratigraphic unit, or as mining entity), precise definitions are required to determine the coal bed thickness used for resource calculations. Wood (p. 5) defines a coal bed as "all coal and partings lying between a roof and floor", but establishes (p. 31) some specific criteria for the exclusion of thin beds, high-ash coal, and noncoal partings from resource calculations. These criteria have been modified for this report to apply to the special case of Pakistan and to clarify certain ambiguities in Wood.

Coal which qualifies for inclusion in the resource calculations of this report is referred to as "qualifying coal". The following definitions, which are modifications or additions to those of Wood, apply to this report:

bench - a stratum of coal separated by partings or excludable partings. A sampled interval within a bed is sometimes also called a bench.

coal - a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, excluding moisture. Coal having 25 weight percent or more, but less than 50 percent ash on the dry basis is called impure coal.

coal bed - all the coal and partings or excludable partings between non-coal, non-parting strata (i.e. roof and floor).

coal zone - a group of coal beds and associated strata which is recognizable as a stratigraphic unit.

excludable parting - an interval of nonqualifying material greater than 1 cm thick, which does not exceed the thickness of both directly overlying and directly underlying qualifying material within a coal bed. An excludable parting differs from a parting in that it can contain nonqualifying coal as well as parting material and is defined by the aggregate thickness of overlying or underlying benches.

minimum qualifying thickness - the minimum qualifying thickness of individual coal beds to be included in resource estimates; for this report 30 cm.

parting - a layer or stratum of non-coal material which does not exceed the thickness of both directly overlying and directly underlying coal benches.

qualifying coal - coal which meets the qualifications for inclusion in resource calculations; for this report, the thickest coal bed which exceeds the minimum qualifying thickness in a particular subzone. There may be additional criteria, such as coal quality, used to qualify coal.

qualifying thickness - (bed) the aggregate thickness of coal minus excludable partings in a bed; (zone) the aggregate qualifying thickness of beds exceeding the minimum qualifying thickness in a zone, or, if no beds in a zone meet the minimum qualifying thickness, the greatest qualifying bed thickness in a zone. The qualifying thickness is the value isopached; for this report the bed method was used.

The definitions and criteria above differ from Wood as follows:

1) The minimum qualifying thickness is 30 cm for this report vs. 75 cm for lignite and subbituminous coal per Wood.
2) The minimum ash criteria is 50 percent on a dry basis vs. 33 percent per Wood (p.10).
3) Partings that are to be excluded from coal bed thickness measurements for the purpose of resource calculations are precisely defined. No formal distinction between physical and excludable partings is made by Wood.

The rationale for adopting items 1 and 2 above are provided in Wood, p.24: "In the United States, beds that contain more than 33 percent ash are excluded; because of the shortage of energy in some countries, however, coal containing more than 33 percent ash is being mined and classified as reserves. Coal beds thinner or more deeply buried than the imposed limits...are mined in other parts of the world...where such mining is taking place the coal should be...recorded in the coal resource figures." Current mining practices and the general shortage of energy in Pakistan warrent a relaxation from the standards used for coal resource classification in the U.S. Thirty cm (1 ft) thick coal beds are being mined in Pakistan. This limit was used for COALREAP analytical sampling and previous resource calculations, and is retained as the minimum qualifying thickness for this report. Fifty percent dry ash was the cutoff for the Boyd (1986) study for power generation feedstock from Lakhra, which is a suitable analogy to the objectives of the Jherruck exploration effort. Material with a higher than 50% dry ash content is probably being mined in Pakistan, but is technically outside the range of coal.

Item 3 above establishes a procedure for defining a coal bed for the purposes of resource calculation that is meant to clarify the criteria given in Wood, in particular by adding precision to the instructions for "omitting benches from calculations if they lie above or below partings that deter their mining" (**thickness of coal for resource calculations**, Wood, p. 31). Some examples of qualifying thickness determinations are shown in figure 11. The resultant thickness values are generally unchanged from those derived using the methodology of Wood, but there are some cases where fewer discrete beds are defined using excludable partings vs. physical partings, and the isopached value thus increases. These considerations are probably not as critical to this study as they were to previous COALREAP resource estimates for the Jherruck area where the resources were calculated by the zone method and many thinner beds were included (SanFilipo and others, 1988). Although the effects on the total resource estimates for the present study appear to be minimal, the importance of maintaining rigorous standards for resource evaluation for the purpose of consistency can not be overstated.

Wood (p.31) specifies that subbituminous coal resource estimates for U.S. coals should generally be reported in the following categories:

	Thickness (m)				
Overburden (m)	0.75 - 1.5	1.5 - 3.0	3.0 - 6.0	6.0 - 12.0	>12
0 - 150		Reserve Base			
150 - 300					
300 - 600					
600 - 900					
900 - 1800					

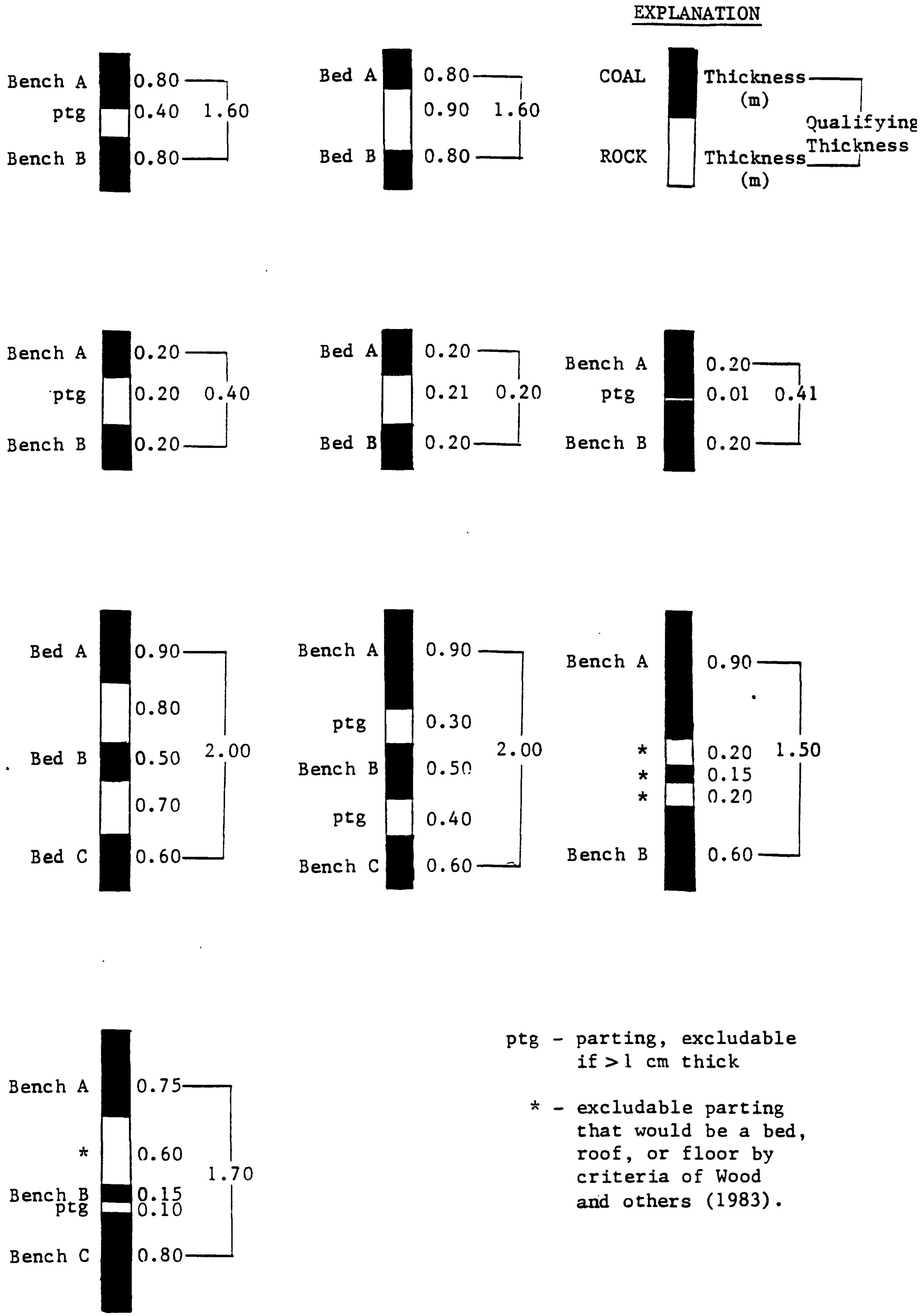

Figure 11. Examples of qualifying thickness criteria.

The reserve base classification above is based on physical criteria that are applicable to current coal mining practices in the U.S. Multiplying the reserve base by a mining recovery factor yields the total reserves. The area outside the box is classified as "subeconomic resources"; the sum total of the area inside and outside the box are the total resources, and subbituminous coal which does not meet the thickness and overburden criteria above are considered other occurrences which are not included in the resource estimates. Within each thickness and overburden category, Wood requires that coal resources be further subdivided according to geologic assurance by assigning reliability categories. The reliability catergories are: measured (within 400 m of a datapoint, e.g. borehole), indicated (0.4 - 1.2 km), inferred (1.2 - 4.8 km), hypothetical (> 4.8 km). The reliability categories for drill holes which penetrate Bara Formation coal in the study area are shown on Plate 15.

The reporting procedures used in this report vary somewhat from the preceeding outline in order to better apply to Pakistan. As previously stated, we have used a minimum coal bed thickness of 30 cm for inclusion in coal resource estimates. Because there is currently no large-scale coal mining in Pakistan, reserves have not been formally distinguished from resources for this report. The resource tables that are included in this report will list overburden categories in 50 m increments, however, and an appendix with resources listed in thickness category increments of 50 cm or smaller is also provided (Appendix 3). The additional detail will enable the reader to tailor the resource estimates to individual "reserve base" standards, and will facilitate comparison with previous reports on the coalfields of Sindh.

Since no mining of Bara coal has occured in the Sonda coal field, the resources calculated for this report are <u>original resources</u> as defined by Wood. Because the coal beds of the study area are too deep to mine by conventional surface methods, and because simultaneous underground mining of more than one bed is probably unlikely given the geologic conditions of the study area, resources have only been calculated for the main bed of the Sonda zone for this report. In addition to the constraints on multiple seam mining, only the main bed was considered for this report because it was intended to serve as a training exercise. Recommendations for additonal work to be completed by GSP in the study area, including calculation of resources for other beds, will be introduced in the concluding section of this report.

Thickness and extent of coal beds

Coal bed thicknesses intercepted at boreholes within the study area are listed in Appendix 2 and summarized in table 5. The procedure for picking coal bed boundaries was to rely primarily on core descriptions, sometimes supplemented by dry-ash analytical values or geophysical logs. Of the suite of geophysical logs typically run for COALREAP drilling, the 4-pi density log was generally the most useful for picking coal intercepts. The procedure employed to pick coal from the 4-pi logs was generally the "half-amplitude" method (i.e. the bed boundary is placed where the log trace intersects a line drawn

Table 5. Summary statistics for coal bed thicknesses, Jherruck area of the Sonda coal field; see Appendix 2 for details. Thicknesses shown are the minimum and maximum qualifying thicknesses intercepted at drill holes; some beds are projected by isopachs to be slightly thicker over small areas between holes (see Plates 9 - 12, 14, and 16).

ZONE/Subzone	Minimum Thickness		Maximum Thickness	
	Map area	Resource area	Map area	Resource area
SOHNARI	0	0	1.78*	1.78*
DADURI	0	0	0.85	0.85
UPPER STRAYS	0	0	0.79	1.21
INAYATABAD	0	0	1.88	1.88
SONDA upper	0	0	2.01	1.80
SONDA main	0	0	6.04	6.04
SONDA lower main	0	0	2.55	2.55
SONDA lower	0	0	0.70	0.44
WASSI	0	0	1.54	1.54
LOWER STRAYS	0**	0**	1.10	1.10
JHERRUCK	0.19**	0.19**	0.76	0.76

*Borehole MT-2 (Plate 1), Pakistan Mineral Development Corp (PMDC), not deep enough to intercept the Bara Fm and not included in Appendix 2. The thickest Sohnari coal bed intercepted by COALREAP drilling was 90 cm.

**No holes were deep enough to precisely determine.

halfway between the maximum deflection of the coal kick and the shale line), but in some cases modified by the experience of the geologist (e.g. using the inflection point).

Isopachs of the main coal bed of the four most important subzones are shown in Plates 9 - 12. The value isopached is the qualifying coal of the thickest persitent bed in each of the four subzones as listed in Appendix 2. Isopachs were constructed by using a ten-point divider to linearaly interpolate between drill holes, and then smoothing the contours by hand. Where the isopachs are shown as dashed, the uncertainty is more often due to coal-bed correlation problems or failure to completely penetrate the coal zone than to unreliablity of the actual thickness measurement.

The thickest coal bed in the Jherruck area occurs in the main subzone of the Sonda coal zone (Plate 9), which in the resource area averages 1.34 m <u>qualifying thickness</u>. This bed is 6.33 m thick at UAS-4, including a 29 cm noncoal parting. As shown in Plate 11, the bed is present over most of the study area, but thickens rapidly towards the centers of three "domes" centered around UAS-4, JK-13 and JK-19. The bed is thicker than 1.5 m over about 15,450 ha, or roughly 29 percent of the resource area, and averages 2.43 m <u>qualifying thickness</u> within this subarea. Additional discussion of the average thickness of this bed within certain mining parameters occurs on p. 67. The three boreholes where the main Sonda bed is shown as absent on Plate 11 (UAS-7, DH-17 and DH-8) are unreliable, and the bed may in fact be present throughout the entire map area. There is no particular sedimentation pattern between the domes that would suggest that "want" areas (areas of little or no coal), such as the area between DH-19 and JK-9, are paleochannels, and these are presumed to be depositional edges of the peat swamps or areas of subsequent marine erosion.

The thickest bed of the Inayatabad zone also occurs in three domaform bodies in the study area, with centers near UAS-4, DH-15 and UAS-8 (Plate 9). The thickest recorded Inayatabad bed is 1.98 m with a 10 cm excludable parting, at UAS-8. The UAS-8 correlation is questionable, however, and this bed may actually be an upper Sonda bed. Over most of the study area this bed is considerably less than 1 m thick, and it pinches out at the peripheries except to the north of UAS-8. If the UAS-8 correlation is correct, this bed appears to thicken in the southern, unexplored part of the Lakhra field. The Inayatabad zone frequently is enclosed by thick sandstone beds and may have been eroded in part.

The thickest Sonda upper subzone coal bed (Plate 10) extends through most of the northern part of the study area in a series of ridgelike bodies which resemble modern peat islands, or back-barrier coals. In the resource area this bed is thickest at JK-18, where it is in two benches, a dirty upper bench 50 cm thick separated from a 1.30 m lower bench by a 46 cm parting. It thickens considerably in the eastern part of the map area, and is 2.31 m thick, with an apparent 30 cm excludable parting, at UAK-3. There is considerable uncertainty in correlation of this bed to the eastern part of the study area, however.

The thickest bed of the Sonda lower main subzone has an apparent geometry more or less similar to the other coal zones, but many critically located holes were not deep enough to completely penetrate this subzone or precisely correlate coal beds, and the geometry shown in Plate 12 can not be considered reliable. The ridgelike body extending from JK-6 to DH-16, for instance, is highly speculative without data from JK-13 and JK-5. Other key holes that are not deep enough are JK-20, UAS-1, UAS-3, and JK-17 (Plate 6). Coal appears to be present in this subzone over most of the northern part of the study area, and a 3.03 m bed with 2.55 m of qualifying coal was intercepted at UAS-6.

The Sonda lower subzone is a poorly defined subzone that was more or less designated to classify coal that is difficult to correlate between the Wassi and Sonda zones (e.g. JK-16, Plate 6). No beds in this subzone were isopached for this report. A 70 cm bed and an 85 cm bed with a 20 cm parting were recorded in the southeastern part of the map area at UAK-3.

The Wassi subzone appears to contain qualifying coal over most of the study area, but most of the boreholes did not completely penetrate the zone. In particular, only two of the JK- series holes, which are the most reliable in terms of core recovery and geophysical log availability, penetrated this zone. We have isopached this bed based on the available data, but the complete map is not included with this report due to its inherent uncertainties. Portions of the map are included in a derivative map to be introduced later in this report (Plate 16). From the available data, this bed appears to occur in a dome centered just southeast of borehole UAS-5, where it is 1.54 m thick.

The Daduri and Upper Stray coals are of insufficient thickness and extent to be commercial within the study area. The thickest recorded Daduri bed is 85 cm at JK-9. A 79 cm Upper Stray bed was intercepted at UAS-8, and a 1.21 m bed which is probably an Upper Stray was intercepted at UAK-14, outside the resource area.

Only a few holes completely penetrated the Lower Stray beds or the Jherruck zone, and the correlation/nomenclature system is dubious for these deeper coals. A 1.10 m bed tentatively assigned to the Lower Stray zone was intercepted in UAS-5, and a 76 cm Jherruck bed was intercepted in DH-18.

Sohnari coal is considered to be part of the Meting-Jhimpir coal field and is of only incidental interest to this report and the COALREAP drilling that is included herein. It is worth noting that a few new mine shafts have been sunk by private leaseholders in the vicinity of UAS-3 and UAS-6 as a result of the Sohnari coal intercepted in those holes. Based on existing information, however, the thick Sohnari coal in the vicinity of PMDC borehole MT-2 (table 5) appears to be of limited extent. Data for the other Meting-Jhimpir boreholes and mines shown on Plate I are included in SanFilipo and others (1988, Part V.1). A few COALREAP Sohnari test holes drilled outside of the Meting-Jhimpir coal field in 1992 were mostly barren (unpublished data USGS and GSP files, report in progress).

Depth to Coal

The shallowest Bara Formation coal intercepted in the map area is the Daduri zone coal at 43 m depth in DH-1. Sohnari coal was intercepted at 12 m in DH-23. The shallowest recorded occurence of the main bed of the Sonda zone, which is the primary focus of this report, is at 118 m in DH-1, which is outside of the resource area. The shallowest main Sonda intercept within the resource area is 129 m at JK-12.

An overburden map of the main Sonda coal bed is shown in Plate 13. This map was constructed by overlaying the structure contour map (Plate 2) on Survey of Pakistan 1:50,000 topographic sheets and subtracting the structure contour value from intersecting elevation contours.

From Plate 13 it can be seen that the major controls on the depth to the main Sonda bed are: 1) the position on the Bolari nose, 2) the amount of erosion by the Indus River, which breaches the structural nose, and 3) the topography created by erosional remnants of resistant carbonate beds, in particular the Laki Formation on the flanks of the nose and as it plunges towards Baran Nadi. Most of the study area west of the Indus River is characterized by broad geomorphic surfaces exposing either the top of the "D" limestone or the middle bench of the Meting Limestone, with depths to the main Sonda bed of about 180 and 240 m respectively. The approximate depth to the main Sonda bed under other prominent geomorphic surfaces is about 140+ m for the "B" limestone, 300 - 330 m for resistant limestone beds in the Meting Shale, and over 350 m for Laki Limestone scarps.

The shallowest depth that the main Sonda bed can be projected to on Plate 13 is about 50 m at Bano. Recent COALREAP drilling that was not explicitly utilized for this report (SanFilipo and others, unpubl. data) indicates that the main Sonda bed actually subcrops below about 80 m of alluvium near Bano; and 80 m is thus probably a good estimate of the shallowest depth to which this bed is preserved within the map area. The bed can be projected to depths of about 360 m below Ganjo Takkar in the northeast part of the map area and nearly 400 m below the Jannat cliffs to the northwest; above the thrusted terrain west of Jannat the bed is probably deeper than 400 m (Plate 3). Toward the boundary with the Lakhra coal field at Baran Nadi in the northern part of the map area, the main Sonda bed is generally about 300 m deep, increasing to about 360 m under the outlying Laki Formation mesas.

Where the main Sonda bed exceeds 1.5 m in qualifying thickness, the overburden varies from about 125 m near JK-12 to 265 m near JK-18 (there is a another, much smaller, area where the bed exceeds 1.5 m in thickness and varies from about 180 m depth near DH-24 to 330 m depth at the cliffs north of Meting Railway Station). Where the bed is more than 3 m thick the overburden varies from about 135 m near DH-20 to 205 m near JK-19 (there is an additional very small faulted area near JK-13 where the bed exceeds 3 m in thickness from 185 to 225 m depth). The depth to coal in the areas where resources were calculated is discussed in greater detail in the next section.

Due to the discrepencies between topographic map elevations and surveyed borehole elevations, and the general stratigraphic changes between drill holes, the contours on Plate 13 are probably accurate to no better than +/- 10 m. Any depth to coal projected for future drilling on the basis of Plate 13 should be verified by observing the geomorphic surfaces as outlined above, bearing in mind the effects of structural migration (e.g.

although the top of the syncline at 2154000E/850000N is slightly higher in the Laki Limestone than the adjacent syncline at 2156000E/850000N, the projected depth to coal is slightly less below the former due to presumed structural migration to the west).

Overburden maps have not been constructed for other beds for this report. Additional maps can be constructed by GSP as a follow up to the training component of this project. The tedious process of intersecting topographic maps with structure contours can be avoided by constructing interburden maps and intersecting them with Plate 13 (ideally after revision to reflect the JTB-holes) to create overburden maps of other beds of interest. In any case, the depth to coal for the other Bara coal beds that have commercial potential within the study area does not vary significantly from the main Sonda bed.

Resource Estimates

Methodology and uncertainty

Coal resource estimates for the main bed of the Sonda coal zone were calculated for a portion of the map area usually referred to as the Jherruck tract (referred to herein as the "resource area"). The resource area is shown on Plate 14 and is defined as the area enclosed by: 1) the Pakistan Railway main line; 2) longitude 68°05′E; 3) latitude 25°02′30"N; 4) Kalri Lake (Sunahri Dhand); and 5) the Hyderabad/Thatta District boundary. As such, the resource area is somewhat larger than the Jherruck tract of GSP (Appendix 1), but conforms exactly to the Sonda north area ("quad") of SanFilipo and others (1988) and thus offers direct comparisons with Appendix 2 of that report. The resource area is 52,656.62 ha as determined by planimeter for this report (the same area measured 54,042 ha when digitized and calculated by computer for SanFilipo and others (1988), a difference of + 2.6%).

Per the methodology of Wood (p.37), a single coal resource map was prepared for computation of resource estimates (Plate 14). The map was made by overlaying the isopachs of the main Sonda bed from Plate 11 on the resource area boundaries, along with the 50 m overburden isopachs from Plate 13 and the geologic assurance categories from Plate 15. Each subarea defined by a coal and/or overburden isopach and/or a reliability circle within the resource area boundaries was planimetered, and the planimetered area was multiplied by the density of subbituminous coal given in Wood (p.22), 13,000 tonnes per ha-m (i.e. specific gravity = 1.30 g/cc). The results were summed by overburden, thickness, and reliabilty categories and are shown in Appendix 3.

Measurements of area by the polar planimeter are good to 4 significant figures, the estimates of specific gravity used are significant to 3 figures, and the estimates of thickness from the isopach maps are generally good to three (sometimes two) figures; we therefore estimate that our resource calculations are generally precise to three significant figures. The methodology of reporting coal resource estimates for subcategories that can range in area by several orders of magnitude creates an intrinsic precision problem, however. In order to maintain the significance of the smaller areas and avoid large rounding errors in the totals, the tonneage estimates in Appendix 3 are generally shown to more than the probable true precision. If each subcategory shown in Appendix 3 was rounded to its true significance, there would be large rounding errors generated in the subtotals and totals. If the subcategories were rounded to the nearest million tonnes in order to avoid rounding errors when adding to true precision of the totals, small areas like the "measured/overburden > 300 m" subcategory would show up as null values. Therefore, the method more-or-less as outlined in Wood (p. 36) of rounding all the numbers in the table to the significance of the smallest value that needs to be shown (in this case to the nearest thousand tonnes) is adopted for Appendix 3 and subsequent tables in this report. References to coal tonneages in the text will be rounded to true significance. This method also enables additional calculations to be made using the data in Appendix 3 without loss of precision, as long as care is taken to qualify the results.

There are considerations of *accuracy* as well as *precision* when estimating the uncertainty of coal resource calculations. Planimetering was done on stable mylar copies of Plate 16 to avoid systematic errors generated by paper shrinkage or registry. Four passes were made for each subarea, using a locally purchased manual (vernier) polar planimeter, and the results were averaged. The manufacturer specifies an accurracy of +/-1% for the planimeter.

The largest source of error in our resource estimates is probably from miscorrelation of coal beds and the general subjectivity of the isopaching process. Based on the observed variability of the coal beds, we estimate (casually) that random errors in the coal thicknesses used to calculate resources could range from as much as 5% in the measured category to as much as 25% in the inferred category. Assuming our correlations are correct, the total resource estimate of 918 million tonnes is probably no better than +/- 100 million tonnes. Estimation of the uncertainty of the resource estimates if there are major errors in coal bed correlations is not possible, but suggestions for subsequent work by GSP to mitigate such errors will be introduced later in this report.

An initial attempt at estimating the coal resources of the Sonda zone was made by measuring the subareas shown in Plate 14 with a digital non-polar planimeter, and the results were presented as a poster at the first South Asia GEOSAS conference in Islamabad, Feb 23-27, 1992 (Khan and others, 1992). The digital planimeters proved to be highly erratic for subareas less than 10 ha, so the process was repeated using the manual polar planimeter. The total resource estimate for the study area was within 1% using these two methods, but there are some significant differences in subarea totals, and only the manually planimeterd results are presented in Appendix 3.

As will be subsequently explained in greater detail, the actual rank of the main Sonda bed is on the boundary of lignite A and subbituminous C. No attempt was made to map the rank difference for this report (Wood p.37, step 3). The average density of lignite is less than 1% smaller than that of subbituminous coal (Wood p.22), which is well within the margin of error of other steps in our resource calculations. Specific gravity was measured for a few of the JK- samples, and the results are discussed in COAL QUALITY (p.96).

Discussion of the results

Main Sonda bed. The results of the coal resource estimates for the main bed of the Sonda zone are summarized in tables 6 - 8. The total in-place resources for the main Sonda bed within the resource area is estimated to be 918 million tonnes. As shown in table 7, about 40 percent of the estimated resource is in the demonstrated (measured plus indicated) category. About 97 percent lies at depths less than 300 m (table 6), and about 92 percent occurs where the bed is thicker than 75 cm (table 8). About 482 million tonnes (53%) qualifies for inclusion in the "reserve base" (thickness ≥ 150 cm, depth ≤ 300 m, Wood, p. 24) criteria for U.S. coal (table 8); of this about 35 million tonnes or 7 percent (4% of total resources) is in the measured category, 237 million tonnes (49%; 26% of total resource) is indicated, and 210 million tonnes (44%; 23% of total resource) is inferred.

Coal recovery in thick seams is subject to limitations in the thickness that can be "worked" by conventional underground mining methods (see Ward, p. 240 -245). About 837 million tonnes, or 91 percent of the total calculated resources, are within a bed-thickness upper limit of 4 m, which would apply to most large-scale underground mining techniques. If the 4 m maximum bed thickness is applied, the total "reserve base" estimate drops to about 401 million tonnes, or 44 percent of total resources. About 744 million tonnes (81%) occur where the bed is 75 cm to 4 m thick and at depths of less than 300 m.

About 79 million tonnes, or 9 percent of the total resources

Table 6. In-place coal resources estimated by overburden and reliability categories (tonnes x 10^3), main Sonda coal bed, Jherruck area of the Sonda coal field. Tonneages rounded to retain the precision of the smallest subcategory (Wood and others, 1983, p. 36). True precision is estimated to be 3 significant figures.

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Total
	Reliability category				
125 - 150	5,817	38,222	35,047	-----	79,086 (9%)
150 - 200	26,553	184,853	128,901	2,509	342,816 (37%)
200 - 250	8,099	74,676	153,889	14,896	251,560 (27%)
250 - 300	1,992	17,126	169,221	29,388	217,727 (24%)
>300	296	2,951	21,792	1,813	26,852 (3%)
Total	42,757 (5%)	317,828 (35%)	508,850 (55%)	48,606 (5%)	918,041 (100%) (100%)

Table 7. In-place coal resources estimated by coal-thickness and reliability categories (tonnes x 10^3), main Sonda coal bed, Jherruck area of the Sonda coal field. Tonneages are rounded to retain the precision of the smallest subcategry of table 6. True precision is estimated to be 3 significant figures (2 significant figures for the 30 - 75 cm subcategories).

Coal Thickness (m)	Measured	Indicated	Inferred	Hypothetical	Total
	Reliability category				
0.30 - 0.75	1,734	12,181	52,646	2,561	69,122 (8%)
0.75 - 1.50	6,021	68,144	240,571	46,045	360,781 (39%)
1.50 - 3.00	17,394	125,502	179,647	----	322,543 (35%)
>3.00	17,608	112,001	35,986	----	165,595 (18%)
Total	42,757 (5%)	317,828 (35%)	508,850 (55%)	48,606 (5%)	918,041 (100%) (100%)

Table 8. In-place coal resources estimated by coal-thickness and overburden categories (tonnes x 10^3), main Sonda coal bed, Jherruck area of the Sonda coal field. Tonneages are rounded to retain the precision of the smallest subcategory of table 6. True precision is estimated to be 3 significant figures (2 significant figures for the 30 - 75 cm subcategories).

Overburden (m)	0.30-0.75	0.75-1.50	1.50-3.00	>3.00	Total
	Qualifying coal thickness (m)				
125 - 150	447	12,330	36,334	29,975	79,086 (9%)
150 - 200	14,349	62,143	135,344	130,980	342,816 (37%)
200 - 250	13,803	113,427	119,690	4,640	251,560 (27%)
250 - 300	37,172	155,106	25,449	----	217,727 (24%)
>300	3,351	17,775	5,726	----	26,852 (3%)
Total	69,122 (8%)	360,781 (39%)	322,543 (35%)	165,595 (18%)	918,041 (100%) (100%)

of the main Sonda bed within the resource area, occur where the bed is thicker than 75 cm and shallower than 150 m, which are approximately the limits of current small-scale underground mining operations in the Lakhra coal field.

The average thickness of any subcategory in Appendix 3 can be arrived at by dividing the tonneage by the product of the area times 13,000. Within the portion of the resource area containing qualifying coal (i.e. meeting the minimum qualifying thickness of 30 cm), the average qualifying thickness of the main Sonda bed is 1.36 m. For the area with less than 150 m overburden the average qualifying thickness is 2.20 m. For the "reserve base" (thickness $\geq$ 1.5 m, overburden $\leq$ 300 m) area of about 15,170 ha, the average qualifying thickness is about 2.45 m.

Other beds. Coal resources were not estimated for other beds as part of this study. Under most conceivable circumstances it is unlikely that multiple-seam mining can occur in the Sonda coal field. It is conceivable, however, that the resource base can be significantly enlarged by considering the thickest bed at any given locality, provided that the bed has sufficient lateral extent to make it mineable, and that the interburden between the main Sonda zone is small enough so that ramping up or down is feasible (e.g. the Daduri bed in JK-9 would not be considered because it is too high to practically ramp up to from the main Sonda bed; see Plate 7). Isopachs of the thickest coal bed that meets these criteria (i.e. beds within the major subzones that have small stratigraphic separation from the main Sonda bed, or the main Sonda bed itself), are shown on Plate 16. It is suggested that GSP recalculate the coal resources based on the isopachs shown in Plate 16 as a continuation of the training excercise and as a first approximation to maximizing the estimated resource potential of the study area. In addition to allowing for the alternative mining techniques mentioned above, this method will establish a reasonable upper limit to the resource estimates by eliminating underestimates due to miscorrelation. Suggestions for additional coal resource studies will be introduced in the concluding section of this report.

Comparison with previous estimates. Comparisons of our results with earlier estimates of coal resources for the study area are difficult because the previous estimates generally included multiple beds and different resource area boundaries. The resource estimate of 3.7 billion tonnes in the first COALREAP report (SanFilipo and others, 1988; hereinafter referred to as PK-82) is for cumulative coal in all of the Sonda coal field west of the Indus River. The resource estimate for the "Sonda North Quad" of Appendix 2 in PK-82 covers the identical area as the resource estimates presented herein, but is subdivided by cumulative qualifying coal in each major zone (there were only 17 boreholes in the resource area when PK-82 was completed, which was insufficient for correlation by bed). The estimate of 1.8 billion tonnes for the Sonda zone within the Sonda North Quad of PK-82 (p. 2-96) thus includes all qualifying coal in the Sonda upper, main Sonda, Sonda lower main, and Sonda lower subzones of the present study, and compares reasonably well with our estimate of 0.9 billion tonnes for the main Sonda bed only (table 8). The estimate of 753 million tonnes for all coal beds thicker than 1.5

m in PK-82 (p. A3-2) also compares well with our estimate of 488 million tonnes for the main bed (see table 8) when the effects of the subordinate subzones included in PK-82 are considered. Kazmi and others (1990) estimated total cumulative resources for all beds in the "Jherruck block", an area which includes most of the present resource area, at 1.8 billion tonnes.

COAL QUALITY

Introduction

The results of physical and chemical tests of coal samples are traditionally reported as standard coal analyses, oxides and trace elements.

Standard coal analysis (fig. 12) includes determination of such classical physical, chemical, and combustion parameters as proximate and ultimate analysis, heat content, forms of sulfur, hardgrove grindability, and free swelling index. The standard analysis for COALREAP samples was performed by commercial laboratories according to standards of the American Society for Testing Materials (ASTM). Proximate analysis (fig. 12) is a basic assay which is often the basis for commercial coal transactions (ASTM, 1990, D3172). Ultimate analysis (fig. 12) involves more complete combustion of the coal and permits more detailed valuation for various uses (ASTM, 1990, 3176).

The inorganic constituents of coal are grouped (Gluskoter and others, 1981) as major elements (>0.5% of whole coal), minor elements (0.02-0.5% of whole coal), and trace elements (< 200 ppm of whole coal). Major and minor elements are traditionally reported in oxide form as a percentage of high-temperature ash

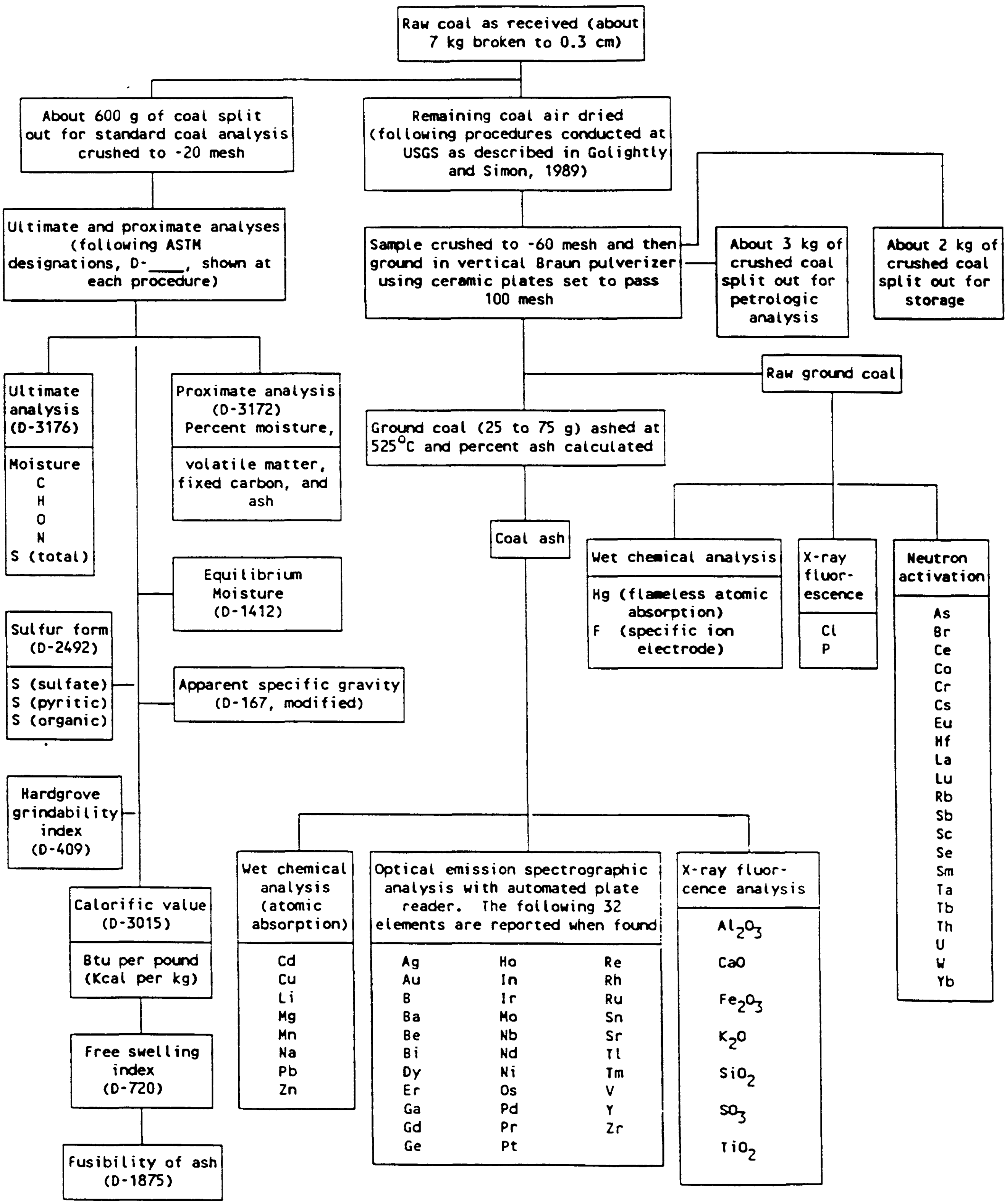

Figure 12. Flow diagram of procedures used for the analysis of USGS coal samples. Note that because of insufficient sample size, all grinding for COALREAP samples, including petrographic and trace element/oxide splits, was done at contractor labs during standard analysis preparation, rather than by using the procedures outlined in Golightly and Simon (1989). Moisture loss or gain after grinding to -60 was not determined for trace element/oxide splits.

(which does not necessarily reflect actual composition after the ashing process, but nominally adds up to 100 percent for a given sample). Trace elements are generally reported as parts-per-million of the whole coal, although some trace elements are analytically determined from the ash. Oxides and trace elements for COALREAP samples were analysed by USGS laboratories according to the procedures outlined in Golightly and Simon (1989) and shown in figure 12.

Detailed discussions of the analytical procedures, the combustion and environmental significances of the various coal-quality parameters, and the potential for byproduct recovery from mineral matter, are included in earlier COALREAP reports, notably Landis, Khan and others (1988a) and Finkleman and others (1993), and will only be briefly discussed further herein.

Sampling procedures

The procedures for sampling coal from COALREAP boreholes have been discussed in detail in previous reports (SanFilipo and others, 1988, 1989; Landis, Thomas, and others 1988, 1992), and will only be summarized here. Coal was described in detail as soon as it was removed from the inner core barrel. If the description was delayed for any reason, the coal was left in the inner barrel or placed in PVC troughs and covered with wet cotten towels until it could be described. Coal was sampled immediately after it was described. Generally, only beds thicker than 30 cm were sampled, but some beds were benched by the occurrence of visible ash, sulfur, resin, or banding, and sample thickness varies accordingly. Samples were double or triple bagged in polyethelene and stored in air-tight plastic barrels and airfreighted to USGS in Reston Va., where they were unpacked and examined (usually without rebagging, but occassionally rebenched or combined, and renumbered). The samples were then shipped to USGS contractor labs (either Geochemical Testing, in Somerset PA, or Dickenson Laboratories in El Paso TX) for grinding and standard analysis. Ground splits were returned from the contract labs, and in most cases submitted to USGS for oxide and trace element analysis. Petrographic and backup splits were retained for most samples. A list of COALREAP samples for the study area is included in Appendix 2.

Ten of the backup splits for UAK- samples were returned to Pakistan and submitted to GSP labs in order to calibrate newly installed equipment that was purchased through COALREAP. Coal samples from the last ten JK- holes drilled (JK-1,2,6,13,15, 16,17,18,19, and 20) were evenly split by chisel in the field and submitted to GSP as well as USGS labs. The results of the GSP analyses are not included in the statistical summaries of this report, and are as yet unpublished.

The procedures for sampling the GSP DH- series boreholes are discussed in Khan (1988). The DH- samples were analyzed by the old (preCOALREAP) GSP labs, and laboratories operated by PMDC and Pakistan Steel Corporation. As these labs are not standardized to USGS labs, the results of the DH- analyses were generally not utilized for this report. Four samples from the DH- drilling program that were analyzed by USGS appear to have lost some moisture while being stored in metal cannisters before shipment, and except as noted, are also not utilized in this report.

Previous Work

The results of the analysis for individual samples from the study area that have been submitted to USGS laboratories have been presented in prior reports, which are referenced in table 9. Statistical summaries of the results of the USGS analyses have also been presented in earlier reports (table 9), one of which (Finkleman and others, 1993) includes data from all of the COALREAP boreholes utilized for our work. Unlike the present study, however, none of the statistical summaries of the previous reports* were sorted by zones or beds, with the exception of Landis and others (1992), which did not include trace elements.

Before being sent to the contractor for standard analysis, the samples collected from boreholes JK-15,16,17,18 and 19 were x-radiographed in Reston and benched in detail based on the distribution of mineral matter visible on the x-ray image. The samples from JK-15 and JK-17 were unfortunately lost in the U.S. mail enroute to the contractor. The results of the remaining samples that were benched in detail will hopefully be the integrated into additional studies that are beyond the scope of this report, including petrographic work. To date, none of the COALREAP samples from the Sonda coal field samples have been analysed petrographically. Hasan (1989, 1990) has petrographically analysed some samples from the DH- holes.

*Schweinfurth and others (1988, Part I, Executive Summary) contains a brief statistical summary of standard analysis for the full Sonda zone, which includes the upper, main, and lower main subzones of this report; the statistics include samples from the UAS-, UAT- [southern Sonda coalfield], and the first three UAK-boreholes.

Table 9. <u>Previous reports on the coal quality of the northern Sonda coal field</u>. The reports listed for the basic analytical suites (proximate analysis, ultimate analysis, major oxides and trace elements) refer to the actual laboratory reports for individual samples. Statistics refers to statistical summaries of the results.

Borehole series	Proximate analysis	Ultimate analysis	Major oxides	Trace elements	Statistics
DH-	1,3*	3*	3*,5*	3*,5*	2*,5*
UAS-	3	3	5	5	2**,5,6
UAK-	4,8***	4	5	5	4**,5,6
JK-	7,8****	7	5	5	5,6,7
JTB-	8,9,10				

References:

1) Ahmed and others (1986), Husain (1986), GSP files

2) Landis, Khan and others (1988a)

3) Landis, Khan and others (1988b)

4) Landis and others (1992)

5) Finkelman and others (1993)

6) This report

7) SanFilipo and others (1993) (USGS analysis)

8) GSP files (GSP analysis)

9) GSP files (PCSIR anlysis)

10) Boyd (1992)

* DH-22,23,24 analyses from USGS or USGS contractor labs

** No trace elements/oxides

*** 10 UAK- splits ground in the U.S.

**** 107 field splits; some benched differently than USGS JK-splits

Statistical Methods

Previous COALREAP reports on the Sonda coal field have generally included machine-generated statistical analyses of various coal quality parameters, using the following measures of central tendency and dispersion: arithmetic mean, population standard deviation, minimum, maximum, range, geometric mean and geometric deviation. In order to provide direct comparability with previous reports, we have included similar computer-generated statistics; some additional computations that were performed manually in order to familiarize the GSP coauthors with basic statistical methods are also included.

While the arithmetic mean is a well-accepted measure of central tendency for many physical systems, it has two flaws when working with coal samples: 1) unless the samples are all of the same thickness and evenly spaced laterally, the arithmetic mean does not represent an average value of what is mined, and therefore does not quantitatively represent potential combustion characteristics or byproducts, and 2) natural occurences of trace elements are commonly positively skewed (i.e. the mode is closer to the low than to the high extremes, Connor, and others, 1976).

In order to mitigate the first problem, we have weighted some of the more important coal quality characteristics by sample thickness for computing averages. Multiplying the thickness-weighted mean by the estimated tonneage of the deposit will theoretically yield a better estimate of the bulk quantity of a given parameter (e.g. sulfur) than would the arithmetic mean, although our method does not rigorously account for borehole spacing (which is in any case reasonably uniform for the study area).

It is common practice to mitigate the second problem by transforming the data logarithmically. We have included computer-generated calculations of the geometric mean (i.e. the antilog of the mean of the logarithms) as well as the arithmetic mean of each coal quality parameter, with no presumption as to which is the better method of estimating central tendency. We have included the population standard deviation and geometric deviation (i.e. the antilog of the standard deviation of the logarithms) as measures of dispersion. If the distribution of any parameter is in fact lognormal, then the geometric mean is the best estimator of central tendency, and the dispersal can be expressed in terms of the geometric deviation in a manner similar to the standard deviation for normal distributions. The formulas used for the computations in this report, and the mathematical relationships of the measures of dispersal to their means, are shown in Appendix 4. Note that in order to maintain consistency with earlier COALREAP reports and existing USGS software, we have used population standard and geometric deviations (i.e. division by n), regardless of sample size, where the sample standard and geometric deviation (i.e. division by n-1) might in fact be more appropriate. Multiplication of our results by $(n/n-1)^{1/2}$ will generally give a better estimate of the true dispersal (see Spiegel, 1961, p.70).

Results of standard analysis

Results of selected coal quality statistics for each of the beds isopached for this report are shown in tables 10 and 11.

Table 10. <u>Selected coal-quality statistics, as-received basis</u>, Jherruck area of the Sonda coal field. Only samples of the thickest bed of each subzone (i.e. the beds isopached on Plates 9 - 12) are included in these figures. The number of samples is indicated by "n". See Appendix 2 for a list of samples included in this table; see Landis, Khan, and others (1988b), Landis and others (1992), and SanFilipo and others (1993) for the raw data. Moist, mineral-matter-free (MMF) BTU's were calculated from the *Parr formula* (see p.82). The last column is weighted by thickness and is considered more meaningful from a mining standpoint than the unweighted mean.

Main Inayatabad bed (n = 14)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	32.72	2.54	28.47	37.60	9.13	33.00
% Ash	10.59	5.18	3.77	24.04	20.27	9.56
BTU (n=13)	7438	762	5819	8401	2582	7592
% Sulfur	2.28	1.42	0.80	6.13	5.33	1.83
% Cl (n=10)	0.06	0.02	0.03	0.08	0.05	0.04
BTU (MMF)	8355	445	7801	9216	1415	8434

Main Sonda upper bed (n = 21)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	33.09	4.61	26.15	48.02	21.87	33.30
% Ash	15.93	6.95	4.07	31.50	27.43	14.70
BTU	6623	855	4791	7741	2950	6780
% Sulfur	3.06	1.80	0.40	7.86	7.46	2.82
% Cl (n=10)	0.11	0.06	0.03	0.23	0.20	0.12
BTU (MMF)	7943	614	6861	8938	2077	8000

Main Sonda bed (n = 66)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	34.63	3.24	24.59	42.19	17.60	34.72
% Ash	8.42	6.45	2.62	36.10	33.48	7.69
BTU	7521	732	4082	8669	4587	7612
% Sulfur	1.50	1.34	0.18	6.13	5.95	1.38
% Cl (n=45)	0.08	0.05	0.02	0.19	0.17	0.07
BTU (MMF)	8255	411	6550	9225	2675	8290

Main Sonda lower bed (n = 21)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	31.12	3.12	25.34	40.09	14.75	31.23
% Ash	13.67	8.03	4.62	34.15	29.53	12.68
BTU	7259	1141	4365	8997	4632	7404
% Sulfur	3.15	1.95	0.85	9.09	8.24	2.72
% Cl (n=14)	0.07	0.04	0.03	0.14	0.11	0.07
BTU (MMF)	8448	687	6668	9626	2958	8532

Table 11. Selected coal-quality statistics, equilibrium-moisture basis, Jherruck area of the Sonda coal field. Only samples of the thickest bed of each subzone (i.e. the beds isopached in Plates 9 - 12) are included in these figures. The number of samples is indicated by "n". See Appendix 2 for a list of the samples included in this table; see Landis, Khan, and others (1988b), Landis and others (1992), and SanFilipo and others (1993) for the raw data. Moist, mineral-matter-free BTU's were calculated from the *Parr formula* (see p.82). The last column is weighted by thickness and is considered more meaningful from a mining standpoint than the unweighted mean.

Main Inayatabad bed (n = 14)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	30.02	2.96	24.91	34.42	9.51	31.35
% Ash	10.95	5.30	4.11	25.18	21.07	9.75
BTU (n=13)	7770	904	6094	9002	2908	7796
% Sulfur	2.37	1.49	0.83	6.42	5.59	1.87
% Cl (n=10)	0.06	0.03	0.03	0.09	0.06	0.05
BTU (MMF)	8711	587	7873	9960	2087	8680

Main Sonda upper bed (n = 21)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	31.06	3.48	22.51	37.72	15.21	31.32
% Ash	16.26	6.90	5.44	32.12	26.68	15.07
BTU	6850	1002	4885	8781	3896	6993
% Sulfur	3.11	1.80	0.53	7.93	7.40	2.89
% Cl (n=10)	0.11	0.06	0.03	0.23	0.20	0.12
BTU (MMF)	8254	697	7013	9517	2504	8308

Main Sonda bed (n = 66)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	31.78	3.04	24.82	41.33	16.51	32.02
% Ash	8.73	6.52	2.70	36.79	34.09	7.97
BTU	7859	834	4160	8929	4769	7933
% Sulfur	1.55	1.37	0.19	6.24	6.05	1.43
% Cl (n=45)	0.09	0.05	0.02	0.20	0.18	0.07
BTU (MMF)	8655	490	6770	9526	2756	8667

Main Sonda lower bed (n = 21)

	Mean	Std dev.	Min	Max	Range	Wtd mean
% Moisture	29.73	3.02	24.27	38.90	14.63	29.95
% Ash	13.85	7.88	4.82	34.64	29.82	12.86
BTU	7423	1246	4144	9611	5467	7551
% Sulfur	3.19	1.90	0.86	8.63	7.77	2.76
% Cl (n=14)	0.07	0.04	0.03	0.14	0.11	0.07
BTU (MMF)	8652	835	6111	10341	4230	8718

In addition to being on a bed-by-bed basis, the presentation in tables 10 and 11 differs from the procedure of reporting standard analysis statistics used in prior COALREAP reports in several important aspects. Up until now, statistics have only been summarized on an "as-received" (AR) basis (e.g. table 10), whereas the results in table 11 are computed on an equilibrium moisture (EM) basis. In addition, tables 10 and 11 include averages weighted by sample thickness, which we feel better represents the quality of the coal as it might be burned than does the arithmetic average. Tables 10 and 11 include only samples that meet the criteria for qualifying coal (i.e. beds thicker than 30 cm, dry ash less than 50 pct); while 30 cm was intended to be the sampling cutoff for COALREAP, a few thinner beds were analyzed and included in the statistics presented in earlier reports, as were several carbonaceous shale beds.

Samples from the entire map area, including those outside the resource area, were used for the statistical tables of this report (i.e. the UAK- samples within the map area were included), but only samples analysed by the USGS contractor labs are included in the tables (e.g. the DH- series GSP analyses were not included). Note that the results of the four DH-samples analyzed by USGS labs are also not included in these statistics because they appear to have dried before analysis. The samples that were included in the calculations for tables 10 and 11 are noted in Appendix 2.

In order to encourage a "hands-on" approach, the statistics shown in tables 10 and 11 were computed by the GSP authors of this report using hand-held calculators, unlike those of prior

COALREAP reports, which were done on mainframe computers by USGS personnel in Reston. Computer generated tables comparable to previous COALREAP reports are introduced later in this report.

Moisture

The moisture content of coal is important both for its direct impacts on utilization as well as for its relationship to other analytical parameters. The moisture content of coal can range from just a few percent for anthracites to well-over 40 percent for lignites. High-moisture (i.e. low-rank) coal has less heating value, is more difficult to transport and burn, and spontaneously combusts more readily than low-moisture coal.

Unlike most other analytical parameters for coal, moisture content can be readily altered during sample handling. In addition, moisture determinations indirectly affect other analytical determinations. The results of standard analysis are commonly reported on an as-received (AR) basis, which is a representation of the moisture content of the sample as it arrives at the laboratory, and is made by adjusting the measured ("as-determined" or AD) values to the moisture lost in preparing the sample under carefully controlled conditions of temperature and air flow (ASTM D121). Most other bases for reporting the results of coal analysis (e.g. dry basis) are made by normalizing the AR or AD results to the moisture content, rather than by direct measurement. The moisture content therefore affects most subsquent determinations; this is particularly important for high-moisture coals like those of the Bara Formation.

Moisture in coal is either "<u>free</u> [i.e. visible] surface moisture...[or], inherent [i.e. bed] moisture entrapped in the coal" in it's natural state (*Wood, p.13-14). The source of free moisture can be groundwater derived from fractures, or moisture introduced during handling. Both free moisture and inherent moisture can be lost by evaporation during handling. Under ideal conditions, the AR moisture will approach the true bed moisture, and for most commercial purposes, AR values are used.

Because of the importance of moisture determinations, and given the potential for moisture loss due to the hot dry climate of the study area and the time required to transport the samples to the U.S., equilibrium moisture (the moisture-holding capacity of the coal at controlled conditions of temperature and humidity) has been determined for many COALREAP samples. Equilibrium moisture is generally considered to be equal to bed moisture, excepting for some low-rank coals where bed moisture is greater than equilibrium moisture (ASTM, 1990, D1412). For each bed that we investigated, the average as-received moisture (table 10) was considerably higher than the equilibrium moisture (table 11). The senior author observed considerable surface moisture on many of the samples that were rebagged before shipment to the contractor labs. It appears that excess water was added to some of the samples at the well site to prevent them from drying, although some of the observed moisture may have been from natural fractures or condensation of bed moisture. We believe that

*the complete definiton of moisture content given in Wood erroneously equates inherent moisture to "residual moisture", see ASTM D121. The definitons of various moisture determinations are especially difficult for low-rank coals (see ASTM D3302).

despite the intrinsic problems with low-rank coal, equilibrium moisture is probably a better measurement of true inherent moisture for this suite of samples than AR moisture, and the analyses of table 11 are thus more valid than those of table 10. It should be noted that when sufficient effort to preserve moisture was not made, severe drying occured; for instance, the as-received moisture from the four DH- samples analysed by USGS (but not included in tables 10 and 11) ranged from 17 to 20 percent.

Rank

The degree of coalification of organic matter by geological processes is measured by the natural progression in rank (fig. 13) from lignite (less coalified) to anthracite (more coalified). Rank provides a means of classifying coals that is useful in predicting generalized behavior in mining, handling, and use (ASTM, 1990, D388). Rank is determined from one of several empirical formulas (*Parr Formulas*, see Wood, p.28) that utilize various standard coal parameters measured on an inherent moisture basis. We have utilized the following *Parr Formula* to estimate rank:

$$\mathbf{BTU\ (MMF) = 100(BTU - 50S)/[100-(1.08A + 0.55S)]}$$

where BTU equals heating value in British Thermal Units per pound, BTU (MMF) equals moist mineral-matter-free BTUs, S equals percent sulfur, and A equals percent ash. We utilized this formula for each bed on both the as-received and equilibrium-moisture basis, using both thickness weighted and unweighted values (tables 10 and 11).

On an as-received basis (table 10), individual samples ranged

Classification of coals by rank [A], [1]

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis): Equal or Greater Than	Fixed Carbon: Less Than	Volatile Matter Limits, percent Dry, Mineral-Matter-Free Basis: Greater Than	Volatile Matter: Equal or Less Than	Calorific Value Limits BTU per pound (Moist,[B] Mineral-Matter-Free Basis): Equal or Greater Than	Calorific Value: Less	Agglomerating Character
I. Anthracite*	1. Meta-anthracite	98	-----	-----	2	------------	--------	nonagglomerating
	2. Anthracite	92	98	2	8	------------	--------	
	3. Semianthracite[C]	86	92	8	14	------------	--------	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	------------	--------	commonly agglomerating[E]
	2. Medium volatile bituminous coal	69	78	22	31	------------	--------	
	3. High volatile *A* bituminous coal	-----	69	31	-----	14 000[D]	--------	
	4. High volatile *B* bituminous coal	-----	-----	-----	-----	13 000[D]	14 000	
	5. High volatile *C* bituminous coal	-----	-----	-----	-----	11 500	13 000	
		-----	-----	-----	-----	10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous *A* coal	-----	-----	-----	-----	10 500	11 500	nonagglomerating
	2. Subbituminous *B* coal	-----	-----	-----	-----	9 500	10 500	
	3. Subbituminous *C* coal	-----	-----	-----	-----	8 300	9 500	
IV. Lignite	1. Lignite *A*	-----	-----	-----	-----	6 300	8 300	
	2. Lignite *B*	-----	-----	-----	-----	------------	6 300	

[A]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15 500 moist, mineral-matter-free British thermal units per pound.

[B]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[C]If agglomerating, classify in low-volatile group of the bituminous class.

[D]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[E]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in the high-volatile *C* bituminous group.

[1]ASTM, 1981, p. 215.

*Modified from ASTM, 1981.

Figure 13. Classification of coal by rank. From Wood and others (1983).

from 6,550 to 9266 BTU (MMF), or from lignite *A* to subbituminous *B* (fig. 13) in apparent rank, although only one small bench sample was of apparent subbituminous *C* rank. On an equilibrium moisture basis (table 11), the samples ranged from 6111 to 10341 BTU (MMF), or lignite *B* to subbituminous *B* in apparent rank (fig. 13), although only one sample was in the lignite *B* range and only one or two samples per bed were in the subbitumonous *B* range. The average apparent rank tends to be near the border between lignite *A* and subbituminous *C* on either basis. The as-received moisture is higher than the equilibrium moisture for most of the samples utilized in this study. As previously stated, we feel that free moisture from groundwater, drilling fluids, or sampling procedures was present in most samples used for this study, and that the equilibrium moisture more closely approximates inherent moisture than the as-received values. Using the weighted means listed in table 11, all four beds rank as subbituminous *C*, which we feel is probably the true rank of Bara coals in the study area. The heating values listed in table 10 are typical for coals of Sindh Province, but are considerably lower than those of most coals from other Provinces of Pakistan, which are typically high-volatile bituminous (see Warwick and Javed, 1990).

Ash

The range of ash values shown in tables 10 and 11 is quite large (e.g. from 2.70 to 36.79 pct in the main Sonda bed on an EM basis), as is the standard deviation from the mean. There is an inherent bias towards high variation of ash content in our methods, however, in that we included impure coal up to the 50 percent dry-ash cutoff, as opposed to the normal USGS criteria of 33 percent (see p. 49-50). The samples with higher ash tend to be from thinner beds, and from table 12, which shows dry ash statistics, it can be seen that all four main beds average well-below the 33 percent cutoff.

Wood (p.13) defines medium-ash coal as that which ranges from 8 to 15 percent ash on an AR basis. From table 10 we see that on a thickness-weighted basis all four main beds fall in the range of medium ash, except the main Sonda bed, which is low-ash (again we feel that the EM basis is more valid for these coals, but this is largely academic in this case). The effect of thickness on the ash values can be seen more clearly by comparing ash isopleths, shown in Plate 17, to the thickness of the main Sonda bed (Plate 11). Clearly, the thick coal around UAS-4 and JK-13 JK-13 is of lower than average ash yield, and from a mining standpoint the main Sonda bed is a low-ash coal. Plate 17 also reinforces the idea that the main Sonda bed is of ombrogenous origin (see p. 32 and 47), and that the lateral pinchouts are probably gradations to carbonaceous shale. Most of the ash in Bara coal beds appears to be disseminated rather than in partings, but there is a vague ash stratification that can be observed within individual coal beds on the x-ray images and in the analytical values of benched samples. Hopefully, further COALREAP studies on the distribution of ash will be done on the samples that were x-rayed and benched in detail. No washability tests have as yet been conducted on coal from the Sonda field. Washability, as well as fouling tests, have been performed on Bara coals from the Lakhra field by a number of testing

Table 12. Ash values by bed, dry basis, Jherruck area of the Sonda coal field. Only samples of the thickest bed of each subzone (i.e. the beds that were isopached on Plates 9 - 12) are included in these figures. N equals the number of samples. See Appendix 2 for a list of the samples included in this table; see Landis, Khan, and others (1988b), Landis and others (1992), and SanFilipo and others (1993) for the raw data. The last column of this table is weighted by thickness and is considered more meaningful from a mining standpoint than the unweighted mean.

Bed name	N	Mean	Std dev.	Min	Max	Range	Wtd mean
Inayatabad	14	15.61	7.26	5.78	33.61	27.83	14.21
Sonda upper	21	23.41	9.48	7.84	44.42	36.58	21.74
main Sonda	66	12.55	8.74	4.00	49.77	45.77	11.53
Sonda lower	21	19.53	10.59	7.00	45.56	38.56	18.10

facilities, with mixed results (see Fuller and Herrick, 1986; Moore, 1986). The ash yields listed in table 10, particularly those for the main Sonda bed, compare favorably with most Pakistani coals (see Warwick and Javed, 1990).

The ash values shown at the boreholes on Plate 17 are composite values for the main Sonda bed weighted by sample bench thickness. Note that the ash values shown on Plate 17 for the DH- series boreholes (including DH-22, DH-23, and DH-24, which were analysed by USGS) are normalized to the weighted average equilibrium moisture of table 11 to make up for apparent drying during handling.

Sulfur

From the range of values and the standard deviations shown in tables 10 and 11, it can be seen that sulfur content within the four main beds of the study area also shows wide dispersion. Individual samples ranged from low sulfur ($\leq$1 %, Wood p. 12) to high sulfur ($\geq$ 3%). On a weighted average basis, however, all four main beds are medium sulfur coals. There is generally a strong correlation between ash content and the concentration of inorganic constituents, including sulfur, in the Sonda coal field (Finkleman and others, 1993), and the wide range of sulfur shown in tables 10 and 11 is probably somewhat related to the wider than normal range of ash content that was included in our definition of qualifying coal (and thus our statistical base). Like the ash, sulfur is also inversely correlated to thickness in our study area, as shown by comparison of sulfur isopleths for the main Sonda bed (Plate 18) to the coal thickness (Plate 11).

Note that the sulfur values shown on Plate 18 are composite values for qualifying coal, and that the values for the DH-boreholes were normalized to the weighted average equilibrium moisture of the other samples.

Although there is obviously some correlation between sulfur and ash content, the sulfur does appear to be somewhat more stratified in the main Sonda bed than does the ash. At UAS-4 for example, the upper 86 cm of the main Sonda bed (sample UAS-4-2A, Appendix 2) has an AR ash yield of 7.01 percent and AR sulfur of 3.14 percent (Landis, Khan and others, 1988b). The remaining 5.18 m of coal in this bed has a weighted AR yield of 4.53 percent ash and 0.64 percent sulfur. Clearly the gross sulfur value of the bed can be greatly reduced by exclusion of the upper bench, which is above a 29 cm parting (Plate 7). Although pyrite was described in the field as being evenly distributed throughout UAS-4-2, the results of analysis indicate that the upper bench is dominated by pyritic sulfur, while below the parting the bed is dominated by organically bound sulfur.

Most of the sulfur in the four main beds is pyritic (see tables 13-16), and probably can be selectively removed. Additional studies on the distribution of mineral matter will hopefully be carried out on the x-rayed samples, as well as additional statistical studies similar to Finkleman and others (1993), but on a bed-by-bed basis. In any case, comparison of coal thickness with sulfur distribution further supports an ombrogenous peat model for the main Sonda bed, and much of the potentially mineable coal in this bed is "low" sulfur. Sulfur values for the Jherruck area coals compare favorably with other coals of Pakistan (see Warwick and Javed, 1990).

Other standard analyses

The results of other standard analyses for study area coals are summarized statistically in tables 13-16. In general, the results of the standard analyses shown in tables 13-16, which include proximate analysis (moisture, volatile matter, fixed carbon, and ash), ultimate analysis (hydrogen, carbon, nitrogen, and oxygen), forms of sulfur (total, sulfate, pyritic and organic), ash-fusion temperatures (initial deformation, softening, and fluid), air-drying loss, and free-swelling index, are similar to those for U.S. coals of comparable heating value, major examples of which are summarized in Appendix 5. The technical significances of these parameters are discussed in detail in Landis, Khan and others (1988a) and Finkelman and others (1993), and will not be further dealt with herein.

Apparent (i.e. including pore space) specific gravity has been measured for 21 COALREAP samples of Bara coal, all from the JK-series drilling. The results ranged from 1.21 to 1.97 g/cc, with an average value of 1.42 (SanFilipo and others, 1993). Of these 21 samples, however, only seven were from qualifying coal from the main Sonda bed. The thickness weighted specific gravity of these samples was 1.24 g/cc, as compared to the value of 1.30 g/cc used for our resource calculations. The weighted average as-received ash value for the seven specific gravity samples was 4.97 percent, however, which when compared to the weighted average of 7.69 percent for all qualifying main Sonda coal (table 10.), implies that 1.30 was a reasonable density value for

Table 13. Statistical summary of standard, oxide, and trace element analyses, main Inayatabad bed, Jherruck area of the Sonda coal field. Values qualified as uncertain by the analyst are excluded; where no results are shown all values were qualified. See Appendix 2 for a listing of the samples included in this table; see Finkelman and others (1993) for the basic data for each sample.

Standard analysis, as-received basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
MOISTURE	14	32.72	2.54	28.47	37.60	9.13	32.62	1.08
VOLMAT	13	29.44	2.51	23.58	33.97	10.39	29.33	1.09
FIXEDC	13	27.13	3.94	16.54	31.29	14.75	26.79	1.18
BM ASH	14	10.59	5.18	3.77	24.04	20.27	9.46	1.61
HYDROGEN	13	6.80	0.40	5.62	7.16	1.54	6.79	1.06
CARBON	13	42.11	4.46	32.56	47.65	15.09	41.86	1.12
NITROGEN	13	0.89	0.12	0.70	1.15	0.45	0.88	1.14
OXYGEN	13	37.54	2.99	30.87	42.49	11.62	37.42	1.09
SULFUR	14	2.28	1.42	0.80	6.13	5.33	1.91	1.80
SULFATE	12	0.07	0.03	0.02	0.13	0.11	0.06	1.73
SULFPYR	12	1.30	0.75	0.37	2.60	2.23	1.09	1.85
SULFORG	12	0.51	0.24	0.20	1.01	0.81	0.45	1.63
BTU	13	7438.08	761.96	5819.00	8401.00	2582.00	7397.03	1.11
ASHDEF	14	2012.14	109.56	1870.00	2190.00	320.00	2009.19	1.06
ASHSOF	14	2065.71	136.05	1890.00	2380.00	490.00	2061.32	1.07
ASHFLD	14	2173.57	166.89	1960.00	2560.00	600.00	2167.36	1.08
ADLOSS	14	22.76	6.28	12.72	30.29	17.57	21.83	1.35
FREESWELL	13	0	---	0	0	---	---	---
ASG	3	1.30	0.01	1.29	1.32	0.03	1.30	1.01

Oxides, ash basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
USGS ASH	9	14.56	5.02	6.20	24.00	17.80	13.61	1.47
SIO2	9	28.44	8.08	18.00	42.00	24.00	27.28	1.34
AL2O3	9	15.13	4.44	8.30	22.00	13.70	14.43	1.37
CAO	9	6.06	2.22	2.90	11.00	8.10	5.67	1.44
MGO	9	2.68	1.15	1.20	4.60	3.40	2.44	1.54
NA2O	9	5.48	3.13	2.00	12.00	10.00	4.70	1.73
K2O	9	0.24	0.06	0.19	0.38	0.19	0.24	1.24
FE2O3	9	20.33	7.23	11.00	35.00	24.00	19.14	1.41
TIO2	9	2.62	0.99	0.91	4.10	3.19	2.39	1.59
P2O5								
SO3	9	18.60	9.02	8.40	38.00	29.60	16.76	1.56

Major and minor elements, weight percent, "air-dried*" whole-coal basis (converted from oxides)

SI	9	2.11	1.24	0.55	4.70	4.15	1.74	1.93
AL	9	1.24	0.71	0.27	2.80	2.53	1.03	1.92
CA	9	0.55	0.05	0.48	0.62	0.14	0.55	1.09
MG	9	0.21	0.06	0.16	0.38	0.22	0.20	1.28
NA	9	0.51	0.16	0.20	0.86	0.66	0.48	1.45
K	9	0.03	0.01	0.02	0.04	0.03	0.03	1.30
FE	9	2.02	0.86	0.68	3.30	2.62	1.81	1.65
TI	9	0.25	0.16	0.03	0.59	0.56	0.19	2.29

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 13 cont. Main Inayatabad bed.

Trace elements, ppm, "air-dried*" whole-coal basis

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
AG	6	0.03	0.01	0.02	0.06	0.04	0.03	1.44
AS	8	2.58	2.84	0.82	10.00	9.18	1.84	2.02
AU								
B	3	67.00	16.39	46.00	86.00	40.00	64.87	1.30
BA	9	45.77	66.26	9.90	230.00	220.10	25.92	2.49
BE	9	2.31	0.90	0.60	3.60	3.00	2.07	1.68
BI								
BR	9	138.62	198.55	5.60	620.00	614.40	42.05	5.29
CD	9	0.02	0.01	0.01	0.04	0.03	0.02	1.60
CE	9	16.62	19.28	4.20	70.00	65.80	11.28	2.19
CL	9	644.44	177.08	300.00	900.00	600.00	615.62	1.38
CO	9	13.41	16.68	2.90	60.00	57.10	8.79	2.25
CR	9	55.56	73.90	9.00	260.00	251.00	32.75	2.54
CS	1	0.67	0.00	0.67	0.67	0.00	0.67	0.00
CU	9	21.09	12.89	4.30	46.00	41.70	16.66	2.10
DY								
ER								
EU	9	0.53	0.46	0.17	1.80	1.63	0.42	1.87
F	5	58.00	30.59	30.00	100.00	70.00	50.36	1.70
GA	9	13.24	4.72	4.70	20.00	15.30	12.25	1.52
GD								
GE	9	9.30	2.78	2.10	11.00	8.90	8.50	1.66
HF	9	1.95	2.56	0.31	9.00	8.69	1.14	2.62
HG	8	0.05	0.04	0.01	0.14	0.13	0.03	2.10
HO								
IN								
IR								
LA	9	10.31	11.55	2.00	42.00	40.00	6.91	2.30
LI	9	10.12	6.52	1.30	24.00	22.70	7.76	2.26
LU	8	0.23	0.12	0.09	0.51	0.42	0.21	1.62
MN	9	42.69	26.46	8.20	110.00	101.80	35.43	1.91
MO	9	1.71	1.23	0.83	4.90	4.07	1.44	1.72
NB	9	2.99	2.46	1.20	9.60	8.40	2.43	1.78
ND	4	9.88	5.10	3.50	17.00	13.50	8.41	1.82
NI	9	27.22	13.26	12.00	58.00	46.00	24.37	1.60
OS								
PB	7	2.84	1.10	1.70	4.40	2.70	2.64	1.47
PD								
PR	6	0.78	0.29	0.50	1.40	0.90	0.74	1.38
PT								
RB								
RE								
RH								
RU								
SB	2	0.21	0.06	0.15	0.26	0.11	0.20	1.32
SC	9	11.14	7.65	2.90	31.00	28.10	9.22	1.83
SE	9	3.18	1.01	1.60	5.10	3.50	3.02	1.38
SM	9	2.07	2.12	0.56	7.90	7.34	1.51	2.06
SN	9	2.22	0.90	1.20	3.70	2.50	2.05	1.50
SR	9	1202.22	345.34	730.00	1700.00	970.00	1151.56	1.35
TA	9	0.62	0.77	0.08	2.70	2.62	0.37	2.68
TB	9	0.31	0.22	0.10	0.89	0.79	0.26	1.80
TE	not run							
TH	9	2.42	2.80	0.25	10.00	9.75	1.47	2.71
TL								
TM								
U	8	0.70	0.40	0.34	1.70	1.36	0.61	1.59
V	9	32.33	15.84	16.00	70.00	54.00	29.15	1.56
W	4	2.38	0.98	1.40	4.00	2.60	2.20	1.46
Y	9	10.83	2.41	5.20	14.00	8.80	10.49	1.32
YB	9	1.48	0.69	0.76	3.20	2.44	1.36	1.50
ZN	9	14.32	8.03	5.30	29.00	23.70	12.18	1.78
ZR	9	40.67	23.63	18.00	100.00	82.00	35.59	1.64
P								

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 14. Statistical summary of standard, oxide, and trace element analyses, main Sonda upper bed, Jherruck area of the Sonda coal field. Values qualified as uncertain by the analyst are excluded; where no results are shown all values were qualified. See Appendix 2 for a listing of the samples included in this table; see Finkelman and others (1993) for the basic data for each sample.

Standard analysis, as-received basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
MOISTUR	21	33.09	4.61	26.15	48.02	21.87	32.80	1.14
VOLMAT	21	27.11	2.90	22.01	32.16	10.15	26.95	1.12
FIXEDC	21	23.88	2.95	17.40	30.01	12.61	23.69	1.14
BM ASH	21	15.93	6.95	4.07	31.50	27.43	14.29	1.64
HYDROGEN	20	6.68	0.58	5.75	8.33	2.58	6.65	1.09
CARBON	20	37.06	5.11	25.59	43.88	18.29	36.68	1.16
NITROGEN	20	0.71	0.17	0.32	0.98	0.66	0.68	1.31
OXYGEN	20	36.94	4.20	31.94	49.70	17.76	36.72	1.11
SULFUR	21	3.06	1.80	0.40	7.86	7.46	2.54	1.93
SULFATE	19	0.06	0.05	0.02	0.22	0.20	0.05	1.96
SULFPRY	20	2.02	1.27	0.02	5.00	4.98	1.39	3.30
SULFORG	20	0.90	1.57	0.06	7.62	7.56	0.51	2.52
BTU	21	6623.00	854.53	4791.00	7741.00	2950.00	6564.29	1.15
ASHDEF	21	2101.43	185.45	1860.00	2560.00	700.00	2093.79	1.09
ASHSOF	21	2188.10	218.36	1890.00	2680.00	790.00	2177.72	1.10
ASHFLD	21	2340.00	238.49	1970.00	2790.00	820.00	2327.85	1.11
ADLOSS	21	26.87	5.13	18.59	42.46	23.87	26.43	1.19
FREESWELL	20	0	---	0	0	---	---	---
ASG	not run							

Oxides, ash basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
USGS ASH	14	19.60	8.73	7.40	40.10	32.70	17.82	1.55
SIO2	14	28.86	9.55	10.00	46.00	36.00	26.77	1.53
AL2O3	14	17.76	8.09	3.40	30.00	26.60	15.34	1.83
CAO	14	5.18	2.61	1.70	11.00	9.30	4.60	1.62
MGO	14	1.56	0.94	0.32	3.70	3.38	1.29	1.90
NA2O	14	4.86	2.77	1.50	11.00	9.50	4.12	1.80
K2O	14	0.24	0.06	0.14	0.36	0.22	0.23	1.28
FE2O3	14	23.49	9.90	9.10	41.00	31.90	21.21	1.60
TIO2	14	2.34	0.80	0.54	3.70	3.16	2.12	1.66
P2O5	5	0.07	0.04	0.03	0.15	0.12	0.06	1.71
SO3	14	14.99	7.98	6.50	30.00	23.50	13.09	1.67

Major and minor elements, weight percent, "air-dried*" whole-coal basis (converted from oxides)

SI	14	2.83	2.02	0.46	8.60	8.14	2.22	2.07
AL	14	2.08	1.69	0.17	6.30	6.13	1.45	2.54
CA	14	0.63	0.31	0.40	1.60	1.20	0.58	1.44
MG	14	0.15	0.05	0.07	0.21	0.14	0.14	1.46
NA	14	0.56	0.14	0.30	0.83	0.53	0.55	1.31
K	14	0.04	0.03	0.01	0.12	0.11	0.03	1.75
FE	14	3.12	1.74	0.62	6.40	5.78	2.63	1.86
TI	14	0.28	0.16	0.03	0.60	0.57	0.23	2.08

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 14 cont. Main Sonda upper bed.

Trace elements, "air-dried*" whole-coal basis, ppm

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
AG	12	0.06	0.03	0.02	0.10	0.08	0.06	1.63
AS	14	2.85	1.80	0.94	7.40	6.46	2.38	2.00
AU								
B	13	143.23	72.25	52.00	300.00	248.00	126.19	1.66
BA	14	56.07	79.76	14.00	340.00	326.00	37.16	2.11
BE	14	2.35	1.01	0.75	4.20	3.45	2.10	1.67
BI								
BR	14	67.86	109.26	4.70	400.00	395.30	21.20	4.34
CD	13	0.05	0.04	0.01	0.15	0.14	0.04	2.39
CE	14	15.77	10.01	3.70	42.00	38.30	13.13	1.84
CL	14	916.43	630.03	100.00	2200.00	2100.00	639.20	2.67
CO	14	20.42	10.38	7.10	43.00	35.90	17.66	1.75
CR	14	38.88	22.08	6.30	93.00	86.70	32.12	1.96
CS	7	0.22	0.09	0.07	0.36	0.29	0.20	1.66
CU	14	32.83	17.94	3.60	68.00	64.40	26.61	2.10
DY	1	1.40	0.00	1.40	1.40	0.00	1.40	0.00
ER								
EU	14	0.58	0.21	0.28	1.10	0.82	0.54	1.41
F	5	30.00	18.97	10.00	60.00	50.00	23.52	2.08
GA	14	17.36	6.54	10.00	30.00	20.00	16.25	1.43
GD	3	7.06	4.93	3.08	14.00	10.92	5.61	1.93
GE	13	11.00	6.53	1.70	24.00	22.30	8.71	2.13
HF	14	1.34	0.69	0.27	3.10	2.83	1.16	1.78
HG	11	0.04	0.03	0.01	0.08	0.07	0.04	2.08
HO	2	0.51	0.30	0.21	0.81	0.60	0.41	2.00
IN								
IR								
LA	14	9.15	5.65	1.80	21.00	19.20	7.51	1.93
LI	13	21.72	16.28	4.00	64.00	60.00	16.28	2.23
LU	14	0.22	0.09	0.11	0.40	0.29	0.21	1.45
MN	14	50.86	31.48	16.00	110.00	94.00	42.07	1.86
MO	14	3.11	2.15	0.72	7.30	6.58	2.47	1.99
NB	14	3.37	2.07	0.96	8.80	7.84	2.88	1.73
ND	8	12.30	7.23	4.48	27.00	22.52	10.40	1.79
NI	14	51.87	25.77	8.20	92.00	83.80	43.43	1.95
OS								
PB	10	6.32	5.09	1.40	18.00	16.60	4.59	2.23
PD								
PR	6	1.30	0.55	0.93	2.50	1.57	1.21	1.41
PT								
RB	1	7.70	0.00	7.70	7.70	0.00	7.70	0.00
RE								
RH								
RU								
SB	8	0.18	0.08	0.06	0.32	0.26	0.16	1.62
SC	14	11.86	5.02	4.70	22.00	17.30	10.86	1.53
SE	14	3.85	1.16	1.90	6.10	4.20	3.67	1.37
SM	14	2.10	0.95	0.86	4.40	3.54	1.91	1.53
SN	14	3.11	1.36	1.30	6.30	5.00	2.85	1.52
SR	14	1050.00	682.93	300.00	2600.00	2300.00	851.13	1.93
TA	14	0.48	0.25	0.06	0.93	0.87	0.39	2.03
TB	14	0.34	0.09	0.20	0.51	0.31	0.33	1.33
TE	not run							
TH	14	1.99	1.10	0.25	4.60	4.35	1.64	2.00
TL								
TM								
U	15	0.96	0.49	0.39	2.00	1.61	0.84	1.69
V	14	52.11	55.87	9.60	240.00	230.40	36.54	2.21
W	2	4.50	3.80	0.70	8.30	7.60	2.41	3.44
Y	14	13.45	4.30	6.00	23.00	17.00	12.78	1.38
YB	14	1.66	0.70	0.75	3.00	2.25	1.52	1.51
ZN	14	19.78	11.67	5.20	45.00	39.80	16.51	1.85
ZR	14	40.50	30.21	13.00	140.00	127.00	33.82	1.75
P	5	61.20	21.07	44.00	87.00	43.00	57.79	1.40

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 15. Statistical summary of standard, oxide, and trace element analyses, main Sonda bed, Jherruck area of the Sonda coal field. Values qualified as uncertain by the analyst are excluded; where no results are shown all values were qualified. See Appendix 2 for a listing of the samples included in this table; see Finkelman and others (1993) for the basic data for individual samples.

Standard analysis, as-received basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
MOISTUR	66	34.63	3.24	24.59	42.19	17.60	34.47	1.10
VOLMAT	66	28.32	3.91	6.38	32.84	26.46	27.83	1.24
FIXEDC	66	28.63	5.21	14.05	53.57	39.52	28.20	1.19
BM ASH	66	8.42	6.46	2.62	36.10	33.48	6.86	1.84
HYDROGEN	66	6.93	0.55	4.11	7.64	3.53	6.91	1.10
CARBON	66	43.02	4.49	21.78	49.73	27.95	42.73	1.13
NITROGEN	66	0.84	0.14	0.43	1.31	0.88	0.82	1.20
OXYGEN	66	39.23	3.28	28.81	46.47	17.66	39.08	1.09
SULFUR	66	1.50	1.34	0.18	6.13	5.95	1.04	2.40
SULFATE	65	0.07	0.09	0.01	0.54	0.53	0.04	2.62
SULFPRY	65	0.88	1.10	0.01	5.17	5.16	0.37	4.86
SULFORG	65	0.53	0.33	0.06	1.68	1.62	0.42	2.05
BTU	66	7521.03	732.48	4082.00	8669.00	4587.00	7477.57	1.12
ASHDEF	66	2040.45	133.22	1820.00	2720.00	900.00	2036.38	1.06
ASHSOF	66	2123.05	169.87	1880.00	2811.00	931.00	2116.63	1.08
ASHFLD	66	2234.88	211.71	1900.00	2811.00	911.00	2225.23	1.10
ADLOSS	66	24.39	6.46	10.31	38.84	28.53	23.41	1.35
FREESWELL	66	0	---	0	0	---	---	---
ASG	7	1.24	0.02	1.21	1.28	0.07	1.24	1.02

Oxides, ash basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
USGS ASH	50	12.42	9.32	4.30	47.60	43.30	10.10	1.84
SIO2	50	23.38	12.93	4.30	60.00	55.70	19.88	1.80
AL2O3	50	14.08	8.24	3.00	32.00	29.00	11.69	1.89
CAO	50	9.81	4.97	0.73	18.00	17.27	8.14	2.01
MGO	50	3.14	1.99	0.55	10.00	9.45	2.53	1.99
NA2O	50	9.07	5.48	0.58	23.00	22.42	7.18	2.15
K2O	50	0.24	0.06	0.13	0.42	0.29	0.23	1.25
FE2O3	50	14.75	9.16	2.70	39.00	36.30	12.07	1.92
TIO2	50	1.92	1.60	0.27	8.30	8.03	1.40	2.25
P2O5	11	0.07	0.05	0.03	0.20	0.17	0.06	1.76
SO3	50	22.01	11.29	2.30	46.00	43.70	18.27	1.98

Major and minor elements, weight percent, "air-dried*" whole-coal basis (converted from oxides)

SI	50	1.78	2.21	0.14	8.80	8.66	0.94	3.06
AL	50	1.18	1.45	0.11	6.50	6.39	0.62	3.08
CA	50	0.60	0.19	0.25	1.60	1.35	0.58	1.28
MG	50	0.16	0.05	0.03	0.32	0.29	0.15	1.44
NA	50	0.57	0.21	0.16	1.50	1.34	0.54	1.42
K	50	0.02	0.02	0.01	0.09	0.08	0.02	1.73
FE	50	1.36	1.46	0.17	7.70	7.53	0.85	2.68
TI	50	0.19	0.26	0.01	1.30	1.29	0.08	3.67

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 15. cont. Main Sonda bed.

Trace elements, "air-dried*" whole-coal basis, ppm

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
AG	38	0.04	0.03	0.01	0.10	0.09	0.03	2.13
AS	26	1.84	1.03	0.50	3.80	3.30	1.56	1.80
AU								
B	33	87.52	55.63	33.00	270.00	237.00	73.63	1.78
BA	50	59.31	114.24	7.30	790.00	782.70	32.06	2.62
BE	44	1.57	1.56	0.11	9.50	9.39	1.10	2.42
BI								
BR	50	111.77	151.13	4.10	610.00	605.90	39.10	4.85
CD	47	0.04	0.04	0.00	0.23	0.23	0.02	2.58
CE	50	9.57	9.29	0.90	45.00	44.10	6.74	2.29
CL	50	1006.80	568.87	200.00	2300.00	2100.00	817.26	2.02
CO	50	12.94	9.80	0.20	33.00	32.80	8.19	3.20
CR	50	23.09	25.90	1.40	130.00	128.60	13.01	3.08
CS	8	0.21	0.11	0.10	0.42	0.32	0.19	1.59
CU	50	21.76	21.15	2.50	94.00	91.50	14.61	2.41
DY								
ER								
EU	50	0.34	0.26	0.01	1.20	1.19	0.25	1.00
F	22	50.45	24.40	20.00	100.00	80.00	44.95	1.62
GA	50	11.28	9.13	0.21	59.00	58.79	8.02	1.00
GD								
GE	42	6.21	5.08	0.30	23.00	22.70	4.28	2.62
HF	50	0.82	0.95	0.04	4.40	4.36	0.45	3.11
HG	42	0.03	0.03	0.00	0.15	0.15	0.01	3.23
HO	13	0.57	0.51	0.15	2.20	2.05	0.44	1.93
IN								
IR								
LA	50	5.82	6.09	0.70	29.00	28.30	3.97	2.32
LI	49	9.81	12.35	0.38	55.00	54.62	4.89	3.39
LU	32	0.16	0.08	0.03	0.40	0.37	0.13	1.79
MN	50	38.22	29.56	6.70	170.00	163.30	29.38	2.09
MO	50	1.58	1.38	0.27	7.60	7.33	1.16	2.20
NB	50	2.66	2.75	0.10	9.50	9.40	1.52	3.09
ND	24	9.20	6.86	3.70	32.00	28.30	7.52	1.81
NI	50	38.00	34.59	1.30	210.00	208.70	25.97	2.62
OS								
PB	41	2.55	2.33	0.61	12.00	11.39	1.92	2.04
PD								
PR	22	1.12	0.52	0.31	2.60	2.29	1.01	1.57
PT								
RB								
RE								
RH								
RU								
SB	18	0.15	0.06	0.07	0.28	0.21	0.14	1.48
SC	50	6.29	5.21	0.15	22.00	21.85	4.16	2.91
SE	50	2.99	0.78	1.80	5.90	4.10	2.90	1.28
SM	50	1.27	1.06	0.06	5.00	4.94	0.92	2.40
SN	44	1.85	1.44	0.63	8.00	7.37	1.50	1.85
SR	50	1344.80	551.36	320.00	4000.00	3680.00	1246.31	1.49
TA	42	0.38	0.41	0.04	2.00	1.96	0.23	2.72
TB	48	0.21	0.14	0.04	0.59	0.55	0.17	1.98
TE	not run							
TH	50	1.20	1.31	0.07	5.80	5.73	0.72	2.82
TL								
TM								
U	30	0.94	1.10	0.25	6.40	6.15	0.70	1.98
V	50	30.76	26.50	1.10	100.00	98.90	19.37	2.96
W	4	1.27	0.24	0.86	1.50	0.64	1.24	1.24
Y	49	9.04	6.30	0.47	35.00	34.53	6.95	2.24
YB	43	1.01	0.57	0.24	2.30	2.06	0.85	1.84
ZN	50	22.85	24.85	1.40	120.00	118.60	13.36	2.95
ZR	50	27.50	23.89	3.00	110.00	107.00	18.95	2.45
P	11	51.82	16.58	44.00	87.00	43.00	49.81	1.30

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 16. Statistical summary of standard, oxide, and trace element analyses, main Sonda lower bed, Jherruck area of the Sonda coal field. Values qualified as uncertain by the analyst are excluded; where no results are shown all values were qualified. See Appendix 2 for a listing of the samples included in this table; see Finkleman and others (1993) for the basic data for each sample.

Standard analysis, as-received basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
MOISTUR	21	31.12	3.12	25.34	40.09	14.75	30.97	1.10
VOLMAT	21	29.35	3.66	20.82	36.07	15.25	29.11	1.14
FIXEDC	21	25.85	3.42	17.49	32.39	14.90	25.61	1.15
BM ASH	21	13.67	8.03	4.62	34.15	29.53	11.83	1.69
HYDROGEN	21	6.59	0.61	4.98	7.46	2.48	6.56	1.10
CARBON	21	40.61	6.68	23.32	50.42	27.10	39.97	1.20
NITROGEN	21	0.75	0.16	0.35	0.99	0.64	0.73	1.28
OXYGEN	21	35.18	3.03	28.43	43.72	15.29	35.05	1.09
SULFUR	21	3.15	1.95	0.85	9.09	8.24	2.66	1.79
SULFATE	21	0.10	0.10	0.01	0.47	0.46	0.07	2.39
SULFPRY	21	2.25	1.71	0.02	6.82	6.80	1.51	3.25
SULFORG	21	0.79	0.46	0.20	2.06	1.86	0.68	1.79
BTU	21	7259.29	1141.36	4365.00	8997.00	4632.00	7154.92	1.19
ASHDEF	21	2066.67	127.52	1920.00	2510.00	590.00	2062.98	1.06
ASHSOF	21	2126.19	169.24	1950.00	2640.00	690.00	2119.88	1.08
ASHFLD	21	2239.52	184.76	2000.00	2720.00	720.00	2232.30	1.08
ADLOSS	21	22.91	4.87	11.68	29.97	18.29	22.32	1.27
FREESWELL	21	0	---	0	0	---	---	---
ASG	1	1.30	---	1.30	1.30	---	1.30	---

Oxides, ash basis, weight percent

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
USGS ASH	13	16.59	5.51	7.90	28.60	20.70	15.70	1.40
SIO2	13	28.69	6.73	18.00	46.00	28.00	27.96	1.25
AL2O3	13	17.05	4.43	8.60	26.00	17.40	16.44	1.32
CAO	13	5.12	1.81	2.60	10.00	7.40	4.83	1.41
MGO	13	1.42	0.50	0.71	2.50	1.79	1.33	1.41
NA2O	13	4.62	2.49	1.40	8.80	7.40	3.92	1.81
K2O	13	0.21	0.07	0.11	0.41	0.30	0.20	1.36
FE2O3	13	24.85	10.43	12.00	45.00	33.00	22.86	1.50
TIO2	13	2.84	1.27	1.50	5.80	4.30	2.60	1.50
P2O5	4	0.04	0.01	0.04	0.05	0.02	0.04	1.14
SO3	13	14.85	4.93	5.70	26.00	20.30	13.95	1.45

Major and minor elements, weight percent, "air-dried*" whole-coal basis (converted from oxides)

SI	13	2.31	1.32	0.87	6.20	5.33	2.04	1.61
AL	13	1.50	0.66	0.56	3.20	2.64	1.37	1.54
CA	13	0.54	0.04	0.46	0.62	0.16	0.54	1.08
MG	13	0.13	0.04	0.07	0.20	0.13	0.13	1.36
NA	13	0.48	0.15	0.24	0.72	0.48	0.45	1.39
K	13	0.03	0.01	0.02	0.06	0.05	0.03	1.46
FE	13	2.97	1.83	0.97	6.70	5.73	2.49	1.80
TI	13	0.29	0.20	0.10	0.86	0.76	0.24	1.81

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

Table 16 cont. main Sonda lower bed

Trace elements, "air-dried*" whole-coal basis, ppm

DATA ITEM	VALUES USED	MEAN	STD DEV	MINIMUM	MAXIMUM	RANGE	GEO MEAN	GEO DEV
AG	11	0.06	0.03	0.02	0.12	0.10	0.05	1.64
AS	12	3.62	2.15	1.50	10.00	8.50	3.18	1.61
AU								
B	9	111.22	54.22	59.00	250.00	191.00	101.49	1.50
BA	13	35.62	17.40	13.00	77.00	64.00	31.65	1.63
BE	13	2.77	1.44	0.82	5.40	4.58	2.40	1.74
BI								
BR	13	103.47	120.45	3.80	440.00	436.20	42.67	4.67
CD	13	0.05	0.02	0.01	0.10	0.09	0.04	1.96
CE	13	16.85	18.97	6.00	81.00	75.00	12.59	1.90
CL	13	683.85	446.07	200.00	1500.00	1300.00	539.00	2.04
CO	13	16.56	6.43	8.10	26.00	17.90	15.23	1.52
CR	13	42.77	39.26	16.00	170.00	154.00	33.51	1.87
CS	4	0.20	0.15	0.07	0.45	0.38	0.15	1.97
CU	13	30.23	13.32	13.00	63.00	50.00	27.84	1.49
DY								
ER								
EU	13	0.56	0.40	0.24	1.80	1.56	0.48	1.67
F	9	48.89	21.83	20.00	100.00	80.00	44.55	1.54
GA	13	15.68	4.54	9.90	26.00	16.10	15.07	1.32
GD	1	1.82	0.00	1.82	1.82	0.00	1.82	0.00
GE	13	13.41	8.60	0.90	29.00	28.10	9.89	2.49
HF	13	1.54	1.63	0.64	7.00	6.36	1.16	1.89
HG	10	0.05	0.04	0.00	0.14	0.14	0.03	2.69
HO	1	0.87	0.00	0.87	0.87	0.00	0.87	0.00
IN								
IR								
LA	13	11.08	14.02	3.20	59.00	55.80	7.88	1.97
LI	13	13.31	6.46	2.30	26.00	23.70	11.33	1.88
LU	12	0.21	0.08	0.09	0.40	0.31	0.20	1.48
MN	13	47.99	48.94	4.90	200.00	195.10	30.78	2.67
MO	13	3.61	2.59	0.87	8.70	7.83	2.65	2.30
NB	13	3.95	2.36	1.60	9.40	7.80	3.39	1.70
ND	6	13.35	8.51	5.60	25.00	19.40	10.85	1.90
NI	13	81.54	102.15	26.00	430.00	404.00	58.00	1.98
OS								
PB	9	3.82	2.64	1.60	8.90	7.30	3.09	1.88
PD								
PR	4	1.68	0.66	1.10	2.70	1.60	1.56	1.46
PT								
RB	1	60.00	0.00	60.00	60.00	0.00	60.00	0.00
RE								
RH								
RU								
SB	6	0.21	0.09	0.13	0.39	0.26	0.20	1.43
SC	13	12.35	9.22	5.60	41.00	35.40	10.34	1.72
SE	13	3.99	1.67	2.50	8.40	5.90	3.74	1.41
SM	13	2.11	1.77	0.89	7.90	7.01	1.74	1.73
SN	13	3.57	2.35	1.10	8.00	6.90	2.86	1.97
SR	13	1050.00	325.60	500.00	1700.00	1200.00	998.25	1.38
TA	13	0.58	0.66	0.18	2.80	2.62	0.43	1.99
TB	13	0.32	0.16	0.15	0.70	0.55	0.29	1.59
TE	not run							
TH	13	2.33	2.83	0.66	12.00	11.34	1.70	1.92
TL								
TM								
U	9	1.21	0.67	0.31	2.80	2.49	1.04	1.76
V	13	45.46	20.49	24.00	89.00	65.00	41.51	1.51
W	1	1.70	0.00	1.70	1.70	0.00	1.70	0.00
Y	13	12.09	4.97	5.30	25.00	19.70	11.16	1.50
YB	13	1.50	0.63	0.60	2.90	2.30	1.36	1.57
ZN	13	17.18	8.88	5.70	39.00	33.30	15.05	1.69
ZR	13	43.46	26.89	17.00	110.00	93.00	37.47	1.68
P	4	40.70	5.72	30.80	44.00	13.20	40.25	1.17

*does not necessarily equate to ASTM air-dried whole coal basis (see text)

resource calculations. The weighted average apparent specific gravity for 3 qualifying Inayatabad samples was 1.30 g/cc, as was the value of a single qualifying Sonda lower main bed.

Chlorine is an important inorganic constituent of coal because of its corrosive effect on boilers. Chlorine was included in the standard wet-chemical analysis of some of the samples (those done by Dickenson Laboratories), and was included in tables 10 and 11 for comparison with the results by x-ray fluorescence to be introduced in the next section. The results of the standard analysis and x-ray fluorescence for chlorine were very similar for all beds.

Results of oxide and trace element analysis

The results of analysis for additional inorganic constituents of Bara coals are summarized in tables 13-16. The significance of these elements in coal is discussed in detail in Finkelman and others (1993) and Landis, Khan and others (1988a), and will only be briefly discussed here. Note that the number of analyses for oxides and trace elements is smaller than the number of standard analysis. This is because: a) there was insufficient sample available for some tests; b) the results for some trace elements (and P_2O_5) "qualified" (i.e. reported by the analyst as "less than" or "greater than" a baseline concentration) and were not utilized for our statistical tables; and, most importantly, c) budgetary constraints prevented the submission of some samples for oxide and trace element analysis. As previously stated, the results of individual samples are presented in Finkelman and others (1993), which also includes statistical tables that use the "qualified" values after mathematical transformation (multiplication by a constant). We did not include the transformed qualified values in our statistical base in order to be directly comparable to previous reports, notably Landis, Khan and others (1988a), and Landis, Thomas and others (1992).

Oxides are shown in tables 13-16 as a percentage of "USGS ASH". USGS ASH is ashed at 525°C (fig. 12), compared to 700°-725°C for the ASTM ash that led to the values shown in tables 10-12. In addition, the USGS procedure does not determine the moisture loss during sample preparation (including crushing), which is done rigorously by the ASTM method. Although the samples utilized for this study were crushed at the contractor labs rather than as shown in fig. 12 or described by Golightly and Simon (1989), the trace element and oxide splits were not necessarily crushed to ASTM standards, and in any case, were not controlled for moisture after receipt by USGS for analysis. The "BM ASH" in tables 13-16 is ASTM AR ash, identical to that of table 10. To what degree the consistently higher USGS ASH yield compared to BM ASH yield is due to moisture loss during preparation, ash volatilization at the higher BM ASH temperature, or other factors, is not clear at this time. For most of our samples the USGS ASH approaches the dry ash yield, and moisture loss would thus appear to be the major factor.

Trace element concentrations are shown in tables 13-16 as parts-per-million "whole coal", which is measured directly from "raw ground coal" (fig. 12) or normalized to USGS ASH ("coal ash, fig. 12), with no corrections made for moisture loss during preparation, and thus is not equivalent to "as-received".

Despite the aforementioned problems, the USGS whole-coal basis for these samples should in theory approach the ASTM "air-dried whole coal basis" (ASTM D3683), and a reasonable approximation to AR basis can probably be made by normalizing the results to the ASTM air-drying loss (ADLOSS tables 13 -16). For comparative purposes, major and minor elements are also shown converted by atomic weights from oxides to ppm "whole coal".

The concentrations of most of the major and minor oxides and trace elements in Bara coals are similar to typical U.S. coals of equivalent rank (Appendix 5). There does appear to be abnormally high concentrations of chlorine and bromine in all four of the beds included in tables 13-16. This might be due to the effects of using NaCl as a drilling additive by IVCC for the drilling of the UAS- and UAK- holes. The chlorine values obtained by wet chemical analysis (tables 10 and 11), however, are all from the JK- series drilled by GSP, presumably without salt additives, and these values are of the same order of magnitude as the results of x-ray flourescence shown in tables 13-16. A more rigorous approach to the chlorine/bromine anomaly and the potential effects of drilling fluids is included in Finkleman and others (1993).

The Bara coal samples from the study area also seem to be enriched in strontium and depleted in barium compared to U.S. coals. Secondary enrichment by groundwater leaching of bedded celestite ($SrSO_4$) veins, which are fairly common in the Laki Formation in the vicinity of the study area, might account for the Sr enrichment. The common occurrence of secondary gypsum veins in the Bara coal beds being mined in the Lakhra field reinforces this idea. The Bara coals also seem to be somewhat enriched in metals like nickel and chromium. The Deccan traps, which underlie the Bara Formation, could be the source of these metals, but based on stratigraphic position, such enrichment would presumably be primary.

CONSTRAINTS ON MINING

There are a number of potential constraints on the mineability of the Sonda coal field, including: 1) hydrology, 2) incompetent roof rock, 3) effects on irrigated areas overlying the thickest coal, and 4) marketability. The major goal of COALREAP, as stated in the PASA, was to evaluate the geologic extent of coal occurrences in Pakistan, Sindh Province in particular, and to quantify the total resource according to internationally accepted standards. Mining feasability studies were not included in the PASA, and neither geomechanical nor hydrological studies were conducted with any of the drilling programs that led to this study. As such, evaluation of the mineability of the Sonda coal field is beyond the scope of this report. In order to make intelligent recommendations for future work in the area, a brief discussion of what can be determined about the potential for coal development from existing data is nevertheless warranted. This is particularly important in light of recent proposals for additional closely spaced drilling in the study area (Kazmi and Siddiqi, 1990, p.267; GSP, 1991), and the general need to allocate the limited resources available to Pakistan for development programs as effectively as possible.

Based on borehole spacing, the JK- drilling program should have been considered predevelopment drilling, and as such, the drilling plan should have included preliminary engineering studies such as outlined in the preceeding paragraph. In early 1991, consideration was being made to begin a major infill drilling program in the study area, again with no provisions for such studies, and at the expense of COALREAP reconnaissance drilling already planned for other areas, notably the Thar Desert. These plans prompted the senior author of this report to initiate a recommendation that an outside consultant be retained to do a preliminary mining feasability study before approval of additional COALREAP drilling within the Jherruck tract. The John T. Boyd Co. (Pittsburgh PA) was retained by USAID to drill four engineering test holes in the study area (the JTB- series) to determine the prudence of further development drilling. Boyd drilled the holes in early 1992 and submitted a report (John T. Boyd Co., 1992) concluding that the tract was not currently economic. As previously stated, we did not use data from the JTB-holes, which were drilled after our work began, to complete our study. The following brief considerations, however, are based on our own data and observations, and are offered to supplement the Boyd conclusions.

Hydrology

As previously stated, COALREAP drilling in the study area consistently encountered loose sand which filled the drill string as high as several meters or tens of meters above the bit after the wireline core barrel was pulled. Considering that the sandstones appeared to be nearly totally unconsolidated, even at depth, it was unclear if the vacuum created by pulling the inner core barrel is sufficient to cause this problem, or whether the sandstones are under hydrostatic pressure. Ten pumping tests conducted by Boyd Co. in two of their boreholes had water yields ranging from 50 to 119 l/min., and Boyd (1992, p.10) concluded that all "sand zones tested are saturated and under pressure". Based on results of water quality analysis (mostly dissolved solids), they suggested that the groundwater was possibly connate water diluted by meteoric and irrigation water.

Examination of Plate 4 shows that the Bara Formation subcrops below Indus alluvium. There is substantial leakage of irrigation water in the alluvial areas, and standing water and associated salt pans are frequently observed. Boyd measured the static water level in one of their holes that was drilled in the alluvial plain at 14 m elevation (i.e. slightly higher than the normal Indus stage). Given the hydraulic connectivity of permeable Bara sands to water-saturated alluvium through subcrops and faults (Plates 3 and 4), we believe that Bara groundwater is subject to continuous recharge in the study area, and that the high levels of dissolved solids may be due to concentration by evaporation in the irrigated areas before recharge, as opposed to being of connate origin. The recharge rate could affect the ability to dewater potential mines in the Sonda coal field, and we concur with the Boyd recommendation for additional studies to identify the source of Bara groundwater before any development work is undertaken.

<u>Roof and Floor Conditions</u>

Within the study area, the Sonda coal zone is well beyond the depth limits of conventional surface mining practices, and therefore can only be reasonably evaluated as an underground mining prospect. As already indicated, the incompetent strata overlying the Sonda zone will cause both roof and shaft-sinking instability.

Boyd estimates that a minimum of 9 m of shale or claystone is necessary to support a mine roof due to the water-saturated sandstones of the study area. They concluded that longwall or retreat mining would result in mine flooding due to roof and floor breaks, and that extraction of coal would be possible only during pillar development, with a recovery factor of merely 15 - 24 percent. Boyd also concluded that the sandstones were channel sandstones that cut out coal beds as well as lutaceous roof rocks, and therefore required a nonmineable buffer zone that extended into some areas of stable roof. They mapped stable roof isoliths and projected sandstone cutouts, and by applying the 9 m clay roof criteria, buffers around the sandstone cutouts and faults, and a one meter minimum coal thickness, estimated a reserve base of 116 million tonnes (204 million tonnes if the cutoff is reduced to a minimum of 5 m clay roof).

As previously stated, mineability is generally beyond the scope of our study. We did, however, attempt to map the percentage of sandstone in the 3 m interval immediately overlying the main Sonda bed (Plate 19), for qualitative purposes (i.e. we did not use any information from Plate 19 to restrict the reserve calculations made from Plate XIV). There is no discernable sedimentation pattern in Plate 19, and it proved to be of almost no predictive value when compared with the four JTB- holes that were drilled after it was constructed. We also produced preliminary maps of: 1) percent sand in the first 1 m of roof, 2) the interval to the first loose sand greater than 1 m thick, and 3) the interval to the first loose sand greater than 3 m thick. No useful facies trends were evident in these three maps, and they are not included with this report. The sandstone geometry is obviously more complex than can be determined at the resolution of Plate 19, and would probably severly impede mine planning. We do not necessarily concur with the channel sandstone model of Boyd, however, and suggest that an attempt at high-resolution sandstone isoliths be undertaken by GSP as a next step in further refining the roof model.

Surface impacts

The contact of modern Indus alluvium and bedrock (Plate 2) more-or-less bisects the thick coal pod around UAS-4 (Plate 11). Nearly all of the southern Indus alluvial areas are cultivated, but farming west of the river is generally less intensely developed than on the east side, probably due to sandier soil within younger meander belts. On a strictly economic basis, subsidence under the cultivated portions of the study area would probably not be a major impediment to mining; it would, however undoubtedly cause severe cultural disruptions to local villages in what is already a politically sensitive area.

The Kalri Baghar canal, which supplies drinking water to Karachi, runs over the thickest coal in the study area, and could potentially be impacted by subsidence if mining occurs, as could many secondary irrigation canals. These canals are generally unlined and have unsophisticated diversion structures, and from an economic standpoint are probably not impediments to properly managed mining. This would be a sensitive issue for any future mine development, however, due to the scarcity and importance of water to the local culture.

Marketability

Perhaps the most serious impediment to development of the Sonda coal field is the proximity of shallower and more easily mineable coal less than 50 km north of the study area at the Lakhra field, which is currently underdeveloped (see Boyd, 1986; SanFilipo and others, 1988, 1990; Huber and Zamir, 1990; and Paracha, 1990). Boyd (1992) estimated the reserves within the Jherruck area at 17.4 million tonnes (116 tonnes reserve base x 15% recovery), recoverable at a cost of $51 to $91 per tonne (excluding profit). The average 1992 sales price of Lakhra coal was $24 per tonne f.o.b. mine (Boyd, 1992). Based on current mining practices, three 50 MW fluidized bed units under construction at Lakhra are optimistically expected to bring the spot coal price up to $48 per tonne (Shahid Ali Beg, General Manager, National Mines, oral commun.). Since there are sufficient remaining reserves at Lakhra to support considerable expansion of existing capacity, and given that the various feasability studies conducted by USAID for large-scale mining at Lakhra have projected mine-mouth prices of $17 to $45 per tonne (Huber and others, 1989), it is unlikely that such spot prices could be sustained at Lakhra under the increased competition expected once the market develops. Pricing thus would appear to be a major constraint to development of the Sonda coal field.

The higher projected mining costs of Jherruck coal could potentially be mitigated by their superior quality compared to Lakhra coal, particularly their significantly lower ash and sulfur content (see Boyd, 1986, v.11; Landis, Khan and others, 1988a). Additional studies of the relative quality of Lakhra and Sonda coals and the consequent effects on utilization costs may be warranted (see Moore, 1986), especially in light of the considerable expenditure of donor funds already invested in exploring these coal fields.

CONCLUSIONS AND RECOMMENDATIONS

by John R. SanFilipo, U.S. Geological Survey

The northeastern part of the Sonda coal field, generally referred to as the Jherruck tract, contains a substantial resource of coal. The thickest and most persistent coal bed, the main bed of the Sonda coal zone, contains nearly one billion tonnes in-place. Although of lower rank than most Pakistani coal from outside of Sindh Province, the Sonda coals compare favorably in grade with other coals of Pakistan, including similar ranking coal from other Sindh coal fields. Mining economics and markets for the area are poorly defined, however, and it is not possible to classify the resource into USGS reserve categories. Despite a considerable drilling effort over the last 12 years, there also remains some uncertainty as to the correlation and geometry of the coal beds, chiefly because the earliest holes (most of the DH- series) were not geophysically logged, and the last holes (the JK- series) were not all drilled to sufficient depth.

Although the geologic model of the Jherruck area could undoubtably be improved with additional drilling, use of public-sector funds for that purpose is probably not warrented at this time. Preliminary mining feasibility studies by the John T. Boyd Co., which are supported by the independent observations of this report, indicate that the tract is of dubious development potential at this time. Sufficient information is now in the public domain to enable the private mining sector to reasonably determine if further drilling of this tract is warranted. Any additional drilling that does take place in the northern Sonda coal field should include a level of hydrologic and geomechanical studies appropriate to the intensity of the drilling effort, and should be preceeded by a market analysis. A cost-benefit analysis of the relative quality of all Pakistani coals probably should be considered before any new large-scale exploration efforts are undertaken in Pakistan with public-sector funding.

In general, future commitments of U.S. donor funds for the purpose of exploratory coal drilling in Pakistan should require that:

1) An adequate drilling plan is prepared, and a USGS or equivalent field supervisor with a clear line of authority is designated. Ideally, the field supervisor will also be given data compilation and report-writing responsibilities.
2) Location and depth of boreholes are approved by the USGS or equivalent field supervisor. Holes should be drilled to a minimum of 40 m below the target coal zone.
3) Geophysical logging is directed by USGS personnel or their

equivalent. The decision to pull back casing and run logs in the open hole should be made soley by the supervising geologist (not the drilling or logging supervisor).

4) Predevelopment drilling (borehole spacing < 3 km) is generally beyond the scope of COALREAP-type drilling and should not take place without prefeasability studies that include mining and economic considerations.
5) All areas to be drilled should first be geologically mapped at scales no smaller than 1:50000.

Apart from the drilling depths, however, the quality of the data collected during the later phases of drilling in the Jherruck area (i.e. the JK- and JTB- holes) is relatively good, and additional useful refinements to the depositional and economic models of the Sonda coal field can be made from existing data. The following excercises are recommended (not necessarily in order of priority) for the purpose of further developing GSP's coal resource evaluation capabilities, and as a starting point for evaluating the potential for utilizing unconventional mining techniques to develop the Sonda coal field:

1) Coal-bed correlations should be revised utilizing the JTB- series drilling. Where the results of the JTB- drilling seriously impacts the maps and sections included in this report, they should be revised, Plate 2 in particular.
2) Interburden maps between the main beds should be drawn, including isopach and lithofacies maps, to determine whether multiple seam mining is possible.

3) Overburden maps should be constructed for the remaining beds as outlined on p. 63, and resources should be calculated for each bed according to the USGS standards utilized in this report.
4) Sandstone isoliths should be drawn to determine depositional environments and roof characteristics. Isoliths should be drawn on interval and bed bases.
5) Resources for the thickest qualifying bed composited from all zones should be calculated utilizing Plate 16 of this report and the overburden maps outlined in item 3 above (see p. 69 - 70).
6) A proper geologic map should be made for the study area, paying special attention to structure.
7) Additional petrographic and coal-quality studies should be conducted, particularly on the samples that were benched in detail for x-ray analysis.

In order to stimulate private-sector interest, consideration should be given at this time to lifting the moratorium on coal leasing that was imposed by the Sindh Government on the Sonda coal field during COALREAP drilling. The moratorium was enacted at the request of the COALREAP cooperating agencies in order to prevent the development of fragmented leasing patterns, such as those that exist in the Lakhra coal field, which can be an encumberance to the potential for large-scale development. If the GOP determines that it is still advisable to maintain the moratorium, it should also consider the option of restricting its application to Bara coal only, because the present leasing restrictions are unintentionally impeding the development of Sohnari coal by preventing the extension of existing leases in the adjacent Meting-Jhimpir coal field, despite the fact that there is insufficient demonstrated Sohnari coal to support the large-scale mining the moratorium was intended to protect.

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Appendices

Appendix 1

Proposal for infill drilling in the Jherruck area of the Sonda coalfield, originally submitted by the Geological Survey of Pakistan to the U.S. Agency for International Development in April, 1987. Portions of annextures ommitted for brevity.

Grams : GEOLOGICAL
Telex: -
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GOVERNMENT OF PAKISTAN

MINISTRY OF PETROLEUM & NATURAL RESOURCES

GEOLOGICAL SURVEY OF PAKISTAN

42-R, Block 6, PECH Society,
Karachi-29

Dated: 21st April, 1987

My dear Dr Noble

You will kindly recall that in the meeting held on the 12th April at Islamabad, which was attended by the USAID, USGS and GSP Senior Staff Members, including Mr. Charles Bliss, yourself. and the Director General GSP, one of the points which were discussed in the meeting was the possibility of drilling by GSP in Sonda area, in order to block out an area with sufficient proved reserves so as to provide incentive to development of coal for power generation. It was decided in this meeting that GSP will submit a proposal indicating the number of holes to be drilled, total meterage, estimated costs and the approximate location where the drilling would be done. The USAID had offered to consider the possibility of making arrangements for meeting the operational costs of the drilling.

We have since prepared tentative plan for drilling 20 bore holes in the area immediately north of Jherruk as shown in the attached sketch map. The cost estimates showing the GSP and USAID inputs are enclosed (see Annexure I). If the facilities desired can be made available by USAID in time, we expect to start the work by the first of September 1987 and complete it within five months using 2 drilling rigs. It is most likely that the work may be completed earlier if no unforeseen drilling problems occur.

It may be recalled that during 1985 GSP had drilled four holes in Lakhra as a result of a similar understanding between USAID and GSP.

It is expected that this drilling project would result in the proving of approximately 76 million tons of coal with indicated reserves of 230 million tons (Total = about 300 m tons). In making this estimate we have been very conservative in our anticipated coal thickness projections. However if the thickness of coal in proposed test holes turns out to be as good as in the existing 10 test holes, the proved reserves can go up significantly and we cannot rule out achieving a target of as much as 100 million tons.

We also anticipate that after this drilling has been completed approximately 30 to 36 more bore holes will be required within this block to raise the level of the proved reserves to about 150 million tons and the indicated reserves to 500 million tons. The second phase of drilling would in fact cover the pre-development drilling which would be comprehensive enough to enable mine planning.

We would appreciate if you could kindly let us know as soon as possible whether USAID concurs with this proposal. As you know, we have two drilling rigs sitting idle at Sonda. I was in the process of pulling these rigs out from Sonda when

(contd. from pre-page)

this idea of GSP's involvement in drilling was mooted out in the meeting on 12th April. I would like to get these rigs shifted from Sonda as soon as possible in case this proposal makes no headway.

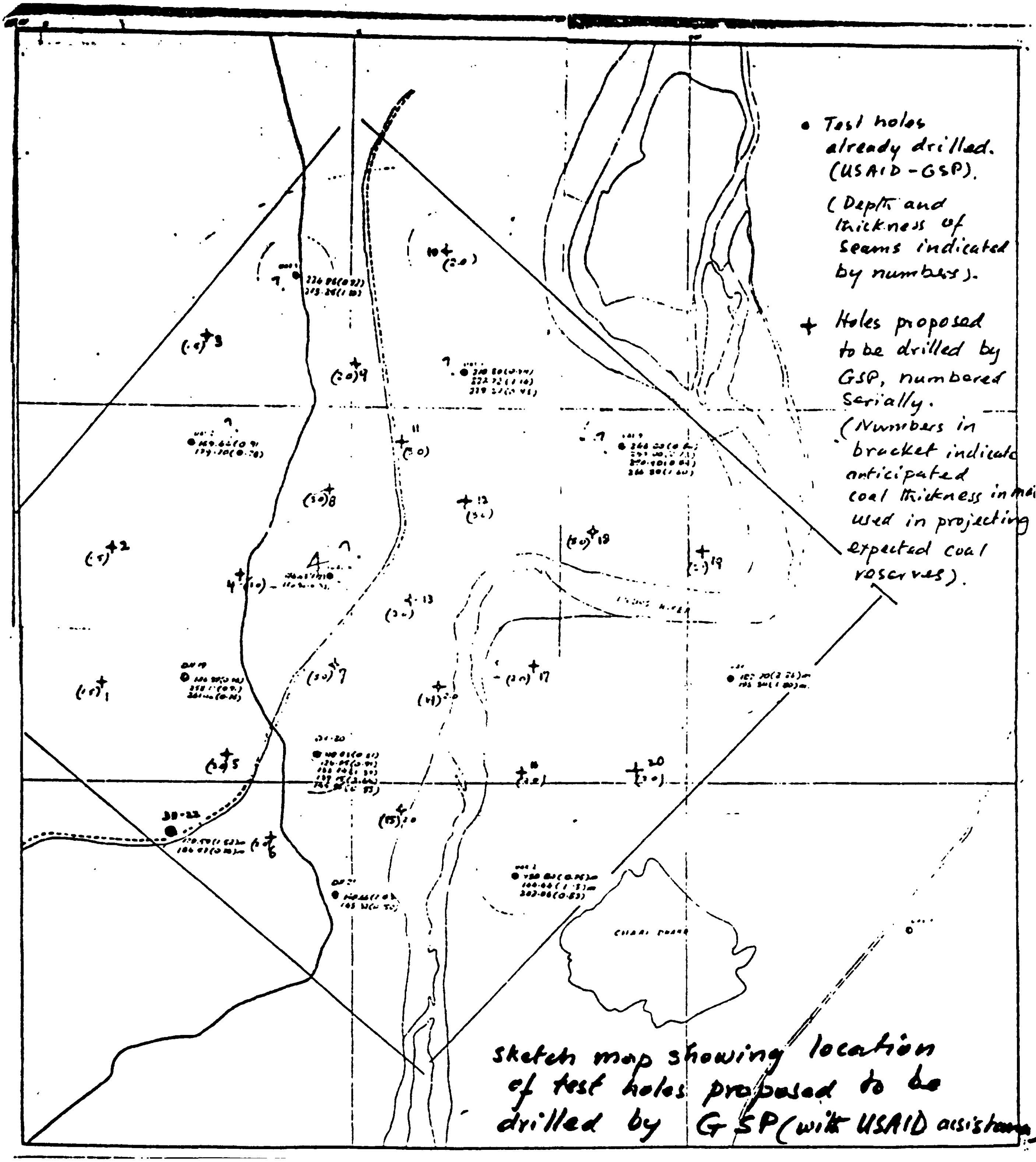
With best wishes,

Yours sincerely,

(A. H. KAZMI)

Dr. Edwin Noble,
C/o Geological Survey of Pakistan,
Pakistan Mineral Dev. Corp. Building,
Sector 13-H/9,
ISLAMABAD

Encls: as above


• Test holes already drilled. (USAID-GSP).
(Depth and thickness of seams indicated by numbers).
+ Holes proposed to be drilled by GSP, numbered serially.
(Numbers in bracket indicate anticipated coal thickness in m used in projecting expected coal reserves).
Sketch map showing location of test holes proposed to be drilled by GSP (with USAID assistance)

Proposed time schedule for drilling and contingent expenditure for 5000 metreage in sind area of 20 bore holes of 250 metre depth each :

AREA	**:**	SIND
TOTAL METREAGE	**:**	5000 Metre.
AVERAGE DEPTH OF HOLES	**:**	250
NO OF HOLES	**:**	20
ACTUAL OPERATIONAL PERIOD	**:**	150 days

Two rigs longyear-38 and 34 will be employed to work in three shifts operation with each rig (unit consisting of crew and equipment for one rig will be shifted from Quetta).

DATE OF STARTING	:	Ist September, 1987
DATE OF COMPLETION	:	28 February , 1988

<u>BREAK UP FOR ONE DRILLING RIG FOR ONE HOLE:</u>

Mobilasation, checking repairs from Quetta to Sind	15 days
Setting and pulling	01 day
Actual operation	12 days
Break down, service and maintenance of drilling units etc.	01 day

Appendix 2.

Revised coal intercepts and sample numbers. Brackets indicate single beds divided into benches, some with unsampled partings or intervening core loss. The symbol * indicates included in the isopached thickness of Plates 9-12,14,16 (i.e. qualifying coal). The symbol & indicates the sample was included in the coal quality statistics in this report. The symbol # indicates the sample was included in the statistics for standard analysis, but trace elements and oxides were not analyzed. Ash is on a dry basis; approximate (~) ash percentages for unsampled benches are estimated from density logs; na indicates no estimate was made. The symbol + indicates the sample description is subdivided. The symbol ^ indicates correlation changed from earlier report(s), notably Ahmed and others (1986), SanFilipo and others (1988), Landis and others (1992), and/or Thomas and others (1992). Some sample numbers have been changed from field numbers. NonCOALREAP sampling (e.g. DH- series) is not noted. Depth adjustments are revisions from core descriptions, based on geophysical logs and accommodated by adjusting the position of core loss. See figure 6 for subzone abbreviations. D.C. = dirty coal; ss = sandstone; sh = shale; carb = carbonaceous; 4pi = 4pi density log, GN = natural-gamma/neutron log.

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-1	D1	Coal (loss)	129.38	129.63	0.25	4pi	---		see below
	D1	Dirty coal	?131.80	?131.94	?0.14	Core	---		Misplaced? no 4pi
	D2	Coal	141.58	141.88	0.30-	Core/4pi	JK-1-1-88	11.30	depth adjusted
		Coal (loss)	141.88	141.93	0.05-	4pi	---		-do-
	USTR	Coal	166.85	166.95	0.10-	Core	---	~25	
		Coal (loss)	166.95	167.08	0.13-	4pi	---	~25	
	USTR	?D.C. (loss)	170.50	170.80	0.30	4pi/res	---	~45	Cave?
	I	?D.C. (loss)	187.03	187.58	*0.55	4pi	---	~50	Coaly shale?
	SU	Coaly shale	192.10	192.61	0.51	Core	JK-1-2-88	53.10	
	SU	Dirty coal	194.78	195.18	*0.40	Core	&JK-1-3-88	25.90	
	SU	Coal	196.09	196.41	0.32	Core	JK-1-4-88	16.37	
	SU	Coal	197.05	197.25	0.20-	Core	JK-1-5-88	na	no USGS analysis
		Coal (loss)	197.25	197.35	0.10-	4pi	---		
	S	Coal	198.98	199.42	*0.44	Core	&JK-1-6-88	18.76	
	SSL	Coal (loss)	210.75	211.15	*0.40-	4pi	---	~25	
		Claystone	211.15	211.30	0.15	4pi/core	---		10 cm lost
		Coal (loss)	211.30	211.50	*0.20	4pi	---	~20	
		Coal	211.50	211.70	*0.20	Core	---	~20	
		Claystone	211.70	211.90	0.20	Core	---		
		Dirty coal	211.90	212.10	*0.20-	Core/4pi	---	~40	4pi lithology
	W	Coal	234.00	234.85	*0.85	Core	JK-1-7-88	19.71	
JK-2	D1	Dirty coal	98.17	98.82	0.65	Core	JK-2-1-88	36.46	
	USTR	Dirty coal	146.01	146.12	0.11	Core	---		
	USTR	Dirty coal	159.55	159.65	0.10	Core/4pi	---		4pi lithology
	SU	D.C. (loss)	179.35	179.47	*0.12-	4pi	---		
		Dirty coal	179.47	179.50	*0.03-	Core/4pi	---		depth adjusted
	S	Coal	187.48	189.50	*2.02	Core	&JK-2-2-88	14.17	
	SSL	Dirty coal	200.88	200.98	0.10	Core	---		
	SSL	Coal	205.98	207.54	*1.56	Core	&JK-2-3-88	15.84	Thick adjusted
	SSL	Dirty coal	208.19	208.26	0.07	Core	---		depth adjusted
	SSL	?Dirty coal	210.83	211.23	0.40	Core/4pi	&+JK-2-4-88	<54.93	4pi lithology
		Carb shale	211.23	211.38	0.15	Core/4pi	+JK-2-4-88	>54.93	
JK-3	USTR	Dirty coal	122.54	122.99	0.45	Core	JK-3-1-B	36.12	
	I	Dirty coal	145.41	145.91	*0.50	Core	&JK-3-1	25.16	
	I	Coaly shale	151.91	152.53	0.62	Core	JK-3-1-A	57.24	
	S	Coaly shale	169.09	169.94	0.85	Core	JK-3-2	68.29	
		Coal (loss)	169.94	170.23	*0.29-	4pi	---		
		Coal	170.23	172.17	*1.94-	Core	&JK-3-3	9.73	
	S	Coal	174.71	174.86	0.15	Core/4pi	---		4pi lithology

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-3 cont.	SSL	Coaly shale	177.66	177.76	0.10	Core/4pi	---		4pi lithology
	SSL	Coal	179.60	180.30	*0.70-	Core	&+JK-3-4	18.51	
		Coal (loss)	180.30	180.39	*0.09 |	4pi	---		
		Coal	180.39	180.69	*0.30-|	Core	&+JK-3-4	18.51	
	SSL	Dirty coal	182.14	182.34	0.20	Core/4pi	---		4pi lithology
	SSL	Dirty coal	182.59	182.82	0.23	Core	---		
	SL	Dirty coal	190.99	191.24	0.25	Core	JK-3-6	40.00	
JK-4	D1	Dirty coal	66.11	66.41	0.30-	Core	JK-4-1	32.18	
		Coal (loss)	66.41	66.46	0.05-|	4pi	---		
	I	Coal	127.87	128.71	*0.84	Core	&JK-4-2	14.09	
		Coaly shale	128.71	128.76	0.05	Core/4pi	---		4pi lithology
	S	Coal	155.92	157.77	*1.85-	Core	&+JK-4-3	7.53	
		Coal (loss)	157.77	159.07	*1.30 |	4pi	---		depth adjusted
		Coal	159.07	160.02	*0.95-|	Core/4pi	&+JK-4-3	7.53	-do-
	S	Coal	162.34	162.69	0.35	Core	JK-4-4	24.33	
	SSL	Dirty coal	166.65	166.90	0.25	Core/4pi	---		4pi lithology
	SSL	Dirty coal	167.70	167.98	*0.28	Core/4pi	---		4pi lithology
JK-5	D1	Dirty coal	131.75	132.10	0.35	Core	JK-5-1	47.91	
	D1	Coaly shale	132.42	132.72	0.30	Core	JK-5-2	58.10	
	I	Coal	189.50	190.40	*0.90	Core	&JK-5-3	12.89	
	?S	Dirty coal	202.95	203.70	*0.75	Core	&JK-5-4	38.82	not deep enough
JK-6	I	Dirty coal	171.38	171.63	*0.25	Core/4pi	---		4pi lithology
	SU	Coal	183.22	183.62	*0.40	Core	&JK-6-1-88	20.81	
		Carb shale	183.62	183.94	0.32	Core	---		
		Dirty coal	183.94	184.08	0.14	Core/4pi	---		4pi lithology
	S	Coal	191.28	193.18	*1.90	Core	&JK-6-2-88	10.48	
	SSL	Coaly sh?	198.23	199.08	0.85	Core	JK-6-3-88	57.40	
	SSL	Coal	200.90	201.15	0.25	Core	---		
	SSL	Coal	203.30	203.60	*0.30	Core	&JK-6-4-88	18.62	
	SL	Dirty coal	216.56	217.00	0.44	Core	JK-6-5-88	45.99	
	SL	Coaly shale	220.60	221.00	0.40	4pi	---		
JK-7	D1	Coaly shale	76.90	77.20	0.30	Core	+JK-7-1	60.52	
		Dirty coal	77.20	77.50	0.30	Core/4pi	+JK-7-1	60.52	4pi lithology
	USTR	Coal?	123.92	124.22	0.30	Core	JK-7-2	10.60	no 4pi response
	USTR	Dirty coal	129.38	129.81	0.43-	Core/4pi	JK-7-3	34.88	samp 3+3A; depth adj
		D.C. (loss)	129.81	129.88	0.07-|	4pi	---		depth adjusted
	I	Dirty coal	148.60	148.70	*0.10-	Core	JK-7-4	na	-do-; no USGS analys
		D.C. (loss)	148.70	148.87	*0.17-|	4pi	---		
	?SU	Coal (loss)	165.67	165.78	0.11-	4pi	---		
		Coal	165.78	166.04	0.26-|	Core	JK-7-5	9.38?	switched 7-6? e-logs
	?SU	Coaly shale	166.98	167.20	0.22	Core/4pi	+JK-7-6	>51.48?	switched 7-5? e-logs
		Dirty coal	167.20	167.60	*0.40	Core/4pi	+JK-7-6	<51.48?	-do-
	?S	Dirty coal	171.59	171.60	*0.01	Core	---		
	LSTR/JRK	Coaly shale	240.50	240.80	0.30	Core/4pi	+JK-7-7	>55.56	Burrowed coal
		Dirty coal	240.80	241.15	0.35	Core/4pi	+JK-7-7	<55.56	4pi lithology
	LSTR/JRK	Dirty coal	243.33	243.83	0.50	Core	JK-7-8	40.39	
	LSTR/JRK	Dirty coal	244.58	244.68	0.10	Core	---		
	LSTR/JRK	Carb shale	247.96	248.61	0.65	Core	---		

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-8	I	Coaly sh (loss)	115.46	115.73	0.27	4pi/GN	---		depth adjusted
	I	Carb ss	?119.78	120.13	0.35	Core	JK-8-CS-1	86.58	
	I	Core loss	120.13	120.58	0.45	Core/4pi			not coal
	I	Carb shale	121.41	121.68	0.27	Core/4pi	JK-8-CS-2	81.29	depth adjusted
	I	Coal	120.58	121.41	*0.83	Core	&JK-8-1	20.53	
	SU	Coaly sh (loss)	135.20	135.45	0.25	4pi/GN	---		depth adjusted
	S	Coal	141.90	145.20	*3.30-	Core	&+JK-8-2	10.73	
		Carb shale	145.20	145.50	0.30 |	Core	JK-8-CS-3	80.94	
		Coal	145.50	146.02	*0.52-|	Core	&+JK-8-2	10.73	
	SSL	Dirty coal	160.20	160.96	*0.76	Core	&JK-8-3	29.26	
JK-9	D1	Coal	68.23	69.08	0.85	Core	JK-9-1	24.88	
	I	?Coaly sh (loss)	163.52	163.72	0.20	4pi/GN	---	~70	
	SU	D.C. (loss)	170.07	170.45	*0.38	4pi/GN	---	~29	
	SU	Coaly shale	173.94	174.06	0.12	Core/4pi	JK-9-2	na	4pi lith; no USGS anl
	S	Dirty coal	179.29	179.69	*0.40	Core	&JK-9-3	27.59	
	S	Coaly shale	183.14	183.45	0.31	Core	JK-9-4	52.61	
	SSL	Coaly shale	193.75	193.87	0.12	Core/4pi	JK-9-5	na	4pi lith; no USGS anl
	SL	Dirty coal	198.77	198.97	0.20	Core	JK-9-6	na	no USGS analysis
	?SL	Dirty coal	201.84	201.99	0.15	Core	JK-9-7	na	
JK-10	D1	Dirty coal	97.74	97.86	0.12	Core/4pi	---		4pi lithology
	USTR	Carb shale	125.44	125.87	0.43	Core	JK-10-2	71.57	
	USTR	Coal	134.78	135.08	0.30-	Core	JK-10-A	19.18	
		Dirty coal	135.08	135.23	0.15-|	Core	---		
	I	Coal	159.57	160.32	*0.75	Core/4pi	&JK-10-B	21.69	depth adjusted
	S	Coal	176.27	177.07	*0.80-	Core/4pi	&JK-10-C-1	15.68	-do-
		Carb shale	177.07	177.27	0.20 |	Core/4pi	JK-10-C-1A	67.85	-do-
		Coal	177.27	178.97	*1.70 |	Core/4pi	&JK-10-C-2	8.00	-do-
		Coal (loss)	178.97	179.08	*0.11 |	4pi	---		-do-
		Coal	179.08	180.14	*1.06-|	Core	&JK-10-C-3	5.66	
	S	Coaly shale	181.30	181.55	0.25	4pi			
	SSL	Coal	190.10	190.50	*0.40	Core	&JK-10-D	24.38	
JK-11	I	Coal	168.09	168.49	*0.40	Core	&JK-11-1	17.93	roof loss not coal
	I	Dirty coal	171.44	171.51	0.07	Core/4pi	---		4pi lithology
	S	Coal	188.48	189.29	*0.81-	Core	&JK-11-2A	9.64	
	S	Coal	189.29	190.59	*1.30-|	Core	&JK-11-2B	8.00	
JK-12	D1	Dirty coal	54.70	55.15	0.45	Core	JK-12-1	25.13	
	D2	Coaly shale	64.20	64.60	0.40	Core/4pi	JK-12-2	58.38	depth adjusted
		Carb shale	64.60	65.00	0.40	Core	---		-do-
		Dirty coal	65.00	65.15	0.15	Core/4pi	JK-12-3	32.83	-do-
		Coaly shale	65.15	65.45	0.30	Core/4pi	JK-12-4	55.86	-do-
	USTR	Coal	89.13	89.76	0.63	Core/4pi	JK-12-5	16.17	depth adjusted
		Underclay	89.76	90.25	0.49	Core/4pi	---		-do-
		Dirty coal	90.25	90.68	0.43	Core/4pi	JK-12-6	39.64	-do-
		Coaly shale	90.68	91.08	0.40	Core/4pi	JK-12-7	63.22	-do-
	I	?Coaly sh (loss)	113.50	113.70	*0.20	4pi/GN	---	~70	
	S	Coal	129.23	130.88	*1.65	Core	&JK-12-8	6.82	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-13	I	D.C. (loss)	171.35	171.59	*0.24	4pi	---	~45	depth adjusted
	SU	Dirty coal	180.43	180.73	*0.30-	Core/4pi	#JK-13-1	27.42	
		D.C. (loss)	180.73	181.00	*0.27-	4pi/GN	---		depth adjusted
	S	Coal	187.89	190.74	*2.85-	Core	#JK-13-2	14.74	Top 67cm dirty 4pi
		D.C. (loss)	190.74	191.29	*0.55-	4pi			
JK-14	USTR	D.C. (loss)	107.50	108.21	0.71	4pi/GN	---	~28	
	I	Coaly sh (loss)	124.50	124.72	0.22	4pi	---		
	I	Dirty coal	125.90	126.25	*0.35	Core/4pi	---		depth adjusted
	I	Coaly shale	131.83	131.90	0.07	Core/4pi	---		
		Dirty coal	131.90	131.98	0.08	Core/4pi	---		Dropped from
		Coaly shale	131.98	132.08	0.10	Core/4pi	---		previous run? All
		Dirty coal	132.08	132.18	0.10	Core/4pi	---		depths adjusted.
		Coaly shale	132.18	132.30	0.12	Core/4pi	---		
	I	Dirty coal	132.75	132.90	0.15	Core/4pi	---	~30	depth adjusted
	SU	Coal	143.47	144.02	* 0.55	Core	&JK-14-A	15.31	
	SU	Dirty coal	145.99	146.06	0.07	Core/4pi	---		4pi lithology
	SU	Dirty coal	147.90	147.95	0.05-	Core/4pi	---		4pi lithology
		D.C. (loss)	147.95	148.08	0.13-	4pi			
	S	Coaly shale	151.59	151.87	0.28	Core	---		
		Coal	151.87	152.93	*1.06-	Core	&JK-14-B1	7.80	
		Coaly shale	152.93	153.21	0.28	Core	JK-14-CS	54.52	
		Coal	153.21	154.84	*1.63	Core	&JK-14-B2	5.49	
		Coal	154.84	156.04	*1.20-	Core	&JK-14-B3	4.00	
JK-15	I	Coal	153.33	154.15	*0.82-	Core/4pi	JK-15-1-88	~28	Sample lost in mail
		Coal (loss)	154.15	154.35	*0.20-	4pi	---	~28	-do-
	?S	Coal	179.70	181.15	*1.45	Core/4pi	JK-15-2-88	~19	-do-
	SSL	Coal (loss)	193.68	194.10	*0.42	4pi	---	~24	
JK-16	USTR	Dirty coal	143.20	143.30	0.10	Core			
	I	Coal	160.81	160.90	*0.09-	Core	#JK-16.1	14.69	Petrographic bench
		Coal	160.90	161.16	*0.26	Core	#JK-16.2	8.73	-do-
		Coal	161.16	161.46	*0.30	Core	#JK-16.3	5.78	-do-
		Coal	161.46	161.67	*0.21	Core	#JK-16.4	11.64	-do-
		Dirty coal	161.67	161.76	*0.09-	Core	#JK-16.5	33.61	-do-
	?S	Coal	179.22	179.53	*0.31	Core	#JK-16.6	21.80	Petrographic bench
	?S	Coal	180.11	180.25	0.14-	Core	JK-16.7	23.68	Petrographic bench
		Dirty coal	180.25	180.35	0.10-	Core	JK-16.8	45.88	-do-
	?W	Coal	210.00	210.30	0.30	Core	JK-16.9	17.72	Petrographic bench
	?W	Coaly shale	212.04	212.21	0.17	Core	JK-16-4A-89	na	no USGS analysis
	?W	Coal	215.45	216.28	*0.83-	Core	JK-16.10	8.14	Petrographic bench
		Dirty coal	216.28	216.35	*0.07-	Core	JK-16.11	41.99	-do-
		Claystone	216.35	216.75	0.40	Core/4pi	---		depth adjusted
	?W	Coal (loss)	216.75	217.00	0.25	4pi	---		depth adjusted
	?W	Dirty coal	219.24	219.44	0.20	Core	JK-16-6-89	~26	no USGS analysis
		Coaly shale	219.44	219.71	0.27	Core	---		
	?W (?LSTR)	Dirty coal	239.36	239.48	0.12-	Core	JK-16.12	46.62	Petrographic bench
		Coal	239.48	239.81	0.33-	Core	JK-16.13	19.10	-do-
	?W (?LSTR)	D.C. (loss)	243.21	243.28	0.07-	4pi	---	~33	
		Dirty coal	243.28	243.38	0.10	Core	JK-16.14	32.56	Petrographic bench
		Coal	243.38	243.58	0.19-	Core	JK-16.15	22.07	-do-
	?W (?LSTR)	Coal	245.15	245.65	0.50	Core	JK-16.16	15.70	Petrographic bench

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-17	D1	Carb shale	173.75	173.90	0.15	Core	JK-17-1A-88	~75	Sample lost in mail
		Coal	173.90	174.30	0.40	Core	JK-17-1-88	~24	-do-
	D2	Coaly shale	185.52	185.82	0.30	Core/4pi	JK-17-2-88	~51	-do-
	D2	Dirty coal	186.08	186.42	0.34	Core	JK-17-3-88	~45	-do-
	USTR	Dirty coal	208.74	209.10	0.36	Core	JK-17-4-88	~40	-do-
	USTR	D.C. (loss)	217.85	217.95	0.10-	4pi		~30	depth adjusted
		Dirty coal	217.95	218.18	0.23-	Core/4pi	JK-17-5A-88	~30	Sample lost in mail
		Carb shale	218.18	218.41	0.23	Core	JK-17-5B-88	~65	-do-
	I	Coal	229.21	229.63	*0.42	Core	JK-17-6A-88	~20	-do-
		Coal	229.63	230.05	*0.42	Core	JK-17-6B-88	~20	-do-
	I	Carb shale	233.04	233.48	0.44	Core	JK-17-7-88	~55	-do-
	?S	Dirty coal	249.28	249.43	*0.15-	Core	JK-17-8A-88	~30	Sample lost in mail
		Coal	249.43	249.63	*0.20	Core	-do-	~15	-do-
		Coal	249.63	249.98	*0.35	Core	JK-17-8B-88	~15	-do-
		Coal	249.98	250.20	*0.22	Core	JK-17-8C-88	~20	-do-
		Dirty coal	250.20	250.30	*0.10-	Core	-do-	~40	-do- NDE?
JK-18	SOH	Coal	50.05	50.38	0.33-	Core	JK-18.1	23.79	Petrographic bench
		Coal (loss)	50.38	50.43	0.05-	4pi	---		depth adjusted
	D1	Coal	166.19	166.79	0.60	Core	JK-18.2	22.42	Petrographic bench
		Coaly shale	166.79	166.94	0.15	Core/4pi	JK-18-2C-89	~55	4pi lith; no USGS anl
	D2	D.C. (loss)	178.48	178.73	0.25	4pi/GN	---	~26	depth adjusted
		Carb shale	178.73	179.23	0.50	Core	---		
		Dirty coal	179.23	179.38	0.15-	Core	JK-18.3	48.66	Petrographic bench
		Dirty coal	179.38	179.53	0.15-	Core	JK-18.4	30.26	-do-
	USTR	Dirty coal	205.94	206.42	0.48	Core	JK-18.5	28.62	-do-
		Coaly shale	206.42	206.58	0.16	Core	JK-18.6	55.14	-do-
	SU	Dirty coal	242.66	242.72	*0.06-	Core	#JK-18.7	33.60	-do-
		Dirty coal	242.72	242.91	*0.19	Core	#+JK-18.8	30.73	-do-
		Sandy coal	242.91	242.99	*0.08	Core	---		in qualifying thk
		Dirty coal	242.99	243.16	*0.17	Core	#+JK-18.8	30.73	Petrographic bench
		Claystone	243.16	243.62	0.46	Core	---		-do-
		Coal	243.62	244.92	*1.30-	Core	#JK-18.9	11.16	-do-
	SU	Dirty coal	247.45	247.80	0.35-	Core	JK-18.10	34.97	-do-
		Dirty coal	247.80	247.88	0.08-	Core/4pi	---	~49	
	SU	Coal	252.06	252.39	0.33-	Core	JK-18.11	21.39	-do-
		Carb shale	252.39	252.67	0.28	Core	---		
		Dirty coal	252.67	252.74	0.07	Core	JK-18.12	33.11	-do-
		Coal	252.74	252.97	0.23-	Core	JK-18.13	14.57	-do-
	SU	Dirty coal	254.80	254.95	0.15	Core	---		
	S	Coal	261.67	262.93	*1.26-	Core	#JK-18.14	6.45	-do-
		Coal	262.93	263.00	*0.07	Core	#JK-18.15	15.64	-do-
		Coal	263.00	263.39	*0.39-	Core	#JK-18-16	9.80	-do-
	S	D.C. (loss)	264.30	264.50	0.20	4pi	---	~40	
	S	D.C. (loss)	264.98	265.13	0.15	4pi	---	~35	depth adjusted
	S	Coal	265.85	266.08	0.23	Core/4pi	JK-18.17	24.60	-do-
		Coaly sh (loss)	266.08	266.64	0.56	4pi	---		-do-
		Coaly shale	266.64	267.02	0.38	Core/4pi	JK-18-11A-89	~55	no USGS analysis
	SSL	Dirty coal	275.57	275.83	*0.26-	Core	#JK-18.18	45.56	Petrographic split
		Coal	275.83	276.97	*1.14-	Core	#JK-18.19	12.28	-do-
		Coaly shale	276.97	277.31	0.34	Core	JK-18.20	51.63	-do-
		Coaly shale	277.31	277.47	0.16	Core	---		
	SSL	Dirty coal	279.27	279.42	0.15	Core/4pi	---	~35	4pi lithology
		Coaly shale	279.42	279.74	0.32	Core	---	~55	Dirty coal ?
		?Coaly sh (loss)	279.74	279.92	0.18	4pi	---	~65	cave? depth adjusted

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
JK-19	D2	D.C. (loss)	133.05	133.32	0.27-	4pi	---	~49	depth adjusted
		Dirty coal	133.32	133.40	0.08-	Core	---	~49	
	USTR	Coaly shale	165.65	165.85	0.20	Core	JK-19-19.1	71.82	
		Coaly shale	165.85	166.56	0.71	Core	JK-19-19.2	67.65	
		Dirty coal	166.56	166.70	0.14	Core	JK-19-19.3	32.95	
	I	Dirty coal	179.47	179.59	*0.12-	Core/4pi	---	~40	depth adjusted
		D.C. (loss)	179.59	179.72	*0.13-	4pi	---	~40	-do-
		Coaly shale (loss)	179.72	180.44	0.72	4pi	---	~65	-do-
		carb shale	180.44	180.97	0.53	Core	---	~75	
	S	Coal	194.38	194.60	0.22-	Core	JK-19-19.4	18.34	Petrographic bench
		Coal	194.60	194.76	0.16	Core	JK-19-19.5	16.76	-do-
		Coal	194.76	195.03	0.27-	Core	JK-19-19.6	21.09	-do-
		Claystone	195.03	195.33	0.30	Core			
		Coaly shale	195.33	195.44	0.11	Core			
		Dirty coal	195.44	195.47	0.03	Core			
		Claystone	195.47	195.83	0.36	Core			
		Coal	195.83	196.03	*0.20-	Core	#JK-19-19.7	10.10	Petrographic bench
		Coal	196.03	196.70	*0.67	Core	#JK-19-19.8	7.75	-do-
		Coal	196.70	197.32	*0.62	Core	#JK-19-19.9	5.12	-do-
		Coal	197.32	197.54	*0.22	Core	#JK-19-19.10	15.10	-do-
		Coal	197.54	198.05	*0.51	Core	#JK-19-19.11	6.08	-do-
		Coal	198.05	198.56	*0.51	Core	#JK-19-19.12	6.62	-do-
		Coal	198.56	199.13	*0.57-	Core	#JK-19-19.13	10.76	-do-
	S	Coal	202.35	202.60	0.25-	Core	JK-19-19.14	18.19	Petrographic bench
		Dirty coal	202.60	202.80	0.20-	Core	JK-19-19.15	26.02	-do-
	S	Dirty coal	204.03	204.28	0.25-	Core	JK-19-19.16	42.60	Petrographic bench
		Coal	204.28	204.66	0.38	Core	JK-19-19.17	11.52	-do-
		Dirty coal	204.66	204.81	0.15-	Core	JK-19-19.18	37.58	-do-
	S	Dirty coal	209.02	209.22	0.20-	Core	JK-19-19.19	32.71	Petrograhic bench
		Coal	209.22	209.32	0.10	Core	JK-19-19.20	18.21	-do-
		Coal	209.32	209.45	0.13	Core	JK-19-19.21	15.18	-do-
		Coal	209.45	209.57	0.12	Core	JK-19-19.22	12.38	-do-
		Dirty coal	209.57	209.62	0.05	Core	JK-19-19.23	29.38	-do-
	SSL	Coaly shale	210.26	210.36	0.10	Core	JK-19-19.24	54.63	Petrographic bench
		Dirty coal	210.36	210.81	*0.45-	Core	#JK-19-19.25	31.79	-do-
		Coal	210.81	212.08	*1.27	Core	#JK-19-19.26	7.00	-do-
		Coal	212.08	212.27	*0.19-	Core	#JK-19-19.27	8.52	-do-
	SSL	Dirty coal	215.17	215.24	0.07-	Core	---	~45	
		D.C. (loss)	215.24	215.41	0.17-	4pi	---	~45	
	SL	Coaly shale	224.10	224.25	0.15	Core/4pi	---	~60	4pi description
JK-20	D1	Dirty coal	122.45	122.50	0.05-	Core	---		
		Coal	122.50	122.95	0.45-	Core	&JK-20-1	16.65	
	S	Dirty coal	199.45	199.80	*0.35-	Core	&JK-20-2AP	49.77	Combined sample A+P
		Coal	199.80	201.05	*1.25	Core	&+JK-20-2BC	<11.93	Combined sample B+C
		Dirty coal	201.05	201.25	*0.20	Core/4pi	&+JK-20-2BC	>11.93	-do-
		Coal	201.25	202.40	*1.15-	Core	&+JK-20-2BC	<11.93	-do-
	S	Coal	204.32	204.82	0.50	Core	&JK-20-3	12.35	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAS-1	^SU	Carb shale	218.74	218.80	0.06	Core	---		
		Coal	218.80	219.74	*0.94	Core	&UAS-1-1	16.20	
		Carb shale	219.74	219.81	0.07	Core	---		
	SU	Coaly shale	223.49	224.08	0.59	Core/4pi	---		
	S	Coal	225.50	225.72	0.22	Core	---		
	S	Dirty coal	226.59	226.94	0.35	Core	UAS-1-2	40.30	
		Carb shale	226.94	227.05	0.11	Core	---		
	S	Coal	227.72	228.86	*1.14-	Core	&UAS-1-3	9.49	
		Clst	228.86	229.32	0.46				
		Coal	229.32	229.34	0.02				
		Carb shale	229.34	229.37	0.03				
		Coal	229.37	230.33	*0.96-	Core	&UAS-1-4	15.97	
		Carb shale	230.33	230.48	0.15				
UAS-2	I	Carb shale	159.40	159.44	0.04				
		Coal	159.44	160.35	*0.91	Core	&UAS-2-1	12.62	
		Carb shale	160.35	160.39	0.04				
	S	Coal	180.20	180.79	*0.59-	Core/4pi	&+UAS-2-2	15.65	
		Carb shale (loss)	180.79	181.04	0.25	4pi			
		Coal (loss)	181.04	181.29	*0.25				
		Coal	181.29	181.48	*0.19-	Core/4pi	&+UAS-2-2	15.65	
	^?SSL	Coal	191.25	191.40	*0.15	Core/HRD	+UAS-2-3	<51.07	HRD lithology
		Coaly shale	191.40	191.70	0.30	Core/HRD	+UAS-2-3	>51.07	
	W	Coal	214.55	215.60	*1.05	4pi	---		cored sand wash?
	W	Dirty coal	217.35	217.70	0.35	4pi	---		cored ss wash?
UAS-3	SOH	Coal	45.00	45.45	0.45	4pi	---		Hole not cored
	SOH	Coal	46.03	46.48	0.45	4pi	---		-do-
	?D1	Dirty coal	178.60	178.80	?0.20	4pi	---		-do- Badly caved
	^?D2	Dirty coal	189.60	189.85	0.25	4pi	---		-do- Caved
	?I	Dirty coal	222.92	223.25	*0.33	4pi	---		Hole not cored
	?SU	?Coaly shale	239.80	242.00	2.20	4pi	---		-do-
	?S	Dirty coal	247.30	247.60	*0.30-	4pi	---		-do-
		Carb shale	247.60	247.82	0.22	4pi	---		-do-
		Coal	247.82	248.32	*0.50-	4pi	---		-do- NDE for SSL
UAS-4	I	Coal	166.40	167.52	*1.12	Core	&UAS-4-1	8.09	Badly caved
		SS? (loss)	167.52	168.18	0.15	4pi	---		Badly caved
	S	Coal	179.52	180.38	*0.86-	Core	&UAS-4-2A	11.20	
		Carb shale	180.38	180.67	0.29	Core			
		Coal	180.67	181.61	*0.94	Core	&UAS-4-2B	6.37	
		Coal	181.61	182.71	*1.10	Core	&UAS-4-2C	4.92	
		Coal	182.71	183.58	*0.87	Core	&UAS-4-2D	4.53	
		Coal	183.58	184.75	*1.17	Core	&UAS-4-2E	5.89	
		Coal	184.75	185.85	*1.10-	Core	&UAS-4-2F	13.55	
	S	Coal	188.00	188.31	0.31	Core	UAS-4-3	17.34	
	^SSL	Coal	196.32	197.07	*0.75	Core	&UAS-4-4	8.97	
	W	?Carb shale	221.57	221.78	0.21	Core	---		Cave? coal?
		Coal	221.78	221.85	0.07	Core	---		
		Carb shale	221.85	222.16	0.31	Core			
		Claystone	222.16	222.41	0.25	Core			
		Coal	222.41	222.80	*0.39	Core	UAS-4-5	21.62	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAS-5	USTR	Coaly shale	154.90	156.00	1.10	4pi/GN	---		Noncore drilling
	I	Coaly shale	183.05	185.96	2.11	4pi/GN	---		-do-
		Coal	185.96	186.25	0.29	4pi/GN			-do-
	I	Dirty coal	190.00	190.45	*?0.45	4pi/GN	---		-do- Badly caved
	SU	Clst (cave)	201.70	202.30	0.60	4pi	---		Nonecore, depth adj
		Claystone	202.30	202.60	0.30	GN			-do-
		Dirty coal	202.60	202.80	0.20	4pi/GN	---		-do-
		claystone	202.80	203.05	0.25	GN	---		-do-
		Coaly shale	203.05	203.40	0.35	4pi/GN	---		-do-
		Claystone	203.40	203.62	0.22	GN	---		-do-
		Dirty coal	203.62	204.24	*0.62	4pi/GN	---		-do-
		Claystone	204.24	205.38	1.14	GN	---		-do-
		Dirty coal	205.38	205.66	0.28	4pi/GN	---		-do-
		Claystone	205.66	206.18	0.52	Core	---		Begin core 205.66
		Dirty coal	206.18	206.49	0.31	Core	UAS-5-1	26.26	
	S	Coal	208.44	209.16	*0.72-	Core	&UAS-5-2	10.74	
		Dirty coal	209.16	209.46	*0.30	Core	&+UAS-5-4	>41.30	
		Coal	209.46	209.72	*0.26	Core	&+UAS-5-4	<41.30	
		Dirty coal	209.72	210.01	*0.29-	Core	&+UAS-5-4	>41.30	
	^SSL	loss	223.34	224.61	1.27	4pi/GN	---		Not coal
		Coal	224.61	225.58	*0.97	Core	&UAS-5-7	19.28	
		loss	225.58	227.91	2.33	4pi/GN	---		Not coal
	^SSL	Dirty coal	230.96	231.00	0.04		+UAS-5-9	>25.59	
		Coal	231.00	231.34	0.34	Core	+UAS-5-9	<25.59	
		Dirty coal	231.34	231.58	0.24	Core	+UAS-5-9	>25.59	
	W	Coaly LS	241.45	241.75	0.30	Core	---		Coaly fossil hash
		loss	241.75	242.24	0.49	4pi/GN	---		Not coal
		Dirty coal	242.24	242.66	*0.42-	Core	---		
		Coal	242.66	243.78	*1.12-	Core	UAS-5-12	18.75	
		loss	243.78	245.01	1.23	Core	---		Not coal
		Carb shale	245.01	245.16	0.15	Core			
	?LSTR	Coal	273.25	274.35	1.10	Core	UAS-5-14	15.59	
UAS-6	SOH	Dirty coal	37.30	37.80	0.50-	4pi	---		Noncore drilling
	SOH	Coal	37.80	38.20	0.40-	4pi	---		Nonecore drilling
	D1	Dirty coal	160.67	160.94	0.27	Core	---		Thicker?: 4pi
	D2	Shelly coal	174.28	174.69	0.41	Core	---		-do- coal/foss hash
	USTR	Dirty coal	199.13	199.32	0.19	Core	---		Caved
	?I	Dirty coal	225.29	225.69	*0.40	Core/4pi	---		
	?SU	Coal	236.23	236.58	0.35	Core	#UAS-6-1	16.51	Bad 4pi
		Carb shale	236.58	236.60	0.02	Core	---		-do-
		Claystone	236.60	237.38	0.78	Core	---		-do-
		Dirty coal	237.38	237.46	0.08	Core/4pi	---		
	?SU	Dirty coal	240.34	240.84	*0.50	Core	#UAS-6-2	34.25	
	?S	SS (loss)	241.50	242.35	0.85	4pi	---		Poss <20 cm coal
		Coal	242.35	242.53	0.18-	Core	---		
		Shale	242.53	242.60	0.07	Core	---		
		Coal	242.60	242.70	0.10-	Core	---		
	?S	Coal	243.69	244.49	*0.80-	Core	#UAS-6-3	7.09	
		Coal	244.49	245.24	*0.75	Core	#UAS-6-4	10.64	
		Dirty coal	245.24	245.34	*0.10-	Core	---		
	?S	Coal (loss)	249.38	249.41	0.03-	4pi	---		
		Coal	249.41	249.70	0.29-	Core	---		
		Loss	249.70	250.09	0.39	4pi	---		Poss top 1 cm coal

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAS-6 cont.	^?SSL	Dirty coal	257.77	258.77	*1.00-	Core	#UAS-6-5	45.73	
		Shale	258.77	259.00	0.23	Core			
		Carb shale	259.00	259.14	0.14	Core			
		Coal	259.14	259.39	*0.25	Core	#UAS-6-6	14.99	
		Shale	259.39	259.50	0.11	Core			
		Coal	259.50	260.80	*1.30-	Core	#UAS-6-7	11.71	Floor badly caved
	^?SSL	Dirty coal	262.07	262.50	0.43	Core	---		Clean? Roof caved
		?SS (loss)	277.23	278.61	1.13	Core/4pi	---		Possibly dirty coal
	?W	Dirty coal	279.68	280.00	*0.32-	Core	---		
		Coal	280.00	280.34	*0.34	Core	UAS-6-8	16.25	
		Dirty coal	280.34	280.44	*0.10-	Core	---		
UAS-7	^?D1	?Coaly shale	224.40	227.15	?2.75	4pi/GN	---		- Unreliable: behind
		Coal/D.C.	227.15	227.65	0.50	4pi/GN	---		slipped HW casing,
	^?USTR	Coal/D.C.	250.60	250.85	0.25	4pi/GN	---		- hole not cored
		?SS	257.80	259.00	1.20	4pi/GN	---		Coal? probably cave
	?USTR	Dirty coal	271.40	271.67	0.27	4pi/GN	---		Not cored
	^?SU	?Dirty coal	298.00	298.20	*0.20	4pi/GN	---		-do-
		Coaly shale	298.20	298.40	0.20	4pi/GN	---		-do-
UAS-8	SOH	?Coaly shale	78.80	79.10	0.30	GN/cuttings			noncore
	SOH	?Coaly shale	80.20	80.80	0.60	-do-			-do-
	SOH	?Coaly shale	82.30	82.90	0.60	-do-			-do-
	D1	Dirty coal	207.45	207.71	0.26	Core/4pi	---		
	USTR	Coal	243.21	244.00	0.79	Core	UAS-8-1	13.36	
	USTR	Coal	254.38	255.03	0.65	Core	UAS-8-2	18.93	
	?I	D.C. (loss)	274.94	275.04	0.10	4pi	---		
		Dirty coal	275.04	275.34	0.30	Core	UAS-8-3	30.14	
	?I	Coal	279.00	280.75	*1.75-	Core	&UAS-8-4	11.07	
		loss	280.75	280.83	0.08	4pi	---		not coal
		Carb shale	280.83	280.85	0.02	Core	---		
		Dirty coal	280.85	280.98	*0.13-	Core			
	?SU	Dirty coal	285.13	285.39	0.26	Core/4pi			Badly caved
	?SU	Dirty coal	291.00	291.65	*0.65	Core	&UAS-8-5	44.42	-do-
	?SU	Coal	292.95	293.51	0.56	Core	UAS-8-6	24.20	
	?S	loss	297.23	297.55	0.32	4pi	---		not coal
		D.C. (loss)	297.55	297.78	0.23-	4pi	---		coal?
		Dirty coal	297.78	297.98	0.20-	Core/4pi	---		coal? 4pi lithology
		Carb shale	297.98	298.08	0.10	Core	---		
		Claystone	298.08	299.00	0.92	Core			out of place? 4pi
		Coal	299.00	300.09	*1.09	Core	&UAS-8-7	22.41	
		Claystone	300.09	300.38	0.29	Core	---		
		Dirty coal	300.38	300.44	0.06	Core	---		
	^?SSL	Dirty coal	309.20	309.40	0.20-	Core	---		out of place? 4pi
		D.C. (loss)	309.40	309.61	0.21-	Core	---		-do-
	^?SSL	Dirty coal	313.88	314.05	*0.17-	Core	&+UAS-8-8	25.60	Good top
		D.C. (loss)	314.05	314.25	*0.20-	4pi	---		
		Dirty coal	314.25	314.38	*0.13	Core	&+UAS-8-8	25.60	Good base
UAS-9	D2	Dirty coal	189.95	190.25	0.30	Core	---		
	USTR	Dirty coal	203.34	203.60	0.26	Core	---		45 cm lost?: 4pi
	?SU	Dirty coal	239.15	239.53	0.38	Core	UAS-9-1	25.82	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAS-9 cont.	SU	Coal	245.76	246.60	*0.84	Core	&UAS-9-2	17.11	
		Carb shale	246.60	247.10	0.50	Core	---		4pi badly caved
	S	Coal	249.94	250.66	0.72	Core	UAS-9-3	22.2	
	S	Coal	252.15	253.00	*0.85	Core	&UAS-9-4	13.80	base caved
	S	Dirty coal	257.23	257.51	0.28	Core	---		
	^SSL	Coal	266.25	267.85	*1.60	Core	&UAS-9-5	12.62	
	W	Coaly shale	282.25	282.60	0.35	Core/4pi	---		
		Coal	282.60	284.00	*1.40	Core	UAS-9-6	9.64	
		Coaly shale	284.00	285.85	1.85	Core/4pi	---		
	W	Dirty coal	286.80	287.20	0.40	Core	---		
UAK-1	^USTR	Dirty coal	165.26	165.81	0.55	Core	UAK-1-1	28.13	I?
	?SU	Coal	182.70	183.10	*0.40-	Core	&UAK-1-2	22.19	
		Coaly shale	183.10	183.50	0.40 |	Core	UAK-1-3	58.48	
		Coal	183.50	184.20	*0.70 |	Core	&UAK-1-4	22.91	
		Dirty coal	184.20	184.96	*0.76-|	Core	&UAK-1-5	33.09	
	^?S	Coal	196.30	197.15	*0.85	Core	&UAK-1-6	10.42	
		Clst (loss)	197.15	197.40	0.25	4pi/GN	---		
		Coaly shale	197.40	197.10	0.70	Core	UAK-1-7	59.26	
	?W	Dirty coal	238.20	238.28	0.08	Core	---		Sandy
	?W	ss (loss)	243.11	245.11	2.00	GN	---		Badly caved
		Dirty coal	245.11	245.14	0.03	Core	---		Sandy
	?W	Dirty coal	249.96	250.46	*0.50	Core	UAK-1-8	39.92	
	?W	Coaly shale	261.01	262.12	1.11	Core/Elogs	---		Probably caved
	?LSTR	Carb shale	278.26	279.46	1.20	Core/Elogs	---		
	?LSTR	Coal (loss)	285.76	285.81	0.05-	4pi	---		W?
		Coal	285.81	286.16	0.35-|	Core	UAK-1-9	19.78	W?
UAK-2	USTR	D.C. (loss)	98.20	98.70	0.50	Core/GN	---		depth adjusted
	SU	Coal	138.80	139.25	*0.45-	Core	&UAK-2-1A	10.25	
		Coal	139.25	139.55	*0.30-|	Core	&UAK-2-1B	7.84	
	S	Coal	144.44	144.78	*0.34-	Core	&UAK-2-2A	7.62	
		Coal	144.78	145.10	*0.32 |	Core	&UAK-2-2B	5.72	
		Coal	145.10	145.34	*0.24-|	Core	&UAK-2-2C	10.48	
		Coaly shale	145.34	145.57	0.23	Core	UAK-2-2D	51.85	
	SL	Dirty coal	165.41	165.49	0.08	Core			
	?W	Coal	202.06	202.14	0.08	Core/4pi	+UAK-2-3	<52.60	4pi lithology
		Coaly shale	202.14	202.50	0.36	Core/4pi	+UAK-2-3	>52.60	-do-
		Coal	202.50	202.64	*0.14-	Core/4pi	+UAK-2-3	<52.60	-do-
		Dirty coal	202.64	202.84	*0.20-|	Core/4pi	+UAK-2-3	<52.60	-do-
		Carb shale	202.84	202.89	0.05	Core/4pi	+UAK-2-3	>52.60	-do-
UAK-3	USTR	Coaly ss	114.65	114.75	0.10	Core	---		
	USTR	Coaly ss	120.63	120.80	0.17	Core	---		
	^I	Dirty coal	148.00	148.10	0.10	Core	---		
	^I	Dirty coal	153.55	153.71	*0.16	Core/4pi	---		depth adjusted
	^SU	Coal (loss)	159.87	160.52	*0.65-	E-logs	---		
		(loss)	160.52	160.82	0.30 |	E-logs	---		not coal
		Coal	160.82	161.02	*0.20 |	Core	&+UAK-3-1	<19.12	
		Dirty coal	161.02	161.22	*0.20 |	Core/Elogs	&+UAK-3-1	>19.12	E-log lithology
		Coal	161.22	162.18	*0.96-|	Core	&+UAK-3-1	<19.12	
		Claystone	162.18	162.42	0.24	Core	---		
		Slst (loss)	162.42	163.20	0.78	E-logs			

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAK-3 cont.	SU	Coal	166.63	167.45	0.82-	Core	UAK-3-2A	14.27	
		Dirty coal	167.45	167.70	0.25-	Core	UAK-3-2B	39.24	
	S	Coal	172.90	173.55	*0.65-	Core	&UAK-3-3A	6.43	
		Coal	173.55	174.25	*0.70-	Core	&UAK-3-3B	4.90	
	^SSL	Coaly sh (loss)	184.20	184.45	0.25	E-logs	---		Caved sandy coal?
	?SL	Coal (loss)	189.30	190.00	0.70	E-logs	---		
	^SL	Coal	203.92	204.20	0.28-	Core/elogs	---		
		Coal (loss)	204.20	204.27	0.07	E-logs	---		
		(loss)	204.27	204.47	0.20	E-logs	---		not coal
		D.C. (loss)	204.47	204.77	0.30-	E-logs	---		
	^SL	Coaly sh (loss)	211.80	212.10	0.30	E-logs	---		Caved sandy coal?
	^SL	Dirty coal	213.45	213.56	0.11	Core/Elogs	---		
	^SL	Coaly sh (loss)	216.45	216.90	0.45	E-logs	---		Caved sandy coal?
	W	SS (loss)	218.80	222.00	3.20	E-logs	---		
		Dirty coal	222.00	222.15	0.15	Core/Elogs	---		
	W	Coaly sh (loss)	226.30	226.85	0.55	E-logs	---		Caved clst? Coal?
	W	Coal (loss)	228.90	229.30	*0.40-	E-logs			
		D.C. (loss)	229.30	229.70	*0.40-	E-logs			
UAK-4	SOH	Dirty coal	119.35	119.80	0.45	4pi/GN	---	~32	
	^?USTR	D.C. (loss)	253.05	253.25	0.20	Core/GN			
	^?USTR	Dirty coal	256.50	256.63	0.13	Core/4pi	---		depth adjusted
	?USTR	Coal	265.28	265.98	0.70	Core	UAK-4-1	9.04	
	?USTR	Carb shale	267.92	268.07	0.15	Core	---		
		?Dirty coal	268.07	268.22	0.15	Core	---		4pi carb sh?
		Carb shale	268.22	268.37	0.15	Core	---		
	I	D.C. (loss)	283.15	283.30	*0.15-	4pi	---		
		Dirty coal	283.30	283.50	*0.20-	Core	---		
	SU	Coal	294.20	295.00	*0.80	Core	&UAK-4-2	16.85	
	S	Carb shale	302.10	302.20	0.10	Core	---		
		Coal	302.20	303.00	*0.80	Core	&UAK-4-3	17.89	
		Carb shale	303.00	303.50	0.50	Core	---		
	S	Dirty coal	304.60	304.83	0.23	Core/4pi	---	~29	4pi lithology, NDE
UAK-5	SOH	Dirty coal	102.51	102.89	0.38	Core/4pi	---	~40	
	D1	Coaly shale	212.62	212.67	0.05	Core	---		
		Coal	212.67	212.97	0.30	Core	UAK-5-1	31.68	
	USTR	Dirty coal	252.67	252.85	0.18	Core/4pi	---	~49	4pi lith top 8 cm
	USTR	D.C. (loss)	254.35	254.70	0.35	4pi	---	~40	depth adjusted
	SU	Coal	289.30	289.98	*0.68	Core	&UAK-5-2	20.33	
	S	Dirty coal	296.27	296.51	0.24	Core	UAK-5-6	39.21	
		Ucly	296.51	296.82	0.31	Core	---		
		Coal	296.82	297.84	*1.02	Core	&UAK-5-5	11.94	
		Ucly	297.84	298.14	0.30	Core	---		
		Dirty coal	298.14	298.33	0.19	Core	UAK-5-8	30.89	
	^?SSL	Coal	313.52	313.95	*0.43-	Core	&UAK-5-3	13.11	
		Coal	313.95	314.23	*0.28	Core	&UAK-5-7	14.16	
		Coal	314.23	314.90	*0.67-	Core	&UAK-5-4	19.70	
	W	Dirty coal	349.48	349.75	0.27	Core	---		Sandy
	W	Dirty coal	356.60	356.70	0.10	Core	---	~45	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAK-6	NOT UTILIZED								
UAK-7	NOT UTILIZED								
UAK-8	^DU	Dirty coal	172.50	172.62	0.12	Core	---		depth not adjusted
	^USTR	Coal	207.05	208.00	0.95	Core	UAK-8-1	26.30	-do-
		Coaly shale	208.00	208.55	0.55	Core	UAK-8-2	67.69	-do-
	^?USTR	Dirty coal	216.75	216.95	0.20	Core	---		Sandy, -do-
	^SU	Coal	253.77	253.86	0.09	Core	---		depth not adjusted
		Clst	253.86	253.96	0.10	Core	---		-do-
		Dirty coal	253.96	254.05	0.09	Core	---		-do-
	^S	Dirty coal	267.65	267.79	0.14	Core	---		
		Coal	267.79	267.99	0.20	Core	---		
UAK-9	NOT UTILIZED								
UAK-10	^?USTR	Dirty coal	86.89	87.14	0.25-	Core	UAK-10-6	32.96	
		Coal	87.14	87.43	0.29 |	Core	UAK-10-7	10.45	
		Coal	87.43	87.73	0.30-|	Core	UAK-10-8	6.90	
	?SU	Coaly shale	97.97	98.05	0.08	Core	---	~60	
	?SU	Coal	101.84	102.24	*0.40	Core	#UAK-10-11	22.89	
	?SU	Coal	107.02	107.34	0.32	Core	UAK-10-1	18.33	
	S	Coal	110.95	111.23	*0.28-	Core	&UAK-10-2	6.93	
		Coal	111.23	111.51	*0.28 |	Core	&UAK-10-3	5.12	
		Coal	111.51	111.79	*0.28 |	Core	&UAK-10-4	4.20	
		Coal	111.79	112.07	*0.28-|	Core	&UAK-10-5	20.06	
	SL	Coal	136.06	136.46	0.40	Core	UAK-10-10	8.54	
	^SL	Coaly shale	146.06	146.44	0.38	Core	UAK-10-9	53.06	
	W	Dirty coal	167.90	168.15	*0.25	Core	---	~45	
	W	Dirty coal	169.70	169.94	0.24	Core	---	~45	
UAK-11	^USTR	Coal	100.80	101.00	0.20	4pi/GN	---		Noncore
		Coal	101.00	101.40	0.40	Core	UAK-11-1	13.70	
	USTR	?Dirty coal	108.15	108.35	0.20	Core	---		Coaly sh?, depth adj
	^SU	D.C. (loss)	157.60	158.80	*1.20-	4pi/GN	---	~30	depth adjusted
		loss	158.80	159.05	0.25 |	4pi/GN	---		-do- not coal
		D.C. (loss)	159.05	159.25	*0.20 |	4pi/GN	---	~30	-do-
		Dirty coal	159.25	159.45	*0.20-|	Core	---	~30	-do-
	S	D.C. (loss)	161.70	162.15	*0.45-	4pi/GN	---		depth adjusted
		Dirty coal	162.15	162.50	*0.35-|	Core	&UAK-11-2	28.46	-do-
	^?SL	D.C. (loss)	188.25	188.65	0.40	4pi/GN	---	~45	depth adjusted
	W	D.C. (loss)	214.55	214.80	*0.25	4pi/GN	---		depth adjusted
UAK-12	SOH	Coal	79.20	80.20	1.00	4pi/GN	---		Noncore
	?D	Carb shale	184.55	184.95	0.40	Core			depth not adjusted
	^?USTR	Coaly shale	213.10	213.40	0.30	Core/Elogs	---		-do- D2?
	^?I	Coal	228.50	228.72	0.22	Core	---		-do- USTR?
	^?I	Dirty coal	231.95	232.15	0.20	Core	---		-do- USTR?
	^?SU	Coal	245.10	245.30	0.20	Core	---		-do- S?
		Coaly shale	245.30	245.46	0.16	Core	---		-do-
	^?S	Coal	252.96	253.18	0.22	Core	---		-do- SSL?
	^?SSL	Coal	263.70	263.75	0.05	Core	---		-do- SL?
	?W	Coal	284.80	285.75	0.75	Core	UAK-12-1	19.66	-do- SL?

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAK-13	^?D1	Dirty coal	63.29	63.39	0.10-	4pi	---		Noncore
		Dirty coal	63.39	63.49	0.10-|	Core	---		was 13-1, no analysis
		Coaly shale	63.49	63.64	0.15	Core			
	^?S	Coal	134.65	135.18	*0.53	Core	#UAK-13-1	18.34	renumbered from 13-2
	^?SL	Coal	163.35	163.55	0.20	Core	+UAK-13-2	13.61	renumbered from 13-3
		Coal	163.55	163.83	0.28	Core	+UAK-13-2		-do-
	^W	Dirty coal	192.48	192.75	*0.27	Core	UAK-13-3	29.11	renumbered from 13-4
UAK-14	DU	D.C. (loss)	65.75	66.15	0.40	4pi	---	~30	
	D1	D.C. (loss)	89.77	90.30	0.53	4pi	---		
		Carb shale	90.30	91.00	0.70	Core			
		Dirty coal	91.00	91.35	0.35	Core	UAK-14-3	30.57	
	D2	?D.C. (loss)	98.34	98.54	0.20	4pi	---		
		Carb shale	98.54	98.86	0.32	Core	UAK-14-2	53.37	
		Coal	98.86	99.48	0.62-	Core	UAK-14-1	11.64	
		Coal (loss)	99.48	99.66	0.18-|	4pi	---	~12	
	USTR	Dirty coal	109.05	109.15	0.10	Core	---		
	^?USTR	Coal (loss)	131.34	132.55	1.21	4pi	---	~15	
	^?SU	D.C. (loss)	153.50	153.73	*0.23-	4pi	---	~45	depth adjusted
		Clst (loss)	153.73	153.85	0.12 |	4pi	---		-do-
		D.C. (loss)	153.85	154.13	*0.28-|	4pi	---	~38	-do-
	^?SU	?Coaly shale	155.32	155.45	0.13	Core/4pi	---	~60	4pi lith/dirty coal?
	^?SU	?Coaly shale	157.20	157.27	0.07	Core/GN	---	~60	GN lith/dirty coal?
	^?S	?Coaly shale	160.35	160.48	*0.13	Core/4pi	---	~60	4pi lith/dirty coal?
	^SSL	Coaly shale	171.96	172.09	0.13	Core/4pi	---	~60	-do-
	^SSL	Coaly shale	175.29	175.80	*0.51	Core/4pi	---	~60	
UAK-15	^D2	D.C. (loss)	114.56	114.66	0.10-	4pi	---	~40	depth adj
		Dirty coal	114.66	114.81	0.15-|	Core	---	~40	
	S	Coal (loss)	182.45	183.00	*0.55-	4pi	---	~12	
		Coaly shale	183.00	183.15	0.15 |	Core	---		
		Coal	183.15	183.55	*0.40 |	Core	&UAK-15-1	6.55	
		Clst	183.55	183.75	0.20 |	Core	---		
		Coal	183.75	184.10	*0.35 |	Core	&UAK-15-2	14.08	
		Coal	184.10	184.45	*0.35 |	Core	&UAK-15-3	5.42	
		Coal	184.45	185.00	*0.55 |	Core	&UAK-15-4	17.74	
		Coal	185.00	185.60	*0.60-|	Core	&UAK-15-5	19.12	
		Carb ss	185.60	186.00	0.40	Core	---		
		Dirty coal	186.00	186.10	0.10	Core	---		
	^?S	Dirty coal	190.05	190.20	0.15-	Core	---		SSL?
		Coal	190.20	190.83	0.63 |	Core	UAK-15-6	14.64	-do-
		Dirty coal	190.83	190.95	0.12-|	Core	---		-do-
	?SL	Dirty coal	195.28	195.52	0.24	Core	---	~40	SSL?
	W	Coal	225.94	226.14	*0.20	Core	---		
UAK-16	UD	Dirty coal	140.30	140.60	0.30	Core	---	~30	
	D2	Dirty coal	181.15	181.30	0.15	Core	---	~30	
		Coaly shale	181.30	181.47	0.17	Core	---	~60	
		Dirty coal	181.47	181.55	0.08	Core	---	~30	
	USTR	Dirty coal	195.71	195.90	0.19	Core	---	~30	
	USTR	Coal	199.60	199.90	0.30	Core	UAK-16-1		
	SU	Dirty coal	221.50	221.65	*0.15-	Core	---		Sandy
		Dirty coal	221.65	222.00	*0.35-|	Core	#UAK-16-2	39.29	

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
UAK-16 cont.	S	Dirty coal	229.23	229.40	*0.17-	Core	---		Sandy
		Coal	229.40	229.80	*0.40-|	Core	#UAK-16-3	12.30	
		Carb shale	229.80	230.00	0.20	Core	---		Caved
		Ucly	230.00	230.72	0.72	Core			
	S	Dirty coal	230.72	230.90	0.18	Core			
	S	Coal	233.80	233.95	0.15	Core	---	~20	
	^SSL	Coal	238.20	238.70	*0.50	Core	&UAK-16-4	12.86	
	^SSL	Dirty coal	240.75	241.20	0.45	Core	---	~30	
	^?SSL	?D.C. (loss)	241.95	242.40	0.45	4pi/	---		Cave?:GN; ucly floor
	W	?D.C. (loss)	259.15	259.55	*0.40	4pi/GN	---		Cave?; ucly floor
	?LSTR	D.C. (loss)	309.45	309.70	0.25-	4pi	---	~40	
		Carb shale	309.70	309.85	0.15 |	Core	---		
		Dirty coal	309.85	310.50	0.65-|	Core	UAK-16-5	34.38	
		Carb shale	310.50	310.58	0.08	Core	---		
		Ucly	310.58	316.10	5.52	Core	---		
DH-1	D	Coal	43.48	43.58	0.10	Core			No E-logs
	USTR	Coal	65.76	66.17	0.41	Core			-do-
	USTR	Dirty coal	80.11	80.62	0.51	Core			-do-
	USTR	Dirty coal	84.02	84.81	0.79	Core			-do-
	^USTR	Coal	99.39	99.52	0.13	Core			-do-
	I	Coal	105.46	105.76	0.30	Core			-do-
	I	Coal	107.34	107.54	0.20	Core			-do-
	I	Coal	107.77	108.20	*0.43	Core			-do-
	S	Coal	118.34	119.66	*1.32	Core			-do-
	W	Coal	144.32	144.42	0.10	Core			-do-
	W	Coal	144.88	145.08	*0.20	Core			-do-
	^LSTR	Coal	197.89	197.94	0.05	Core			-do-
	^LSTR	Coal	200.03	200.11	0.08	Core			-do-
	LSTR/JRK	Coal	207.24	207.65	0.41	Core			-do-
	LSTR/JRK	Coal	210.79	210.94	0.15	Core			-do-
DH-2	DU	Coal	45.80	46.16	0.36	Core			-do-
	^S	Coal	175.72	176.63	*0.91	Core			-do-
	^S	Coal	185.29	185.37	0.08	Core			-do-
	^W	Coal	214.91	215.11	*0.20	Core			-do-
DH-3	D2	Coal	67.92	68.02	0.10	Core			-do-
	USTR	Coal	109.55	109.60	0.05	Core			-do-
	^I	Coal	134.19	134.37	*0.18	Core			-do-
	^S	Coal	172.39	173.30	*0.91	Core			-do-
	^SSL	Coal	177.34	177.39	*0.05	Core			-do-
DH-4	D	Dirty coal	46.20	46.61	0.41	Core			-do-
	I	Coal	108.64	108.67	*0.03	Core			-do-
	SU	Coal	120.88	121.18	*0.30	Core			-do-
	S	Coal	124.26	124.69	*0.43	Core			-do-
	^?SL	Coal	149.02	149.07	0.05	Core			-do-
DH-5	D	Coal	63.73	63.78	0.05	Core			-do-
	USTR	Coal	97.61	97.87	0.25	Core			-do-
	S	Coal	146.00	146.10	*0.10	Core			-do-

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
DH-6	^SU	Coal	133.17	133.38	*0.20	Core			-do-
	^SU	Coal	136.42	136.45	0.03	Core			-do-
	^S	Coal	139.12	139.48	*0.36	Core			-do-
	^SSL	Coal	148.46	148.62	*0.15	Core			-do-
	^W	Coal	173.38	173.63	*0.25	Core			-do-
	^W	Dirty coal	173.63	173.66	0.03	Core			-do-
	^LSTR	Coal	213.03	213.08	0.05	Core			-do-
DH-7	D2	Coal	74.78	74.93	0.15	Core			-do-
	USTR	Coal	106.32	106.52	0.20	Core			-do-
	^USTR	Coal	112.22	112.25	0.03	Core			-do-
	^USTR	Coal	118.57	118.67	0.10	Core			-do-
	^I	Coal	131.83	132.24	*0.41	Core			-do-
	^I	Coal	137.49	137.80	0.30	Core			-do-
	^S	Coal	153.34	154.25	*0.91	Core			-do-
DH-8	^D1	Coal	54.18	54.23	0.05	Core			-do-
	^D2	Coal	61.62	61.85	0.23	Core			-do-
	^D2	Dirty coal	61.85	61.93	0.08	Core			-do-
	USTR	Coal	82.12	82.58	0.46	Core			-do-
	^?USTR	Coal	96.39	96.92	0.53	Core			-do-
	^W	Coal	178.79	178.82	*0.03	Core			-do-
DH-9	USTR	Coal	66.19	66.27	0.08	Core			-do-
	USTR	Coal	66.42	66.68	0.25	Core			-do-
DH-10	USTR	Coal	96.49	96.62	0.13	Core			-do-
	^I	Coal	139.62	140.23	*0.61	Core			-do-
	^I	Coal	145.14	145.44	0.30	Core			-do-
	^I	Coal	146.56	146.69	0.13	Core			-do-
	^SU	Coal	173.69	173.84	*0.15	Core			-do-
	^S	Coal	175.67	176.58	*0.91	Core			-do-
	^S	Coal	176.94	177.24	0.30	Core			-do-
DH-11	D2	Coal	84.58	84.78	0.20	Core			-do-
	USTR	Coal	106.98	107.16	0.18	Core			-do-
	^S	Coal	146.43	146.91	*0.48	Core			-do-
DH-12	^USTR	Coal	139.73	140.06	0.33	Core			-do-
	^I	Dirty coal	154.58	154.71	*0.13-	Core			-do-
		SS	154.71	154.81	0.10	Core			-do-
		Dirty coal	154.81	154.94	*0.13-	Core			-do-
	S	Dirty coal	167.46	167.79	*0.33	Core			-do-
	S	Coal	168.53	168.58	0.05	Core			-do-
	SL	Coal	179.04	179.07	0.03	Core			-do-
	W	Dirty coal	206.88	207.62	*0.74	Core			-do-
DH-13	USTR	Coal	111.84	111.97	0.13	Core			-do-
	USTR	Coal	123.62	123.77	0.15	Core			-do-
	USTR	Coal	125.48	125.23	0.05	Core			-do-
	I	Coal	143.05	143.10	*0.05	Core			-do-
	SONDA U	Coal	159.03	159.16	*0.13	Core			-do-
	S	Dirty coal	161.72	162.08	*0.36	Core			-do-
	LSTR	Dirty coal	220.12	220.35	0.23	Core			-do-

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
DH-14	USTR	Dirty coal	67.41	67.64	0.23-	Core			-do-
		Coaly shale	67.64	67.69	0.05	Core			-do-
		Dirty coal	67.69	67.87	0.18	Core			-do-
		Coaly shale	67.87	67.92	0.05	Core			-do-
		Dirty coal	67.92	68.28	0.36-	Core			-do-
	^I	Coal	114.83	114.88	0.05	Core			-do-
	^I	Coal	115.34	115.52	*0.18	Core			-do-
	^SU	Coal	136.80	137.00	*0.20	Core			-do-
	^S	Coal	140.49	140.59	0.10	Core			-do-
	^S	Coal	140.79	140.84	0.05	Core			-do-
	^S	Coal	141.05	141.46	*0.41	Core			-do-
DH-15	USTR	Coal	87.83	87.93	0.10	Core			-do-
	USTR	Dirty coal	92.51	92.97	0.46	Core			-do-
	I	Dirty coal	115.01	115.72	0.71	Core			-do-
	I	Dirty coal	117.35	118.14	*0.79	Core			-do-
	^?I?SU	Coal	132.18	132.28	0.10	Core			-do-
	S	Dirty coal	148.16	148.77	*0.61	Core			-do-
DH-16	I	Coal	130.10	130.33	*0.23	Core			-do-
	^S	Coal	171.73	172.03	0.30	Core			-do-
	^S	Coal	172.47	172.83	*0.36	Core			-do-
	^SSL	Coal	180.95	181.36	*0.41	Core			-do-
	?W	Coal	187.38	187.46	*0.08	Core			-do-
DH-17	D2	Coal	53.52	53.62	0.10	Core			-do-
DH-18	SOH	Coal	41.15	41.30	0.15	Core			-do-
	D1	Coal	186.84	187.14	0.30	Core			-do-
	I	Coal	225.86	226.21	*0.36	Core			-do-
	?S	Coal	240.79	242.67	*1.88	Core			-do-
	?W	Coal	281.89	281.99	0.10	Core			-do-
	?W	Coal	283.01	283.16	*0.15	Core			-do-
	LSTR	Coal	315.95	316.08	0.13	Core			-do-
	LSTR	Coal	319.13	319.28	0.15	Core			-do-
	JRK	Coal	356.67	357.38	0.71	Core			-do-
	JRK	Coal	359.87	360.63	0.76	Core			-do-
	JRK	Coal	364.24	364.34	0.10	Core			-do-
DH-19	^USTR	Coal	131.67	132.13	0.46	Core			-do-
	^USTR	Coal	146.53	146.96	0.43	Core			-do-
	^I	?Sandy coal	159.35	159.72	*0.37	Core			-do-
	^SU	Dirty coal	184.40	185.17	*0.76	Core			-do-
	^S	Coal	188.47	188.77	*0.30	Core			-do-
	^S	Coal	191.24	191.29	0.05	Core			-do-
	^W	Coal	229.06	229.11	*0.05	Core			-do-
	^?JRK/LSTR	Coal	258.62	259.53	0.91	Core			-do-
	^?JRK/LSTR	Coal	261.14	261.90	0.76	Core			-do-
	^?JRK/LSTR	Coal	274.88	274.93	0.05	Core			-do-

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
DH-20	D1	Coal	64.52	65.07	0.56	Core			
	USTR	Dirty coal	108.71	109.02	0.30	4pi			Core depth/4pi lith
	I	Coal	118.85	119.46	*0.61	Core			
	SU	Coal	124.66	125.57	0.91	Core			
	SU	Coal	131.75	133.12	*1.37	Core			
	S	Coal	139.17	141.61	*2.44	Core			
	S	Dirty coal	144.02	144.20	0.18	Core			
	S	Coal	145.57	146.13	0.56	Core			
	S	Dirty coal	148.18	148.49	0.30	Core			
	W	Dirty coal	191.90	192.20	*0.30	Core			
DH-21	DU	D.C. (loss)	52.81	53.42	0.61	4pi			depth adjusted
	D1	Dirty coal	62.87	63.30	0.43	Core			
	D2	Dirty coal	70.78	70.74	0.46	Core			
	S	Coal	148.67	150.50	*1.83	Core			
	W	D.C. (loss?)	196.65	196.93	*0.28-	4pi			4pi lithology
		Dirty coal	196.93	197.08	*0.15-	Core/4pi			4pi lithology
	^LSTR/JRK	Dirty coal	221.13	221.43	0.30	Core/4pi			4pi lithology
		Clst (loss)	221.43	221.65	0.32	4pi/GN			Not coal
	^LSTR/JRK	Dirty coal	229.36	229.82	0.46	Core/4pi			4pi lithology
	^LSTR/JRK	Dirty coal	230.91	231.32	0.41	Core/4pi			-do-
DH-22	D1	Dirty coal	87.35	87.78	0.43	Core/4pi			4pi lithology
	I	Dirty coal	152.70	153.16	*0.46	Core/4pi			4pi lithology
	S	Coal	179.53	181.05	*1.52	Core	DH-22-1-85	18.33	
	S	Dirty coal	182.14	182.32	0.18	Core			Revised 4pi lith
	S	Coal	184.58	185.34	0.76	Core	DH-22-2-85	20.47	USGS analysis
	^SSL	Dirty coal	190.65	190.80	*0.15	Core			Revised 4pi lith
	SL	Dirty coal	199.77	198.87	0.10	Core/4pi			4pi lithology
	SL	Dirty coal	203.86	204.14	0.28	Core/4pi			4pi lithology
		Coaly shale	204.14	204.65	0.51	Core/4pi			-do-
	SL	Dirty coal	204.65	204.85	0.20	Core/4pi			-do-
	^LSTR/JRK	Dirty coal	248.59	248.74	0.15	Core			
	^LSTR/JRK	Coal	257.12	257.42	0.30	Core			
DH-23	SOH	Dirty coal	11.89	12.19	0.30	Core			
	I	Coal	197.82	198.12	*0.30	Core			
	S	Coal	220.52	221.89	*1.37	Core	DH-23-1-85	10.70	USGS analysis
		loss	221.89	222.65	0.76	Core			"carb sh/coal"
DH-24	USTR	Coal	133.40	133.86	0.46	Core			
	S	Coal	176.78	177.57	*0.79	Core	DH-24-1-86	10.27	USGS analysis
	S	Coal	178.79	178.99	0.20	Core			
DH-25	D1	Coal	62.97	63.02	0.05	Core			
	S	Coal	145.08	145.49	*0.41	Core			
	?W	Coal	173.61	173.66	0.05	Core			
DH-26	?USTR	Coal	108.10	108.41	0.30	Core			
	?SU	Coal	122.83	122.96	*0.13	Core			
	?S	Coal	131.60	131.90	*0.30	Core			

Drill hole	Subzone	Description	From (m)	To (m)	Thickness (m)	Info source	Sample number	% ash	Remarks
DH-27	USTR	?Coal	90.37	90.53	0.16	Core			Carb sh?: E-logs
	USTR	Carb shale	108.66	108.97	0.31	Core			
	I	Carb shale	120.85	120.90	0.05	Core			
	SU	Coal (loss)	129.20	130.40	*1.20	4pi			depth adjusted
	SU	?Dirty coal	134.55	135.05	0.50	4pi			"Claystone", depth adj
	SU	Carb shale	137.46	137.62	0.16	Core			
		Dirty coal	137.62	137.92	0.30-	Core			
		Dirty coal	137.92	137.97	0.65-	4pi			"Claystone", depth adj
	S	Coaly shale	142.34	137.62	0.41	Core			
		Coal	142.75	143.51	*0.76	Core			
		Carb shale	143.51	143.87	0.36	Core			NDE full S/SSL

Appendix 3. - Coal resources of the main bed of the Sonda coal zone, by overburden, thickness, and reliability categories. Tonneage and area generally shown to greater than true precision in order to avoid rounding errors when adding small numbers (see text p. 59-61, and Wood and others, 1983, p. 36). True precision is estimated to be: a) thickness: 2 - 3 significant figures, b) area: 4 significant figures, c) tonnage: 2 - 3 significant figures.

Overburden 125 -150 m

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.30 - 0.50	25.00	133000	5.38	28000					30.38	161000
0.50 - 0.75	6.45	43000	31.18	243000					37.63	286000
0.75 - 1.00			13.70	142000	76.61	893000			90.31	1035000
1.00 - 1.50			189.12	3409000	483.06	7886000			672.18	11295000
1.50 - 2.00	96.04	2144000	451.00	9966000	57.24	1321000			604.28	13431000
2.00 - 2.50	40.32	1232000	166.13	4775000	133.10	3978000			339.51	9985000
2.50 - 3.00	8.06	267000	137.09	4901000	212.90	7750000			358.05	12918000
3.00 - 3.50	9.10	396000	103.89	4434000	164.11	6827000			277.10	11657000
3.50 - 4.00	26.96	1337000	89.92	4346000	43.95	2114000			160.83	7797000
4.00 - 4.50	5.05	265000	105.24	5741000	54.43	3021000			164.72	9027000
4.50 - 5.00			4.00	237000	20.97	1257000			24.97	1494000
Subtotal	216.98	5817000	1296.65	38222000	1246.33	35047000			2759.96	79086000

Overburden 150 -200 m

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.30 - 0.50	130.94	705000	398.58	2114000	199.92	1071000			729.44	3890000
0.50 - 0.75	76.74	603000	692.23	5769000	517.40	4087000			1286.37	10459000
0.75 - 1.00	52.59	556000	649.94	7265000	722.87	7826000	178.23	2085000	1603.63	17732000
1.00 - 1.50	106.89	1746000	1202.15	20062000	1424.24	22179000	31.05	424000	2764.33	44411000
1.50 - 2.00	108.75	2438000	861.21	19159000	828.24	18529000			1798.20	40126000
2.00 - 2.50	96.65	2784000	599.20	17531000	1053.54	30650000			1749.39	50965000
2.50 - 3.00	70.14	2554000	549.92	19907000	624.47	21792000			1244.53	44253000
3.00 - 3.50	86.18	3658000	532.65	22160000	233.24	9707000			852.07	35525000
3.50 - 4.00	92.61	4555000	385.14	18674000	34.01	1640000			511.76	24869000
4.00 - 4.50	58.07	3146000	250.84	13879000	33.47	1845000			342.38	18870000
4.50 - 5.00			182.66	11265000	117.84	7428000			300.50	18693000
5.00 - 5.50	1.64	115000	318.14	21837000	32.26	2147000			352.04	24099000
5.50 - 6.00	44.35	3356000	70.97	5231000					115.32	8587000
6.00 - 6.50	4.30	337000							4.30	337000
Subtotal	929.85	26553000	6693.63	184853000	5821.50	128901000	209.28	2509000	13654.26	342816000

cont.

Appendix 3 cont.

Overburden 200 - 250 m

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.30 - 0.50	13.00	71000	172.99	902000	783.00	4073000			968.99	5046000
0.50 - 0.75	20.00	179000	349.19	2865000	699.12	5713000			1068.31	8757000
0.75 - 1.00	77.06	874000	351.57	3971000	2303.75	25638000	1432.26	14896000	4164.64	45379000
1.00 - 1.50	103.57	1685000	1109.11	18466000	3012.70	47897000			4225.38	68048000
1.50 - 2.00	152.38	3285000	1021.63	22274000	1560.22	33911000			2734.23	59470000
2.00 - 2.50	36.69	1025000	330.24	9599000	975.27	28174000			1342.20	38798000
2.50 - 3.00	14.50	537000	342.75	12402000	243.98	8483000			601.23	21422000
3.00 - 3.50	10.65	443000	104.52	4197000					115.17	4640000
Subtotal	427.85	8099000	3782.00	74676000	9578.04	153889000	1432.26	14896000	15220.15	251560000

Overburden 250 - 300 m

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.30 - 0.50			51.62	240000	673.65	3826000			725.27	4066000
0.50 - 0.75			2.61	20000	3474.58	30525000	281.45	2561000	3758.64	33106000
0.75 - 1.00	34.60	403000	399.02	4583000	6687.56	75373000	265.18	26686000	938.36	107045000
1.00 - 1.50	32.26	461000	448.74	7295000	2580.69	40164000	10.65	141000	3072.34	48061000
1.50 - 2.00	50.00	1128000	230.91	4988000	899.45	19333000			1180.36	25449000
Subtotal	116.86	1992000	1132.90	17126000	14315.93	169221000	2557.28	29388000	18122.97	217727000

Overburden > 300 m

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.30 - 0.50					148.79	812000			148.79	812000
0.50 - 0.75					291.53	2539000			291.53	2539000
0.75 - 1.00			39.25	485000	261.29	2767000	164.11	1813000	464.65	5065000
1.00 - 1.50	20.32	296000	158.06	2466000	625.80	9948000			804.18	12710000
1.50 - 2.00					275.27	5726000			275.27	5726000
Subtotal	20.32	296000	197.31	2951000	1602.68	21792000	164.11	1813000	1984.42	26852000
Total	1711.86	42757000	13102.49	31782800	32564.48	508850000	4362.93	48606000	51741.76	918041000

Not included in resource estimates

	Measured		Indicated		Inferred		Hypothetical		Subtotal	
Thickness (m)	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes	Area (ha)	Tonnes
0.0 - 0.30	74.95	-----	410.21	------	429.70	------			914.86	------
Total area	1786.81		13512.70		32994.18		4362.93		52656.62	

Appendix 4.

Conversion Factors

Metric		English
1 meter (m) = 100 centimeter (cm)	=	39.37 inches
1 kilometer (km) = 1000 meters (m)	=	0.621 miles
1 hectare (ha) = 0.01 sq. km.	=	2.471 acres = 0.003861 sq miles
1 hectare meter (ha-m)	=	8.107 acre feet
1 tonne = 1000 kg	=	1.1023 short tons = 2205 pounds
1 kilocalorie (kcal)	=	3.968 british thermal units (BTU)

Statistical Equations

$$\text{mean} = \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{weighted mean} = WM = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

where n = the number of samples and w = a weighting factor (e.g. bed thickness)

$$\text{population standard deviation} = \sigma = \left[\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}\right]^{\frac{1}{2}}$$

for normal distributions:

$x-\sigma <$ ~68% of the population $< x+\sigma$

$x-2\sigma <$ ~95% of the population $< x+2\sigma$

$$\text{geometric mean} = GM = e^a \quad \text{where } a = \sum_{i=1}^{n} \ln(x_i)$$

$$\text{geometric deviation} = GD = e^b \text{ where } b = \left[\frac{\sum_{i=1}^{n} (\ln(x_i) - a)^2}{n}\right]^{\frac{1}{2}}$$

for lognormal distributions:

$GM/GD <$ ~68% of the population $< GM \cdot GD$

$GM/(GD)^2 <$ ~95% of the population $< GM \cdot (GD)^2$

Appendix 5. Statistical summary of coal quality, selected low-rank U.S. coals (from Landis, Khan, and others, 1988a).

a) Statistical summary of subbituminous C coal samples from northeast Wyoming, USA, excluding zero and qualified values.

STATISTICS FOR FOLLOWING STANDARD COAL ANALYSIS ITEMS ON "AS RECEIVED" BASIS 1/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
MOISTUR	200	26.34	8.13	0.755	41.80	41.04	24.33	1.61
VOLMAT	200	29.88	4.77	0.897	39.70	38.80	29.05	1.37
FIXEDC	200	32.09	6.22	0.635	47.70	47.06	30.97	1.43
BMASH	200	9.41	6.23	0.172	41.00	40.83	7.86	1.88
HYDROGN	151	6.02	1.00	1.293	7.02	5.73	5.89	1.28
CARBON	151	44.81	8.32	9.506	64.40	54.89	43.78	1.27
NITROGN	151	0.91	0.30	0.133	1.75	1.62	0.86	1.46
OXYGEN	151	35.18	8.75	7.338	52.80	45.46	33.71	1.38
SULFUR	190	0.90	0.90	0.060	6.50	6.44	0.67	2.10
SULFATE	179	0.06	0.13	0.001	1.34	1.34	0.03	3.14
SULFPYR	191	0.35	0.53	0.010	4.50	4.49	0.16	3.70
SULFORG	194	0.52	0.35	0.010	2.36	2.35	0.43	1.98
BTU	197	7671.98	1462.74	187.279	11194.00	11006.72	7413.09	1.41
ASHDEF	126	2172.53	154.44	1524.137	2910.00	1385.86	2167.06	1.07
ASHSOF	126	2246.30	154.27	1550.344	2910.00	1359.66	2240.93	1.07
ASHFLD	126	2310.26	162.39	1576.551	2910.00	1333.45	2304.38	1.07
ADLOSS	149	19.07	7.97	0.500	33.00	32.50	15.08	2.52

1/ Items 1-12 and 17 in percent; heat value in Btu/lb, to convert to K cal/kg multiply by 0.556, and items 14-16 in degrees Fahrenheit.

STATISTICS FOR FOLLOWING DATA ITEMS ON ASH BASIS 2/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
USGSASH	249	11.81	6.74	3.360	44.30	40.94	10.46	1.60
SIO2	236	29.95	12.64	4.800	67.00	62.20	27.26	1.57
AL2O3	252	14.67	4.31	3.270	30.00	26.73	13.99	1.38
CAO	252	15.72	7.49	0.340	36.12	35.78	13.12	2.05
MGO	253	3.72	2.03	0.420	12.30	11.88	3.17	1.82
NA2O	237	1.21	1.06	0.040	6.59	6.55	0.77	2.93
K2O	248	0.70	0.53	0.040	2.91	2.87	0.54	2.09
FE2O3	252	9.08	6.68	1.387	48.00	46.61	7.50	1.81
TIO2	171	0.78	0.26	0.200	1.67	1.47	0.73	1.46
P2O5	195	0.97	1.50	0.030	20.00	19.97	0.63	2.66
SO3	206	15.83	7.45	0.300	37.99	37.69	13.47	1.97

2/ Samples ashed at 525°C. Ash and oxide analyses in percent. MgO and Na_2O determined from Atomic absorption, remainder from X-ray fluorescence.

(Continued)

Appendix 5a continued (northeast Wyoming):

STATISTICS FOR FOLLOWING DATA ITEMS ON WHOLE-COAL BASIS 3/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
AG	19	0.08	0.12	0.012	0.49	0.48	0.04	2.77
AS	251	6.02	8.30	0.330	60.00	59.67	3.54	2.67
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR AU								
B	249	49.74	22.87	4.610	138.60	133.99	43.95	1.71
BA	249	319.80	222.55	21.600	2221.67	2200.07	263.33	1.92
BE	216	0.72	0.71	0.108	4.81	4.70	0.53	2.11
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR BI								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR BR								
CD	159	0.24	0.23	0.018	1.31	1.29	0.17	2.35
CE	55	24.27	16.28	6.023	83.43	77.40	19.81	1.89
CL	27	150.68	182.40	100.000	1065.31	965.31	121.82	1.62
CO	244	2.87	3.36	0.493	33.00	32.51	2.10	2.02
CR	248	8.59	8.78	0.730	62.22	61.49	6.18	2.18
CS	6	0.61	0.37	0.124	1.22	1.10	0.48	2.18
CU	248	13.08	8.81	2.100	83.20	81.10	11.03	1.78
DY	8	2.57	0.94	1.405	3.97	2.56	2.40	1.45
ER	6	1.43	0.33	0.818	1.74	0.92	1.39	1.30
EU	19	0.29	0.17	0.098	0.86	0.76	0.25	1.61
F	237	87.57	91.55	20.000	678.92	658.92	66.44	1.96
GA	244	3.37	2.52	0.636	15.82	15.18	2.77	1.82
GD	4	3.23	1.44	1.567	5.12	3.55	2.89	1.62
GE	66	2.74	2.65	0.254	11.75	11.49	1.71	2.78
HF	6	0.54	0.16	0.385	0.87	0.49	0.52	1.30
HG	254	0.11	0.11	0.010	1.09	1.08	0.09	1.91
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR HO								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IN								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IR								
LA	150	10.77	7.96	2.352	56.22	53.87	9.05	1.74
LI	244	5.25	4.90	0.343	25.51	25.17	3.60	2.43
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR LU								
MN	237	68.15	66.73	1.485	468.00	466.51	41.55	2.92
MO	233	2.45	3.70	0.276	41.00	40.72	1.61	2.24
NB	83	3.54	2.78	0.747	13.29	12.54	2.71	2.05
ND	62	15.36	7.85	2.936	42.12	39.19	13.21	1.81
NI	249	7.86	8.07	0.739	64.54	63.80	5.66	2.16
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR OS								
PB	193	6.57	6.99	0.840	55.37	54.53	4.69	2.16
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PD								
PR	6	7.45	1.15	6.067	9.35	3.28	7.37	1.16
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PT								
RB	3	27.49	23.21	7.000	59.94	52.94	18.68	2.43
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RE								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RH								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RU								
SB	243	0.53	0.45	0.096	2.60	2.50	0.40	2.00
SC	243	2.22	1.53	0.493	11.24	10.75	1.87	1.75
SE	247	1.31	1.03	0.142	12.57	12.43	1.09	1.82
SM	9	0.90	0.35	0.423	1.64	1.22	0.83	1.46
SN	26	1.93	2.64	0.226	12.42	12.19	1.13	2.60
SR	249	192.35	131.68	14.800	889.00	874.20	149.51	2.14
TA	6	0.02	0.01	0.005	0.03	0.03	0.01	1.80
TB	6	0.14	0.04	0.072	0.22	0.14	0.13	1.38
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TE								
TH	35	3.75	3.06	0.890	13.60	12.71	2.69	2.28
TL	2	1.20	0.48	0.715	1.68	0.97	1.10	1.53
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TM								
U	35	2.79	2.26	0.450	9.34	8.89	1.94	2.44
V	249	19.98	17.84	2.250	150.53	148.28	15.59	1.96
W	6	0.06	0.03	0.026	0.12	0.09	0.05	1.62
Y	249	6.89	6.32	0.986	37.90	36.92	5.16	2.05
YB	229	0.62	0.55	0.092	4.17	4.08	0.48	1.97
ZN	249	20.74	18.97	1.163	129.03	127.87	14.74	2.34
ZR	249	18.87	16.92	1.500	132.90	131.40	14.41	2.06

3/ Elemental analyses in parts per million (ppm).

Appendix 5 continued:

b) Statistical summary of lignite samples from North Dakota, USA, excluding zero and qualified values.

STATISTICS FOR FOLLOWING STANDARD COAL ANALYSIS ITEMS ON "AS RECEIVED" BASIS 1/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
MOISTUR	222	38.38	5.61	23.100	57.20	34.10	37.95	1.17
VOLMAT	222	25.95	2.84	17.900	40.00	22.10	25.80	1.11
FIXEDC	222	26.89	4.26	7.800	36.80	29.00	26.50	1.20
BMASH	222	8.78	4.46	3.500	30.70	27.20	7.97	1.52
HYDROGN	213	6.80	0.49	5.000	7.70	2.70	6.78	1.08
CARBON	213	37.44	4.35	18.800	49.10	30.30	37.17	1.13
NITROGN	213	0.60	0.13	0.200	1.00	0.80	0.59	1.24
OXYGEN	213	45.46	4.34	31.300	59.80	28.50	45.24	1.10
SULFUR	222	0.99	0.67	0.100	4.90	4.80	0.81	1.88
SULFATE	183	0.09	0.16	0.010	1.34	1.33	0.04	3.36
SULFPYR	212	0.40	0.56	0.010	4.13	4.12	0.19	3.51
SULFORG	213	0.52	0.31	0.020	1.79	1.77	0.44	1.84
BTU	222	6210.11	842.94	2625.000	8270.00	5645.00	6144.83	1.16
ASHDEF	180	2116.97	143.85	1810.000	2620.00	810.00	2112.17	1.07
ASHSOF	180	2201.06	148.65	1880.000	2745.00	865.00	2196.10	1.07
ASHFLD	179	2268.32	143.29	1940.000	2655.00	715.00	2263.81	1.07
ADLOSS	192	28.53	7.00	3.300	49.90	46.60	27.42	1.37

1/ Items 1-12 and 17 in percent; heat value in Btu/lb, to convert to K cal/kg multiply by 0.556, and items 14-16 in degrees Fahrenheit.

STATISTICS FOR FOLLOWING DATA ITEMS ON ASH BASIS 2/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
USGSASH	256	12.14	5.72	3.900	38.10	34.20	11.15	1.48
SIO2	251.	23.46	14.00	1.050	73.00	71.95	19.42	1.92
AL2O3	252	9.64	3.40	2.460	22.87	20.41	9.06	1.43
CAO	251	16.83	6.67	3.500	38.15	34.65	15.41	1.56
MGO	256	5.76	2.18	1.410	11.51	10.10	5.31	1.53
NA2O	256	4.56	3.80	0.190	16.70	16.51	2.98	2.74
K2O	216	0.56	0.50	0.050	2.30	2.25	0.41	2.20
FE2O3	252	8.57	6.11	0.120	49.58	49.46	6.74	2.11
TIO2	205	0.65	0.53	0.090	6.40	6.31	0.56	1.63
P2O5	116	0.33	0.33	0.040	1.57	1.53	0.21	2.62
SO3	194	22.06	8.32	0.940	45.00	44.06	20.18	1.60

2/ Samples ashed at 525°C. Ash and oxide analyses in percent. MgO and Na_2O determined from Atomic absorption, remainder from X-ray fluorescence.

(Continued)

Appendix 5 b continued (North Dakota):

STATISTICS FOR FOLLOWING DATA ITEMS ON WHOLE-COAL BASIS 3/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
AG	14	0.20	0.19	0.004	0.64	0.64	0.11	3.87
AS	235	7.81	7.27	1.000	63.00	62.00	5.63	2.25
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR AU								
B	256	132.96	77.96	9.360	595.00	585.64	115.29	1.72
BA	255	595.50	703.32	12.800	6100.00	6087.20	401.24	2.53
BE	151	0.93	1.37	0.084	13.72	13.64	0.59	2.38
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR BI								
BR	3	0.21	0.07	0.126	0.29	0.17	0.20	1.41
CD	34	0.28	0.47	0.012	2.65	2.64	0.14	3.10
CE	18	17.16	18.89	4.092	83.70	79.61	12.01	2.14
CL	37	173.78	64.57	100.000	350.00	250.00	162.03	1.46
CO	222	2.59	6.33	0.054	68.25	68.20	1.34	2.50
CR	252	6.32	9.38	0.251	64.00	63.75	3.70	2.55
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR CS								
CU	256	6.92	6.53	1.280	77.56	76.28	5.60	1.81
DY	6	7.42	9.38	0.858	27.90	27.04	3.87	3.01
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR ER								
EU	4	0.14	0.08	0.040	0.26	0.22	0.11	1.96
F	170	45.19	38.42	15.000	230.00	215.00	36.51	1.80
GA	240	3.08	2.70	0.380	16.05	15.67	2.33	2.05
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR GD								
GE	43	3.50	3.09	0.125	13.37	13.24	2.20	2.95
HF	4	1.45	1.42	0.600	3.91	3.31	1.00	2.21
HG	255	0.14	0.13	0.010	1.23	1.22	0.11	2.13
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR HO								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IN								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IR								
LA	67	7.54	6.55	1.700	41.85	40.15	6.12	1.78
LI	250	3.95	3.78	0.335	33.48	33.14	2.89	2.24
LU	HAS INSUFFICENT VARIANCE TO CALCULATE STATISTICS							
MN	256	85.12	84.58	7.280	668.16	660.88	61.24	2.26
MO	238	3.56	18.16	0.266	279.00	278.73	1.72	2.32
NB	84	3.02	2.04	0.507	10.65	10.14	2.47	1.90
ND	3	46.17	30.41	9.210	83.70	74.49	32.76	2.54
NI	252	3.85	7.71	0.553	83.70	83.15	2.33	2.25
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR OS								
PB	205	4.24	3.17	0.350	29.04	28.69	3.49	1.87
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PD								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PR								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PT								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RB								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RE								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RH								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RU								
SB	247	0.56	0.69	0.070	7.30	7.23	0.39	2.21
SC	218	2.07	1.86	0.340	13.95	13.61	1.59	2.00
SE	239	0.82	0.48	0.154	3.35	3.20	0.71	1.66
SM	3	0.67	0.19	0.400	0.80	0.40	0.63	1.39
SN	4	0.64	0.09	0.493	0.71	0.22	0.63	1.16
SR	255	356.42	187.41	41.850	1337.00	1295.15	309.78	1.74
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TA								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TB								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TE								
TH	157	2.39	2.02	0.280	12.24	11.96	1.77	2.17
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TL								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TM								
U	230	1.58	1.81	0.200	13.00	12.80	1.14	2.08
V	256	11.19	14.40	1.095	108.50	107.40	7.10	2.47
W	3	0.05	0.02	0.025	0.07	0.05	0.04	1.55
Y	238	6.40	7.16	1.100	83.70	82.60	4.71	2.07
YB	205	0.63	0.77	0.100	8.37	8.27	0.44	2.14
ZN	235	11.00	17.77	0.536	170.40	169.86	5.70	2.92
ZR	255	21.98	22.32	1.920	158.00	156.08	15.40	2.26

3/ Elemental analyses in parts per million (ppm).

c) Statistical summary of lignite samples from the Gulf Coast of Texas, USA, excluding zero and qualified values.

STATISTICS FOR FOLLOWING DATA ITEMS ON "AS RECEIVED" BASIS 1/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
MOISTUR	84	27.26	8.68	3.230	49.30	46.07	25.50	1.50
VOLMAT	84	30.86	4.80	18.000	46.94	28.94	30.49	1.17
FIXEDC	84	27.85	5.33	12.900	37.22	24.32	27.26	1.24
BMASH	84	13.96	7.71	5.090	45.33	40.24	12.41	1.59
HYDROGN	84	6.17	0.70	3.440	7.80	4.36	6.13	1.13
CARBON	84	42.64	7.19	24.100	65.97	41.87	42.00	1.19
NITROGN	84	0.77	0.17	0.400	1.14	0.74	0.75	1.27
OXYGEN	84	35.38	7.08	12.070	50.50	38.43	34.51	1.27
SULFUR	80	1.05	0.59	0.400	3.41	3.01	0.93	1.63
SULFATE	73	0.04	0.03	0.010	0.19	0.18	0.03	2.26
SULFPYR	77	0.27	0.40	0.010	2.73	2.72	0.13	3.60
SULFORG	77	0.82	0.45	0.290	2.76	2.47	0.72	1.59
BTU	84	7362.92	1263.48	4274.000	12282.00	8008.00	7251.96	1.19
ASHDEF	82	2171.23	140.57	1930.000	2705.00	775.00	2166.84	1.07
ASHSOF	82	2245.68	148.24	1980.000	2800.00	820.00	2240.94	1.07
ASHFLD	81	2329.72	154.45	2030.000	2660.00	630.00	2324.61	1.07
ADLOSS	55	15.89	5.94	1.290	35.46	34.17	14.40	1.69

1/ Items 1-12 and 17 in percent; heat value in Btu/lb, to convert to K cal/kg multiply by 0.556, and items 14-16 in degrees Fahrenheit.

STATISTICS FOR FOLLOWING DATA ITEMS ON ASH BASIS 2/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
USGSASH	111	18.59	9.21	6.200	44.30	38.10	16.61	1.60
SIO2	110	40.28	12.29	15.000	64.03	49.03	38.27	1.39
AL2O3	111	15.33	5.32	3.700	30.68	26.98	14.33	1.47
CAO	111	12.04	5.82	1.052	27.51	26.45	10.44	1.79
MGO	111	2.12	1.25	0.216	8.29	8.07	1.74	1.97
NA2O	106	0.70	0.96	0.067	5.66	5.59	0.48	2.19
K2O	111	0.57	0.38	0.102	1.93	1.83	0.45	2.01
FE2O3	111	6.71	4.57	0.890	24.00	23.11	5.33	2.01
TIO2	111	1.08	0.41	0.385	2.59	2.21	1.02	1.43
P2O5	39	0.08	0.05	0.018	0.26	0.24	0.07	1.80
SO3	109	14.41	5.79	2.190	29.31	27.12	13.09	1.60

2/ Samples ashed at 525°C. Ash and oxide analyses in percent. MgO and Na_2O determined from Atomic absorption, remainder from X-ray fluorescence.

(Continued)

Appendix 5c continued (Gulf coast of Texas):

STATISTICS FOR FOLLOWING DATA ITEMS ON WHOLE-COAL BASIS 3/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
AG	49	0.15	0.28	0.009	2.02	2.02	0.10	2.41
AS	111	4.12	3.05	0.340	18.40	18.06	3.34	1.89
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR AU								
B	111	129.13	69.15	29.100	333.00	303.90	112.02	1.72
BA	111	152.55	106.38	13.020	512.40	499.38	121.93	1.98
BE	107	2.35	2.41	0.306	18.12	17.82	1.74	2.07
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR BI								
BR	37	0.72	0.64	0.177	2.92	2.74	0.53	2.13
CD	66	0.19	0.16	0.019	0.84	0.82	0.14	2.38
CE	51	28.30	26.89	5.300	134.54	129.24	20.18	2.23
CL	42	217.14	199.17	100.000	870.00	770.00	167.37	1.91
CO	110	3.39	2.71	1.010	18.60	17.59	2.77	1.80
CR	110	12.75	7.36	3.300	43.80	40.50	10.95	1.74
CS	35	0.54	0.69	0.053	3.70	3.65	0.32	2.66
CU	111	19.64	10.26	3.450	50.22	46.77	17.07	1.73
DY	6	6.71	3.04	2.144	11.28	9.14	5.88	1.74
ER	2	3.86	1.42	2.436	5.28	2.84	3.59	1.47
EU	45	0.42	0.23	0.117	1.22	1.10	0.37	1.67
F	96	111.56	91.36	19.999	650.00	630.00	81.80	2.27
GA	110	7.00	3.65	1.965	17.28	15.31	6.11	1.70
GD	7	4.93	2.02	3.082	9.28	6.20	4.60	1.43
GE	79	5.15	4.82	0.574	24.92	24.35	3.67	2.27
HF	42	1.49	1.48	0.200	8.90	8.70	1.06	2.24
HG	110	0.19	0.14	0.010	0.61	0.60	0.14	2.62
HO	3	2.12	0.79	1.053	2.94	1.88	1.94	1.56
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IN								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IR								
LA	59	16.06	13.21	3.000	73.78	70.78	12.02	2.15
LI	111	11.29	8.86	0.744	48.64	47.90	8.35	2.25
LU	42	0.21	0.18	0.048	0.98	0.93	0.17	1.92
MN	111	133.03	91.73	17.980	475.80	457.82	104.06	2.10
MO	82	3.09	1.99	0.130	9.05	8.92	2.33	2.44
NB	81	8.98	8.64	0.459	38.19	37.73	5.86	2.64
ND	30	24.39	13.19	3.488	49.56	46.07	19.86	2.06
NI	111	9.32	9.66	1.310	92.82	91.51	7.14	2.03
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR OS								
PB	83	6.79	3.51	1.740	16.20	14.46	5.94	1.69
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PD								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PR								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR PT								
RB	6	17.45	16.22	6.000	52.00	46.00	12.60	2.11
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RE								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RH								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR RU								
SB	105	0.81	0.44	0.180	2.60	2.42	0.70	1.70
SC	111	4.62	2.50	1.010	12.32	11.31	4.01	1.72
SE	110	6.28	3.03	2.300	16.00	13.70	5.60	1.62
SM	42	1.87	1.07	0.589	5.29	4.70	1.59	1.79
SN	37	12.63	24.59	0.337	144.00	143.66	5.94	3.22
SR	111	247.88	230.00	20.400	1149.20	1128.80	176.27	2.23
TA	42	0.09	0.12	0.001	0.57	0.57	0.04	3.90
TB	41	0.31	0.19	0.010	0.76	0.75	0.25	2.20
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TE								
TH	103	4.66	3.47	0.500	23.70	23.20	3.58	2.14
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TL								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TM								
U	110	2.23	1.22	0.430	6.95	6.52	1.92	1.78
V	111	35.29	22.31	3.534	98.70	95.17	28.68	1.98
W	41	0.27	0.32	0.033	1.76	1.73	0.18	2.46
Y	109	16.49	19.32	3.930	164.92	160.99	12.54	1.89
YB	111	1.40	1.16	0.261	8.25	7.98	1.14	1.81
ZN	111	17.87	26.07	1.743	201.45	199.71	10.54	2.61
ZR	111	80.64	117.06	6.450	743.40	736.95	44.34	2.77

3/ Elemental analyses in parts per million (ppm).