DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

COAL RESOURCES OF THE LAKHRA AND SONDA COAL FIELDS, SOUTHERN SIND PROVINCE, PAKISTAN

A PROGRESS REPORT

Part I - Executive Summary

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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ABSTRACT

An estimated 4,780 million tonnes of original coal resources were present in the Lakhra and Sonda coal fields of this report: 1,080 million tonnes in Lakhra and 3,700 million tonnes in Sonda. The area of this estimate is 143,237 hectares: 46,569 in Lakhra and 96,668 in Sonda.

The total estimated original coal resources by reliability category and in millions of tonnes, are: Lakhra - measured and indicated 540, inferred 510, hypothetical 30; Sonda - measured and indicated 500, inferred 2,520, hypothetical 680. All coal beds 0.3 m thick or greater and having less than 50 percent ash (dry basis) were included as "qualifying coals" in the resource estimate, otherwise the criteria used for this assessment were taken from Wood and others (1983). Additional estimates were made for coal beds 0.75 m thick or greater. About 470 million tonnes, or nearly 45 percent, of the original coal resources in Lakhra and 2,120 million tonnes, or nearly 60 percent, of the resources in Sonda are in beds 0.75 m thick or greater.

Accurate estimates of remaining coal resources in the Lakhra field are difficult to make because information on past production is unreliable; however, probably at least 95 percent of Lakhra's original coal resources remain. All of the estimated resources for the Sonda coal field remain because exploitation has not begun there.

Coal resources were estimated for 7 of the 9 identified coal zones in Lakhra and 6 of the 7 zones in Sonda, but the bulk of the resources occur in only a few zones in each field. In Lakhra, the No. 1, No. 2, and No. 2A zones originally contained an estimated 660 million tonnes of coal resources within the study area; coal bed thicknesses in these zones range from a thin film to about 5 m, including partings, and depths to the top of the No. 2A zone range from 20 to 275 m. In Sonda, the Sonda zone contains an estimated 2,060 million tonnes of coal with almost 90 percent of these resources in the northern half of the Sonda field; coal bed thicknesses in this zone range from about 6.3 m to the vanishing point and the depth to the top of the zone ranges from 115 to 300 m.

It is inferred that the Lakhra and Sonda coal fields, and perhaps even discrete coal zones, or beds, are continuous with one another, but confirmation of this requires additional drilling in the southern part of the Lakhra area.

The calculated rank of the coal in both fields ranges from lignite A to subbituminous C. Average values, in percent, for some quality parameters for 219 samples, on the as-received basis, are: moisture 28.4, ash 18.3, sulfur 4.7, fixed carbon 25.2, volatile matter 27.9, and oxygen 33.1. Average heat value is about 3,710 Kcal/kg. Some quality parameters exhibit noticeable differences between the two coal fields. For example, average percentages for ash and sulfur, on the as-received basis, are 19.1 and 5.5, respectively, for Lakhra coals versus 15.7 and 2.6, respectively, for Sonda coals; heat value for Lakhra samples is about 3,660 Kcal/kg where as that for Sonda samples is about 3,870 Kcal/kg.

Closer coordination of all parties engaged in coal-resource assessment work is recommended and a synthesis of existing information, supplemented by

new field work, should be done before the next large-scale drilling program is started in Sind.

This assessment was conducted jointly by the Geological Survey of Pakistan and the U.S. Geological Survey under the auspices of the Government of Pakistan and the U.S. Agency for International Development.

INTRODUCTION

Beginning in August 1985, the Geological Survey of Pakistan (GSP) and the United States Geological Survey (USGS) have been conducting a joint coal-resource assessment of southern Sind Province, Pakistan. These activities have been characterized as the Sind Coal Resource Exploration and Assessment Program and will be referred to hereinafter as Sind COALREAP, or COALREAP. Sind COALREAP has been carried out under the auspices of the Government of Pakistan (GOP) and the United States Agency for International Development (USAID).

This Executive Summary is a summary of progress in Sind COALREAP activities in the Lakhra and Sonda coal fields of Sind Province (fig. 1): the area of this report, hereinafter called the study area, is shown in figure 2. Detailed discussions of the geology, coal resources, and coal quality of the study area are provided in Parts II through VI of the complete report (see Appendix 1 for the outline): 1:50,000 scale base maps and derivative maps of the study area are included in Part V of the report. This report is produced in partial fulfillment of Project 391-0478; Energy Planning and Development Project, Coal Resource Assessment Component 2a of USAID, and item 2 of the Participating Agency Service Agreement (PASA) No. 1PK-0478-P-1C-5068-00, between USAID and USGS. The reasons why this report is in partial fulfillment of the PASA are discussed in detail both below and in Part II. All of the information available as of May 1987 on the geology and coal resources of the study area has been included explicitly in this assessment. Some post-May 1987 information developed by Sind COALREAP activities near the town of Jherruck (fig. 2) and in the Indus East area (fig. 1) has been included implicitly in this assessment as edge control to the study area.

This report on the coal resources of the Lakhra and Sonda coal fields has been prepared in 6 parts (Appendix I) in order to incorporate the large volume of basic information that has accumulated on coal occurrence and coal quality in the study area. The complete report may be inspected at the offices of the Geological Survey of Pakistan in Quetta and Karachi, Pakistan; USAID, Islamabad, Pakistan; and the Library of the USGS, Reston, VA.

The following syntheses of the results of drilling and other activities in the study area--coal resources, coal isopach maps, structure maps, coal overburden maps, lithologic columnar sections, detailed coal-zone and coal-bed sections, correlation diagrams, structure sections, statistical summaries of coal-quality attributes, and coal sample cataloging-- that appear in Parts II through VI were generated by, or with the aid of, the National Coal Resources Data System (NCRDS) at the USGS National Center in Reston, Virginia.

Substantial coal resources have been discovered as a result of COALREAP in the study area; however, as of the date of this report, COALREAP work has not been completed for a large part of the area as originally planned (fig. 2, study area proposed in 1985). Dacoit (bandit) interference in November 1986, in the Lakhra area, forced a halt to all COALREAP drilling and related activities in both the northernmost and southern parts of the Lakhra area (fig. 2, areas of vertical lines only). Subsequent COALREAP activities in the Sonda coal field (fig. 2) were conducted with accompanying guards provided by GSP; nevertheless, it was still considered unsafe to return to the Lakhra area to complete drilling there during the remainder of the COALREAP activities that were completed as of May 1987.

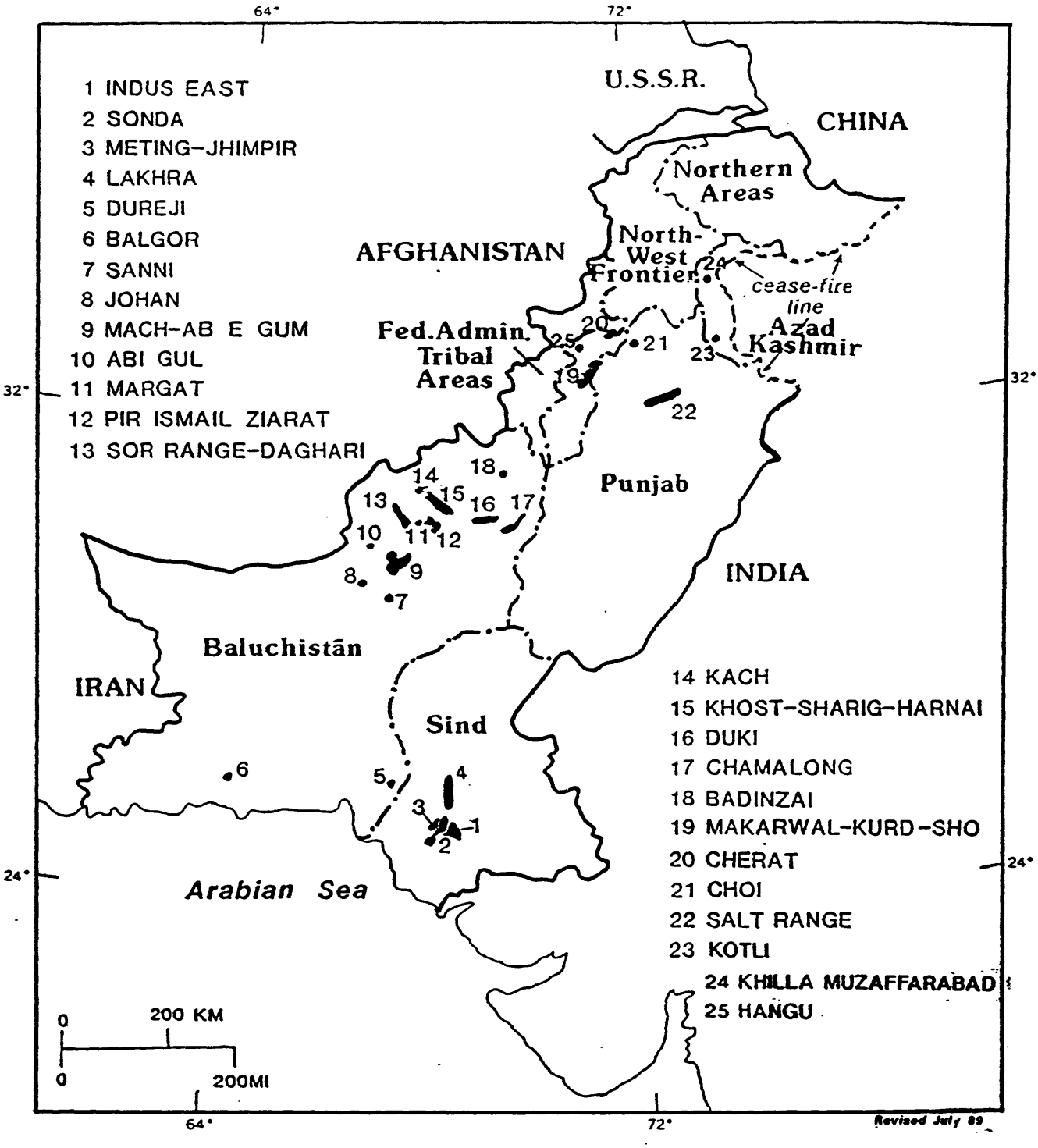

Figure 1. Location of Pakistan coalfields and occurrences.

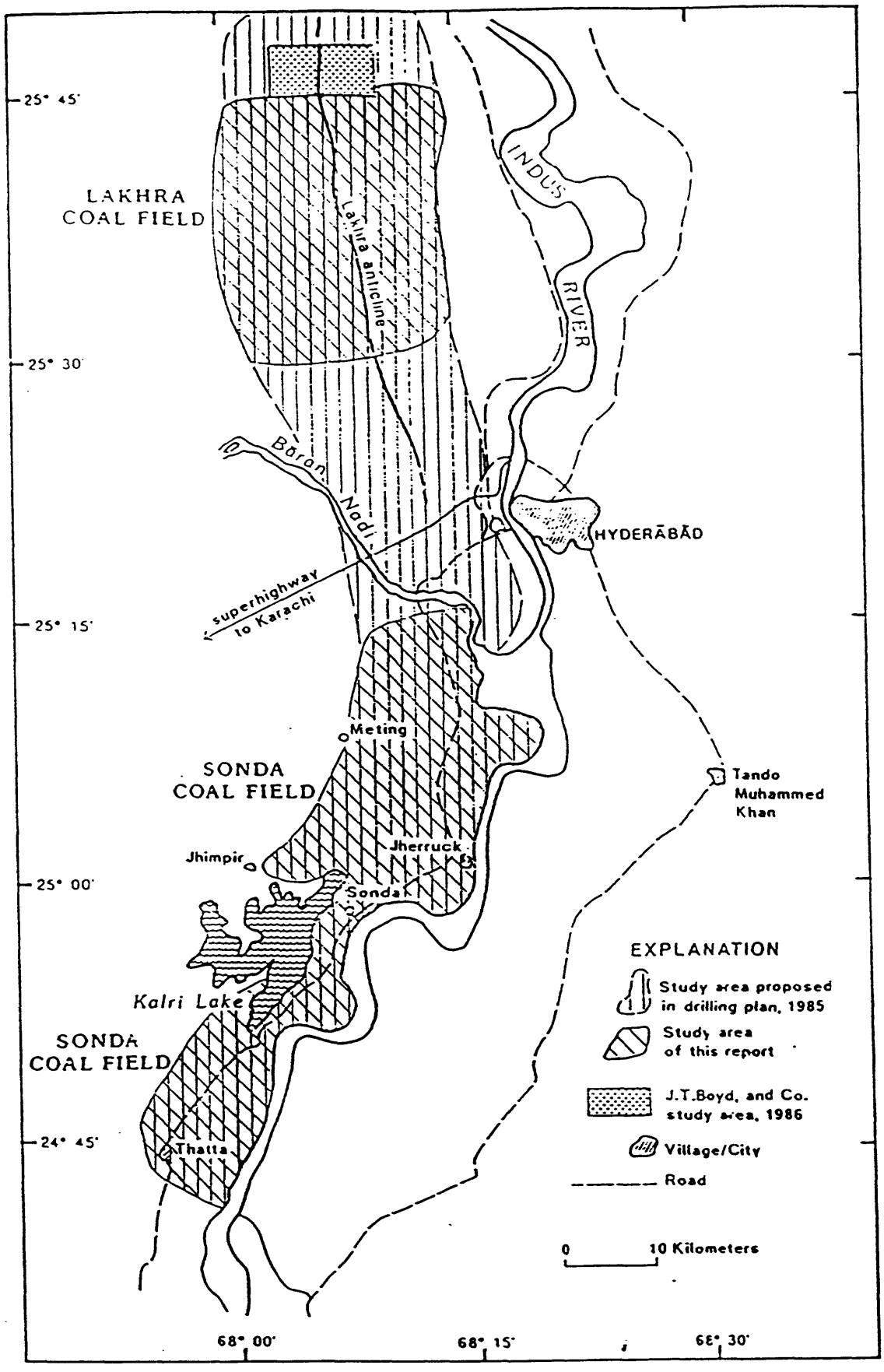

Figure 2. Map showing study area covered in this report compared to area proposed for study in drilling plan.

Enough new information has been obtained about the coal resources of the study area, however, to provide a significant contribution to a better understanding of the occurrence, quantity, and quality of the coal resources. This report also enables us to make recommendations for additional COALREAP work that will be required for a better understanding of the distribution and quality of the coal resources of Sind Province.

This report supersedes the report by Thomas and others (1988) which provided preliminary results of COALREAP drilling in the study area.

BACKGROUND AND SCOPE OF WORK

Coal has been known in the Lakhra area (fig. 2) since 1855 when Baluch tribesmen discovered coal at a shallow depth in Lailian Khuh (between UAL-6 and UAL-9, fig. 3) while digging for water. Exploitation of Lakhra coal did not begin until 1959, however, when a small mine was opened near Lailian Khuh. Since then, numerous small mines have been opened in the Lakhra field, but production had only risen to about 300,000 tonnes per year as of 1986 (Ahmed and others, 1986): most of the coal is sold in Sind and Punjab to fire brick-kilns.

Based on information presented by Ahmed and others (1986), the rank of coal in the Lakhra field ranges from lignite A to subbituminous C; combined reserves and resources in the Lakhra field were estimated to be about 300 million tonnes.

In contrast to the Lakhra coal field, coal in the Sonda field was not discovered by accident. In 1981, GSP discovered coal in the central Sonda area by the application of sound geologic principles (Ahmed and others, 1984a). As of 1986, the GSP had drilled 25 holes in this area (fig. 4). For details of the 25 holes see Ahmed and others, 1984a, and Parts II and VI of this report. Exploitation of Sonda coal has not begun; the shallowest coal beds of at least 1 m in thickness, discovered by the GSP, were reported by Ahmed and others (1986) to lie at depths in excess of 80 m. Many coal beds in the Lakhra and Meting-Jhimpir fields are more accessible.

Estimated rank of Sonda coal is lignite A to subbituminous C, as reported by GSP (Ahmed and others, 1986). Estimated resources within the area explored by the GSP (fig. 4) were reported to be in excess of 280 million tonnes.

The relatively small Meting-Jhimpir coal field (fig. 1) lies along the western edge of the study area, approximately between the towns of Meting and Jhimpir (fig. 2). The coal in this field occurs in beds that are stratigraphically much higher and geologically younger than those discussed in this report. The coal is of moderately good quality and is in thin, discontinuous beds. Although exploited from small mines, coal beds are not considered to be extensive enough to warrant a large assessment effort at this time. Thus, this coal field is not discussed further in this part (Part I) of the report.

In August 1985, USAID, as part of its long range "Energy Planning and Development Project" in Pakistan, contracted with the USGS to aid the GSP in a large, multidisciplinary program to assess Pakistan's coal resources. The first two years of this program were to be spent, in part, assessing the Lakhra and Sonda coal fields and the area between, to determine if those areas

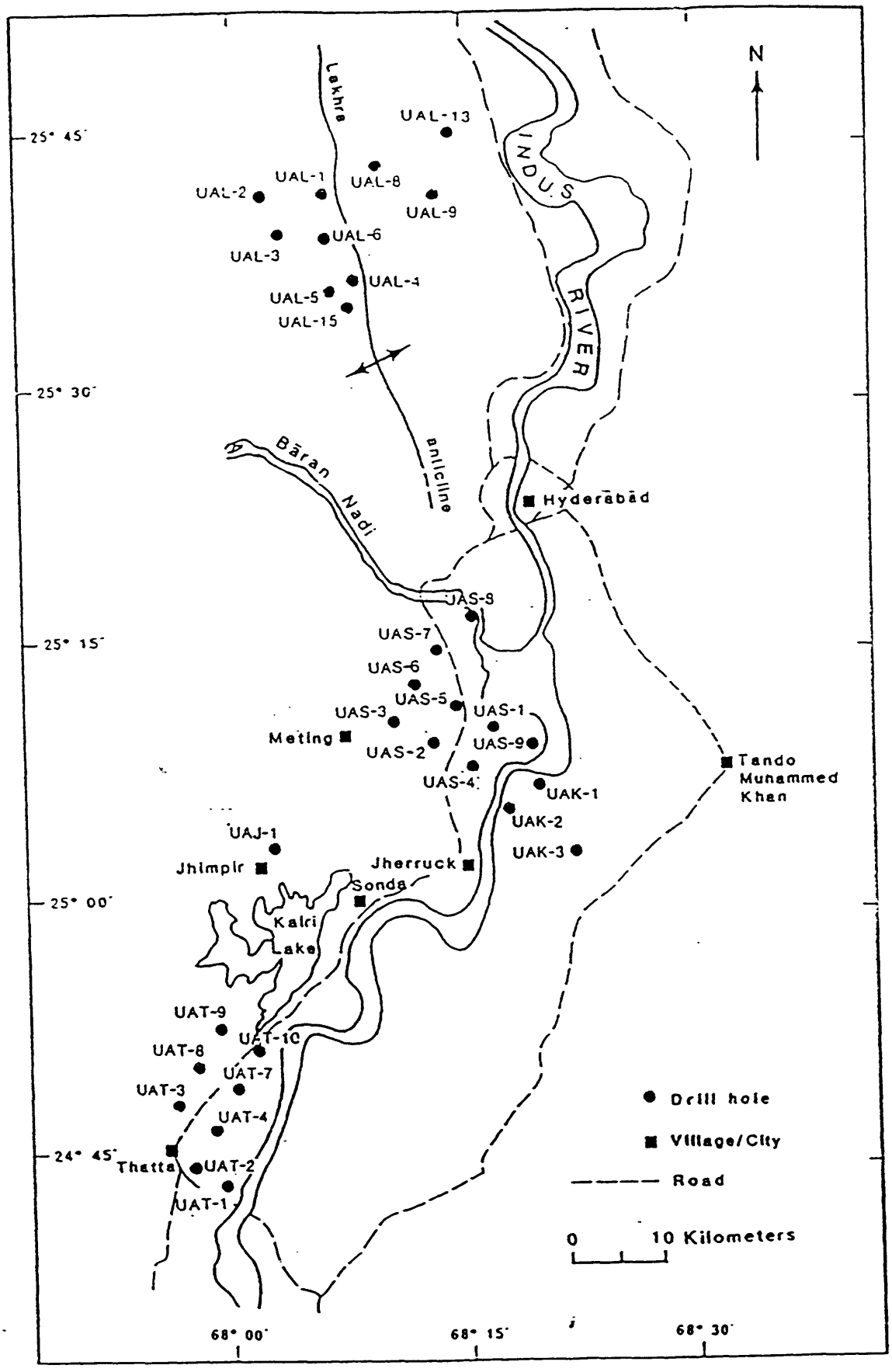

Figure 3. General location of holes drilled by IVCC between April 1986 and May 1987.

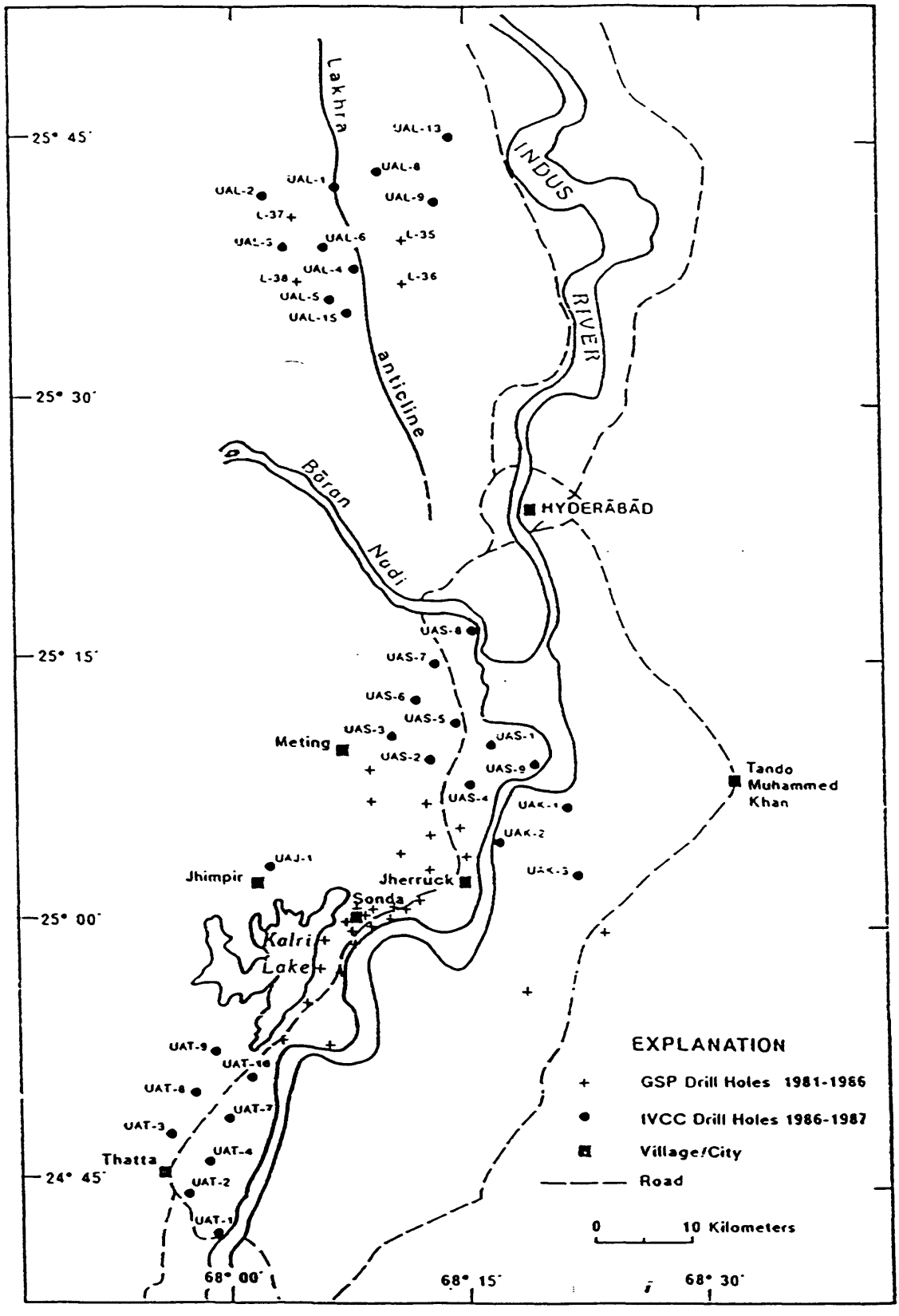

Figure 4. Generalized location of Geological Survey of Pakistan (GSP) drill holes (unnumbered) and COALREAP (IVCC, GSP) drill holes (numbered) in or near the study area, 1981 through May, 1987.

indeed contained the abundance of coal resources suggested by the earlier work of GSP (Ghani and others, 1973; Ahmed and others, 1984a and b; GSP and USGS, 1988) and other agencies (Memon and others 1976; JICA, 1981; and Boyd, 1985).

The scope of work covered by this report includes: 1) a joint assessment by GSP and USGS of the Lakhra and Sonda coal fields, using methodology specified in USGS Circular 891 (Wood and others, 1983), as modified for Pakistan; 2) an evaluation of coal quality, including coal sampling from existing mines in the Lakhra coal field; and 3) monitoring and oversight by USGS of separate USAID-issued, private-sector contracts for drilling and geophysical logging. The area to be assessed excluded the area identified as the J.T. Boyd study area on figure 2.

USAID prepared to issue a drilling contract in the last half of 1985; the contract was finally issued to Indus Valley Construction Company, Ltd. (IVCC) of Lahore, Pakistan, in March 1986. A contract for geophysical logging of drill holes and training for GSP personnel in geophysical logging techniques had previously been negotiated directly between USAID and Geoscience Associates of Boulder, Colorado. GSP and USGS prepared a drilling plan for the private-sector drilling in the fall of 1985 (Schweinfurth and others, 1985) and USGS assisted USAID in preparing the drilling contract during that same period of time.

Drilling commenced in the northern part of the Lakhra area in April 1986, and continued under this contract until May 1987, when a total of 31 holes had been drilled (Thomas and others, 1988); one additional hole, UAL-7, was abandoned at a depth of 15 m and did not provide any useful information. The locations of these 31 holes are shown in figure 3: 27 holes in the study area (UAL 1-6, 8, 9, 13, 15; UAS 1-9; UAT 1-4, 7-10); one hole west of the study area near Jhimpir (UAJ-1); and 3 holes east of the Indus River (UAK 1-3). After May 1987, USAID extended the IVCC contract to permit the drilling of 13 more holes in the Indus East area between the towns of Jherruck, Tando Muhammed Khan, and Hyderabad (fig. 3) (Landis and others, 1988). The Indus East area is being evaluated by a separate report in preparation, but the results of drilling by IVCC and the analyses of coals of the UAJ-1 and UAK1-3 holes are also summarized in Part II of this report and the raw data are presented in Part III.

Drilling in the study area was interrupted twice between April 1986 and April 1987. Drilling was suspended during the summer of 1986 to avoid the extreme heat of Sind and in November 1986, dacoits, as previously mentioned, caused an interruption for almost 3 weeks. The dacoit activity also caused four holes in Lakhra (UAL-9, 13, and 15, (fig. 3) and UAL-7, not shown) to be abandoned before they could be completed to total depths and geophysically logged, and prevented GSP from surveying any of the locations of the holes that were drilled in Lakhra.

Locations of the holes shown in figure 3 were recommended by USGS and GSP (Schweinfurth and others, 1985) and were based on: 1) the area to be investigated, 2) maximum hole depths of about 400 m, 3) drilling already done by GSP (fig. 4), and 4) 10,000 m of drilling (about 50 percent each of rotary and coring) planned by USAID for its private-sector drilling contract. Basic data from holes drilled by GSP in the study area between 1981 and 1986 (fig. 4) are provided in Part VI. The resulting combined area investigated by these

2 drilling programs consists of about 46,569 hectares in the Lakhra area and 96,668 hectares in the Sonda area for a grand total of about 143,237 hectares (detailed maps at scales of 1:50,000 and 1:100,000 are provided in Part V).

The original drilling plan required about 16 more holes to be drilled in the southern Lakhra area, but that plan had to be abandoned because of the dacoit activity. The funds for those 16 holes went into: 1) deeper drilling of a few holes within the study area, 2) one hole (UAJ-1) drilled near Jhimpir to test for shallow coal beds in the Meting-Jhimpir coal field, and 3) three holes (UAK-1,2,3) drilled east of the Indus River to begin exploration of that area because drilling near Jherruck (fig. 4) indicated that exploration for coal resources should be extended to that area.

Three IVCC drilling rigs were usually in operation during the drilling program and this required the constant attention of GSP and USGS project personnel. GSP personnel, working out of tent camps at each drill site, described drilling samples and cores, collected coal samples, and prepared field reports; GSP supervisory personnel worked out of Hyderabad. USGS personnel, working out of Hyderabad, provided training for GSP personnel, guidelines and oversight for describing cuttings and core and collecting coal samples, and monitoring of the IVCC and Geosciences Associates contracts.

A program of sampling in coal mines was carried out by GSP and USGS personnel during the summer and fall of 1985. The results of this coal sampling program are summarized in Part II of this report and the details are included in Part IV. GSP also investigated coal mines in the Lakhra coal field between 1985 and 1986. The results of these investigations have been integrated into this report and the details of that work are provided in Parts II through VI of the report.

Demands of the drilling program and security problems in the Lakhra area prevented USGS personnel and their GSP counterparts from conducting the field work necessary to complete a comprehensive reconnaissance coal-resource assessment for the study area. Travel to the northwest of the study area, where the coal-bearing rocks are reportedly exposed, was specifically prohibited by USAID. Nevertheless, some time was spent by USGS personnel analyzing aerial photographs of the region to develop a basis for conducting field work and for examining specific problem areas in the field whenever travel to those areas should again become possible. Completion of field work is extremely important if a satisfactory assessment of the coal resources of the study area, as well as those of the rest of southern and western Sind Province, is to be made.

COAL RESOURCES

Coal geology

The coal deposits of the study area (fig. 2) were lain down during the Paleocene epoch along the western edge of the Indo-Pakistani subcontinent while it was drifting northward to its present position attached to the Eurasian continent. These coal deposits are in the Bara Formation (figs. 5-7) where they occur in discrete zones of one or more coal beds. The Bara Formation underlies all of the study area and probably also underlies the unexplored area between the Lakhra and Sonda coal fields (figs. 2 and 7). The Bara Formation was not completely penetrated by any of the Sind COALREAP drill

holes. The relationship of the Bara Formation with superjacent rock units is shown in the representative columnar sections of figures 5 and 6, and in figure 7 which is a generalized geologic map of a part of Sind Province that includes the study area. (A more detailed discussion of the geology is provided in Part II, Chapter 2.)

At least nine coal zones were penetrated in the Bara Formation in the Lakhra field and seven in the Sonda coal field (figs. 5 and 6). These coal-bearing zones attain thicknesses of as much as 35 m and appear to be lenticular; typical zone and bed thicknesses are about 10 m and 0.75 m, respectively. The deeper coal zones usually were penetrated only by holes drilled on structurally high areas (figs. 4 and 7). Individual coal beds, which tend to be less persistent than the zones they occupy, may reach a thickness of as much as 6.3 m. A few coal zones and beds are relatively persistent and they contain the bulk of the original coal resources in the study area.

The No. 2 coal zone (fig. 5) of the Lakhra coal field covers an area of about 9,000 hectares in the study area where qualifying coal (coal in beds 30 cm thick or greater with less than 50 percent ash) is 1 m or thicker and is as thick as 3.8 m. In some places, the apparent thickening of the No. 2 coal zone may be actually the result of the No. 2 coal zone merging with the No. 1 zone. In the Sonda coal field the thicker coal zones and beds tend to occurto the north of Sonda village (fig. 2) in the northern part of the field. Qualifying coal in the Sonda zone (fig. 6) is thicker than 1 m over an area of about 50,000 hectares, and is as thick as 7.1 m.

The coal zones and beds in the Bara Formation are intercalated in places with beds containing marine fossils, and the Bara Formation is overlain by the partly marine Lakhra Formation (figs. 5, 6, and 7). At some places, marine fossils occupy borings in the tops of coal beds in both coal fields and, presumably, these borings were made by marine organisms during the late peat or early lignite stages of the beds. Other strata intercalated with the coal zones consist of thin beds of dense gray clay, beds of gray shale of varying thickness, and thin to very thick beds of relatively clean, very friable sandstone, much like the sand of a modern beach or off-shore bar. These sand beds make up the bulk of the Bara Formation in the study area. This sandstone is very difficult to drill because of its caving tendences and is nearly impossible to recover as core; coring operations are slowed to as little as a few meters per 24 hours in such beds.

The presence of marine beds intercalated with coal zones, marine fossils in borings in the tops of coal beds, the marginal marine aspect of sandstone beds, and the mostly marine nature of the Lakhra Formation, which overlies the Bara Formation lead to the inference that the coal beds in the Bara Formation were deposited in a broad, low-lying, wet, paralic environment, along the western edge of the Indo-Pakistani subcontinent that was subjected to relatively rapid, widespread, fluctuations in sea level. The implications of this interpretation are that individual coal zones or beds will tend to be elongated parallel to paleo- shorelines and may be diagonally stacked landward from the shoreline. Conversely, if terrestrial processes were more predominant, the coal beds would be diagonally stacked toward the sea. Furthermore, this scenario suggests that coal deposits like those in the study area may have been deposited along much of the western side of the

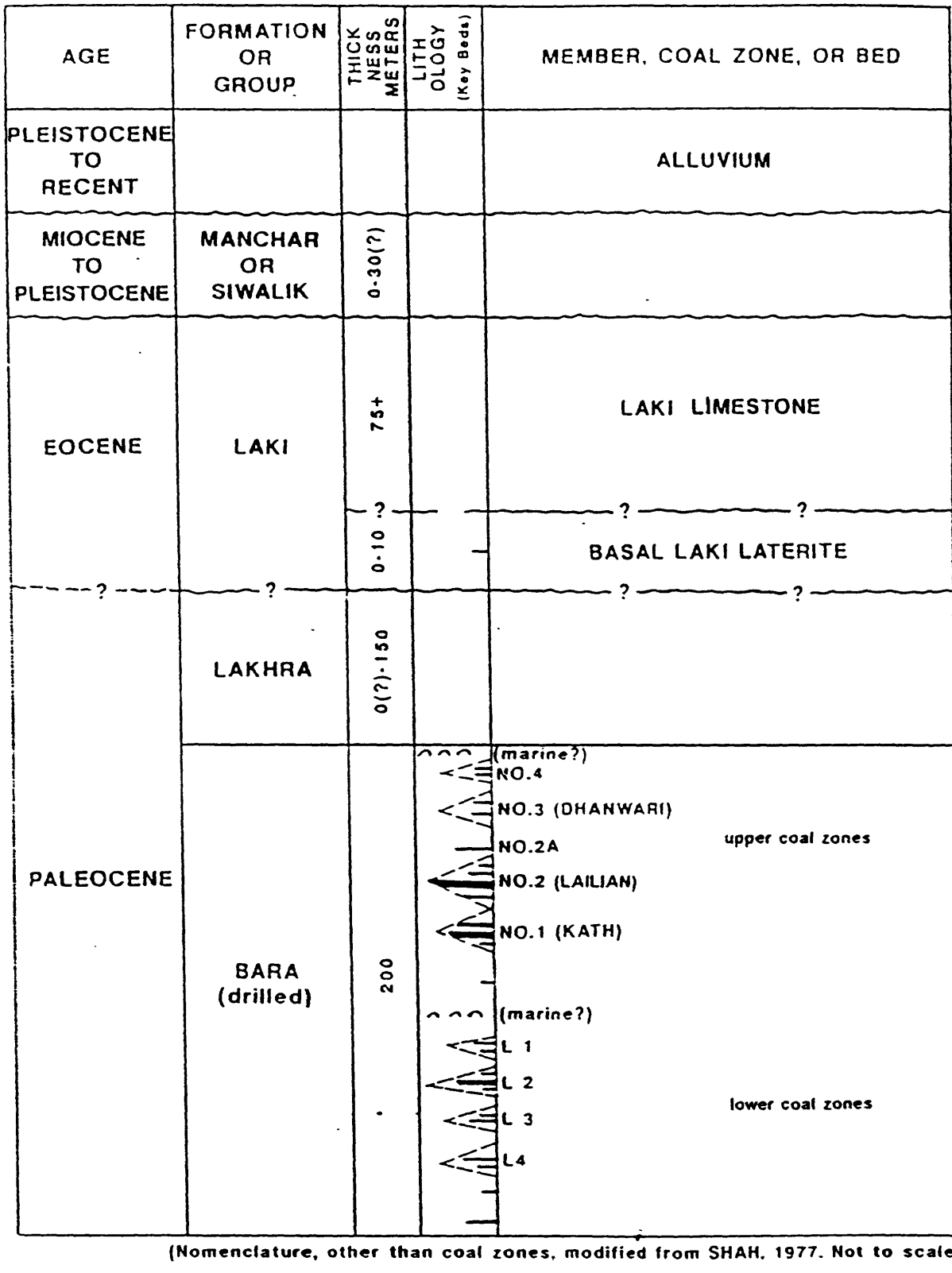

Figure 5. Generalized columnar section of the study area in the Lakhra coal field showing coal zone names adopted for this report. None of the nomenclature shown has been formally approved by the Statigraphic Committee of Pakistan.

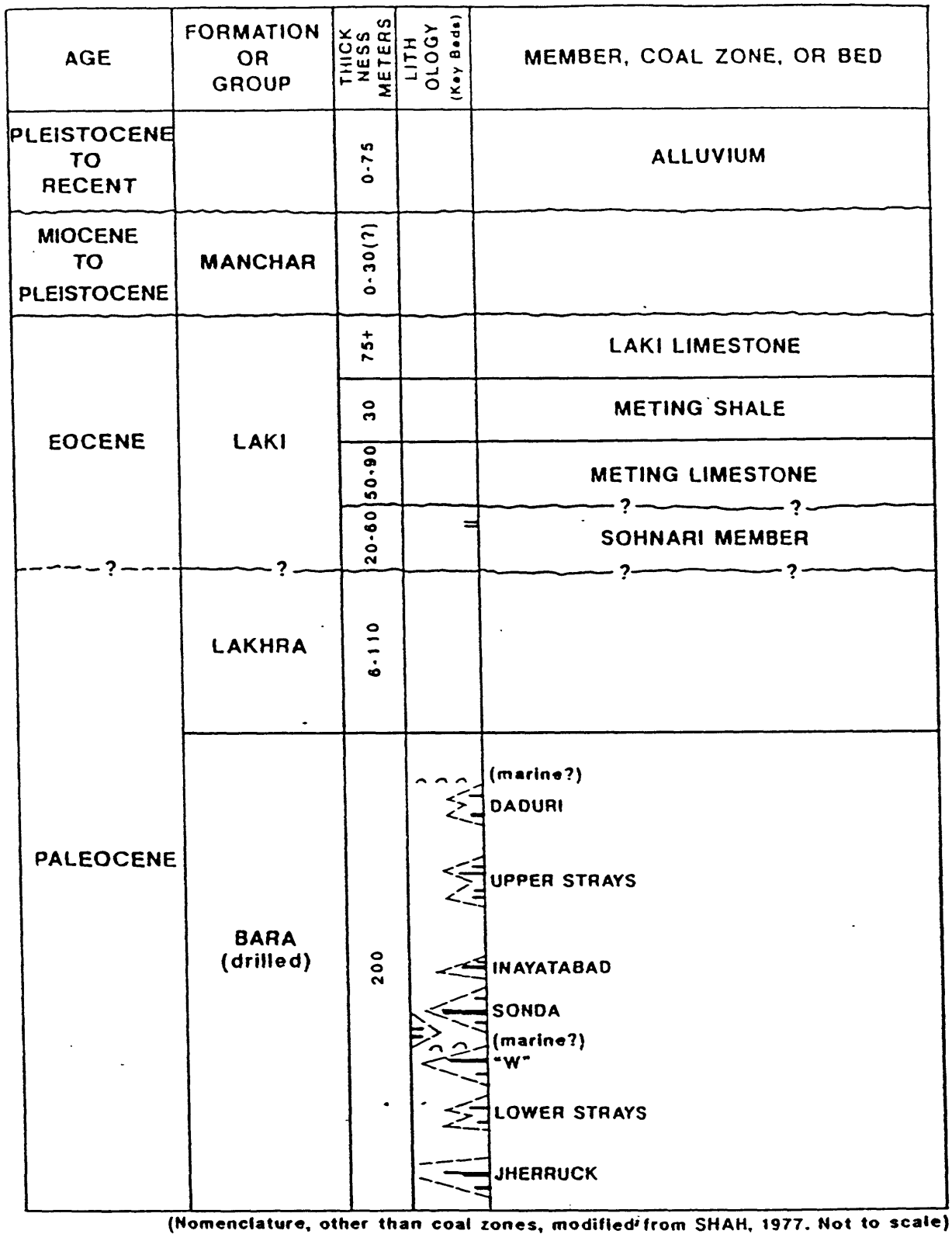

Figure 6. Generalized columnar section of the study area in the Sonda coal field showing coal zone names adopted for this report. None of the nomenclature shown has been formally approved by the Stratigraphic Committee of Pakistan.

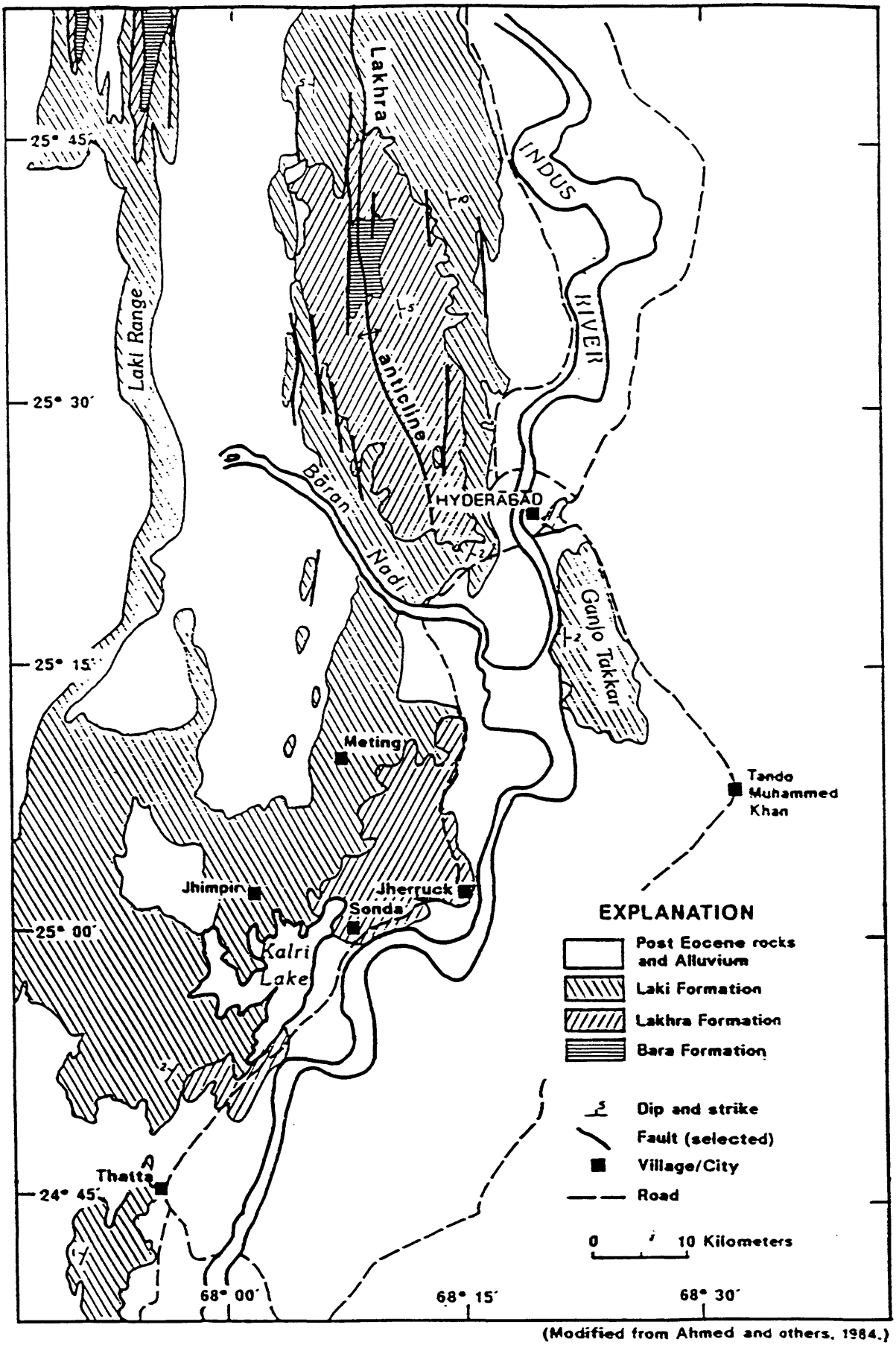

Figure 7. Generalized geologic map of the study area and vicinity.

subcontinent before it collided with Eurasia and may have been preserved at depth, as in the Sonda field, in areas between southern Sind and the Salt Range coal field of Punjab Province (fig. 1). Paleocene strata equivalent to the Bara Formation are reported to occur from Hyderabad to the Salt Range (Bakr and Jackson, 1964) and coal beds of equivalent age and setting to coal beds in the study area occur in the Salt Range (Peter Warwick, USGS, 1988, written communication).

Structurally, the study area contains two major, highly faulted anticlines, one each in the Lakhra and Sonda areas. The Lakhra anticline (fig. 7) is well exposed at the surface and has been known for a long time; COALREAP drilling was conducted mostly within the core area of this structure (fig. 4). Rocks in the Lakhra anticline are offset by a few large and numerous small, generally north-south trending faults that appear in most cases to have normal displacement. The anticline may also be bounded on the east and west by larger faults of undetermined kind.

The presence of an anticline in the Sonda area (fig. 7) was not reported prior to this study. The structure visible from the surface is that of a broad west-northwestward sloping homocline with its top just west of the Indus River (fig. 7). Several of the holes drilled during Sind COALREAP, closer to the river than previous holes, provided evidence that there is an eastern limb to the structure, indicating that it is an anticline. The Sonda anticline, however, appears to be much broader than the Lakhra anticline and it may also prove to be more complexly distorted by large faults than the Lakhra anticline.

Both anticlines appear to plunge toward one another under Baran Nadi (fig. 7), which would imply that the coal-bearing strata under Baran Nadi are buried more deeply. Other surface indications, lineaments on aerial photos, for example, suggest that a structural discontinuity may separate the two anticlines in the Baran Nadi area. More field work and drilling in that area are needed to determine the structural and stratigraphic relationships.

Coal quantity

Original resources of coal in the study area are estimated to be 4,780 million tonnes. Of this about 1,080 million tonnes are estimated for the Lakhra coal field and about 3,700 million tonnes for the Sonda field. The criteria used for these resource calculations are shown in table 1; and the resource totals or figures are shown in table 2. All calculations were performed by NCRDS and the details are provided in Parts II and V.

These estimates of coal resources were made in accordance with the suggestions in Wood and others (1988), USGS Circular 891 entitled "Coal Resource Classification System of the U.S. Geological Survey", except for minimum coal bed thickness and ash content. Coal beds as thin as 0.3 m and as high in ash as 50 percent (on the dry basis) are currently mined in Pakistan so the parameters used in this assessment for minimum bed thickness and maximum ash content were 0.3 m and 50 percent, respectively (table 1).

The thicknesses of qualifying coal beds within each coal zone, along with coal zone/bed correlations, were recorded and entered into NCRDS to produce the coal zone isopach and overburden maps of Part V. Detailed coal zone

Table 1. Criteria used for calculating the orginal coal resources of the parts of the Lakhra and Sonda coalfields covered in this report.

1. Qualifying coal beds:

Minimum thickness	0.3 m
Maximum ash (dry basis)	50%

2. Overburden categories:

0- 75 m
75-150 m
150-300 m
>300 m

3. Reliability categories in km from point of observation:

Measured	0 -0.4 km
Indicated	0.4-1.2 km
Inferred	1.2-4.8 km
Hypothetical	>4.8 km

4. Density:

13,000 tonnes per hectare meter

Table 2. Estimated original coal resources within the area studied, by coal field and principal coal zones and by reliability and overburden categories (million tonnes).

Lakhra (fig. 2, 46,569 hectares)

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Totals*
0- 75	89	143	38	---	270
75-150	47	193	239	---	479
150-300	7	60	231	28	326
Totals*	143	396	508	28	1,076*

Sonda (fig. 2, 96,668 hectares)

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Totals*
0- 75	3	17	73	19	112
75-150	13	86	246	27	372
150-300	44	337	2,115	457	2,953
>300	0	3	83	180	266
Totals*	60	443	2,517	683	3,702*

Lakhra - No. 2 zone (fig. 5, 23,041 hectares)

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Totals*
0- 75	52	49	10	---	111
75-150	16	56	46	---	118
150-300	2	13	37	---	52
Totals*	70	118	93	---	281

Lakhra - No. 1 zone (fig. 5, 23,920 hectares)

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Totals*
0- 75	14	45	11	---	70
75-150	15	56	76	---	147
150-300	2	14	51	---	67
Totals*	31	115	138	---	283*

Sonda - Sonda zone (fig. 6, 81,578 hectares)

Overburden (m)	Measured	Indicated	Inferred	Hypothetical	Totals*
0- 75	--	--	--	---	--
75-150	9	58	192	26	285
150-300	25	201	1,253	233	1,713
>300	--	2	22	40	65
Totals*	34	261	1,468	299	2,063*

* Totals may not add due to rounding.

sections at a scale of 1 cm equal 0.1 m are provided in Parts III and VI. Coal quantities within each thickness, reliability, and overburden category, were then calculated by NCRDS using the GARNET software program (USGS developed, see Olsen, 1977, 1980). Coal resources were calculated for the upper 7 numbered coal zones (fig. 5) in the Lakhra coal field and for the upper 6 named coal zones in the Sonda field: resources were not calculated for the other coal zones, or beds, shown in figures 5 and 6 because of inadequate information.

Estimates of original coal resources for some zones were also made for two additional categories of minimum coal-bed thicknesses--0.75 m and 1.5 m. Original resources in beds 0.75 m thick or greater were estimated to be 2,600 million tonnes, or just over half of the estimated resources for both fields combined. With respect to the amounts for each coal field (table 2), resources in beds 0.75 m thick or greater were estimated to be about 470 million tonnes or nearly 45 percent of the field total for Lakhra, and about 2,120 million tons, or nearly 60 percent of the total for Sonda. Coal beds 1.5 m thick or greater were found in only 3 zones--the Nos. 2 and 1 in Lakhra (fig. 5) and the Sonda in Sonda (fig. 6). Original resources in beds 1.5 m thick or greater in each of these zones were estimated to be about 24 percent, 15 percent, and 37 percent, respectively, of the totals for each zone. In millions of tonnes, approximate original resources in beds 1.5 m thick or greater in each of these zones are: No. 2, 66; No. 1, 42; and Sonda, 753.

Remaining coal resources of the Lakhra coal field could not be estimated at the time of this study because records of past coal production are unreliable. It is estimated, however, that because of the small annual production from Lakhra , the mining methods used, and the relatively short history of mining, that approximately 95 percent of the original coal resource remains in the part of the Lakhra coal field covered by this report. As much as 25 percent of the coal in the No. 2 coal zone at depths of less than 150 m may be, or may become, lost in mining, and thus unavailable, because of the poor recoverability of current mining practices. Remaining resources are the same as original resources in Sonda because exploitation has not begun there.

Coal quality

This summary of coal quality is based on the results of analysis of 219 samples from coal beds in the Bara Formation within the study area. This sample group is made up of 70 coal-mine and 94 drill-core samples from the Lakhra field and 55 drill-core samples from the Sonda field: 46 of the coal samples from Sonda are from the northern part of the area (figs. 2 and 4). An additional 95 coal samples were collected from coal mines in the Lakhra field and 4 from drill holes in the Sonda field, but they had dried out before being analyzed resulting in analyses that do not compare, on the as-received basis, with the samples that had been properly handled and, consequently, they are not included in this summary. However, the results of the analyses of those 99 samples are presented in Parts II and IV where they can be compared with other samples on the dry basis.

Coal samples were also collected from several mines and one drill hole in the Jhimpir coal field (fig. 1); but, because this report does not include coverage of the Jhimpir field, the results of analyses of the Jhimpir samples are not included here. However, they are presented in Parts II and IV, for timely release of the results.

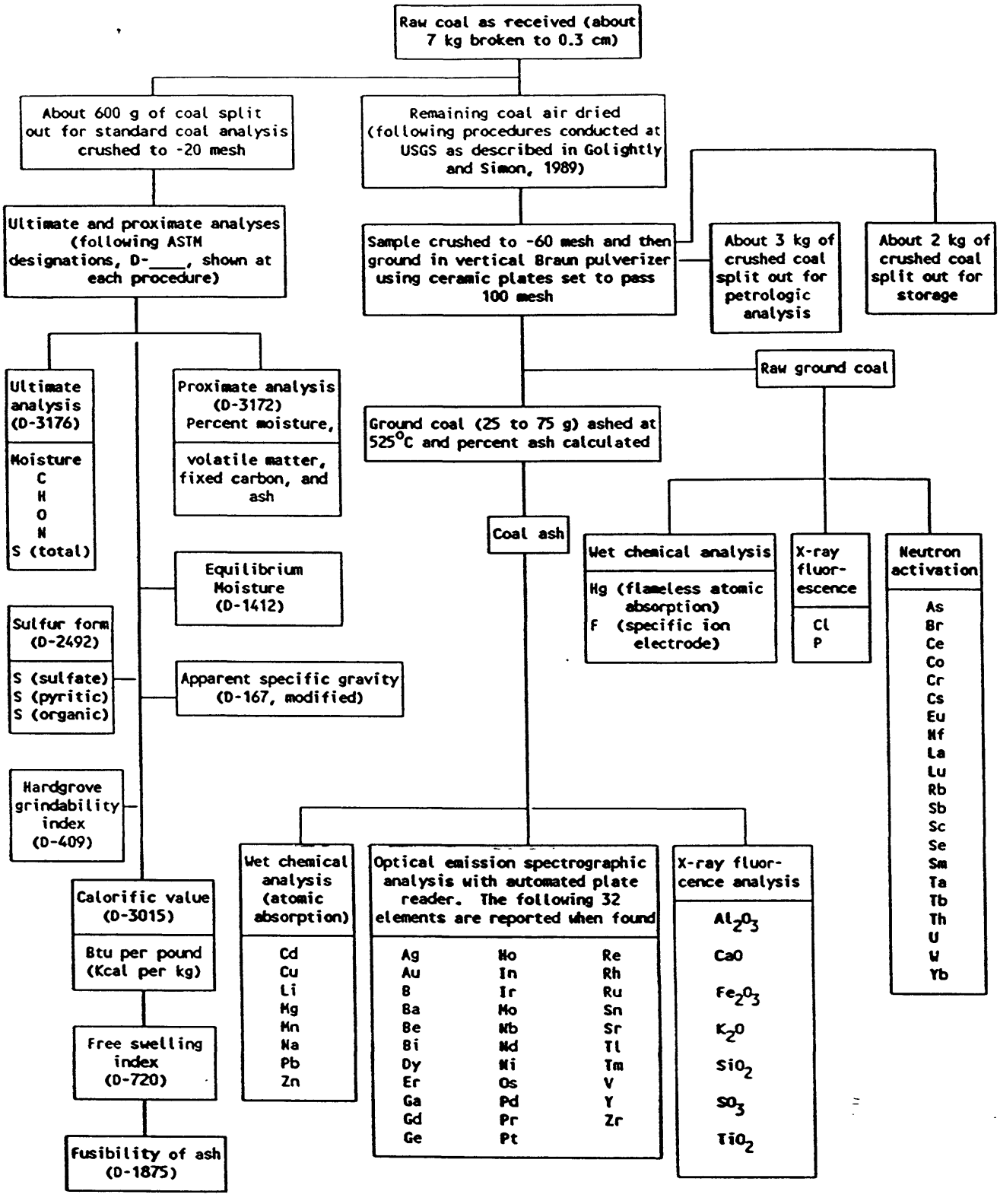

Figure 8. Flow diagram of procedures used for the analysis of coal samples collected as part of the Sind COALREAP, 1985 to 1987, from the Lakhra, Sonda, and Meting-Jhimpir coal fields. (ASTM-American Society for Testing and Materials, GT-Geochemical Testing Company, USGS-United States Geological Survey.)

The analytical results presented here are for coal samples that were collected, packaged, and analyzed following standard procedures (Schopf, 1960; Dutcher, 1978; ASTM, 1986). All analyses were performed following the procedures shown in figure 8. Standard coal analyses shown on the left-hand side of figure 8 were performed by Geochemical Testing Company of Somerset, Pennsylvania, under contract to USGS; elemental and oxide analysis procedures shown on the right-hand side of figure 8 were performed by USGS analytical laboratories in Reston, Virginia. Details of all the analytical results currently available for both the standard and elemental/oxide analyses, along with cross-references to sample localities and coal zone/bed names, are given in Part IV.

Standard coal analyses have been performed on all coal samples collected during Sind COALREAP; however, of the 219 samples covered in this summary elemental/oxide analyses have been completed to date for only 37 of the mine and 65 of the drill-core samples from Lakhra, and none have been completed for the samples from Sonda. Results of the elemental and oxide analysis for the remaining samples will be added to Part IV as they become available.

The results of both standard and elemental/oxide analyses are entered into the International Coal Chemistry (ICHEM) data file of the National Coal Resources Data System (NCRDS) at USGS National Center, Reston, Virginia. After assimilation into ICHEM, the analytical data may be statistically analyzed for central tendencies (means, standard deviations), combined into tabular form (tables 3 and 4), or used to plot computer generated maps of specific parameters such as ash, sulfur, or heat value.

Statistical summaries of the standard coal analyses on the as-received basis for the 164 coal samples from Lakhra and the 55 from Sonda are presented by individual coal field and for both fields combined in table 3. Table 4 contains a statistical summary of the elemental and oxide analyses for the 102 samples from the Lakhra area that received those analyses. Statistical summaries of the standard coal analyses, on the as-received basis, for the three principal coal zones in the study area (table 2)--the No. 2 and No. 1 of Lakhra and the Sonda coal zone of Sonda--are provided in table 5. Many more details for all samples, including additional statistical parameters, are given in Parts II and IV.

The calculated apparent rank (Parr formula) of the coals in the Lakhra and Sonda fields is lignite A to subbituminous C.

Proximate analysis data for coal (moisture, ash, volatile matter, fixed carbon; table 3) are used as indicators of coal quality, to classify coal, to determine the market value of the coal, and as a guide to furnace design. The proximate analyses of the Pakistan coals are very similar to those of the Gulf Coast lignites. In contrast to the Fort Union lignites, the Pakistan coals have higher ash but lower moisture.

Ultimate analysis data (H, C, N, O, S; table 3) of coal are used in combustion calculations, conversion studies, and in predicting corrosion problems. The data also provide a convenient and uniform method for comparing coals. The ultimate analyses of the Lakhra and Sonda coal samples are well within the range of expected values for ranks of lignite A to subbituminous C.

Table 3. Summary of selected statistics for standard coal analyses, on the as-received basis, for 164 mine and drill-core samples from the Lakhra coal field, 55 drill-core samples from the Sonda coal field, and both sample sets combined, excluding zero and qualified values.

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

	Lakhra Coal Field						Sonda Coal Field						Both Coal Fields					
DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE
MOISTUR	164	27.6	5.46	9.71	38.09	28.38	55	31.15	4.30	20.13	38.77	18.64	219	28.46	5.42	9.71	38.77	29.06
VOLMAT	164	27.9	3.83	18.27	38.61	20.34	55	28.12	4.04	16.23	37.33	21.10	219	27.98	3.88	16.23	38.61	22.38
FIXEDC	164	25.3	5.34	9.81	38.21	28.40	55	24.96	4.37	10.51	31.29	20.78	219	25.23	5.12	9.81	38.21	28.40
BMASH	164	19.2	10.34	4.28	49.15	44.87	55	15.77	10.70	2.80	48.08	45.28	219	18.33	10.54	2.80	49.15	46.35
HYDROGN	164	6.0	0.79	3.67	7.42	3.75	55	6.56	0.69	4.67	7.45	2.78	219	6.12	0.81	3.67	7.45	3.78
CARBON	164	36.3	7.74	13.22	53.59	40.37	55	38.74	7.25	16.44	47.86	31.42	219	36.94	7.69	13.22	53.59	40.37
NITROGN	164	0.7	0.16	0.16	0.98	0.82	55	0.69	0.13	0.31	0.92	0.61	219	0.67	0.15	0.16	0.98	0.82
OXYGEN	164	32.3	4.50	18.01	40.89	22.88	55	35.56	4.44	23.68	43.70	20.02	219	33.15	4.70	18.01	43.70	25.69
SULFUR	164	5.5	2.39	1.20	14.78	13.58	55	2.68	1.64	0.37	7.74	7.37	219	4.78	2.54	0.37	14.78	14.41
SULFATE	164	0.4	0.56	0.01	4.61	4.60	55	0.05	0.03	0.01	0.17	0.16	219	0.34	0.51	0.01	4.61	4.60
SULFPYR	164	3.8	2.29	0.28	13.78	13.50	55	2.00	1.41	0.09	5.49	5.40	219	3.36	2.25	0.09	13.78	13.69
SULFORG	164	1.2	0.68	0.01	3.59	3.58	55	0.63	0.37	0.07	2.11	2.04	219	1.09	0.67	0.01	3.59	3.58
BTU/lb	164	6587	1344	2313	9452	7139	55	6958	1273	2898	8687	5789	219	6680	1337	2313	9452	7139
ASHDEF	161	2129	194	1900	2760	860	55	2116	269	1850	2800	950	216	2126	216	1850	2800	950
ASHSOF	159	2189	203	1940	2760	820	53	2167	276	1880	2800	920	212	2184	224	1880	2800	920
ASHFLD	157	2329	220	1960	2800	840	51	2256	259	1960	2790	830	208	2311	232	1960	2800	840

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

Table 4. Summary of selected statistics for oxide analyses, on the ash basis, and elemental analyses, on the as-received basis, for 37 mine and 65 drill-core samples from the Lakhra coal field, excluding zero and qualified data.

STATISTICS FOR FOLLOWING DATA ITEMS ON ASH BASIS 1/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
USGSASH	102	24.9	12.25	6.70	63.70	57.00	22.17	1.62
SIO2	102	27	9.99	7.96	56.39	48.43	24.78	1.51
AL2O3	102	16	6.09	3.04	32.25	29.21	14.65	1.57
CAO	102	5	3.80	0.43	24.59	24.16	4.16	2.07
MGO	100	2	1.16	0.18	6.96	6.78	1.67	1.92
NA2O	102	1.2	1.37	0.09	10.38	10.28	0.87	2.29
K2O	102	0.47	0.23	0.12	1.47	1.35	0.42	1.61
FE2O3	102	30	10.63	4.85	56.47	51.61	28.27	1.50
TIO2	102	1.4	0.68	0.31	5.00	4.68	1.21	1.63
P2O5	53	0.08	0.03	0.03	0.22	0.19	0.07	1.50
SO3	102	9.8	7.50	2.00	43.51	41.51	7.61	2.06

1/ 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)

Table 4. (Continued)

STATISTICS FOR FOLLOWING DATA ITEMS ON WHOLE-COAL BASIS 2/

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE	GEO MEAN	GEO DEV
AG	98	0.1	0.07	0.025	0.41	0.38	0.08	1.86
AS	102	2.9	2.24	0.380	18.00	17.62	2.38	1.87
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR AU								
B	99	130	35.97	49.580	284.24	234.66	123.37	1.34
BA	102	73	119.43	6.680	1005.80	999.12	45.53	2.34
BE	101	2.9	1.42	0.737	7.92	7.18	2.56	1.65
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR BI								
BR	102	5.5	8.57	0.435	54.80	54.36	2.81	2.88
CD	97	0.16	0.12	0.013	0.67	0.65	0.12	2.17
CE	101	10	11.62	0.319	52.46	52.14	5.86	3.18
CL	70	990	1234.97	100.000	5779.98	5679.98	562.79	2.78
CO	101	11	15.85	0.088	87.93	87.84	5.44	3.73
CR	101	12	14.53	0.228	76.25	76.02	6.17	3.31
CS	84	0.21	0.27	0.004	1.27	1.26	0.11	3.15
CU	102	32	21.21	6.030	116.28	110.25	26.54	1.86
DY	3	15	7.51	5.976	24.35	18.38	13.18	1.80
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR ER								
EU	101	0.32	0.37	0.008	2.22	2.21	0.19	2.89
F	76	55	37.89	20.000	180.00	160.00	45.89	1.77
GA	59	8.9	4.66	3.006	22.26	19.25	7.88	1.61
GD	3	8.4	4.56	3.320	14.39	11.07	7.13	1.82
GE	82	5.4	5.43	0.737	36.43	35.69	3.86	2.20
HF	102	0.45	0.56	0.005	2.93	2.92	0.24	3.23
HG	47	0.04	0.02	0.005	0.10	0.10	0.03	2.06
HO	3	5.6	1.86	3.636	8.12	4.48	5.34	1.39
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IN								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR IR								
LA	102	5.7	6.44	0.139	29.22	29.08	3.12	3.26
LI	102	23	17.81	0.402	85.40	85.00	15.05	2.84
LU	101	0.08	0.07	0.003	0.38	0.38	0.05	2.48
MN	102	140	180.15	1.485	1371.75	1370.26	73.05	3.28
MO	59	4.7	4.61	0.598	26.89	26.30	3.21	2.37
NB	102	8.2	7.35	0.556	37.21	36.65	5.88	2.30
ND	92	33	19.83	5.338	92.25	86.91	26.89	1.96
NI	102	52	38.34	3.752	214.00	210.25	39.99	2.11
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR OS								
PB	102	9.7	6.08	0.505	27.15	26.65	7.78	2.08
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	14	7.9	6.15	1.189	18.30	17.11	5.12	2.75
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	83	0.16	0.09	0.054	0.55	0.50	0.14	1.67
SC	101	2.9	2.54	0.025	12.10	12.08	1.85	3.03
SE	98	4.9	1.58	1.570	10.30	8.73	4.64	1.40
SM	102	1.3	1.35	0.032	7.78	7.74	0.75	2.92
SN	46	5.3	3.44	1.085	17.94	16.86	4.49	1.78
SR	97	400	644.14	44.590	4740.00	4695.41	242.40	2.29
TA	101	0.18	0.25	0.003	1.30	1.30	0.09	3.51
TB	102	0.17	0.18	0.004	1.12	1.12	0.11	2.72
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TE								
TH	101	3.5	2.35	0.183	12.60	12.42	2.68	2.16
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TL								
THERE WERE LESS THAN TWO POSITIVE-VALUED ITEMS FOR TM								
U	93	1.4	2.15	0.250	18.40	18.15	0.97	2.07
V	102	45	26.35	2.278	131.52	129.24	35.94	2.07
W	49	1	2.85	0.046	19.86	19.81	0.36	3.19
Y	100	19	12.21	3.886	96.95	93.06	16.17	1.65
YB	101	0.61	0.60	0.025	4.07	4.04	0.42	2.46
ZN	102	56	46.01	4.464	265.68	261.22	40.86	2.27
ZR	102	54	42.05	2.814	214.90	212.09	40.42	2.22

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

Table 5. Summary of selected statistics for standard coal analysis, on the as-received basis, for the three coal zones containing the most resources (table 2) in the Lakhra and Sonda coal fields.

DATA ITEM	VALUES USED	MEAN	STD DEV	XMIN	XMAX	RANGE
			No. 2 zone, Lakhra coal field			
MOISTUR	84	28.81	4.53	17.830	37.56	19.73
VOLMAT	84	27.63	3.61	18.380	36.02	17.64
FIXEDC	84	25.46	4.96	11.260	36.10	24.84
BMASH	84	18.10	10.14	4.280	48.14	43.86
HYDROGN	84	6.15	0.72	3.910	7.42	3.51
CARBON	84	36.98	7.59	14.180	53.59	39.41
NITROGN	84	0.67	0.15	0.230	0.97	0.74
OXYGEN	84	33.38	4.18	20.190	40.89	20.70
SULFUR	84	4.73	2.11	1.200	13.35	12.15
SULFATE	84	0.35	0.31	0.020	1.54	1.52
SULFPYR	84	3.39	2.10	0.410	12.02	11.61
SULFORG	84	0.99	0.47	0.010	2.29	2.28
ADLOSS	84	22.39	5.09	13.000	34.92	21.92
BTU/lb	84	6680	1318	3030	9450	6430
ASHDEF	82	2150	180	1920	2740	820
ASHSOF	81	2220	191	1980	2760	780
ASHFLD	80	2390	205	2020	2800	780
			No. 1 zone, Lakhra coal field			
MOISTUR	36	27.52	6.11	9.710	35.72	26.01
VOLMAT	36	29.06	3.48	18.550	35.68	17.13
FIXEDC	36	26.77	5.40	9.810	38.21	28.40
BMASH	36	16.66	8.44	6.690	48.41	41.72
HYDROGN	36	6.09	0.73	3.870	7.14	3.27
CARBON	36	38.64	6.62	15.320	50.97	35.65
NITROGN	36	0.70	0.13	0.250	0.98	0.73
OXYGEN	36	32.83	4.17	18.010	38.98	20.97
SULFUR	36	5.08	1.54	2.060	8.30	6.24
SULFATE	36	0.35	0.45	0.010	2.37	2.36
SULFPYR	36	3.25	1.58	0.280	6.20	5.92
SULFORG	36	1.47	0.72	0.150	3.03	2.88
ADLOSS	36	21.95	6.64	4.250	29.38	25.13
BTU/lb	36	6970	1128	2920	8740	5830
ASHDEF	35	2100	185	1900	2610	710
ASHSOF	35	2160	209	1950	2740	790
ASHFLD	34	2240	201	2000	2710	710
			Sonda zone, Sonda coal field			
MOISTUR	48	33.31	5.14	22.220	48.02	25.80
VOLMAT	48	28.00	3.80	16.670	37.33	20.66
FIXEDC	48	25.54	4.02	16.240	31.63	15.39
BMASH	48	13.15	9.32	2.800	39.10	36.30
HYDROGN	48	6.79	0.68	4.670	8.33	3.66
CARBON	48	39.53	6.49	21.870	47.86	25.99
NITROGN	48	0.72	0.12	0.430	0.93	0.50
OXYGEN	48	37.58	4.97	26.190	49.70	23.51
SULFUR	48	2.23	1.77	0.180	7.74	7.56
SULFATE	47	0.04	0.03	0.010	0.14	0.13
SULFPYR	48	1.64	1.46	0.040	5.49	5.45
SULFORG	48	0.55	0.37	0.060	2.11	2.05
ADLOSS	48	23.23	6.69	10.110	42.46	32.35
BTU/lb	48	7060	1155	3950	8690	4740
ASHDEF	48	2100	239	1820	2730	910
ASHSOF	47	2170	260	1880	2800	920
ASHFLD	45	2250	243	1960	2790	830

For each coal zone: items 1-12 in percent; heat value in Btu/lb, to convert to Kcal/kg multiply by 0.556; and items 14-16 in degrees Fahrenheit.

Sulfur values, especially in the Lakhra field are higher than those encountered in U.S. rank-equivalent coals. However, over 70 percent of the sulfur in the Pakistan samples is in the form of pyrite compared to about 20 percent in the U.S. samples. Thus, it may be possible to substantially reduce the sulfur content of the Pakistan coals through coal cleaning procedures.

Fusibility of the coal ash (table 3) from the Pakistan samples, an indicator of fouling and slagging behavior, is virtually identical to that of the Gulf Coast lignites and slightly higher than that of the Fort Union lignites. The levels for fusibility in table 3 suggest that the coals in Sind Province tend to have a high slagging potential.

Analytical data on oxide and trace element composition of coal ash and whole coal (table 4) provide information about ash composition and concentration levels of trace elements such as arsenic (AS), cadmium (CD), mercury (HG), and selenium (SE) that may be environmentally hazardous if present in large-enough amounts. Based on the statistical summary of analyses, reported in table 4, only selenium (SE), among the environmentally hazardous elements is elevated (mean of 4.9 ppm) relative to averages for similar coals from North Dakota (mean of 0.8 ppm) and northeastern Wyoming (mean of 1.3 ppm) and is somewhat comparable to Texas Gulf Coast lignites (mean of 6.3 ppm) where there are local problems with toxic runoff from ash dumps (Houston Chronicle, 1982). (More data on U.S. coals similar to those in southern Sind are provided in Part II, Chapter 3.)

An elevated chlorine (CL) level in Sind coals (mean of about 1,000 ppm, table 2) is the only other potential problem apparent from the results of the trace-element analyses. A level of chlorine this high, almost an order of magnitude higher than in comparable U.S. coals, can result in the production of excess hydrochloric acid when burned, leading to accelerated corrosion of furnace linings and boiler tubes. It is recommended that additional studies be focused on both selenium and chlorine in the coals of southern Sind.

The oxide and trace element content of most of the coal samples from the Sonda field were not yet available when this report was written. Results for 4 samples collected by GSP in 1985 from 3 core holes in the northern part of the Sonda field (presented in Part II, Chapter 3, and Part IV) indicate that values for selenium and chlorine might be lower in Sonda, but 4 samples are far too few for a definitive answer.

The oxide composition of coal ash may be used in conjunction with tests such as ash-fusibility determinations to assist in predicting the slagging and fouling behaviour of coals during combustion. The presence of CaO (table 4) in a coal may, for example, offset the amount of limestone required in a fluidized-bed combustion system to reduce sulfur emissions. More detailed information is provided in Part II, Chapter 3 and in Part IV and a report on some of the Lakhra coal-mine samples was previously released by F.O. Simon and others in 1988.

RECOMMENDATIONS FOR FUTURE WORK

Sind Province, general

A regional synthesis of existing geologic information complemented by new outcrop information should be completed in Sind before further large-scale,

coal-exploration drilling programs are begun. The new study should include the results from recent PMDC drilling that were not available for this report and a thorough reexamination in a regional sense of the geologic data from the "Boyd" tract (fig. 2). As previously explained, Sind COALREAP in the study area, conducted between 1985 and 1987, was not completed as originally planned; however, the studies that were completed have identified a number of coal-resource related geologic problems with regard to stratigraphic correlations, geologic structures, and structural styles. A better understanding of these geologic conditions may lead to the discovery of more coal resources at shallow depths and will help define potential mining difficulties that may result from problems such as friable strata in the overburden and the abundance of faults. Some specific examples of geologic problems requiring solutions are: 1) the nature of the boundary fault on the west side of the Lakhra anticline; 2) the relationship between the Lakhra anticline, the Sonda anticline, and the structural style east of the Indus River (fig. 7); and 3) the possibility of a stratigraphic rise of coal zones (figs. 5 and 6) in the Lakhra coal field versus the Sonda coal field (the reasons for completing this work are discussed in detail in Part II). Many of these problems have not been resolvable from the drilling completed to date. Although another immediate large-scale drilling program in Sind is not recommended, the drilling of some coal exploration holes in selected localities in support of a regional synthesis would provide dividends in planning for future large-scale drilling programs as well as in immediate local results. The approximate locations of the near term drill holes are shown by stars in figure 9. Numbers with the stars suggest the order of priority for drilling at each location based on current PASA obligations. Geologic, security, or logistical considerations may cause drilling priorities to be reordered. More detail is provided below under each coal field.

As a general rule, all agencies conducting coal-resource assessment work should adopt similar, fairly rigorous standards for collecting and processing basic field information in order to maintain comparability and consistency in the results. Interpretations of basic information may properly vary, but the basic information to support interpretations should be complete and consistent. This report is based on all the information that was available to May 1987; however, much of the older information was either incomplete and/or inconsistent in content and format and much time was lost in adapting those older materials for use in this report.

Coordination between the GSP and other Pakistan national and provincial agencies responsible for coal assessment should be improved. Greater sharing of plans and information would lead to greater efficiencies in the assessment of Pakistan's coal resources. The appointment of a specific technical person from each appropriate agency to participate in an interagency coal-resource-assessment coordinating committee is recommended. The sharing of information and plans would lead to greater efficiencies in coal-resource assessments. Another benefit resulting from better coordination would be that expertise and equipment could be shared and all coal-exploration drill holes would be geophysically logged. Geophysical logs are essential for coal resources assessment work in many areas and especially so in Sind where it is very difficult to correlate coal beds and other strata within the Bara Formation without them.

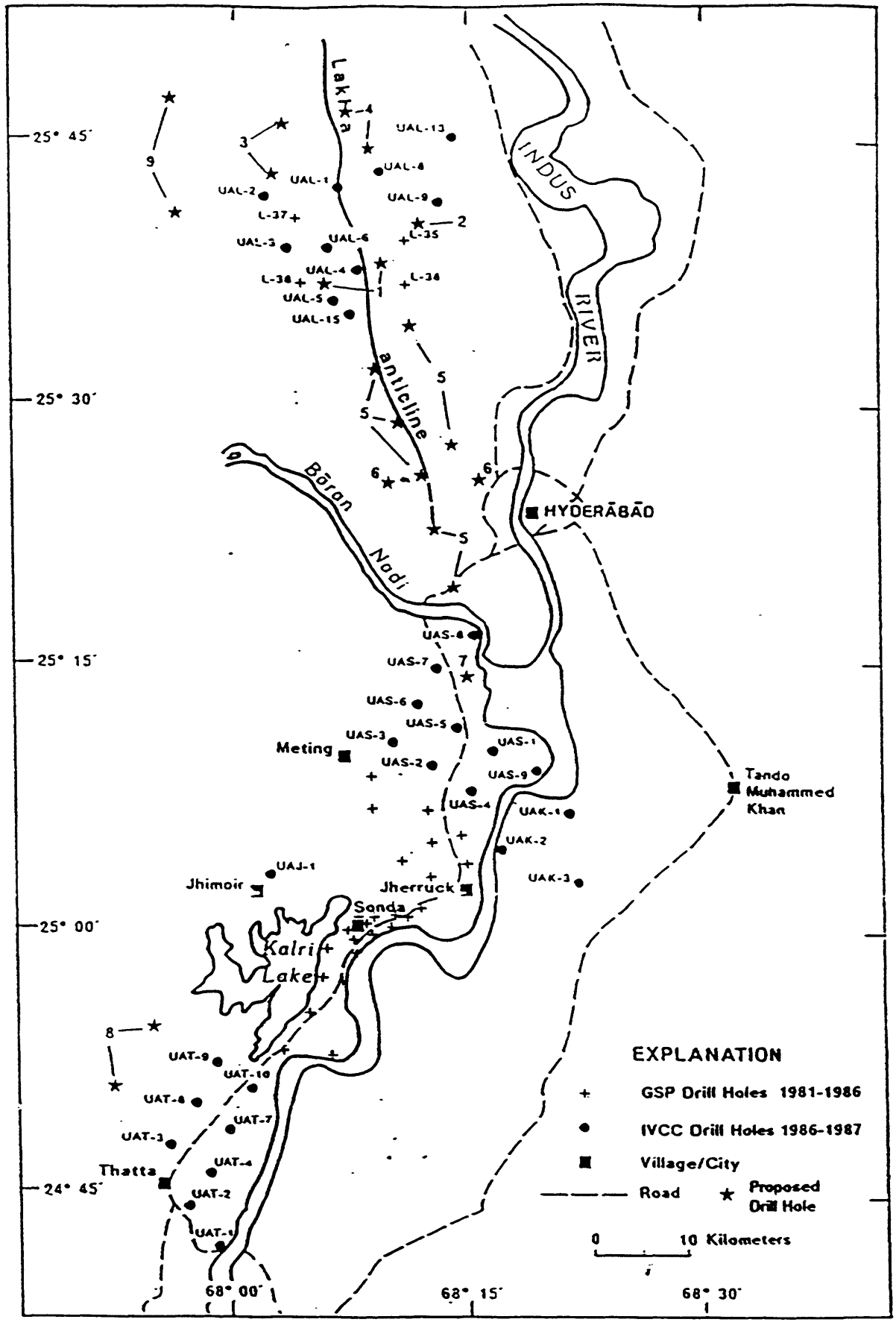

Figure 9. Twenty-one recommended near-term drilling locations in order of priority. (See Part II, Chapter 2 for additional details.)

Mines and mined-out areas in the Lakhra coal field should be inventoried in greater detail. This would provide an assessment of coal mined and lost in mining so that a better estimate of remaining resources could be made. The results of these investigations should be made widely available. In addition, in order to facilitate national large-scale growth and take the best advantage of remaining coal resources, it is suggested that the appropriate licensing authorities investigate the possibility of developing logical mining units (LMUs) for future coal leasing and mining in Sind. This approach could be very helpful in relieving the poor coal recoverability caused by small, fragmented, inefficient lease holdings and especially beneficial if current plans for large-scale power generation are to include a private-sector component of coal supply.

Lakhra area

The southern, northern, and western Lakhra areas are almost completely unexplored, and should be selectively drilled, along with some infill drilling in central Lakhra.

In the central Lakhra area, one or two holes should be drilled east or west of UAL-4 (1, fig. 9) to test for a suspected shallow coal zone or bed in that area. A coal zone intercepted between 28 and 40 m in UAL-4 contained coal that appears to be only slightly more weathered than other deeper coals in the area. One hole (2, fig. 9) should be drilled along the apparent depositional strike of the No. 2 coal zone to fill an information gap left by poor core recovery in that interval in nearby holes. It is suggested, however, that the holes at locations 1 and 2 on figure 9 should not be drilled unless some system is installed for the orderly development of Lakhra coal deposits as recommended above in paragraph 4 under Sind Province, general. The problem is that as soon as a shallow mineable coal bed is discovered another small mine is opened thereby reducing the possibility for large-scale development of the coal deposit.

In northern and western Lakhra at least two and possibly four holes (3 and 4, fig. 9) should be drilled on each side of the area of the most active mining to verify coal bed occurrence and correlations. In the southern Lakhra area, 5 to 7 holes (5, fig. 9) should be drilled either along the axial trace of the anticline or in topographic lows to the east of the axis to establish subsurface correlations between the Lakhra and Sonda coal fields.

Two holes should be drilled west of the Lakhra anticline (9, fig. 9) to test for the extent of coal beds similar to what was found by private sector coal companies in several shallow mines just west of the western boundary fault. (For more details see Part II, Chapter 2.)

Sonda area

One hole should be drilled between UAS-5 and UAS-8 (7, fig. 9) to help determine the Lakhra/Sonda structural transition, but additional holes should not be drilled in the Sonda area until the results of drilling in the Jherruck and Indus East areas are evaluated.

Sohnari beds

The coal beds of the Meting-Jhimpir coalfield lie in the Sohnari Member of the Laki Formation (fig. 6). These beds also crop out in the Lakhra area, so it is suggested that one or two holes be drilled in the southern Lakhra area, well back from the outcrop, to test for coal (6, fig. 9). One or two holes should be also drilled west of UAT-8 and 9 (8, fig. 9) to test for coal in the Sohnari. Additional work in the Meting-Jhimpir area may be warranted because the Sohnari lies at shallow depths along the western edge of the present study area and more thorough study may result in discoveries similar to those made in the Bara Formation of the Sonda area.

REFERENCES CITED

Ahmed, Waheeduddin, Husain, Farhat, and Khan, I.A., 1984a, Geology and subsurface details of Sonda-Thatta coal field, Sind, Pakistan: Geological Survey of Pakistan, Geologic maps series, no. 12, scale 1:50,000.

Ahmed, Waheeduddin, Durrazai, M.I., Husain, Farhat, Subhani, A.M., and Jaleel, A., 1984b, Isopach map of the Lailian coal seam, Lakhra, Sind, Pakistan: Geological Survey of Pakistan, Geologic map series, no. 13, scale 1:50,000.

Ahmed, Waheeduddin, Husain, Farhat, Khan, I.A., and Khan, M.S., 1984(?)c, Sind coal fields and location of the newly established Thatta-Sonda Paleocene coalbelt: Geological Survey of Pakistan Map, scale 1:250,000 (unpublished).

Ahmed, Waheeduddin, Gauhar, S.H., and Siddiqi, R.A., 1986, Coal resources of Pakistan: Geological Survey of Pakistan Records, vol. 73, 55 p.

American Society for Testing and Materials, 1986, Annual book of ASTM Standards; vol. .05.05, Gaseous Fuels; Coal and Coke: ASTM, Philadelphia, Pennsylvania, 565 p.

Bakr, M.A., and Jackson, R.O., 1964, Geological map of Pakistan: Geological Survey of Pakistan, scale 1:2,000,000.

Boyd, J.T., Company, 1985, Overview of Lakhra coalfield, Lakhra coal project, Sind Province, Pakistan: John T. Boyd Company Report no. 1800.5A, vol. 5A, 115 p., 4 maps.

Dutcher, R.R., Editor, 1978, Field discription of coal; American Society for Testing and Materials Special Technical Publication 661, 71 p., ASTM, Philadelphia, Pennsylvania.

Geological Survey of Pakistan (GSP) and U.S. Geological Survey (USGS) 1988, National coal exploration plan (Pakistan): U.S. Geological Survey Open file report 88-251, 81 p. [Also U.S. Geological Survey Project report (IR) PK-70.]

Ghani, M.A., Harbour, R.L., Landis, E.R., and Kebblish, William, 1973, Geology and coal resources of the Lakhra coal field, Hyderabad area, Pakistan: U.S. Geological Survey Open file report 75-553, 77 p. [Also U.S. Geological Survey Project report (IR) PK-55.]

Golightly, D.W. and Simon, F.O., eds. 1989, Methods for sampling and inorganic analysis of coal: U.S. Geological Survey Bulletin 1823, 72 p.

Houston Chronicle, 1982, Lake's recovery still in doubt following fish kill settlement: Houston, Texas, p. 4, sect. 1, Sept. 6, 1982.

Japan International Cooperation Agency, 1981, Feasibility report for Lakhra coal mining and power station project: Japan International Cooperation Agency (JICA), Tokyo, Japan, 424 p.

Landis, E.R., Thomas, R.E., Outerbridge, W.F., Wnuk, Christopher, Durrani, N.A., Khan, R.A., and Shah, A.A., 1988, Report on COALREAP drilling and related activities, September 1987 to March 1988, conducted in the Indus East coal area, Southern Sind Province, Pakistan: U.S. Geological Survey Project report (IR) PK-80; Part A-Summary, 16 p.; Part B-Lithologic Logs, 401 p.; Part C-Geophysical Logs, 300 p.

Memon, A.S., Alam, Shaji, Mohuiddin, Mohammad, and Wahid, Abdul, 1976, Geological report on part of Lakhra coal field, near Khanot, District Dadu, Sind: Pakistan Mineral Development Corporation, Hyderabad, Pakistan, 44 p.

Olsen, A.C., 1977, Graphic analysis of resources by numerical evaluation techniques (GARNET): Computers and Geosciences, v. 1, pp. 539-545, (Pergamon Press).

Olsen, A. C., 1980, GARNET--Computer application software for NCRDS: U.S. Geological Survey Open file report 80-228, 160 p.

Schopf, J.M., 1960, Field description and sampling of coal beds: U.S. Geological Survey Bulletin No. 1111-B, 70 p.

Schweinfurth, S.P., SanFilipo, J.R., Simon, F.O., and Khan, R.A., 1985, Plan for coal-resources-assessment drilling and related activities, Sind Province, Pakistan: U.S. Geological Survey Project Report (IR) PK-69, 28 p.

Shah, S.M.I., Editor, 1977, Stratigraphy of Pakistan: Geological Survey of Pakistan Memoirs, vol. 12, 138 p.

Simon, F.O., Khan, R.A., Landis, E.R., and Hildebrand, R.T., 1988, Chemical and physical characterization of mine samples from Lakhra coal field, south Sind, Pakistan: U.S. Geological Survey Open file report 87-662, 94 p. [Also U.S. Geological Survey project report (IR) PK-73.]

Thomas, R.E., Landis, E.R., and Khan, R.A., 1988, Report on coal resource assessment program drilling and related activities, April 1986 to May 1987, Southern Sind Province, Pakistan: U.S. Geological Survey Open file report 88-275, Part A-Summary, 21 p.; Part B-Lithologic Logs, 780 p., Part C-Geophysical Logs, 697 p. [Also U.S. Geological Survey project report (IR) PK-78.]

Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resources classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

APPENDIX 1

Coal Resources of the Lakhra and Sonda Coal Fields

Southern Sind Province, Pakistan

A Progress Report

Geological Survey of Pakistan Project Report (IR) PK-82

1988

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ORGANIZATION OF THE REPORT

Part I - Executive Summary..... one book

Part II - Geology, coal resources, and coal quality..... one book
- Preface
- Chapter 1. Introduction
- Chapter 2. Geology and coal resources, with recommendations for future work
- Chapter 3. Coal quality

Part III - Basic stratigraphic information collected cooperatively by the Geological Survey of Pakistan and the U.S. Geological Survey between July 1985 and May 1987 from coal-exploration drill holes and coal-mine investigations..... two binders

Part IV - Basic analytical data for coal samples collected between July 1985 and May 1987..... one binder

Part V - Basic information used for coal-resource calculations.. one binder, one folio

Part VI - Basic stratigraphic information collected by the Geological Survey of Pakistan between 1981 and 1986 from coal-exploration drill holes and coal-mine investigations..... two binders

APPENDIX 2

Conversion Factors

Metric Units		English Units
Tonnes x 1.102	=	Short tons
Hectares x 2.471	=	Acres
Kilogram calories/ kilogram x 1.798 (K cal/kg)	=	British thermal units/pound (Btu/lb)
Square kilometers x 0.386	=	Square miles
Kilometers x 0.621	=	Miles
Meters x 39.37	=	Inches
Hectare meters x 8.1	=	Acre feet