DEPARTMENT OF THE INTERIOR
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Palynological Contribution to Geologic Mapping of Coal-Bearing Upper Paleocene Rocks in the Lower Indus Coal Region, Pakistan

By

Norman O. Frederiksen[1]

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[1]Reston, Virginia

CONTENTS

FIGURES

TABLES

ABSTRACT

This report is based on study of 75 pollen-bearing samples from eight coreholes in the northern, southwestern, and central parts of the Lower Indus coal region, Sind Province, Pakistan. Samples were from the Bara Formation, Lakhra Formation, and the Sohnari and Meting Limestone Members of the Laki Formation, in ascending order. Pollen data support planktic foraminiferal evidence that the entire Bara-Lakhra-Sohnari sequence is late Paleocene in age. Pollen data also support planktic foraminiferal evidence in suggesting that limestone immediately overlying the Sohnari Member in the northern part of the coal region represents the Meting Limestone Member of the Laki Formation, of Paleocene age.

The west side of the Lower Indus coal region (represented by corehole UAL-2 in the northwest and the UAT area in the southwest) was higher topographically, receiving more nonmarine deposits, than the east side of the region, at least from late Bara through much of Lakhra time. Uplift on the west side of the region, followed by erosion or nondeposition, probably occurred during late Lakhra time.

The uppermost coal beds in the Bara Formation of UAL-2 are younger than the uppermost Bara coal beds in UAL-13.

In coreholes UAJ-1, DH-18, UAK-5, and UAK-7, in the central part of the coal region, most strata assigned to the thick Sohnari Member are age-equivalent to much of the Lahkra Formation in the UAL area to the north, where the Sohnari is thin. In UAJ-1 and DH-18, the Sohnari Member includes a shelly sequence that may represent a tongue of the Lakhra Formation.

INTRODUCTION

The Geological Survey of Pakistan (GSP) and the U.S. Geological Survey (USGS) have been cooperatively investigating the coal resources of Pakistan under the sponsorship of the U.S. Agency for International Development (USAID). This paper discusses the results of palynological research conducted in conjunction with the current coal resource exploration and assessment program (COALREAP) which began in 1985, for the coal fields of southern Sind Province.

Upper Paleocene coal-bearing and associated strata in the Lower Indus Basin of southern Sind Province (figs. 1, 2) were deposited in a variety of lower coastal plain, deltaic, and shallow marine environments (Hunting Survey Corporation, 1961; Usmani and Ahmed, 1986; Warwick and others, 1987). Therefore, lateral facies changes are common in this stratigraphic package, and it is difficult to correlate strata by means of lithology and geophysical logs. The purpose of this report is to work out pollen correlations among representative cored sections of the area in order to better understand the distribution of coal beds and the possible diachronism of formation boundaries in this region.

Seventy-five samples from eight coreholes were studied for this report (figs. 2-4). However, palynological samples were collected only from selected intervals of each cored section (figs. 3, 4). In the UAL area in the northern part of the region, the entire cored section was sampled, except for the weathered uppermost part, in

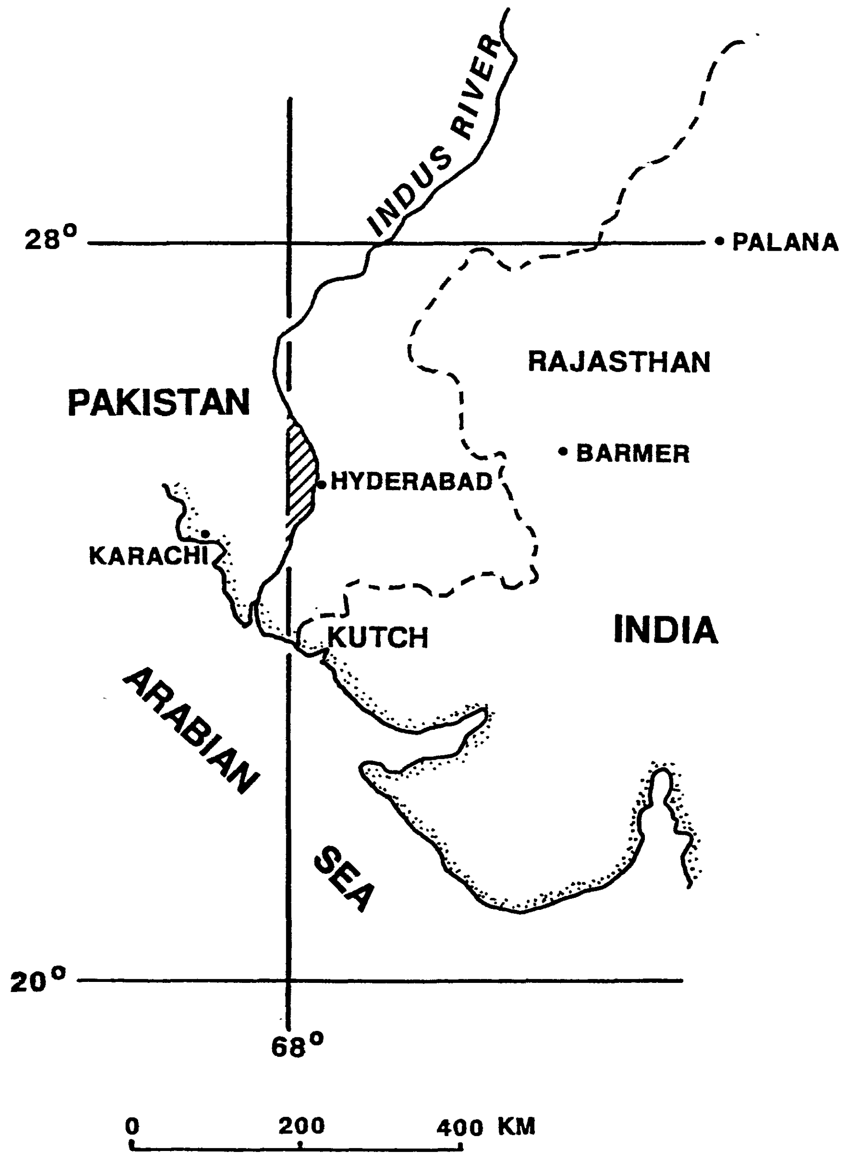

Figure 1. Map showing the location of the Lower Indus Basin, Sind Province, Pakistan, and comparison localities in western India (table 3). The shaded area is the Lower Indus coal region.

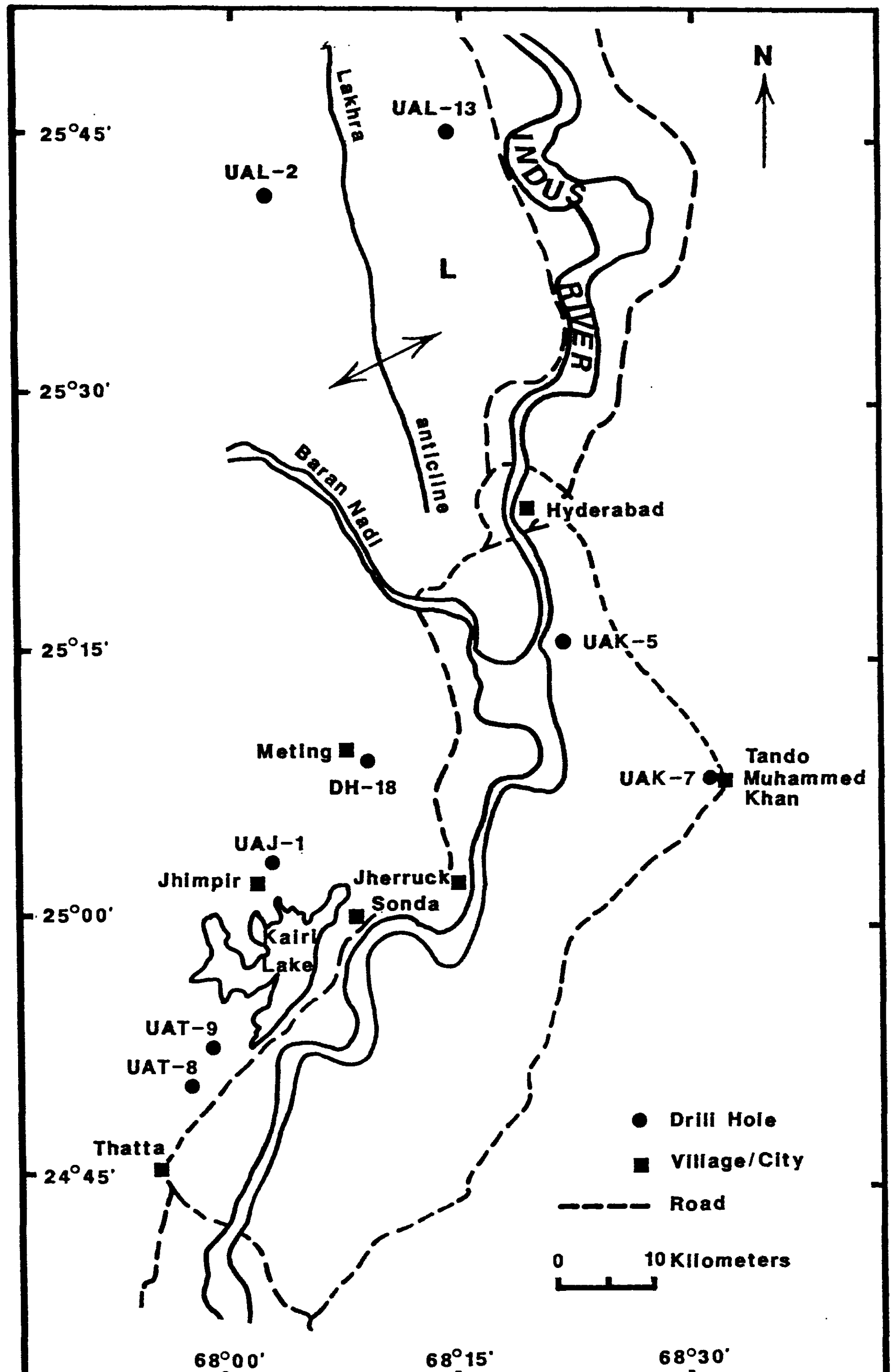

Figure 2. Map of southern Sind Province showing location of coreholes studied for this report. L = type area of the Lakhra Formation.

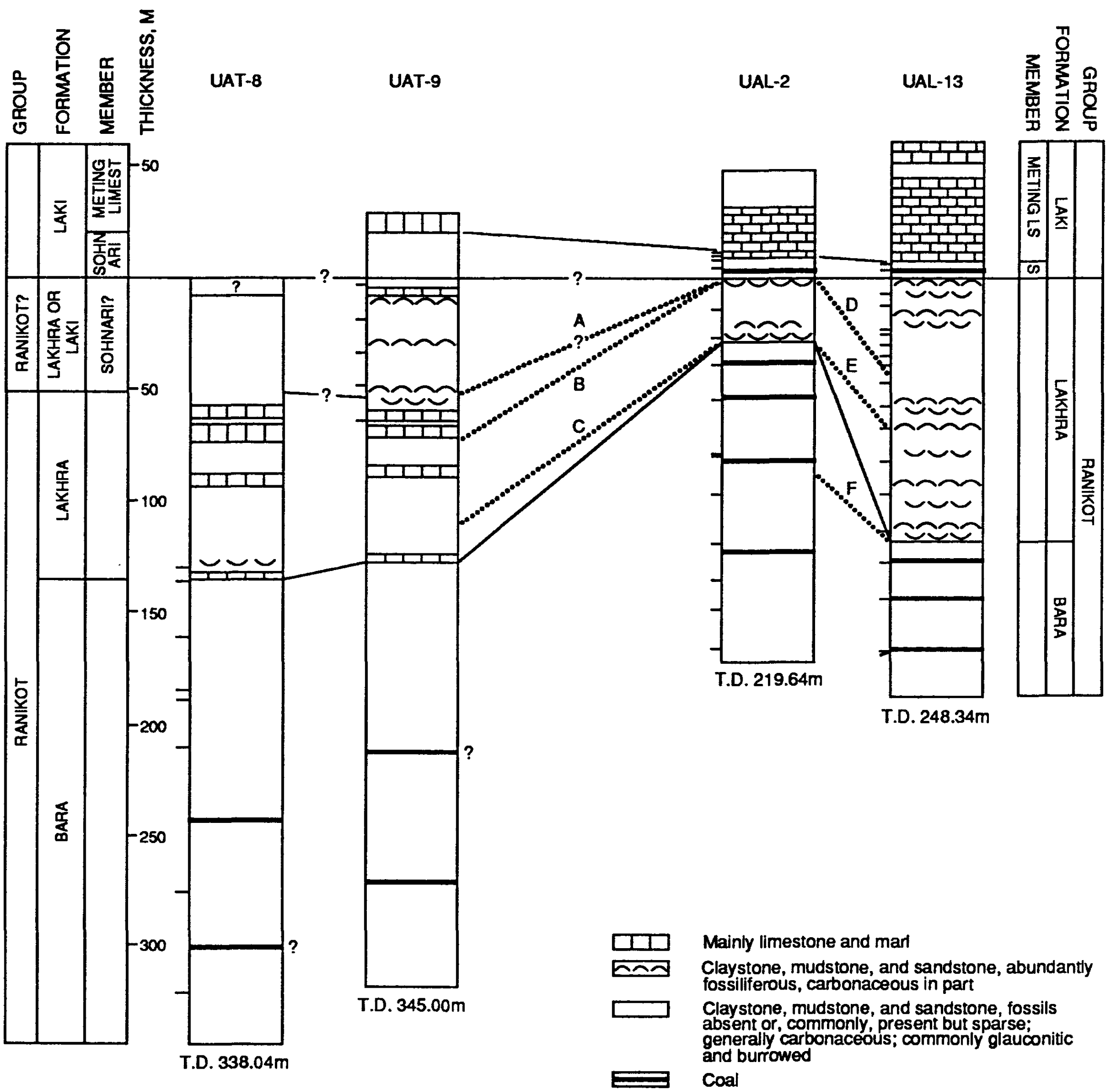

Figure 3. Stratigraphic columns for coreholes UAT-8, UAT-9, UAL-2, and UAL-13 showing correlations based on lithologic data (solid lines) and palynological data (dotted lines). Datum is the base of the Sohnari Member of the Laki Formation (assuming the Sohnari is relatively thin in the UAT area). Ticks show sample positions. In UAT-8, the thickness of the Lakhra-Sohnari interval was estimated based on the thickness of the interval in UAT-9.

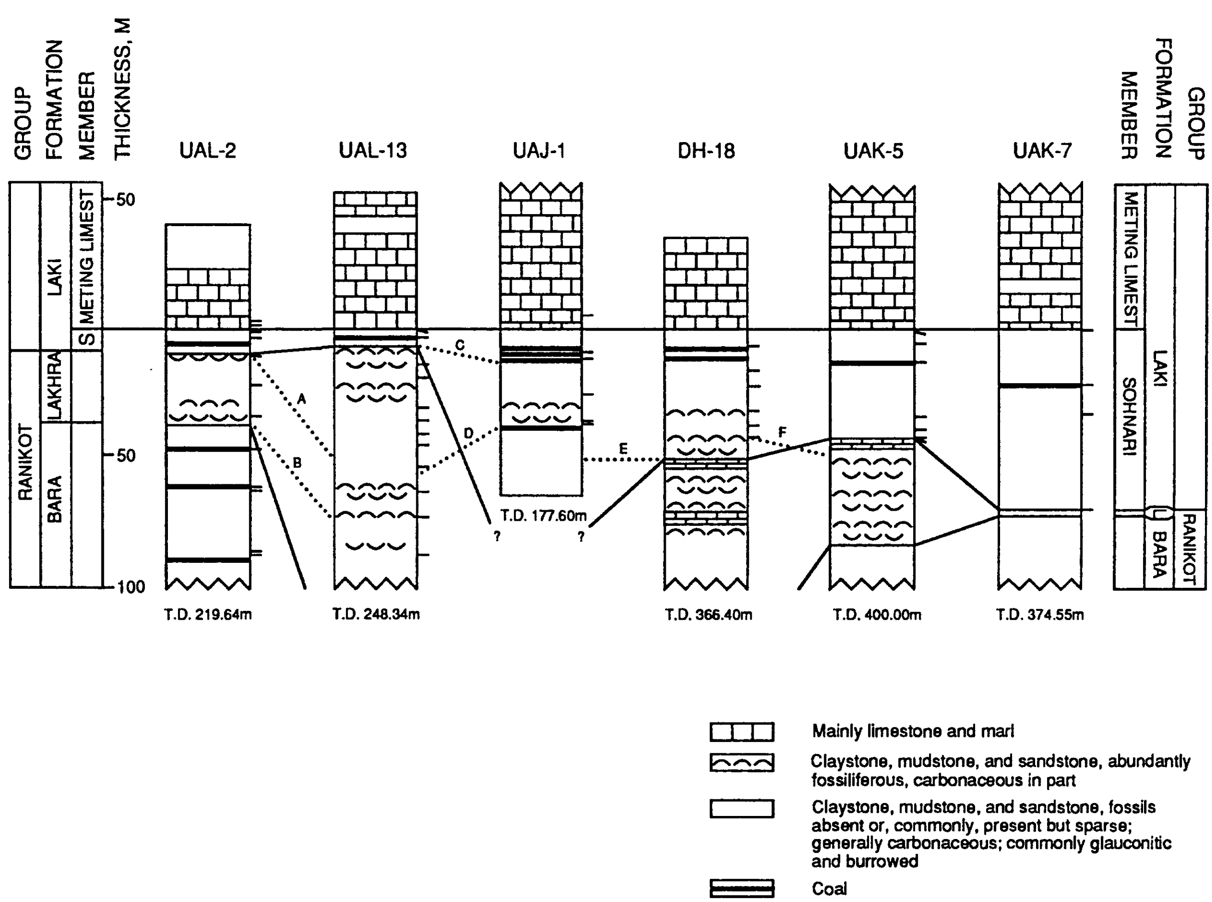

Figure 4. Stratigraphic columns for the Sohnari Member of the Laki Formation and adjacent strata in coreholes UAL-2, UAL-13, UAJ-1, DH-18, UAK-5, and UAK-7 showing correlations based on lithologic data (solid lines) and palynological data (dotted lines). Palynological correlation lines A and B in figure 4 are the same as palynological correlation lines D and E in figure 3. Datum is the top of the Sohnari Member of the Laki Formation. Ticks show sample positions.

each corehole. In a composite section formed of coreholes UAT-8 and UAT-9, in the southwestern part of the region, the Bara and Lakhra Formations were sampled, and perhaps also part of the Sohnari Member of the Laki Formation (depending on how the Lakhra and Sohnari are defined in that area) (see table 1); in the remaining four coreholes, the Sohnari, and its boundary with the underlying Lakhra, were of main interest.

Correlations in this report are based on observed stratigraphic distributions of pollen species in each of the eight coreholes examined (tables 4-10). As will be explained in the section on "Method of Graphic Correlation," the critical data points for correlation are the range bases and range tops of the species, which are displayed in the graphic correlation diagrams (figs. 5, 7-11). For most of the species listed in these tables, only presences or absences are noted; however, for the *Retistephanocolpites* group, I counted individuals of each "species" within the group.

Nearly all unweathered core samples examined for this paper from the Bara Formation, Lakhra Formation, and Sohnari Member of the Laki Formation contained abundant, well preserved pollen. However, nearly all unweathered samples from the Meting Limestone Member and Meting Shale Member of the Laki Formation (from coreholes UAL-2 and UAK-5) were barren of pollen.

No pollen recognized as reworked was observed in the samples. This is not surprising considering that the source of the late Paleocene sediments in southeastern Pakistan is thought to have been the Indian Shield (Hunting Survey Corporation, 1961).

Sixty-three pollen taxa are mentioned in this report. They are listed in table 2.

Table 1. Paleocene and lower Eocene stratigraphic units of the Lower Indus coal region. Thicknesses from Nuttall (1925), Hunting Survey Corporation (1961), Ghani and others (1973), Cheema and others (1977), Husain (1986), and Akhtar and others (1988).

Unit	Thickness (m) in study region
Laki Formation	125-244
Laki Limestone Member	60-183
Meting Shale Member	29
Meting Limestone Member	43
Sohnari Member	0-71
Ranikot Group	540-670
Lakhra Formation	1.8-244
Bara Formation	305-914
Khadro Formation	61-180

Table 2. List of pollen species.

Species number	Formal name (pending further taxonomic study)
1	*Milfordia minima* Krutzsch 1970 + *M. hungarica* (Kedves 1965) Krutzsch & Vanhoorne in Krutzsch 1970
3	*Psilodiporites hammenii* Varma & Rawat 1963
5	*Psilodiporites erdtmanii* (Varma & Rawat 1963) Venkatachala & Rawat 1972
7	*Triporopollenites* sp. A
9	*Triporopollenites* sp. B
11	*Triatriopollenites* sp. A
13	*Triatriopollenites* sp. B
15	*Triatriopollenites?* sp. C
17	"*Myricaceoipollenites dubius*" Venkatachala & Kar 1972
19	aff. "*Tricolporipites tiliaceaeformis*" Biswas 1962
21	*Cricotriporites* sp. A
23	"*Tricolporipites jerdoni*" Biswas 1962
25	*Echitriporites trianguliformis* van Hoeken-Klinkenberg 1964
27	*Triangulorites triradiatus* (Saxena 1979) Kar 1985
29	*Triangulorites bellus* (Sah & Kar 1970) Kar 1985
31	*Triangulorites* sp. A
33	*Proxapertites* sp. A (psilate)
35	*Proxapertites assamicus* (Sah & Dutta 1966) Singh 1975
37	*Proxapertites operculatus* (van der Hammen 1954) van der Hammen 1956

39 *Proxapertites cursus* van Hoeken-Klinkenberg 1966

41 *Assamialetes emendatus* Singh 1975 emend. Singh & Tripathi 1986

43 *Spinizonocolpites prominatus* (McIntyre 1965) Stover & Evans 1973

45 *Spinizonocolpites* sp. A

47 *Grimsdalea* sp. A

49 *Incrotonipollis burdwanensis* (Baksi, Deb, & Siddhanta 1979) Baksi in Jansonius & Hills 1981

51 *Incrotonipollis neyvelii* (Baksi, Deb, & Siddhanta 1979) Baksi in Jansonius & Hills 1981

53 *Longapertites* sp. A (psilate)

55 *Longapertites* sp. B (punctate)

57 *Longapertites retipilatus* Kar 1985

59 *Longapertites* sp. C (reticulate)

61 *Longapertites* sp. D (reticulate)

63 *Longapertites* sp. E, aff. *Quilonipollenites sahnii* Rao & Ramanujam 1978

65 *Longapertites* sp. F (reticulate)

67 *Retimonosulcites ovatus* (Sah & Kar 1970) Kar 1985

69 *Matanomadhiasulcites maximus* (Saxena 1979) Kar 1985

71 *Matanomadhiasulcites* sp. A

73 *Brevitricolpites* sp. A

75 *Intrareticulitis brevis* (Sah & Kar 1970) Kar 1985

77 *Retitrescolpites* sp. A

79 *Retitrescolpites* sp. B

81 New genus A (tricolpate, baculate) sp. A

83 New genus A (tricolpate, baculate) sp. B

85 New genus A (tricolpate, baculate) sp. C

87 New genus B (tricolpate, geniculate) sp. A

89 *Porocolpopollenites* aff. *P. ollivierae* (Gruas-Cavagnetto 1976) Frederiksen 1983

91 cf. *Porocolpopollenites*, sp. A

93 *Callophyllumpollenites* cf. *C. rotundus* Sah & Kar 1974

95 *Yeguapollis* sp. A

97 *Spinaepollis* sp. A

99 Normapolles n. gen. C sp. A

101 *Cupanieidites* aff. *C. flabelliformis* Venkatachala & Rawat 1972

103 *Cupanieidites flaccidiformis* Venkatachala & Rawat 1972

105 *Cupanieidites* sp. A

107 *Iugopollis tetraporites* Venkatachala & Rawat 1972

109 *Polygalacidites clarus* Sah & Dutta 1966

111 New genus D (stephanocolporate, unornamented poles) sp. A

Retistephanocolpites spp.

113	4-colpate
115	5-colpate
117	6-colpate
119	7-colpate
121	8-colpate
123	9-colpate
125	10-colpate

PALYNOLOGICAL MATERIALS AND METHODS

The samples discussed in this report were processed using normal palynological techniques of HCl; HF; HNO_3; short centrifugation with soapy water to remove fines; heavy liquid separation using a $ZnCl_2$ liquid of 1.8 s.g.; staining with Bismark brown; and screening on 10 µm sieves. The residues were mounted in glycerine jelly.

METHOD OF GRAPHIC CORRELATION

The principles and practice of graphic correlation have been described in detail in previous papers (Shaw, 1964; Miller, 1977; Edwards, 1984, 1989; Frederiksen, 1988a), but a brief explanation is given here of some aspects of the method.

Graphic correlation diagrams are plots and interpretations of biostratigraphic and lithologic events. A biostratigraphic event is either a species range top or a range base; such events displayed in this paper (figs. 5, 7-11) are based on the original occurrence data for each pollen species in each stratigraphic section (tables 4-10). Lithologic events can be based on various kinds of stratigraphic and geophysical data (Edwards, 1989), but in this paper the only lithologic events shown on the graphic correlation diagrams are contacts between lithostratigraphic units.

Conventional symbols for biostratigraphic events are o (range base) and + (range top). Next to each biostratigraphic event symbol is an event number by which the kind of event (range base or top) and the species may be identified. In table 2, each species is given an odd numbered designation; in the graphic correlation diagrams, range bases are identified by the species number, and range tops are identified by the next higher integer than the species number. For example, *Proxapertites cursus* is species 39; the range base of this species in any particular section is event 39, and the range top of the species is event 40.

Evaluation of each event is very important. What is most desirable is a species that occurs in many samples between its range base and its range top, because then it is possible to have more confidence that the observed range base and top of that species are close to being near the true stratigraphic positions of the events. In the diagrams, I have used this criterion (high degree of sample presence) to identify certain events as being more significant than the others, and I have placed an asterisk next to the event number for each of these presumably high-quality events.

Error boxes are drawn for some events. An error box represents the area on the graph within which the true range top or base is most likely to occur (Edwards, 1984). In most of the diagrams of this paper, error boxes are only used for high-quality events.

On a graphic correlation diagram, two stratigraphic sections are arranged at right angles to each other. One of the main purposes of such diagrams is to correlate among sections, two at a time; however, one or both of these sections may be composite sections.

To plot a range top of a particular species, the sample is noted that has the topmost occurrence of the species in the section represented by the horizontal axis of the chart; likewise, the sample is noted that has the topmost occurrence of the same species in the section represented by the vertical axis. An imaginary line is drawn upward from the sample on the horizontal axis and toward the right from the sample on the vertical axis, and where the two imaginary lines cross, an event symbol is plotted. A similar procedure is used to plot the positions of range bases on the diagram. Thus, a graphic correlation diagram is basically a simple XY graph.

The means of depicting an interpreted correlation between sections is by drawing a line of correlation (LOC) through the array of event points and error boxes; in a general way, the line will extend from lower left to upper right on the chart because the base of each of the two sections being compared is in the lower left corner.

In theory, the significance of the line of correlation is that, if it is correctly drawn, one can correlate any stratum of one section with a particular stratum in the other section. For example, one could pick a stratum in the section represented by the horizontal axis, go vertically up to the LOC, then proceed straight left, and where this imaginary line touches the vertical axis, that stratum of the vertical axis should be correlative with the stratum picked on the horizontal axis.

The line of correlation in a graphic correlation diagram also can be used to combine two sections into a single composite section, as is done in figure 7, where a composite palynostratigraphic section is formed from UAL-2 and UAL-13 using the line of correlation in figure 5.

STRATIGRAPHY

Paleocene and lower Eocene strata in the Lower Indus coal region are assigned to the Ranikot Group and the Laki Formation (table 1). The lowermost formation of the Ranikot Group is the Khadro Formation (*Cardita beaumonti* beds of early authors) of early Paleocene and perhaps latest Cretaceous age (Krishnan and others, 1957; Williams, 1959; Cheema and others, 1977); the Khadro Formation was not studied for this report.

The Bara and Lakhra Formations, which overlie the Khadro Formation, have been described in several papers mainly on the basis of outcrops (for example, Nuttall, 1932; Hunting Survey Corporation, 1961; Cheema and others, 1977) but have become much better known as a result of drilling in the study region (Ghani and others, 1973; Warwick and others, 1987). The Bara Formation ("Lower Ranikot" of early authors) appears to represent largely nonmarine to brackish-water deposition. It consists mainly of sandstone, siltstone, shale, and coal. The detrital rocks are commonly carbonaceous and pyritic, and some detrital strata are varyingly calcareous, glauconitic, burrowed, and shelly.

The Lakhra Formation ("Upper Ranikot" of early authors) appears to represent largely brackish-water to shallow marine deposition. It contains some carbonaceous detrital strata like the Bara, but the distinctive rocks of the Lakhra are foraminiferal limestone, marl, and shell hash beds; the Lakhra is, on the average, much more calcareous and shelly than the Bara. In much of the study area, the Lakhra is delimited by its uppermost and lowermost limestone beds (figs. 3, 4), but in the northern part of the region, in the UAL area (figs. 2, 3), the Lakhra is delimited by its uppermost and lowermost shell-rich beds.

The contact between the Bara Formation and the Lakhra Formation appears to be conformable. Indeed, because some strata of the two formations are very similar to each other, the two formations may be thought of as interfingering with each other near their contact; thus, the placement of a contact between these formations at the lowest limestone or shell bed of the Lakhra is somewhat arbitrary. The lower and upper contacts of the Lakhra Formation may also be defined differently in a particular area depending on whether the definition depends on outcrop, core, or geophysical data (J. R. SanFilipo, oral commun., 1989).

Overlying the Ranikot Group is the Laki Formation (Laki Series, Laki Group, or Laki Limestone of early authors), which has been described by Nuttall (1925), Hunting Survey Corporation (1961), Ghani and others (1977), Cheema and others (1973), Thomas and others (1988), and Outerbridge and others (in press). This formation consists of four members, in ascending order the Sohnari, Meting Limestone, Meting Shale, and Laki Limestone Members.

The Sohnari Member of the Laki Formation* was termed the Basal Laki Laterite by early authors; the name is also spelled Sonhari Member by, for example, Shah (1977, fig. 8), Husain (1986), and Frederiksen (1988b). In outcrop, the Sohnari Member is mainly ferruginous clay and sandstone, but in the subsurface it is mainly carbonaceous shale, sandstone, and coal, very similar in general

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*The Sohnari Member of the Laki Formation is now considered to be a separate formation, part of the Ranikot Group (Outerbridge and others, in press), but this new stratigraphic terminology could not be incorporated into the present report.

lithology to the Bara Formation. The Meting Limestone and Laki Limestone Members are similar to each other lithologically; they consist mainly of light-colored massive to thin-bedded limestone and marl containing abundant large foraminifers. The Meting Shale Member is mainly limestone containing larger foraminifers, interbedded with shale.

At individual outcrops or in individual cores, no unconformity is evident between the Lakhra Formation and the overlying Sohnari Member of the Laki Formation. However, Nuttall (1932) and Ghani and others (1973) observed that progressively older rocks of the Ranikot Group directly underlie the Sohnari Member northward in the region and particularly in the area of the Lakhra anticline (fig. 2); thus, these authors concluded that an unconformity exists between the Lakhra and Sohnari particularly in the northern part of the region. Nuttall (1932) considered that the Lakhra-Sohnari unconformity resulted from slight tilting and then erosion of the Lakhra Formation in pre-Sohnari time. Ghani and others (1973, p. 18) pointed out that "little or no angular discordance can be seen at the contact" of the Lakhra and Sohnari at individual localities, but in the northern half of the Lower Indus coal region, they measured what they considered to be an erosional dip of about 0.3° northward on the top of the Lakhra Formation. Hunting Survey Corporation (1961) suggested, alternatively, that lack of upper Lakhra strata in the northern part of the region might have been due in part to nondeposition during a period of gentle uplift in the region.

AGE

The Bara and Lakhra Formations have long been known to be Paleocene in age, mainly on the basis of larger foraminifers (e.g., Khan, 1957; Williams, 1959; Hunting Survey Corporation, 1961; Cheema and others, 1977). Earlier workers since the time of Nuttall (1925, 1926) considered the entire Laki Formation to be early Eocene in age, but recently the Sohnari Member and the overlying lowermost limestone beds of the Laki have been shown on the basis of planktic foraminifers to be late Paleocene (Mohan, 1982; Usmani, 1983).

In most of the Lower Indus basin, the lowest limestone of the Laki Formation that overlies the Sohnari Member is considered to belong to the Meting Limestone Member of the Laki. However, Nuttall (1925) concluded that in the northern part of the basin, for example in the UAL area of the present report (fig. 2), the limestone above the Sohnari represents the Laki Limestone Member. He believed that the post-Sohnari parts of the Laki Formation were deposited by a transgressing sea onlapping northward over an erosion surface at the top of the Sohnari Member. Thus, Nuttall (1925) considered that an unconformity existed at the top of the Sohnari, and the Meting Limestone and Meting Shale Members were missing from the northern part of the basin because of nondeposition. Nuttall (1925) differentiated the Laki Limestone Member from the Meting Limestone Member because they appeared to have different faunas (mainly of larger foraminifers), but at the same time he noted that the differences were slight. Usmani (1983) studied planktic foraminifers from the lowermost limestone of the Laki Formation in the type area of the Lakhra Formation (fig. 2), that is, from rocks that Nuttall (1925) would presumably have assigned to the Laki Limestone Member. Usmani found the planktic foraminifers in these rocks to be late Paleocene in age, which suggests that the lowest part of the Laki Formation in the northern part of the region (including the UAL area) does belong to the Paleocene Meting Limestone Member.

Only two pollen-bearing samples were available from limestone overlying the Sohnari in the study region, and both samples were from UAL-2. These two samples contain only sparse pollen assemblages (table 4); however, none of the distinctive early Eocene pollen species from southwestern India (Kar, 1985) were found in these two samples, which appear to be Paleocene in age. Therefore, to the extent that negative data (nonappearance of certain species) can be trusted, pollen data support the probable presence of the Meting Limestone Member immediately overlying the Sohnari Member in the northern part of the coal region.

Table 3 lists pollen species that have been reported from Paleocene and lower Eocene rocks of western India (fig. 1) and which have also been found in the Bara Formation, the Lakhra Formation, and the Sohnari Member of the Laki Formation of Sind Province. Table 3 includes only a fraction of the species in both regions because my interest in the Pakistan samples is biostratigraphic; thus, I did not record or identify rare species or those difficult to identify consistently. Nevertheless, it is apparent that the Bara-Lakhra-Sohnari sequence has more species in common with Paleocene than with lower Eocene strata of western India, and it is not surprising that the largest similarity is with upper Paleocene strata of Kutch, not far east of Sind Province. In short, pollen data support planktic foraminiferal evidence that the entire Bara-Lakhra-Sohnari sequence is late Paleocene in age.

STRUCTURE

The most conspicuous structure in the study area (fig. 2) is the Lakhra anticline, a doubly plunging symmetrical structure having dips on the flanks as steep as 6° (Ghani and others, 1973). Several small north-striking anticlines and synclines and steep dip-slip faults are also present in the region, but in most areas of the region, dips of the strata are generally 2° or less (Nuttall, 1925; Ghani and others, 1973).

CORRELATIONS

UAL-2 and UAL-13

Coreholes UAL-2 and UAL-13 are in the northern part of the Lower Indus coal region; UAL-13 is 20.4 km east-northeast of UAL-2 (fig. 2). Eighteen samples were analyzed from UAL-2, including samples from the Bara Formation, the Lakhra Formation, the Sohnari Member of the the Laki Formation, and from limestone overlying the Sohnari Member that, as stated previously, probably represents the Meting Limestone Member of the Laki Formation. Nineteen samples were analyzed from UAL-13, including samples from the Bara Formation, the

Table 3. Pollen species in the Bara Formation, the Lakhra Formation, and the Sohnari Member of the Laki Formation of southern Pakistan and also in some formations of western India. Indian data from Jain and others (1973), Kar (1985), and Sah and Kar (1974).

Species	Palana, Rajasthan (lower Eocene)	Naredi Fm., Kutch (lower Eocene)	Barmer, Rajasthan (Paleocene)	Matanomadh Fm., Kutch (Paleocene)
Callophyllumpollenites rotundus	?			
Cupanieidites granulatus			?	
Intrareticulitis brevis		X	X	X
Matanomadhiasulcites kutchensis				X
Matanomadhiasulcites maximus				X
Polygalacidites clarus			X	
Proxapertites assamicus	X			X
Proxapertites cursus			X	
Proxapertites operculatus	X	X	X	X
Retistephanocolpites spp.	X	X	X	X
Spinizonocolpites prominatus		X		X
Triangulorites bellus		X		X
Triangulorites triradiatus			X	X

Lakhra Formation, and the Sohnari Member of the Laki Formation. The detailed pollen occurrence data are shown in tables 4 and 5.

Figure 5 is a graphic correlation diagram for coreholes UAL-2 and UAL-13. UAL-2 is west of the Lakhra anticline and UAL-13 is east of it (fig. 2). However, if the Lakhra anticline is no older than Pleistocene in age (Outerbridge and Khan, 1989), it did not affect sedimentation during late Paleocene time.

An obvious feature of the two sections is that the Lakhra Formation is much thinner in UAL-2 than in UAL-13 (fig. 3). Three possible explanations for this phenomenon are that (1) part of the Lakhra in UAL-2 is missing by unconformity; (2) there is a facies change between the two coreholes, that is, some rocks assigned on lithologic grounds to the Lakhra Formation in UAL-13 are represented by Bara-facies rocks in UAL-2 (fig. 6); and (3) the Lakhra Formation in UAL-2 was deposited at a much slower rate in the UAL-2 area than in the UAL-13 area, that is, that the Lakhra represents a very condensed section in UAL-2.

From the array of palynological event points in figure 5, and from the lithologic data indicating little change in thickness of the Sohnari Member between UAL-2 and UAL-13 (fig. 3), it seems clear that the line of correlation bends at least twice in the upper part of the Bara-Lakhra-Sohnari section in figure 5; therefore, I have drawn the line of correlation as having three segments, labeled LOC-1, LOC-2, and LOC-3. These abrupt changes in slope of the line of correlation mean that, late in Paleocene time, the rate of deposition in the UAL-2 area changed greatly at least twice relative to the rate of deposition in the UAL-13 area.

Segment LOC-1 shows correlation of the lower part of the cored sections in UAL-2 and UAL-13. The line is drawn to intersect the maximum number of error boxes, with particular attention to error boxes of events thought to be of higher quality.

Most of the events in the upper right corner of the diagram are species range tops, but a few are range bases. In UAL-13, many species have range tops in the upper part of the section, but the tops are not all at one horizon; rather, the species drop out gradually upsection, mainly within the relatively thick interval from 118.61-118.67 m to 68.62-68.69 m depth, that is, within the interval from the middle of the Lakhra Formation to the lowermost part of the Sohnari Member of the Laki Formation. In contrast, in UAL-2, there is a distinct concentration of range tops in the sample from 51.03-51.11 m depth (uppermost part of the Lakhra Formation). If the position of LOC-1 on the diagram is reasonably correct, then it appears that LOC-2 must have a very steep slope (representing a very condensed uppermost Lakhra to lower Sohnari section in UAL-2), or LOC-2 may well be vertical on the diagram (representing an unconformity in UAL-2). The exact position of LOC-2 is uncertain because no samples were available between the uppermost part of the Lakhra and the middle part of the Sohnari in UAL-2. In the diagram, I have chosen what seems to me to be the most likely correlation between UAL-2 and UAL-13, and I have shown LOC-2 as being a vertical line that follows the contact between the Lakhra and the Sohnari in UAL-2 (vertical dashed line in the diagram). It cannot be determined from the pollen occurrence data whether the upper and lower boundaries of the Sohnari are diachronous; LOC-3 is a

Table 4. Pollen occurrence data in samples from corehole UAL-2.

BARA											L			LAKI				FORMATION
														S		ML		MEMBER
B4071 R	B4071 Q	B4071 P	B4071 N	B4071 M	B4071 L	B4071 K	B4071 J	B4071 I	B4071 H	B4071 G	B4071 F	B4071 E	B4071 D	B4243 A	B4071 C	B4071 B	B4071 A	SAMPLE
214.23-214.35	197.13-197.19	183.48-183.54	167.57-167.87	144.95-145.03	129.10-128.13	127.87-127.90	127.16-127.19	102.45-102.51	101.78-101.80	87.37-87.42	74.82-74.88	62.74-62.79	51.03-51.11	43.57	40.30-40.37	38.64-38.72	38.98-37.07	DEPTH,M.
·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	X	1 - Milfordia minima + M. hungarica
·	·	·	·	X	·	·	·	X	·	·	X	·	X	X	X	X	X	3 - Psilodiporites hammenii
X	·	·	·	·	·	·	·	·	·	X	X	X	·	·	·	·	·	5 - Psilodiporites erdtmanii
·	·	·	·	·	X	·	X	·	·	·	X	·	X	·	X	·	·	7 - Triporopollenites sp. A
·	X	·	X	·	·	·	·	·	·	X	·	X	·	·	·	·	·	9 - Triporopollenites sp. B
·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	X	·	X	11 - Triatriopollenites sp. A
X	X	X	X	X	X	·	X	·	·	X	X	·	X	·	·	·	·	13 - Triatriopollenites sp. B
·	·	·	·	·	X	·	·	·	·	·	X	·	X	·	·	·	·	15 - Triatriopollenites? sp. C
·	·	X	X	·	X	X	X	·	·	·	·	·	·	X	X	·	X	17 - "Myricaceoipollenites dubius"
·	·	·	·	·	·	·	·	·	·	·	·	·	·	X	X	·	·	19 - Aff. "Tricolporipites tiliaceaeformis"
·	·	·	·	·	·	·	·	·	·	·	·	X	·	·	?	·	X	21 - Cricotriporites sp. A
X	X	X	X	X	·	·	X	X	X	X	X	X	·	X	·	·	·	25 - Echitriporites trianguliformis
·	·	·	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	27 - Triangulorites triradiatus
·	·	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	·	29 - Triangulorites bellus
·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	X	31 - Triangulorites sp. A
·	·	·	X	·	·	·	·	·	·	·	·	·	X	·	·	·	·	33 - Proxapertites sp. A
X	X	·	X	X	·	X	X	X	X	X	X	X	X	X	X	·	X	35 - Proxapertites assamicus
·	X	X	·	·	·	·	·	·	·	X	·	·	·	·	·	·	·	37 - Proxapertites operculatus
·	·	·	X	X	X	·	X	·	·	X	X	·	X	·	·	·	·	39 - Proxapertites cursus
X	X	X	X	X	·	·	·	X	·	X	·	X	X	·	·	·	·	41 - Assamialetes emendatus
X	·	X	X	X	X	·	X	X	·	·	X	X	X	·	·	·	·	43 - Spinizonocolpites prominatus
·	·	X	X	·	·	·	·	·	·	·	·	·	·	·	·	·	·	45 - Spinizonocolpites sp. A
·	X	·	·	·	·	·	·	·	·	·	X	·	·	·	·	·	X	47 - Grimsdalea sp. A
·	·	·	X	·	·	·	·	X	·	·	·	·	X	·	·	·	·	49 - Incrotonipollis burdwanensis
X	·	·	X	·	·	·	·	·	·	·	·	·	·	·	·	·	·	51 - Incrotonipollis neyvelii
·	X	·	X	·	X	·	·	·	·	·	·	·	X	·	·	·	·	53 - Longapertites sp. A
·	·	X	X	X	·	·	·	·	·	X	X	X	X	·	·	·	·	55 - Longapertites sp. B
X	·	·	·	X	X	·	·	X	·	X	X	X	·	·	·	·	·	57 - Longapertites retipilatue
·	·	X	X	·	·	·	X	·	·	·	X	·	X	·	·	·	·	59 - Longapertites sp. C
·	·	·	·	·	X	·	·	·	·	·	·	·	X	·	·	·	·	61 - Longapertites sp. D
·	·	X	X	X	X	·	X	·	X	·	X	·	X	·	X	·	·	65 - Longapertites sp. F
·	·	·	·	X	X	P	·	P	·	P	·	X	·	·	·	·	·	69 - Matanomadhiasulcites maximus
·	·	·	·	·	·	·	·	·	·	·	·	X	·	·	X	·	·	71 - Matanomadhiasulcites sp. A
·	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	·	X	73 - Brevitricolpites sp. A
·	X	·	X	·	·	·	·	·	·	·	·	·	?	X	X	·	X	75 - Intrareticulitis brevis
·	·	·	·	X	X	X	X	X	·	X	X	X	X	·	·	·	·	77 - Retitrescolpites sp. A
·	·	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	·	79 - Retitrescolpites sp. B
·	X	X	X	·	·	X	X	·	·	X	·	X	X	·	X	·	·	81 - New genus A, sp. A
X	·	·	·	X	·	·	·	X	·	·	X	·	·	·	·	·	·	83 - New genus A, sp. B
·	·	·	·	·	·	·	·	·	·	·	·	·	X	X	·	·	·	85 - New genus A, sp. C
·	·	·	·	·	·	·	·	·	·	X	X	·	·	·	·	·	·	87 - New genus B, sp. A
X	·	·	X	X	X	X	X	X	·	·	·	·	X	X	·	·	X	89 - Porocolpopollenites aff. P. ollivierae
·	·	X	X	·	X	·	·	X	·	X	X	·	·	·	·	·	·	91 - Cf. Porocolpopollenites, sp. A
·	·	X	·	·	·	·	·	·	·	X	·	·	X	·	·	·	·	93 - Callophyllumpollenites cf. C. rotundus
·	·	X	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	95 - Yeguapollis sp. A
·	X	X	X	X	·	·	X	·	·	X	·	X	·	·	·	·	·	101 - Cupanieidites aff. C. flabelliformis
X	·	·	X	X	X	X	·	X	·	X	X	X	X	X	·	·	·	103 - Cupanieidites flaccidiformis
·	·	·	X	·	X	·	·	X	·	·	X	X	·	·	·	·	·	105 - Cupanieidites sp. A
·	·	·	·	X	X	·	·	·	·	·	·	·	X	X	·	X	X	107 - Iugopollis tetraporites
·	·	·	·	X	·	·	·	·	·	·	·	X	X	·	·	·	·	109 - Polygalacidites clarus
·	·	·	·	·	·	·	·	·	·	X	·	·	·	·	·	·	·	111 - New genus D sp. A
·	·	1	·	·	·	·	·	·	·	·	·	·	·	·	1	·	·	115 - Retistephanocolpites 5-colpate
3	1	7	2	1	1	·	6	1	·	2	1	2	3	1	·	·	2	117 - Retistephanocolpites 6-colpate
·	·	1	·	·	1	·	·	·	·	·	1	·	1	·	2	·	·	119 - Retistephanocolpites 7-colpate
·	·	·	·	·	·	·	·	·	·	·	·	·	1	·	·	·	·	121 - Retistephanocolpites 8-colpate

Table 5. Pollen occurrence data in samples from corehole UAL-13.

FORMATION	BARA				LAKHRA												LAKI		
MEMBER																	SOHN-ARI		
SAMPLE	R4054 R	R4054 Q	R4054 P	R4054 N	R4054 M	R4054 L	R4054 K	R4054 J	R4054 I	R4054 H	R4054 G	R4245 G	R4245 F	R4054 F	R4245 C	R4054 E	R4054 C	R4054 B	R4054 A
DEPTH,M.	228.37-228.41	227.36-227.42	204.91-204.96	187.80-187.85	174.00-174.07	158.04-158.10	143.00-143.03	128.01-128.05	118.61-118.67	108.43-108.50	100.00-100.07	95.83-95.93	90.72-90.81	86.10-86.16	73.66-73.74	68.62-68.69	57.25-57.30	57.10-57.15	54.88-54.93
1 - Milfordia minima + M. hungarica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X
3 - Psilodiporites hammenii	.	.	.	X	X	.	X	X	.	X	.	X	.	.	.	.	.	X	X
5 - Psilodiporites erdtmanii	.	.	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7 - Triporopollenites sp. A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	X	X
9 - Triporopollenites sp. B	.	.	.	.	X	.	.	.	.	.	.	.	.	.	X	.	.	.	.
11 - Triatriopollenites sp. A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	X	X
13 - Triatriopollenites sp. B	X	X	X	X	X	X	X	X	X	X	X	.	X	X	.	.	.	.	?
15 - Triatriopollenites? sp. C	.	.	.	?	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.
17 - "Myricaceoipollenites dubius"	.	X	X	.	.	.	.	.	X	.	.	.	.	.	.	.	X	X	.
19 - Aff. "Tricolporipites tiliaceaeformis"	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.	.	X
21 - Cricotriporites sp. A	.	.	.	.	X	.	.	.	.	.	.	.	.	.	X	.	X	X	X
25 - Echitriporites trianguliformis	X	X	.	X	X	X	X	X	X	X	X	X	X	X	X	X	.	.	.
27 - Triangulorites triradiatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.	.	X
29 - Triangulorites bellus	.	.	.	.	.	.	.	.	.	X	.	.	X	.	.	.	.	.	.
31 - Triangulorites sp. A	.	.	.	.	.	.	.	.	.	.	X	.	.	.	.	X	.	.	.
33 - Proxapertites sp. A	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
35 - Proxapertites assamicus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.	.	X
37 - Proxapertites operculatus	.	X	.	.	X	.	.	.	X	X	X	X	.	X	.	.	.	.	.
39 - Proxapertites cursus	.	.	.	X	X	X	X	X	X	.	.	.	.	.	.	.	.	.	.
41 - Assamialetes emendatus	.	X	.	X	X	X	X	X	X	X	X	X	X	.	.	.	.	.	.
43 - Spinizonocolpites prominatus	.	X	.	X	X	X	X	X	X	X	X	X	X	.	X	.	.	X	X
45 - Spinizonocolpites sp. A	.	.	.	X	X	.	X	X	X	X	.	X	X	.	.	.	.	.	.
47 - Grimsdalea sp. A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X
49 - Incrotonipollis burdwanensis	.	.	.	.	.	.	.	.	X	X	X	.	.	.	.	X	.	.	.
51 - Incrotonipollis neyvelii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	.	.	.
53 - Longapertites sp. A	X	.	.	X	.	.	X	.	.	.	.	.	X	.	.	.	.	.	.
55 - Longapertites sp. B	X	X	.	X	.	X	X	X	X	.	.	.	X	.	X	.	.	.	.
57 - Longapertites retipilatus	X	.	.	X	X	X	X	.	.	X	X	X	X	X	X	X	.	.	.
59 - Longapertites sp. C	X	.	.	X	X	X	X	X	.	.	X	.	.	.	.	.	.	.	X
61 - Longapertites sp. D	.	.	.	.	.	X	.	X	.	X	.	.	.	.	X	.	.	.	.
63 - Longapertites sp. E	.	.	.	X	.	X	.	.	X	X	X	.	.	.	.	.	.	.	.
65 - Longapertites sp. F	X	X	.	X	X	X	X	X	X	X	X	X	.	.	.	X	.	.	.
67 - Retimonosulcites ovatus	X	.	.	.	.	X	.	.	X	.	.	.	.	.	.	.	.	.	.
69 - Matanomadhiasulcites maximus	X	X	.	.	X	.	X	?	.	.	X	.	.	.	.	.	.	.	.
73 - Brevitricolpites sp. A	.	.	.	.	X	.	X	.	.	.	.	.	.	.	X	.	.	.	.
75 - Intrareticulitis brevis	.	.	.	.	.	.	.	.	.	.	.	.	X	.	X	X	X	X	X
77 - Retitrescolpites sp. A	.	.	X	X	.	X	.	.	.	X	X	.	.	.	.	.	.	.	.
79 - Retitrescolpites sp. B	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
81 - New genus A, sp. A	.	X	.	.	.	.	.	.	.	.	.	X	.	.	X	.	.	.	.
83 - New genus A, sp. B	.	.	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.
85 - New genus A, sp. C	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	X	.	.	.
87 - New genus B, sp. A	.	.	.	.	.	.	X	X	.	.	.	.	.	.	.	X	.	.	.
89 - Porocolpopollenites aff. P. ollivierae	.	X	.	X	X	X	X	X	X	.	?	.	.	.	.	?	.	.	.
91 - Cf. Porocolpopollenites, sp. A	X	.	.	X	X	X	X	X	.	?	.	.	X	.	X	X	.	.	.
93 - Callophyllumpollenites cf. C. rotundus	.	.	.	X	.	.	X	X	.	.	.	.	.	.	.	X	.	.	.
95 - Yeguapollis sp. A	.	.	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
97 - Spinaepollis sp. A	.	.	.	X	.	.	.	X	X	.	.	.	.	.	.	.	.	.	.
101 - Cupanieidites aff. C. flabelliformis	.	.	.	.	.	X	X	X	X	X	X	.	.	.	.	.	.	.	.
103 - Cupanieidites flaccidiformis	X	X	X	X	X	X	X	.	X	X	X	X	.	.	.	X	.	.	.
105 - Cupanieidites sp. A	.	X	.	.	X	.	.	.	X	.	.	.	.	X	X	X	.	.	.
107 - Iugopollis tetraporites	.	.	.	.	X	.	.	.	X	.	.	.	.	.	.	.	.	.	.
109 - Polygalacidites clarus	.	.	.	X	.	.	.	.	.	X	.	.	.	.	X	X	.	.	.
111 - New genus D sp. A	.	.	.	.	X	.	.	.	.	.	X	.	.	.	X	.	.	.	.
115 - Retistephanocolpites 5-colpate	1	.	.	1	.	.	.	.	1	.	1	.	.	.	.	1	2	.	1
117 - Retistephanocolpites 6-colpate	1	4	2	2	1	.	1	.	.	.	2	.	.	.	1	2	1	1	1
119 - Retistephanocolpites 7-colpate	.	.	.	2	.	1	.	1	1	.	1	.	.	.	.	1	.	.	.
121 - Retistephanocolpites 8-colpate	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	1	.
123 - Retistephanocolpites 9-colpate	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1
125 - Retistephanocolpites 10-colpate	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.

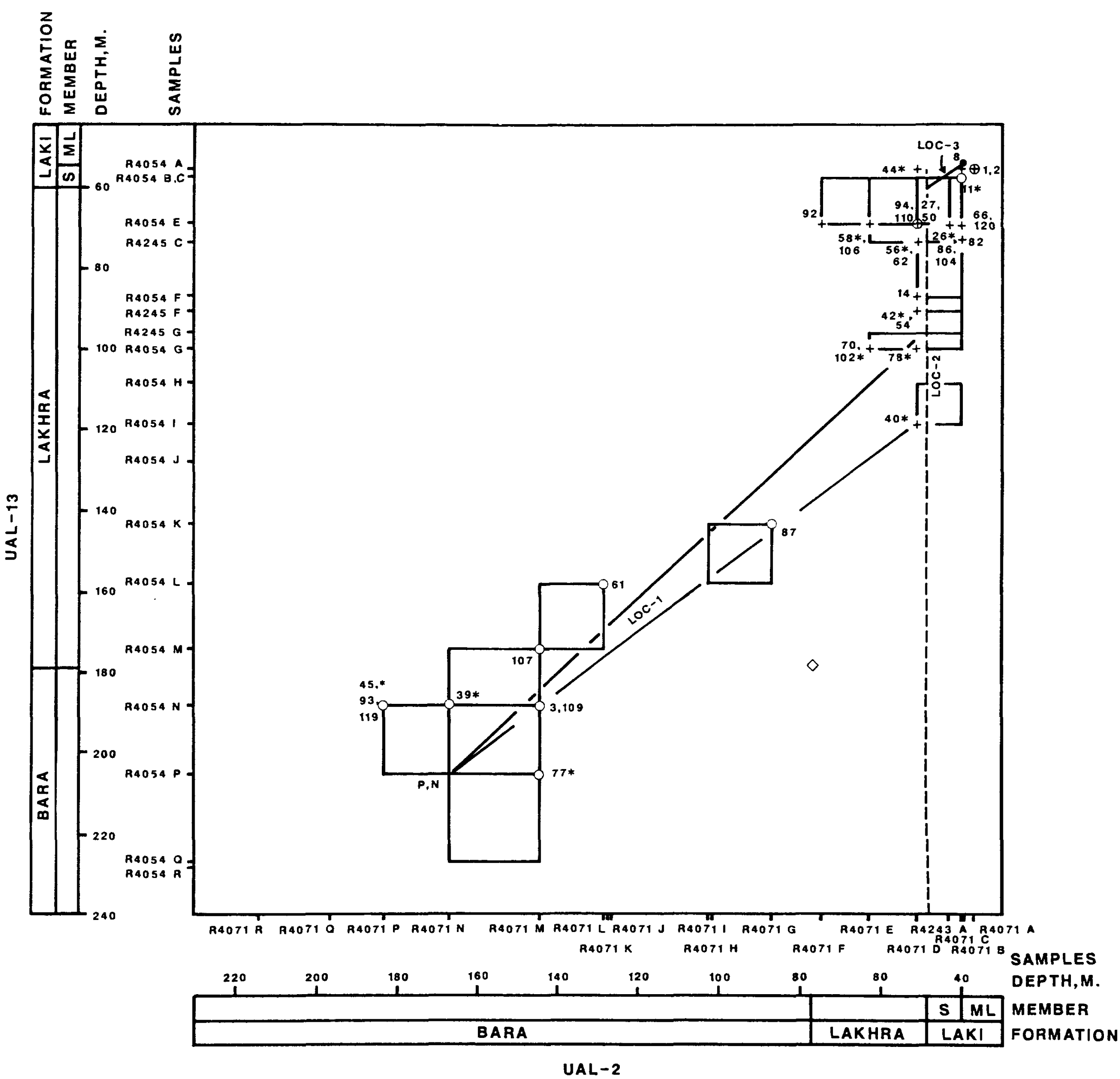

Figure 5. Graphic correlation diagram for coreholes UAL-2 and UAL-13. The vertical dashed line is the contact between the Lakhra Formation and the Sohnari Member of the Laki Formation in UAL-2. The diamond is the contact between the Bara Formation and the Lakhra Formation; the filled circle is the contact between the Sohnari and Meting Limestone Members of the Laki Formation. Point P, N is the intersection on the diagram of the positions of sample R4054P of UAL-13 and sample R4071N of UAL-2. ML = Meting Limestone Member; S = Sohnari Member.

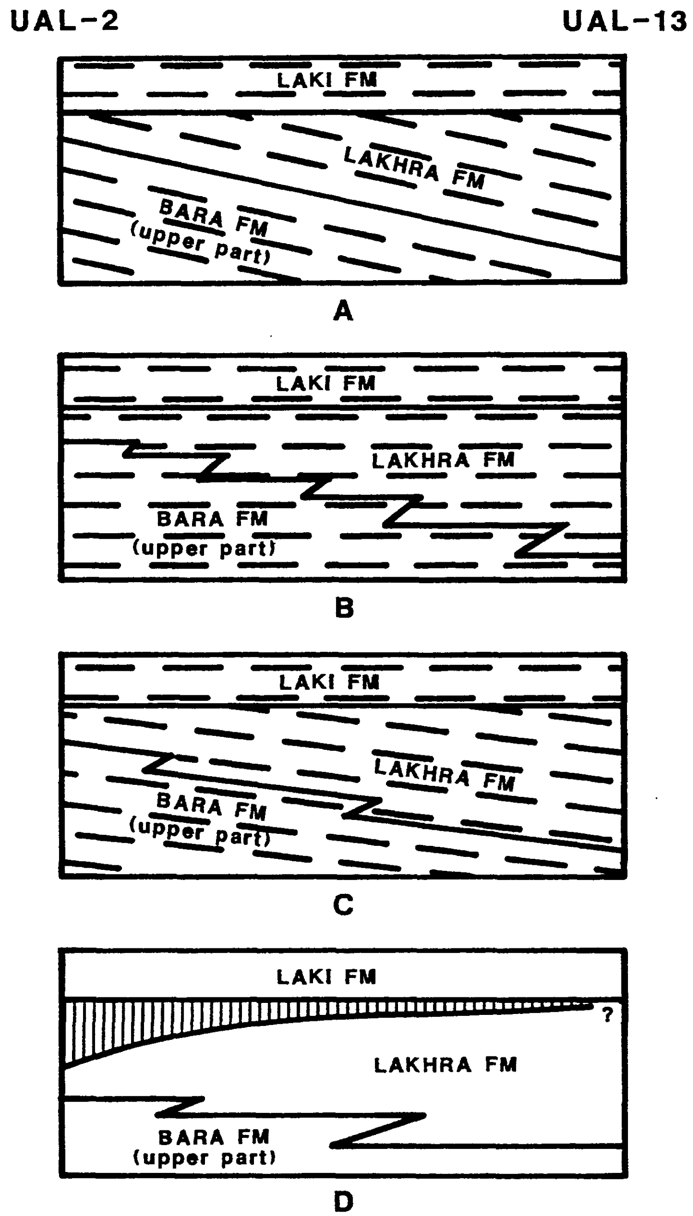

Figure 6. Possible explanations for the west-southwestward thinning of the Lakhra Formation between coreholes UAL-2 and UAL-13 in the northern part of the Lower Indus coal region. Dashed lines are inferred time lines. A, post-Lakhra, pre-Laki uplift and erosion; angular unconformity greatly exaggerated. B, late Paleocene, pre-Laki facies change due to marine transgression. C, combination of A and B: facies change followed by uplift and erosion. D, time-stratigraphic diagram showing the same interpretation as C; in this type of diagram, all horizontal lines are time lines.

speculative line of correlation that would be correct if the lower and upper contacts of the Sohnari were synchronous in the two coreholes.

As pointed out previously, only two sparsely pollen-bearing samples were available from limestone (probably the Meting Limestone Member of the Laki Formation) overlying the Sohnari in the UAL area. Therefore, the changes, if any, of pollen assemblages across the Sohnari-Meting Limestone Member boundary are poorly known.

Stratigraphic relations between coreholes UAL-2 and UAL-13 are easier to visualize in figure 3 than in figure 5. Figure 3 shows the two corehole sections side by side and has palynological correlation lines between the two sections based on the lines of correlation of figure 5. Figures 3, 5, and 6C-D suggest the following:

1. The upper part of the Bara Formation of UAL-2 is the same age as the lower part of the Lakhra Formation of UAL-13 (between palynological correlation lines E and F in fig. 3).
2. An unconformity is probably present between the Lakhra and Sohnari of UAL-2 such that strata equivalent to the upper part of the Lakhra of UAL-13 are missing (represented by a hiatus) in UAL-2 (between the datum line and palynological correlation line D in fig. 3). Between UAL-13 and UAL-2, the erosional dip on the top of the Lakhra is about 0.15° WSW; this contrasts with a generalized erosional dip of about 0.30° N on the top of the Lakhra measured by Ghani and others (1973) in the northern half of the Lower Indus coal region.
3. The uppermost coal beds in the Bara Formation of UAL-2 are younger than the uppermost Bara coal beds in UAL-13.

In short, the lines of correlation in figure 5 indicate that the Lakhra Formation is much thinner in UAL-2 than in UAL-13 due to both an unconformity and a facies change (fig. 6C-D). Thus, this study suggests that Nuttall (1932) and Ghani and others (1973) were only partly correct in their conclusion that the Lakhra Formation thins northward in the region because it was partly eroded away or was never deposited.

As pointed out previously, figure 5 shows a relative concentration of pollen range tops late in Lakhra time even in UAL-13. Two obvious possible explanations are as follows:

1. There was actually a normal, slow rate of plant extinction late in Lakhra time. The extinction rate only looks relatively fast because the upper Lakhra even of UAL-13 is a compressed section, that is, it represents a very slow rate of deposition or perhaps this interval has several small unconformities within it; or
2. The apparent rapid rate of plant extinction/migration late in Lakhra time is real, presumably caused by a rapid change in climate and (or) some other aspect of the environment.

In the absence of obvious small unconformities within the upper part of the Lakhra Formation of UAL-13, I favor the second of these alternatives. An unconformity might be present at the Lakhra-Sohnari contact in UAL-13 (fig. 6D), but insufficient pollen data are available to answer this question. The presence of a probable unconformity between the Lakhra and Sohnari in UAL-2 suggests that (1) no strata were deposited in the UAL-2 area late in Lakhra time, or (2) uplift and erosion in the UAL-2 area, at the end of Lakhra time but before the beginning of Sohnari time, removed strata of late Lakhra age from that region. As stated previously, upper Bara strata of UAL-2 appear to be a facies equivalent of early Lakhra strata of UAL-13. This means the sea transgressed over the UAL-13 area much earlier than over the UAL-2 area. After the Lakhra sea reached the UAL-2 area and marine deposition had occurred there for some time, there was uplift in the UAL-2 area that took place (1) during late Lakhra time (resulting in nondeposition) or (2) between Lakhra and Sohnari times (resulting in erosion of upper Lakhra strata).

Composite Section, UAL-2 + UAL-13

A composite palynological section for the UAL area was obtained by combining data from coreholes UAL-2 and UAL-13 based on the lines of correlation in figure 5, as follows:

1. LOC-1 was extended at a constant angle of slope downward and to the left from point P, N; that is, it was assumed that the ratio of rate of deposition in UAL-13 to the rate in UAL-2 was the same prior to P, N time as it was after this time.
2. It was assumed that an unconformity exists between the Lakhra Formation and the Sohnari Member of the Laki Formation in UAL-2 and that the upper and lower boundaries of the Sohnari are synchronous in the two coreholes, that is, it was assumed that the positions of lines of correlation LOC-2 and LOC-3 in figure 5 are correct.

The entire composite palynological section for the UAL area appears as the vertical axis of figure 7, and the upper part of this composite section also appears in several other graphic correlation diagrams. This composite section is scaled in composite units, which are arbitrary units used for reference; in the composite section for the UAL area, each composite unit is equal to 1 m of thickness in UAL-13. The 100 composite unit "depth" was arbitrarily set at the highest sample of the composite section.

UAT-8 and UAT-9

Coreholes UAT-8 and UAT-9 are in the southwestern part of the Lower Indus coal region (fig. 2). UAT-8 is 5.1 km south-southwest of UAT-9. UAT-8 was rotary drilled from 0 to 181.85 m and cored below that depth to a total depth of 338.04 m; UAT-9 was cored from 3.95 to 94.05 m and rotary drilled from that depth to total depth of 345.00 m. Because the two sections are so similar especially with regard to distinctive limestone and coal beds (fig. 3), it was not difficult to construct a composite cored section for these two holes (horizontal axis in fig. 7) which included the Bara and Lakhra Formations and the Sohnari Member of the Laki Formation. Unfortunately, the upper part of the Lakhra-Sohnari interval was deeply weathered in UAT-9 and had been eroded away at the site of UAT-8. The detailed pollen occurrence data for coreholes UAT-8 and UAT-9 are shown in table 6.

Figure 7 is a graphic correlation diagram for composite sections UAT-8 + UAT-9 and UAL-2 + UAL-13. It is evident that the rate of deposition was more rapid in the UAT area than in the UAL area; note the smaller thickness scale in the UAT section than in the UAL section (in the UAL section, one composite unit represents 1 m in corehole UAL-13).

Line of correlation 1 (LOC-1) attaches more importance to event 65 (range base of *Longapertites* sp. F) than does LOC-2, which takes more account of all events in the lower left part of the diagram. For reasons not discussed here, events 38 and 58, in the upper right part of the diagram, are thought to be facies-dependent and therefore not good time markers. Lines of correlation 1 and 2 and the diamond symbols in figure 7 show that the base of the Lakhra Formation in the UAT area is closer in age to the base of the Lakhra in UAL-2 than in UAL-13 (palynological correlation lines C and E in fig. 3). Furthermore, in the UAT area, just as in UAL-2, the upper part of the Bara Formation appears to be the same age as the lower part of the Lakhra Formation in UAL-13 (interval below palynological correlation lines C and E in fig. 3).

Above the error box for events 64 and 78 (range tops of *Longapertites* sp. E and *Retitrescolpites* sp. A, respectively), placement of the line of correlation is uncertain but is critical for the interpretation of the depositional and structural history of the area. Interpretation of the geologic history of the UAT area is complicated by the ambiguous lithology of the Lakhra-Sohnari interval in the area, as represented by the section in corehole UAT-9. Distinct limestone beds are present in UAT-9 that could be used to demarcate the Lakhra from the Sohnari. If the Lakhra in this corehole is defined as extending from the first limestone above the Bara to the first limestone below the Sohnari, then the Sohnari in UAT-9 is relatively thin (limited to strata between the datum line and the base of the Meting Limestone Member of the Laki Formation in fig. 3). However, if this definition of the Lakhra is followed, then much of the Lakhra in UAT-9 either lacks obvious marine fossils or contains only sparse mollusks and foraminifers. Apparently for this reason, Nuttall (1925, p. 428) defined the outcropping Sohnari south of Thatta (fig. 2), not far from UAT-9, as including "thin

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Figure 7 (following page). Graphic correlation diagram for composite sections UAL-2 + UAL-13 and UAT-8 + UAT-9. In figures 7, 9, 10, and 11, each unit in the composite thickness scale for UAL-2 + UAL-13 equals 1 m in section UAL-13. Composite section UAT-8 + UAT-9 was formed by correlating limestone and coal beds in the two coreholes (fig. 3). The depth scale for the UAT area is that of UAT-9. Depths shown for UAT-8 samples are inferred depths at which the samples would have been taken had they been sampled in UAT-9. Diamonds are the positions of the contact between the Bara and Lakhra Formations in UAT-8 + UAT-9 vs. UAL-2 (diamond-2) and UAL-13 (diamond-13); the triangle is the contact between the Lakhra Formation and the Sohnari Member of the Laki Formation; and the filled circle is the contact between the Sohnari and Meting Limestone Members of the Laki Formation. M and ML = Meting Limestone Member; S = Sohnari Member.

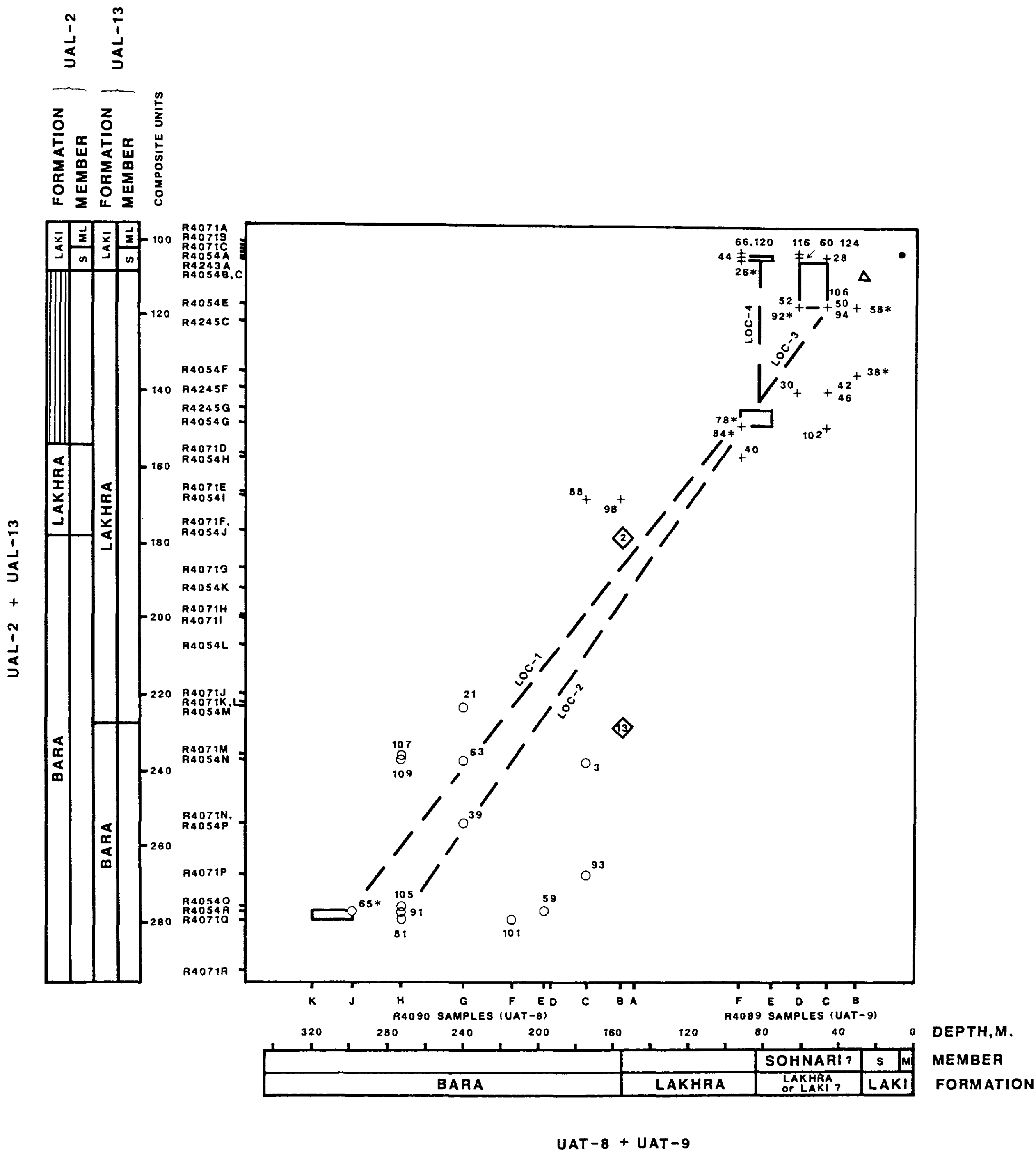
UAL-2
UAL-13
FORMATION
MEMBER
FORMATION
MEMBER
COMPOSITE UNITS
UAL-2 + UAL-13
LAKI
LAKHRA
BARA
R4090 SAMPLES (UAT-8)
R4089 SAMPLES (UAT-9)
DEPTH,M.
MEMBER
FORMATION
SOHNARI ?
LAKHRA or LAKI ?
LAKI
LOC-1
LOC-2
LOC-3
LOC-4
UAT-8 + UAT-9

Figure 7

Table 6. Pollen occurrence data in samples from coreholes UAT-8 and UAT-9.

FORMATION	BARA								?	L	?	LAKI or LAKHRA			
MEMBER									?		?	SOHNARI ?			
SAMPLE	R4090 K	R4090 J	R4090 H	R4090 G	R4090 F	R4090 E	R4090 D	R4090 C	R4090 B	R4090 A	R4089 F	R4089 E	R4089 D	R4089 C	R4089 B
COREHOLE	UAT-8										UAT-9				
DEPTH, M.	314.18-314.29	293.66-293.73	268.07-266.17	235.57-235.64	202.72-202.79	181.32-181.39	177.16-177.21	153.59-153.66	129.07-129.17	122.44-122.51	93.22-93.33	76.85-76.92	62.60-62.66	47.49-47.62	32.02-32.08
1 - Milfordia minima + M. hungarica	·	·	·	·	·	·	·	·	·	·	·	X	X	·	·
3 - Psilodiporites hammenii	·	·	·	·	·	·	·	X	X	·	·	X	·	·	·
13 - Triatriopollenites sp. B	?	·	·	·	·	·	·	·	·	·	·	·	·	·	·
17 - "Myricaceoipollenites dubius"	·	·	·	·	·	·	·	·	·	·	·	X	X	X	X
21 - Cricotriporites sp. A	·	·	·	X	X	X	X	X	X	·	X	X	X	X	X
23 - "Tricolporipites jerdoni"	·	·	·	·	·	·	·	·	·	·	·	X	X	·	·
25 - Echitriporites trianguliformis	·	X	·	X	·	·	X	X	X	X	X	·	·	·	·
27 - Triangulorites triradiatus	X	·	X	·	·	·	·	·	·	X	X	·	X	X	·
29 - Triangulorites bellus	·	·	X	·	·	X	·	·	·	·	X	·	X	?	·
35 - Proxapertites assamicus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
37 - Proxapertites operculatus	X	X	·	X	·	X	·	X	X	·	X	X	X	·	X
39 - Proxapertites cursus	·	·	·	X	·	·	·	X	·	·	X	·	·	·	·
41 - Assamialetes emendatus	P	·	·	X	·	X	·	X	·	·	·	·	·	X	·
43 - Spinizonocolpites prominatus	·	·	·	X	·	X	X	X	X	X	X	·	·	·	·
45 - Spinizonocolpites sp. A	·	·	·	·	·	·	X	X	·	·	·	·	·	·	·
49 - Incrotonipollis burdwanensis	X	·	X	·	·	·	·	X	X	·	X	·	X	X	·
51 - Incrotonipollis neyvelii	X	·	·	·	·	·	·	X	X	·	·	X	X	·	·
53 - Longapertites sp. A	·	·	·	·	·	X	·	·	·	·	·	·	·	·	·
55 - Longapertites sp. B	X	X	X	X	·	X	X	X	X	X	X	X	X	X	X
57 - Longapertites retipilatus	X	X	X	·	·	·	X	·	·	·	X	X	X	X	X
59 - Longapertites sp. C	·	·	·	·	·	X	·	X	·	·	·	·	X	·	·
61 - Longapertites sp. D	·	·	·	·	·	·	·	·	·	·	X	·	·	·	·
63 - Longapertites sp. E	?	·	·	X	X	X	X	X	X	X	X	·	·	·	·
65 - Longapertites sp. F	·	X	·	X	X	X	X	X	X	X	X	·	·	·	·
67 - Retimonosulcites ovatus	X	·	·	·	·	X	X	X	·	·	·	·	·	·	·
69 - Matanomadhiasulcites maximus	X	X	·	·	·	·	·	X	X	X	·	X	X	·	X
73 - Brevitricolpites sp. A	·	·	·	·	·	·	·	X	·	·	·	·	·	·	·
75 - Intrareticulitis brevis	X	·	X	·	·	·	·	·	·	·	·	X	X	X	X
77 - Retitrescolpites sp. A	X	·	X	·	·	X	·	·	X	·	X	·	·	·	·
79 - Retitrescolpites sp. B	·	·	X	·	·	·	·	·	·	·	·	·	·	·	·
81 - New genus A, sp. A	·	·	X	·	X	·	X	X	·	·	·	·	·	·	·
89 - Porocolpopollenites aff. P. ollivierae	·	·	·	·	X	X	X	X	X	X	X	·	·	·	·
91 - Cf. Porocolpopollenites, sp. A	·	·	X	X	·	·	·	·	X	X	X	·	X	·	·
93 - Callophyllumpollenites cf. C. rotundus	·	·	·	·	·	·	·	X	X	X	·	·	X	X	·
95 - Yeguapollis sp. A	·	·	·	·	·	X	·	·	·	·	·	·	·	·	·
97 - Spinaepollis sp. A	X	·	X	·	·	·	X	·	X	·	·	·	·	·	·
99 - Normapolles n. gen. C sp. A	·	·	·	·	·	·	·	·	·	·	·	X	·	·	·
101 - Cupanieidites aff. C. flabelliformis	·	·	·	·	X	·	X	·	X	·	·	X	·	X	·
103 - Cupanieidites flaccidiformis	·	·	X	·	X	·	X	X	X	X	X	X	X	·	X
105 - Cupanieidites sp. A	·	·	X	·	·	·	X	X	·	·	X	·	X	X	·
107 - Iugopollis tetraporites	?	·	2	·	·	·	X	·	·	·	·	X	·	·	·
109 - Polygalacidites clarus	·	X	·	·	·	·	·	·	X	·	·	·	·	·	·
115 - Retistephanocolpites 5-colpate	·	·	·	·	·	·	·	·	·	·	1	1	1	·	·
117 - Retistephanocolpites 6-colpate	·	2	·	2	1	·	·	·	·	·	2	·	·	·	·
119 - Retistephanocolpites 7-colpate	1	·	·	·	1	2	·	·	1	·	·	1	·	·	·
121 - Retistephanocolpites 8-colpate	1	·	·	2	·	·	·	1	3	·	2	2	3	1	1
123 - Retistephanocolpites 9-colpate	1	·	·	·	·	·	1	·	·	·	·	1	1	·	·
125 - Retistephanocolpites 10-colpate	·	·	1	·	·	·	·	·	·	·	·	·	·	·	·

impure limestones containing *Assilina granulosa* [a large foraminifer], and the stratigraphical break at this point with the underlying Upper Ranikot [= Lakhra Formation] is less than that seen elsewhere in Sind." Thus, Nuttall would probably consider the Sohnari in UAT-9 to be relatively thick, as in UAJ-1, DH-18, UAK-5, and UAK-7 (figs. 2, 4), rather than thin. Possible lower contacts of the Sohnari Member in UAT-9 are shown in figure 3 by the correlation lines with question marks.

In the graphic correlation diagram for the UAT and UAL composite sections (fig. 7), LOC-3 has a slope intermediate between those of LOC-1 and LOC-2. LOC-3 implies that

1. the upper part of the Lakhra Formation (or the lower part of a thick Sohnari Member) in the UAT area is about the same age as the upper part of the Lakhra in UAL-13; and
2. the upper contact of the Sohnari is approximately synchronous in the UAT and UAL areas. If the Sohnari is thought to be relatively thin in UAT-9, then, according to LOC-3, the lower contact of the Sohnari is also approximately synchronous in the UAT and UAL areas.

However, the correlations of the Lakhra and Sohnari that are implied by LOC-3 are poorly supported by pollen data.

LOC-4 is a second possible position of the line of correlation above events 64 and 78 on the diagram (fig. 7). The strongest evidence in favor of LOC-4 is that at least eight range tops occur in sample R4089 F in UAT-9 (table 6). Furthermore, the possibly important range base of *Milfordia minima* + *M. hungarica* (event 1 in fig. 7) occurs in the next higher sample (R4089 E) in UAT-9. LOC-4 implies that (1) a very rapid environmental/climatic change, leading to a distinct change in the flora, occurred in the UAT area but not in UAL-13; or that (2) there is an unconformity in the UAT section. If LOC-4 is correctly placed, then I think it is most probably explained by the presence of an unconformity in the UAT section (palynological correlation line A in fig. 3) that has the following implications:

1. Previous authors (and fig. 5 of this paper) have suggested the presence of an unconformity between the Lakhra and Sohnari in various parts of the Lower Indus coal region; thus, it seems more likely that the unconformity in UAT-9 is between the Lakhra and Sohnari than within the Lakhra. Therefore, the part of the section in UAT-9 that includes samples R4089 B-E (fig. 7) should probably be assigned to the Sohnari Member of the Laki Formation, in apparent agreement with Nuttall (1925), and the Sohnari of the UAT area is thus similar in thickness to the Sohnari of coreholes UAJ-1, DH-18, UAK-5, and UAK-7 in the central part of the coal region (fig. 4).
2. Although rocks are missing in UAT-9 (as in UAL-2) that would be correlative with the upper part of the Lakhra Formation in UAL-13, the Lakhra of UAT-9 does include a relatively thin interval (between palynological correlation lines A and B in fig. 3) that is present in UAL-13 but missing by unconformity in UAL-2.

In short, if there is an unconformity in the UAT-9 section, as inferred from the position of LOC-4 in figure 7, and if the strata overlying the unconformity belong to the Sohnari Member, then the similarities between the UAL-2 and UAT-9 sections suggest that, on the west side of the Lower Indus coal region, upwarping followed by erosion and (or) nondeposition occurred between late Lakhra and Sohnari times. Furthermore, the upper part of the nonmarine to brackish-water Bara Formation of the UAL-2 and UAT coreholes, in the west, is correlative with the lower part of the brackish-water to shallow marine Lakhra Formation in UAL-13, in the east (fig. 6B); therefore, it appears that the west side of the Lower Indus coal region was already higher topographically than the east side of the region in late Bara-early Lakhra time.

DH-18 and UAJ-1

Six pollen-bearing samples were analyzed from the Sohnari Member of the Laki Formation in corehole DH-18 and six also from the same member in corehole UAJ-1; these coreholes are in the west-central part of the Lower Indus coal region and are 16.2 km apart (figs. 2, 4). The detailed pollen occurrence data for coreholes DH-18 and UAJ-1 are shown in tables 7 and 8.

No direct correlation between the two coreholes could be obtained from the sparse array of events in figure 8; most of the events in the diagram are in the upper right corner. However, DH-18 and UAJ-1 could be correlated individually with composite section UAL-2 + UAL-13 (figs. 9, 10).

Figure 9 is a graphic correlation diagram for coreholes DH-18 and UAL-2 + UAL-13. Most weight has been given to the three pollen events that seemed to be of highest quality (102, range top of *Cupanieidites* aff. *C. flabelliformis*; 58, range top of *Longapertites retipilatus*; 104, range top of *Cupanieidites flaccidiformis*).

The top of the Lakhra Formation in DH-18 is placed at the top of the highest limestone bed below the carbonaceous strata of the overlying Sohnari Member of the Laki Formation. However, if the Lakhra-Sohnari contact is defined in this way, then shelly strata similar to those of the Lakhra are included in the lower part of the Sohnari Member in DH-18 (fig. 4), and the Sohnari is much thicker in DH-18 than in UAL-2 and UAL-13 (fig. 4). The lines of correlation in figure 9 indicate that most of the thick Sohnari in DH-18 is correlative with a large part of the Lakhra Formation in UAL-13 (see also fig. 4, palynological correlation lines D and E).

Line of correlation 1 (LOC-1) in figure 9 attaches more importance to event 104 (range top of *Cupanieidites flaccidiformis*) than does LOC-2; if LOC-1 is approximately correct, then the top of the Sohnari Member of the Laki Formation is younger in DH-18 than in the UAL area. LOC-2 is a speculative line suggesting that the top of the Sohnari is synchronous between DH-18 and the UAL area. In short, the line of correlation in figure 9 cannot be drawn with enough accuracy to determine whether the top of the Sohnari is the same age in DH-18 as it is in the UAL area.

Figure 10 is a graphic correlation diagram for coreholes UAJ-1 and UAL-2 + UAL-13. The thickness of the Sohnari Member of the Laki Formation is uncertain in UAJ-1 because the hole was still in Sohnari at total depth of 177.60 m (fig. 4). However, as in DH-18, the Sohnari is much thicker in UAJ-1 than in the UAL area. The Sohnari of UAJ-1 is interesting because it includes a distinct sequence of strata similar to the Lakhra Formation between 142.10

Table 7. Pollen occurrence data in samples from corehole DH-18.

FORMATION	LAKI						
MEMBER	SOHNARI						
SAMPLE	R3722 C	R3722 B	R3722 A	R4034 D	R4034 C	R4034 B	
DEPTH, M.	78.21	72.19-72.38	66.52-66.62	57.30	45.87	40.54	
	•	X	X	X	X	•	1 - Milfordia minima + M. hungarica
	•	•	•	•	X	•	3 - Psilodiporites hammenii
	•	•	X	•	•	X	7 - Triporopollenites sp. A
	•	•	X	X	•	•	9 - Triporopollenites sp. B
	X	•	?	•	•	X	11 - Triatriopollenites sp. A
	•	•	X	•	•	?	13 - Triatriopollenites sp. B
	X	X	X	X	X	X	17 - "Myricaceoipollenites dubius"
	•	•	•	X	•	X	19 - Aff. "Tricolporipites tiliaceaeformis"
	X	X	X	X	•	X	21 - Cricotriporites sp. A
	•	•	X	•	X	•	23 - "Tricolporipites jerdoni"
	•	•	X	•	•	•	27 - Triangulorites triradiatus
	•	•	•	X	X	•	31 - Triangulorites sp. A
	•	•	•	•	X	•	33 - Proxapertites sp. A
	X	X	X	X	X	X	35 - Proxapertites assamicus
	X	X	X	X	X	X	37 - Proxapertites operculatus
	•	•	•	•	•	P	39 - Proxapertites cursus
	•	•	•	•	X	•	49 - Incrotonipollis burdwanensis
	X	•	•	X	•	•	51 - Incrotonipollis neyvelii
	•	•	X	•	•	•	53 - Longapertites sp. A
	•	•	•	•	X	•	55 - Longapertites sp. B
	•	X	•	X	X	•	57 - Longapertites retipilatus
	•	•	X	•	•	•	67 - Retimonosulcites ovatus
	•	•	X	•	X	X	75 - Intrareticulitis brevis
	•	•	•	•	•	X	89 - Porocolpopollenites aff. P. ollivierae
	•	•	?	•	X	•	91 - Cf. Porocolpopollenites, sp. A
	X	X	X	X	X	•	99 - Normapolles n. gen. C sp. A
	•	X	X	•	•	•	101 - Cupanieidites aff. C. flabelliformis
	•	•	X	X	X	•	103 - Cupanieidites flaccidiformis
	•	X	•	X	•	•	105 - Cupanieidites sp. A
	•	•	•	X	•	•	107 - Iugopollis tetraporites
	•	•	•	•	2	•	115 - Retistephanocolpites 5-colpate
	•	•	1	1	1	•	117 - Retistephanocolpites 6-colpate
	•	1	•	•	2	•	121 - Retistephanocolpites 8-colpate
	•	1	•	2	1	2	123 - Retistephanocolpites 9-colpate
	•	•	1	•	•	•	125 - Retistephanocolpites 10-colpate

Table 8. Pollen occurrence data in samples from corehole UAJ-1.

FORMATION: LAKI						
MEMBER: SOHNARI						
SAMPLE	B4244 F	B4244 E	B4244 D	B4244 C	B4244 B	B4244 A
DEPTH,M.	150.10	148.78	138.20	124.07	121.42	116.92
1 - Milfordia minima + M. hungarica	•	•	•	•	X	•
3 - Psilodiporites hammenii	•	•	•	X	•	X
7 - Triporopollenites sp. A	X	X	X	•	•	•
11 - Triatriopollenites sp. A	X	•	•	X	X	•
13 - Triatriopollenites sp. B	•	•	X	X	•	•
17 - "Myricaceoipollenites dubius"	X	X	X	X	X	•
19 - Aff. "Tricolporipites tiliaceaeformis"	•	•	•	X	•	X
21 - Cricotriporites sp. A	X	X	X	X	X	X
23 - "Tricolporipites jerdoni"	X	•	•	X	X	•
27 - Triangulorites triradiatus	X	•	•	•	•	X
29 - Triangulorites bellus	•	•	•	•	•	X
33 - Proxapertites sp. A	•	X	•	•	•	•
35 - Proxapertites assamicus	X	X	X	X	X	X
37 - Proxapertites operculatus	X	X	X	•	•	X
39 - Proxapertites cursus	•	•	•	•	X	•
41 - Assamialetes emendatus	•	X	•	X	X	X
43 - Spinizonocolpites prominatus	•	•	•	X	X	•
45 - Spinizonocolpites sp. A	X	•	•	•	•	•
49 - Incrotonipollis burdwanensis	•	•	•	•	•	X
51 - Incrotonipollis neyvelii	•	•	•	•	•	X
53 - Longapertites sp. A	•	X	X	X	•	•
55 - Longapertites sp. B	•	X	•	X	X	•
57 - Longapertites retipilatus	X	X	X	X	X	X
67 - Retimonosulcites ovatus	•	•	•	•	•	X
69 - Matanomadhiasulcites maximus	•	X	•	•	•	X
71 - Matanomadhiasulcites sp. A	•	•	•	•	•	X
75 - Intrareticulitis brevis	X	X	X	X	X	X
89 - Porocolpopollenites aff. P. ollivierae	•	•	•	X	X	•
91 - Cf. Porocolpopollenites, sp. A	•	X	•	•	•	•
93 - Callophyllumpollenites cf. C. rotundus	•	•	•	•	•	X
97 - Spinaepollis sp. A	•	X	•	•	•	•
103 - Cupanieidites flaccidiformis	X	X	P	X	X	X
107 - Iugopollis tetraporites	•	•	X	X	•	X
113 - Retistephanocolpites 4-colpate	•	•	•	•	1	•
115 - Retistephanocolpites 5-colpate	•	1	2	2	3	1
117 - Retistephanocolpites 6-colpate	•	•	3	1	1	1
119 - Retistephanocolpites 7-colpate	1	1	1	•	5	1
121 - Retistephanocolpites 8-colpate	•	3	5	•	6	9
123 - Retistephanocolpites 9-colpate	2	1	2	2	3	3
125 - Retistephanocolpites 10-colpate	•	3	•	•	•	1

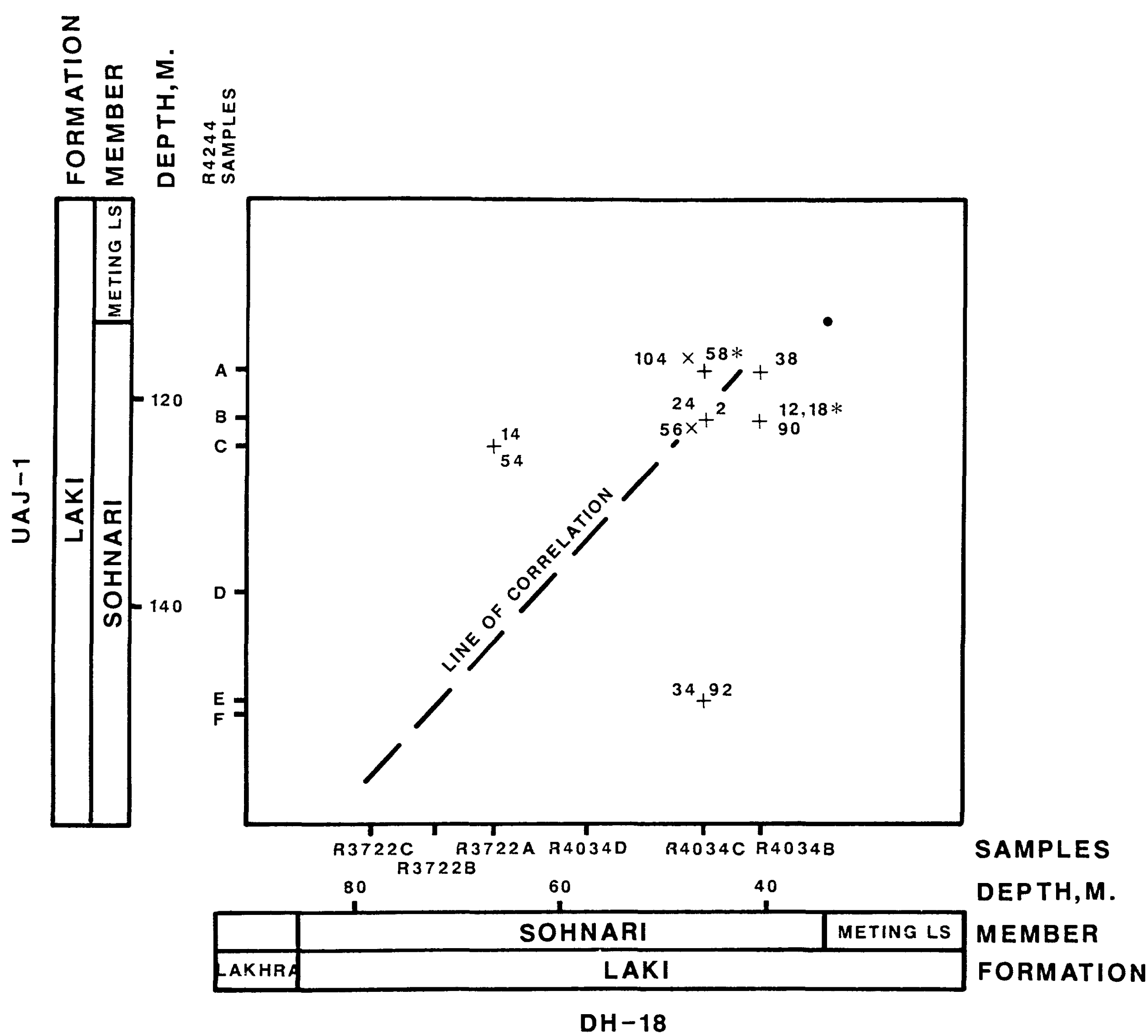

Figure 8. Graphic correlation diagram for parts of coreholes DH-18 and UAJ-1. The filled circle is the contact between the Sohnari and Meting Limestone Members of the Laki Formation. The line of correlation (LOC) is not based directly on the events plotted in this diagram; rather, the LOC shown here is based on correlation of each corehole with composite section UAL-2 + UAL-13 (figs. 9 and 10). The symbol X next to several event numbers indicates events that are considered to be of high quality in other graphic correlation diagrams of this report.

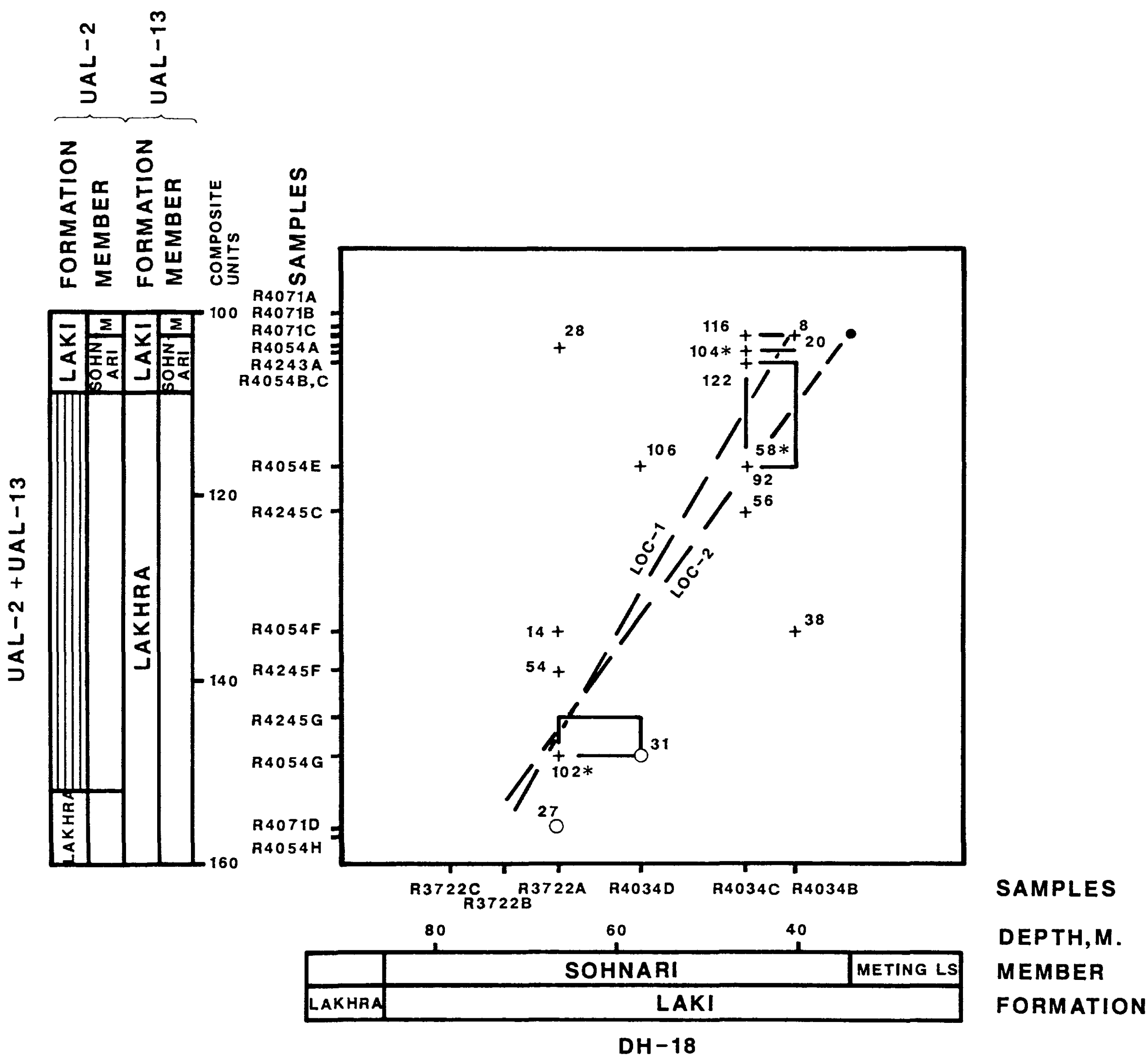

Figure 9. Graphic correlation diagram for parts of corehole DH-18 and composite section UAL-2 + UAL-13. The filled circle is the contact between the Sohnari and Meting Limestone Members of the Laki Formation. M = Meting Limestone Member.

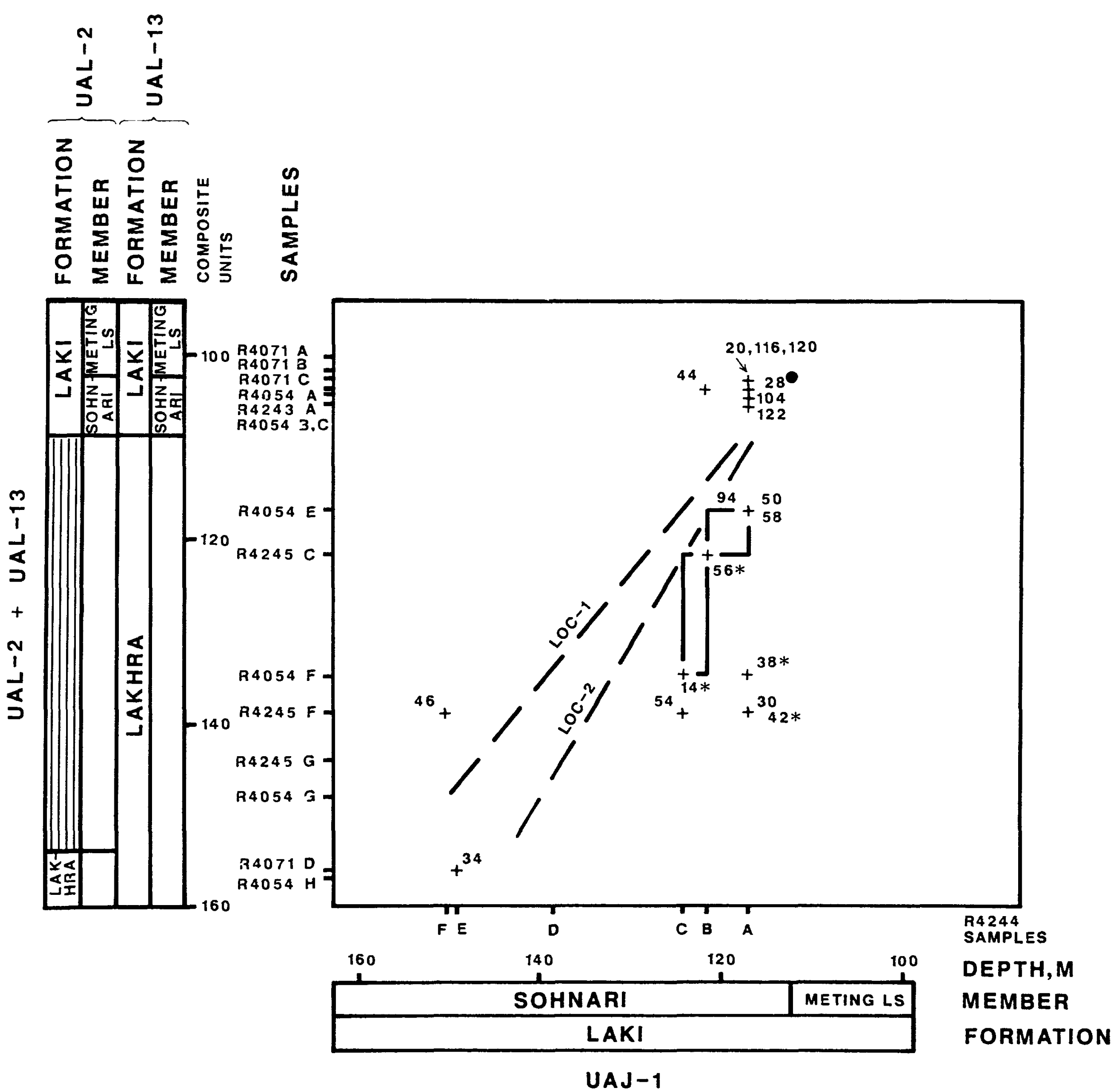

Figure 10. Graphic correlation diagram for parts of corehole UAJ-1 and composite section UAL-2 + UAL-13. The filled circle is the contact between the Sohnari and Meting Limestone Members of the Laki Formation.

and 146.80 m depth (fig. 4); rocks in this sequence consist of claystone, siltstone, and sandy limestone or calcareous sandstone, all containing abundant shells and foraminifers.

Pollen events are sparse particularly in the lower left part of figure 10; therefore, the position of the line of correlation is highly speculative. Two possible lines of correlation have been drawn, both of them assuming that the top of the Sohnari is the same age in UAJ-1 as in the UAL area, which may or may not be true. The lines of correlation in figure 10 indicate that most of the thick Sohnari in UAJ-1 is correlative with the Lakhra Formation of UAL-13 (palynological correlation lines C and D in fig. 4).

As noted previously, figure 8 contains too few pollen events to permit direct correlation between coreholes DH-18 and UAJ-1. However, both of these coreholes could be correlated at least roughly with the composite section for the UAL area (figs. 9, 10). Therefore, by using common correlation points from DH-18 and UAJ-1 to UAL-2 + UAL-13 (assuming an average position of the line of correlation in figs. 9 and 10), it was possible to draw a correlation line as shown in figure 8; however, the exact position of this line is uncertain. The line of correlation indicates that the lower part of the Sohnari Member in UAJ-1 is correlative with strata assigned to the upper part of the Lakhra Formation in DH-18 (below palynological correletion line E in fig. 4), and that the shelly sequence between the coal zones in the Sohnari of UAJ-1 is probably approximately the same age as the shelly strata in the lower part of the Sohnari of DH-18 (above palynological correletion line E in fig. 4). It appears that most strata assigned lithologically to the Sohnari Member of the Laki Formation in coreholes DH-18 and UAJ-1 are correlative with strata assigned to the Lakhra Formation in UAL-13 to the north. The shelly sequences within the Sohnari of UAJ-1 and DH-18 could be considered tongues of the Lakhra Formation (fig. 4).

UAK-5 and UAK-7

Six samples from the Sohnari Member of the Laki Formation and one sample from the very top of the Lakhra Formation were analyzed from corehole UAK-5, and four samples from the Sohnari were analyzed from corehole UAK-7, in the east-central part of the Lower Indus coal region (figs. 2, 4). The two coreholes are 18.2 km apart. Lithologic logs for coreholes UAK-5 and UAK-7 are given in Akhtar and others (1988), and geophysical logs for these coreholes are given in Ahmed amd UR-Raman (1988). The detailed pollen occurrence data for coreholes UAK-5 and UAK-7 are shown in tables 9 and 10.

The Sohnari is relatively thick in both coreholes (fig. 4). The remarkable feature of corehole UAK-7 is that the Lakhra Formation in this section appears to be less than 2 m thick (Akhtar and others, 1988).

Coreholes UAK-5 and UAK-7 proved difficult to correlate with each other and with other coreholes because of a scarcity of pollen events in the lower part of the Sohnari in the UAK area. For purposes of obtaining a composite section for UAK-5 + UAK-7, I assumed that the middle part of the Lakhra Formation was the same age in each of these two coreholes. Whether this assumption is

Table 9. Pollen occurrence data in samples from corehole UAK-5. L = Lakhra Formation.

FORMATION	L	LAKI					
MEMBER		SOHNARI					
SAMPLE	R4246 Z	R4246 Y	R4246 X	R4246 W	R4246 U	R4246 T	R4246 S
DEPTH,M.	132.85-132.96	132.50-132.60	129.00-129.10	123.90-124.00	102.69-102.74	95.00-95.12	90.44-90.54
1 - Milfordia minima + M. hungarica	X	·	X	X	·	·	·
3 - Psilodiporites hammenii	·	·	·	·	·	·	X
7 - Triporopollenites sp. A	·	·	X	X	·	P	·
9 - Triporopollenites sp. B	·	·	·	·	X	·	·
11 - Triatriopollenites sp. A	·	X	·	·	·	·	·
17 - "Myricaceoipollenites dubius"	X	X	X	X	X	·	·
19 - Aff. "Tricolporipites tiliaceaeformis"	·	·	·	·	·	·	X
21 - Cricotriporites sp. A	X	X	X	X	·	X	X
23 - "Tricolporipites jerdoni"	·	·	·	·	·	X	·
29 - Triangulorites bellus	·	·	·	·	·	·	?
35 - Proxapertites assamicus	X	X	X	X	X	X	X
37 - Proxapertites operculatus	X	·	X	X	X	X	X
39 - Proxapertites cursus	·	X	·	·	·	·	·
41 - Assamialetes emendatus	·	X	·	·	X	X	X
47 - Grimsdalea sp. A	·	·	X	X	·	·	·
49 - Incrotonipollis burdwanensis	·	·	·	X	·	·	·
51 - Incrotonipollis neyvelii	X	·	·	·	·	·	·
53 - Longapertites sp. A	·	X	·	·	X	·	·
55 - Longapertites sp. B	X	X	X	·	X	X	·
57 - Longapertites retipilatus	X	X	X	X	X	X	X
59 - Longapertites sp. C	·	X	·	·	·	·	X
63 - Longapertites sp. E	·	·	X	·	·	·	·
75 - Intrareticulitis brevis	X	X	X	X	X	X	X
89 - Porocolpopollenites aff. P. ollivierae	·	·	·	·	·	·	X
91 - Cf. Porocolpopollenites, sp. A	·	·	·	·	X	·	·
93 - Callophyllumpollenites cf. C. rotundus	·	·	·	·	X	·	·
99 - Normapolles n. gen. C sp. A	·	·	X	X	·	·	·
101 - Cupanieidites aff. C. flabelliformis	X	·	X	·	·	·	X
103 - Cupanieidites flacciddiformis	·	X	X	·	X	X	X
105 - Cupanieidites sp. A	·	·	·	·	·	X	·
107 - Iugopollis tetraporites	·	·	·	·	·	X	X
115 - Retistephanocolpites 5-colpate	·	·	·	·	·	5	2
117 - Retistephanocolpites 6-colpate	·	·	·	·	·	·	1
119 - Retistephanocolpites 7-colpate	·	·	·	·	·	1	2
121 - Retistephanocolpites 8-colpate	·	2	·	·	·	3	4
123 - Retistephanocolpites 9-colpate	·	5	·	·	·	3	2
125 - Retistephanocolpites 10-colpate	·	1	·	·	·	·	·

Table 10. Pollen occurrence data in samples from corehole UAK-7.

FORMATION	LAKI			
MEMBER	SOHNARI			
SAMPLE	R4240 D	R4240 C	R4240 B	R4240 A
DEPTH,M.	265.03	227.85	216.00	194.17
3 - Psilodiporites hammenii	•	×	•	•
7 - Triporopollenites sp. A	•	×	•	•
9 - Triporopollenites sp. B	×	•	×	×
11 - Triatriopollenites sp. A	•	×	×	•
17 - "Myricaceoipollenites dubius"	•	×	×	×
19 - Aff. "Tricolporipites tiliaceaeformis"	•	×	×	×
21 - Cricotriporites sp. A	•	×	×	×
23 - "Tricolporipites jerdoni"	•	×	•	•
27 - Triangulorites triradiatus	×	•	•	•
35 - Proxapertites assamicus	×	×	×	×
37 - Proxapertites operculatus	•	×	×	•
39 - Proxapertites cursus	×	•	•	•
41 - Assamialetes emendatus	•	×	×	×
43 - Spinizonocolpites prominatus	×	•	•	•
55 - Longapertites sp. B	•	×	×	•
57 - Longapertites retipilatus	×	×	×	×
59 - Longapertites sp. C	×	•	×	•
61 - Longapertites sp. D	×	•	•	•
63 - Longapertites sp. E	×	×	•	•
65 - Longapertites sp. F	×	•	•	•
67 - Retimonosulcites ovatus	×	•	•	•
69 - Matanomadhiasulcites maximus	×	•	•	•
75 - Intrareticulitis brevis	•	×	×	×
81 - New genus A, sp. A	•	•	×	•
89 - Porocolpopollenites aff. P. ollivierae	•	•	×	×
93 - Callophyllumpollenites cf. C. rotundus	•	•	•	×
103 - Cupanieidites flaccidiformis	×	P	×	•
105 - Cupanieidites sp. A	×	•	•	•
113 - Retistephanocolpites 4-colpate	•	1	•	•
115 - Retistephanocolpites 5-colpate	•	2	1	1
117 - Retistephanocolpites 6-colpate	•	2	1	1
119 - Retistephanocolpites 7-colpate	•	•	1	•
121 - Retistephanocolpites 8-colpate	•	2	2	1
123 - Retistephanocolpites 9-colpate	•	2	4	2
125 - Retistephanocolpites 10-colpate	•	•	1	•

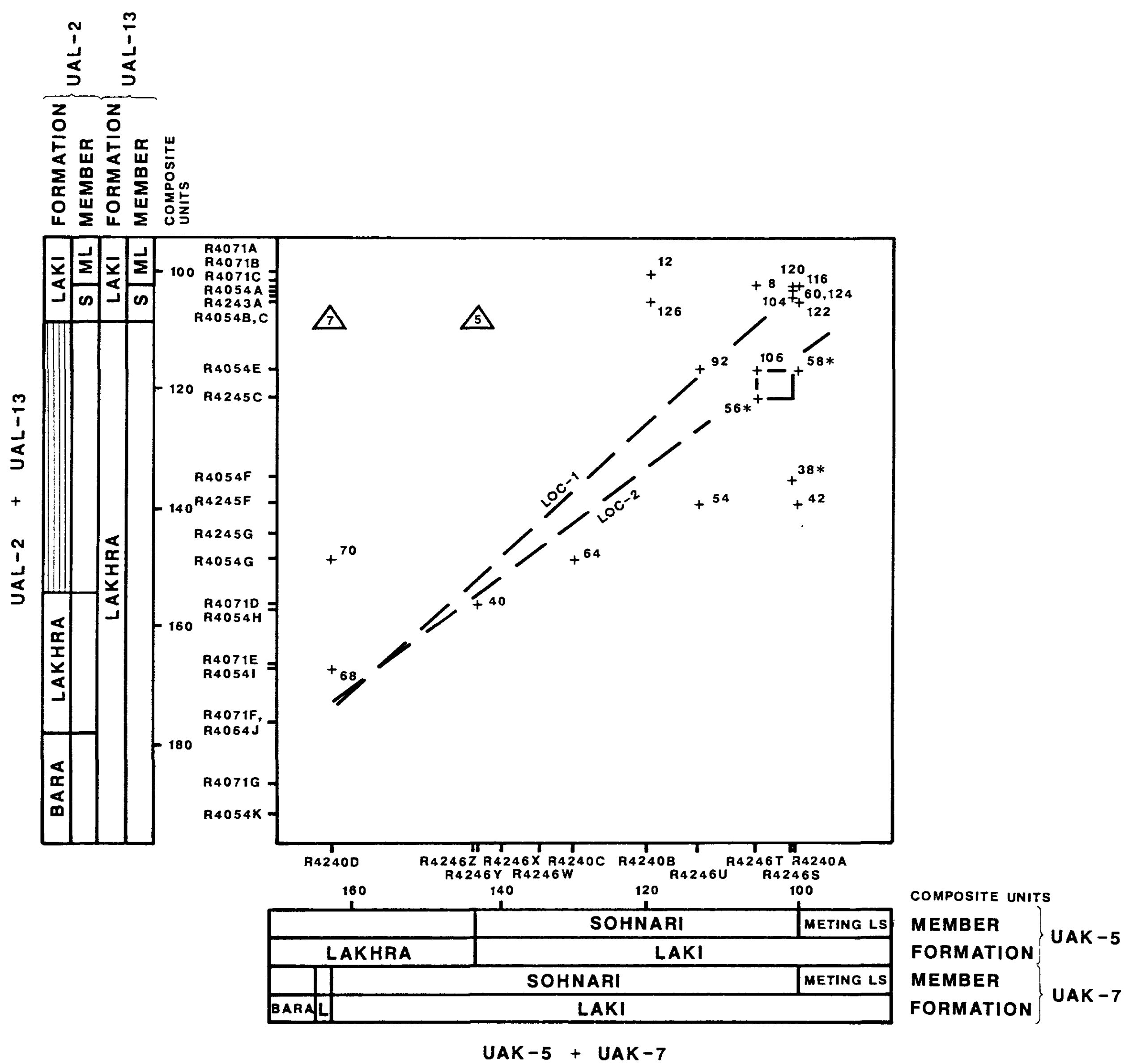

Figure 11. Graphic correlation diagram for composite sections UAL-2 + UAL-13 and UAK-5 + UAK-7. Each unit in the composite thickness scale for UAK-5 + UAK-7 equals 1 m in section UAK-5; the 100 composite unit "depth" was arbitrarily set at the boundary between the Sohnari and Meting Limestone Members of the Laki Formation. Triangles represent the base of the Laki Formation in UAL-2 + UAL-13 vs. UAK-5 (triangle-5) and UAK-7 (triangle-7). R4246 samples are from UAK-5, and R4240 samples are from UAK-7. L = Lakhra Formation; ML = Meting Limestone Member; S = Sohnari Member.

exactly true or not is probably not very important for purposes of comparing the composite section for the UAK area with the composite section for the UAL area to the north (fig. 11).

Line of correlation 1 (LOC-1) in figure 11 assumes that the top of the Sohnari Member is the same age in the two composite sections, whereas LOC-2 gives weight to event 56 (range top of *Longapertites* sp. B) (as mentioned previously, events 38 and 58 are not thought to be good time markers). Regardless of which line of correlation is more accurate, the array of events indicates that most of the thick Sohnari of the UAK area is the same age as the upper part of the Lakhra Formation in the UAL area (see also fig. 4).

Palynological correlation line F in figure 4 connects strata in DH-18 and UAK-5 that are in turn correlative with strata at a "depth" of 160 composite units in UAL-2 + UAL-13 (figs. 9 and 11). The position of line F is not exactly known, but it does indicate that the Lakhra-Sohnari boundary is roughly the same age in DH-18 as in UAK-5.

CONCLUSIONS

1. Pollen evidence supports planktic foraminiferal evidence that the entire Bara-Lakhra-Sohnari sequence in the Lower Indus coal region is Paleocene in age.
2. Only two pollen-bearing samples were available from strata directly overlying the Sohnari Member of the Laki Formation in the study region. However, pollen data support planktic foraminiferal evidence in suggesting that limestone immediately overlying the Sohnari Member in the northern part of the coal region is the Meting Limestone Member of the Laki Formation, of Paleocene age. Thus, if an unconformity does exist between the Sohnari and the overlying limestone strata in the northern part of the region, such an unconformity is likely to represent only a small hiatus. The palynological data are not sufficient to determine whether the top of the Sohnari Member is the same age in the various coreholes examined.
3. In the northern part of the coal region (UAL area):
    a. The Lakhra Formation is much thinner in UAL-2 than in UAL-13 probably partly by unconformity (strata equivalent to the upper part of the Lakhra of UAL-13 are missing in UAL-2) and partly by facies change (the upper part of the Bara Formation of UAL-2 is the same age as the lower part of the Lakhra Formation of UAL-13). Thus, the thin Lakhra Formation of UAL-2 is correlative only with the middle part of the thick Lakhra of UAL-13.
    b. Within the Bara Formation, the uppermost coal beds of UAL-2 are younger than the uppermost coal beds in UAL-13.
4. In the southwestern part of the coal region (UAT area):
    a. A distinct unconformity appears to exist, probably between the Lakhra Formation and the Sohnari Member of the Laki Formation, such that strata equivalent to the upper part of the Lakhra of UAL-13, to the north, are missing in the UAT area.

b. The Sohnari of the UAT area is relatively thick as it is in coreholes UAJ-1, DH-18, UAK-5, and UAK-7 in the central part of the coal region.
c. The base of the Lakhra Formation in the UAT area is closer in age to the base of the Lakhra in UAL-2 than in UAL-13 to the north; furthermore, in the UAT area, just as in UAL-2, the upper part of the Bara Formation appears to be the same age as the lower part of the Lakhra Formation in UAL-13.

5. The apparent similarities between the UAL-2 and UAT sections suggest that:
   a. In late Bara-early Lakhra time, the west side of the Lower Indus coal region was higher topographically, receiving more nonmarine deposits, than the east side of the region, which was receiving more marine deposits.
   b. During late Lakhra time, uplift followed by erosion or nondeposition occurred on the west side of the coal region while marine deposition continued to the east.
6. In the central part of the coal region (coreholes UAJ-1, DH-18, UAK-5, and UAK-7), the Sohnari is much thicker than in the UAL area, in the northern part of the region, because of a facies change: most strata assigned to the Sohnari in UAJ-1, DH-18, UAK-5, and UAK-7 are age-equivalent to much of the interval assigned to the Lahkra in the UAL area. The Sohnari Member includes a shelly sequence, perhaps a tongue of the Lakhra Formation, in UAJ-1 and DH-18.

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