UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE STRATIGRAPHY AND COAL RESOURCE POTENTIAL OF THE SOHNARI MEMBER OF THE LAKI FORMATION IN SINDH PROVINCE, PAKISTAN: A PROGRESS REPORT

by

CHRISTOPHER WNUK, U.S. Geological Survey

JOHN R. SANFILIPO, U.S. Geological Survey

FARAH FATMI, Geological Survey of Pakistan

MOHAMMAD FARIDUDDIN, Geological Survey of Pakistan

Open-File Report 91-326

Report prepared jointly by the Geological Survey of Pakistan and the U.S. Geological Survey under the auspices of the U.S. Agency for International Development

1991

CONTENTS

ABSTRACT..... 1

INTRODUCTION..... 2

METHODS..... 3

RESULTS AND DISCUSSION..... 5
Lithology of the Sonhari Member..... 5
Depositional Environments..... 16
Stratigraphy..... 16
Comparison of Lithology between Sohnari and Lakhra Strata..... 18
Coals and Rooted Zones..... 19
Regional Stratigraphic and Lithologic Trends..... 23
Stratigraphic Anomalies..... 25

CONCLUSIONS AND RECOMMENDATIONS..... 27

ACKNOWLEDGEMENTS..... 27

REFERENCES..... 29

APPENDIX 1..... 34
SECTION TA-1..... 34
SECTION SMJ-1..... 39
SECTION JRK-1..... 41
SECTION JRK-2..... 42
SECTION JRK-3..... 43
SECTION LS-1..... 45
SECTION LS-3..... 48
SECTION LS-4..... 50
SECTION LN-1..... 52
SECTION LN-1A..... 54
SECTION LN-2..... 55
SECTION SON-1..... 57
SECTION SON-2..... 58
SECTION SON-3..... 60
SECTION SON-4..... 61
SECTION SON-5..... 62
SECTION SON-6..... 63
SECTION NA-15..... 64
SECTION NA-15A..... 66
SECTION AMN-35..... 67

ILLUSTRATIONS

FIGURE 1: Location of measured sections..... 4

FIGURE 2-2D: North - south cross-section..... 7-12

FIGURE 3: East - west cross section..... 13

TABLES

TABLE 1: Map coordinates of the measured sections and drill holes through the Sohnari Member in south Sind, Pakistan..... 6

TABLE 2: Sohnari coal thickness and depth..... 20

ABSTRACT

This progress report releases new data on the stratigraphy and lithology of the Paleocene Sohnari Member of the Laki Formation. Sixteen new outcrop sections were measured in the area between Thatta and the north end of the Lakhra Anticline, and two new mine sections were measured in the Meting-Jhimpir Coal Field. This report also re-evaluates existing data about the Sohnari member published in SanFilipo and others (1988), SanFilipo and others (1989), Outerbridge and others (in press) and Wnuk, Fariduddin, Fatmi and SanFilipo (in press).

The Sohnari Member ranges between 4 and 58 m in thickness and is primarily composed of shale/claystone (65%) and sandstone (21%) with minor percentages of siltstone, mudstone, conglomerate, and coal. Coal has not been found in outcrop but is widespread in the subsurface, occurring in 91% of the core holes. Coal accounts for 0% to 5% of the total thickness of any one section; the thickest bed reported is 1.78 m thick.

The Sohnari was deposited in neritic tidal flat, estuarine, and coastal swamp and marsh environments. It grades downward into the mixed marine clastics and foraminiferal carbonates of the Lakhra Formation. Upward the Sohnari becomes less terrestrial/coastal and more marine in aspect, grading into Lakhra-like marine clastics. There is a sharp contact between the Sohnari Member and the overlying Meting Limestone and Shale Member of the Laki Formation. On the basis of lithology, a depositional hiatus of unknown duration is inferred at this contact.

INTRODUCTION

Geologic investigations and exploratory drilling by various organizations including the Geological Survey of Pakistan (GSP), the United States Geological survey (USGS), the Pakistan Mineral Development Corporation (PMDC), the Water and Power Development Authority (WAPDA), The United States Agency for International Development (USAID), the Japan International Cooperation Agency (JICA), and the Sind Arid Zone Development Authority (SAZDA) indicate that the south Sind region is underlain by sizable coal deposits. The results of these various exploration efforts are reported in Blanford (1869), Ghani and others (1973), Memon and others (1976), Japan International Cooperation Agency (1981), Geologic Associates Inc. (1985), John T. Boyd Company (1985, 1986), Landis and others (1988), Schweinfurth and Husain (1988), SanFilipo and others (1989), SanFilipo and others (1990), and SanFilipo and others (in press).

The majority of the known coal deposits in south Sind occur in the Paleocene Bara Formation and all of the exploration activity has been directed almost exclusively toward assessing the coal potential of this unit. Less voluminous coal deposits are known to occur in the Paleocene Sohnari Member. However, the Sohnari strata have been ignored as a potential exploration target despite the fact that this member supports a mining industry in the Meting-Jhimpir area.

This report is a compilation of measured sections of the Sohnari Member including parts of the underlying Lakhra Formation and the overlying Meting Limestone and Shale Member. This data was gathered with two purposes in mind, (1) to assess the potential of the Sohnari Member as a coal exploration target, and (2) to contribute to our understanding of the stratigraphic and lithologic variability of Sohnari strata. This second objective will provide data critical to the development of depositional

models of the Sohnari strata and will lead to an improvement in the efficiency of coal exploration in both the Sohnari and the underlying Bara strata as well.

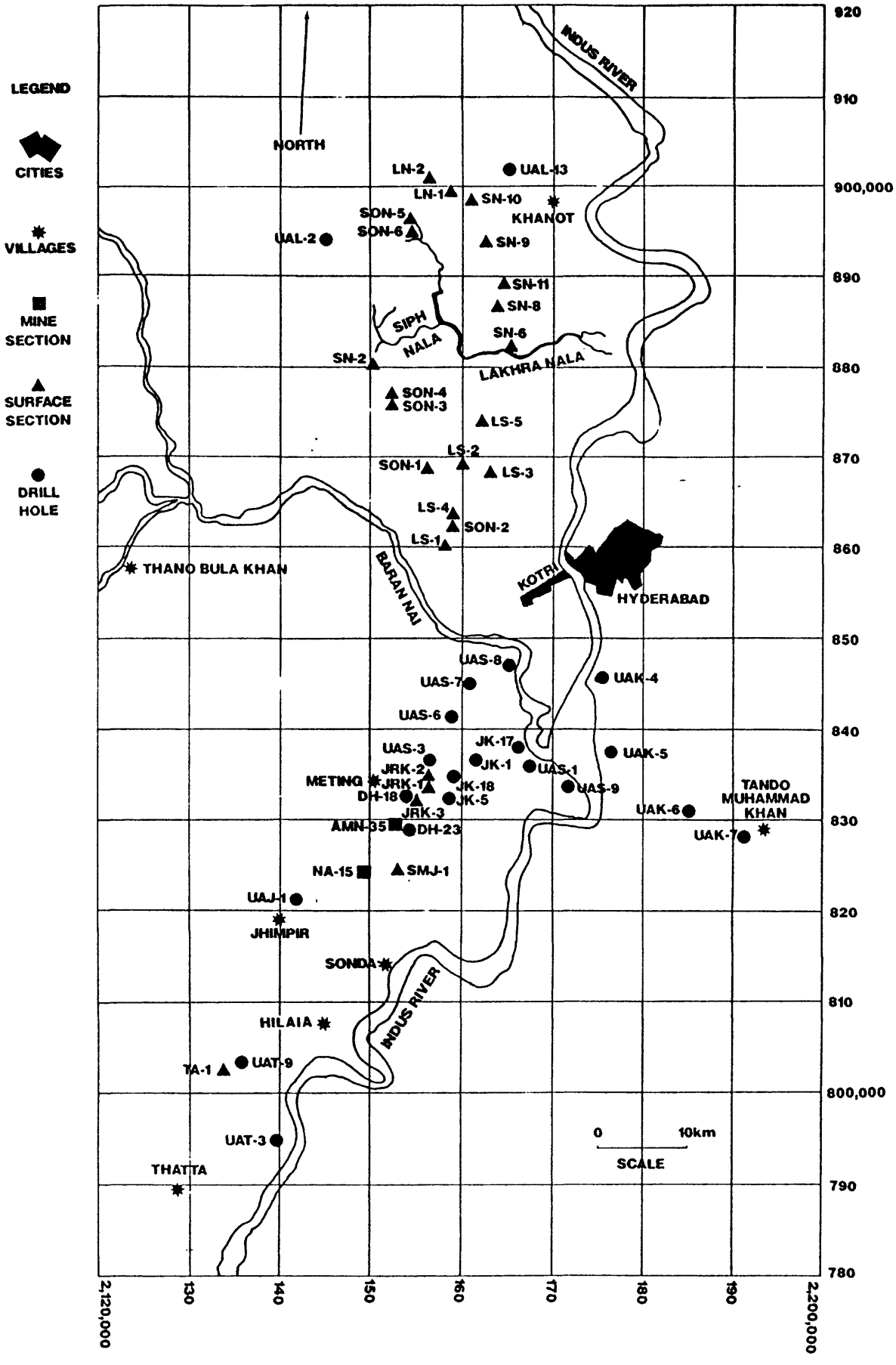
METHODS

Though the area between Thatta and the north end of the Lakhra Anticline has been drilled extensively by various public and private sector entities (more than 200 holes), these holes were intended to penetrate the coal-bearing zones of the Bara Formation. As a result, the majority of these holes either spudded below the Sohnari Member or drilled through the Sohnari Member using non-coring methods to reduce drilling costs.

Some pertinent information about the Sohnari Member was obtained from a re-evaluation of the results of the GSP drilling in the Sonda area (the DH program), and the GSP/USGS Coal Resource Exploration and Assessment Program (COALREAP) drilling done between Thatta and the north end of the Lakhra Anticline. Ninety-six holes (listed and described in SanFilipo and others, 1988) were drilled in the study area by the GSP and USGS. Of these, 28 (29%) contained Sohnari strata, and 20 of these (21%) contained a complete Sohnari section (see Figure 1 for locations). The other 8 holes either spudded in the Sohnari or in Indus alluvium that covered partially eroded Sohnari strata. However, except for COALREAP drill hole UAL-13 which was restudied in detail at the GSP's Sonda core storage facility, the reassessment of the GSP and COALREAP data was confined to the information contained in the existing field notes and the geophysical logs.

In order to supplement the existing drill hole data about the Sohnari, a comprehensive program of Sohnari outcrop measurements was conducted between Thatta (approximately 75 km southwest of Hyderabad) and the north end of the Lakhra Anticline (approximately 50 km north-northwest of

FIGURE 1


LEGEND
CITIES
VILLAGES
MINE SECTION
SURFACE SECTION
DRILL HOLE
NORTH
INDUS RIVER
LN-2
LN-1
UAL-13
SN-10
KHANOT
SON-5
SON-6
UAL-2
SN-9
SN-11
SN-8
SIPH NALA
SN-6
SN-2
LAKHRA NALA
SON-4
SON-3
LS-5
LS-2
SON-1
LS-3
LS-4
SON-2
LS-1
THANO BULA KHAN
BARAN NAI
KOTRI
HYDERABAD
UAS-8
UAS-7
UAK-4
UAS-6
JK-17
UAS-3
JK-1
UAS-1
UAK-5
JRK-2
METING
JRK-1
JK-18
DH-18
JK-5
UAS-9
TANDO MUHAMMAD KHAN
UAK-6
JRK-3
AMN-35
DH-23
UAK-7
NA-15
SMJ-1
UAJ-1
JHIMPIR
SONDA
INDUS RIVER
HILAIA
TA-1
UAT-9
UAT-3
THATTA
0
10km
SCALE
920
910
900,000
890
880
870
860
850
840
830
820
810
800,000
790
780
2,120,000
130
140
150
160
170
180
190
2,200,000

Hyderabad). Sections were measured using a Jacob's Staff and hand level. Two sections were also measured in the Sohnari coal mines in Meting-Jhimpir area. These were measured with a tape.

The Sohnari Member is poorly exposed south of Hyderabad and there are few sections with well exposed upper and lower contacts. All of the most complete sections in this area were described and measured. North of Hyderabad, Sohnari strata are better exposed, so efforts were made to keep sections separated by approximately 4 km.

Sixteen Sohnari sections (TA-1, SMJ-1, JRK-1, JRK-2, JRK-3, LS-1, LS - 3, LS-4, LN-1, LN-2, SON-1, SON-2, SON-3, SON-4, SON-5, and SON-6) and two mine sections (NA-15 and AMN-35) are described in Appendix 1 and illustrated in Figures 2 and 3. Eight other sections (LS-2, LS-5, SN-2, SN-6, SN-8, SN-9, SN-10, and SN-11) and one drill hole (UAL-13) are illustrated in Figures 2 and 3, but are described in detail in another publication (Wnuk, Fariduddin, Fatmi, and SanFilipo, in press). Lithologic descriptions and geophysical logs of the COALREAP drill holes that were not re-evaluated in this study can be found in Landis and others (1988) and in SanFilipo and others (1988).

The map coordinates for the 47 surface sections, mine sections, and COALREAP and GSP drill holes that contain Sohnari sediments and were considered in this study are given in Table 1.

RESULTS AND DISCUSSION

Lithology of the Sohnari Member

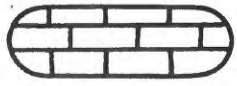
Analysis of the lithology of the complete Sohnari sections published in the appendix of this report and in Wnuk, Fariduddin, Fatmi, and SanFilipo (in press) indicates that the Sohnari Member (of the Laki Formation) consists primarily of shale/claystone (65%) and sandstone (21%)

TABLE 1

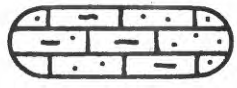
Map coordinates of the measured sections and drill holes through the Sohnari Member in south Sind, Pakistan.

	SECTION	NORTHING	EASTING
1.	UAT-3	794,955 m	2,139,818 m
2.	TA-1	802,400 m	2,133,800 m
3.	UAT-9	803,254 m	2,135,603 m
4.	UAJ-1	821,496 m	2,141,892 m
5.	NA-15	824,100 m	2,149,200 m
6.	SMJ-1	824,500 m	2,153,100 m
7.	UAK-7	828,194 m	2,191,315 m
8.	DH-23	829,095 m	2,153,880 m
9.	AMN-35	829,250 m	2,153,150 m
10.	UAK-6	830,970 m	2,185,023 m
11.	JRK-3	832,050 m	2,154,900 m
12.	JK-5	832,200 m	2,158,454 m
13.	DH-18	832,352 m	2,153,881 m
14.	UAS-9	833,764 m	2,171,727 m
15.	JRK-1	833,900 m	2,156,400 m
16.	JRK-2	834,300 m	2,156,450 m
17.	JK-18	834,513 m	2,159,546 m
18.	UAS-1	835,853 m	2,167,167 m
19.	UAS-3	836,515 m	2,156,351 m
20.	JK-1	836,583 m	2,161,340 m
21.	UAK-5	837,643 m	2,176,470 m
22.	JK-17	838,264 m	2,166,273 m
23.	UAS-6	841,261 m	2,158,782 m
24.	UAS-7	845,115 m	2,160,849 m
25.	UAK-4	845,780 m	2,175,220 m
26.	UAS-8	847,037 m	2,165,005 m
27.	LS-1	860,250 m	2,157,900 m
28.	SON-2	862,500 m	2,158,900 m
29.	LS-4	863,400 m	2,158,850 m
30.	LS-3	868,200 m	2,162,900 m
31.	SON-1	868,550 m	2,156,250 m
32.	LS-2	869,200 m	2,160,100 m
33.	LS-5	873,850 m	2,162,000 m
34.	SON-3	875,950 m	2,152,150 m
35.	SON-4	876,600 m	2,152,050 m
36.	SN-2	880,400 m	2,150,300 m
37.	SN-6	882,000 m	2,165,000 m
38.	SN-8	886,650 m	2,163,800 m
39.	SN-11	889,200 m	2,164,150 m
40.	SN-9	894,000 m	2,162,500 m
41.	UAL-2	894,100 m	2,145,000 m
42.	SON-6	894,900 m	2,154,500 m
43.	SON-5	896,000 m	2,154,700 m
44.	SN-10	898,500 m	2,160,950 m
45.	LN-1	899,150 m	2,158,550 m
46.	LN-2	901,100 m	2,156,400 m
47.	UAL-13	901,900 m	2,165,200 m

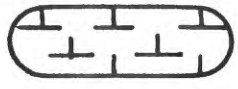
LEGEND FOR FIGURES 2 AND 3



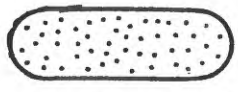
LIMESTONE



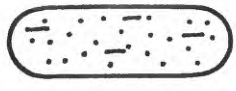
ARGILLACEOUS/ARENACEOUS LIMESTONE



MARL

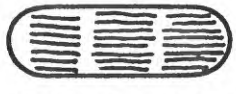


SANDSTONE

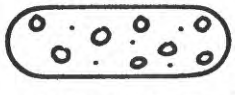


CLAYEY SANDSTONE

SILTSTONE

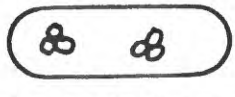


CLAYSTONE/SHALE

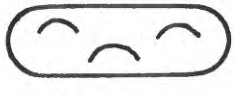


CONGLOMERATE

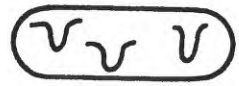
COAL



FORAMINIFERA

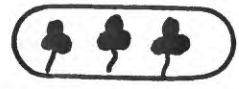


SHELLS

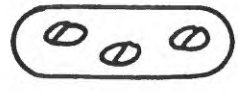


BURROWS

ROOTS

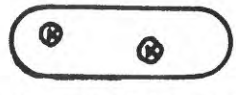


CARBONACEOUS DEBRIS

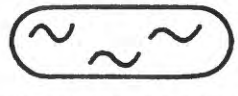


CALCAREOUS NODULES

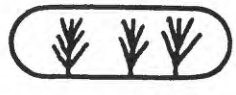
PYRITE



KAOLINITE NODULES

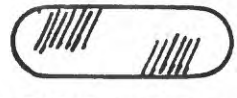


GLAUCONITE

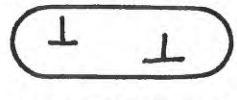


PLANT FOSSILS

RIPPLES



CROSS-BEDDING



CALCAREOUS

FIGURE 2A

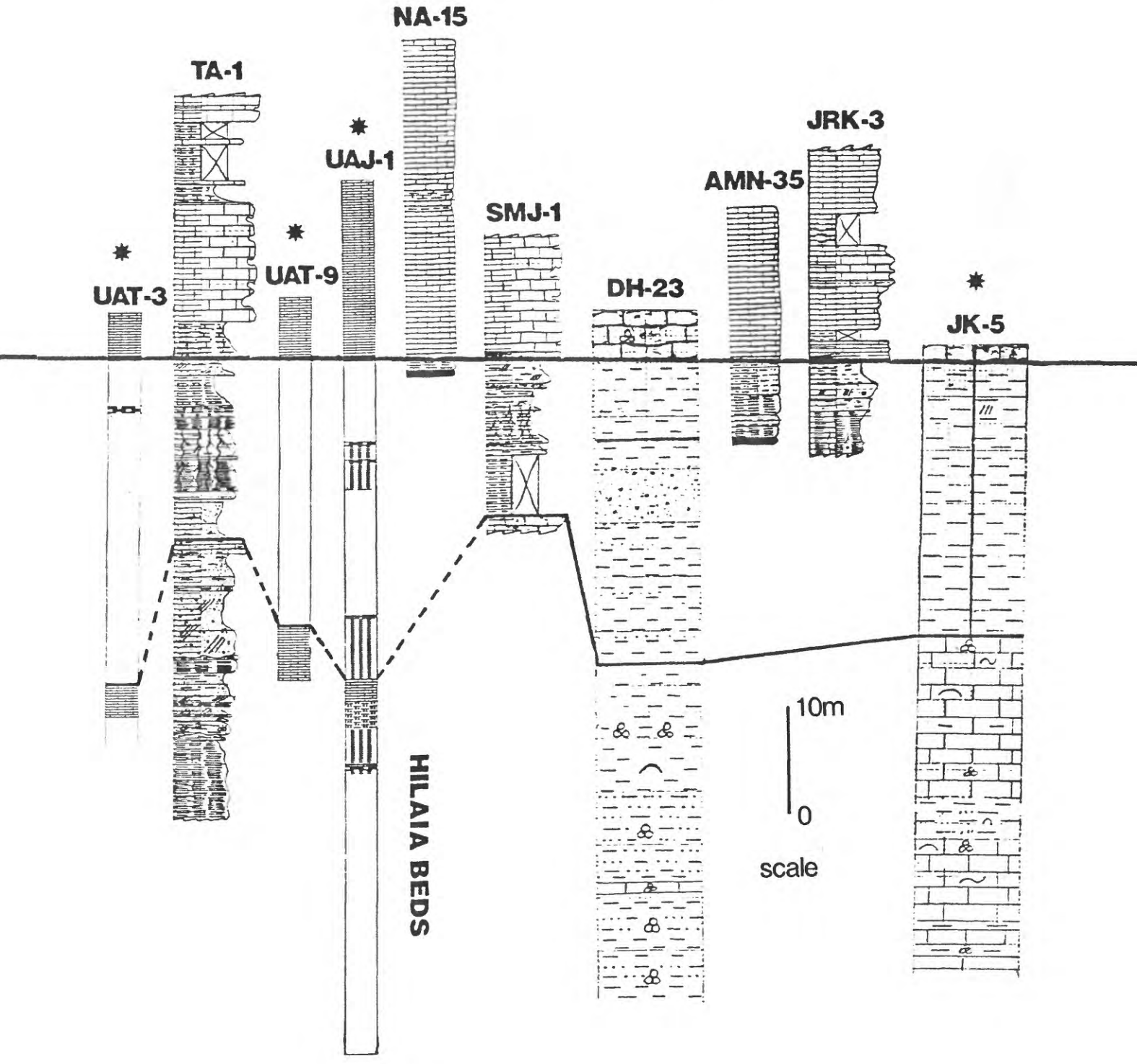

NA-15
TA-1
UAJ-1
JRK-3
AMN-35
SMJ-1
UAT-3
UAT-9
DH-23
JK-5
10m
0
scale
HILAIA BEDS

FIGURE 2B

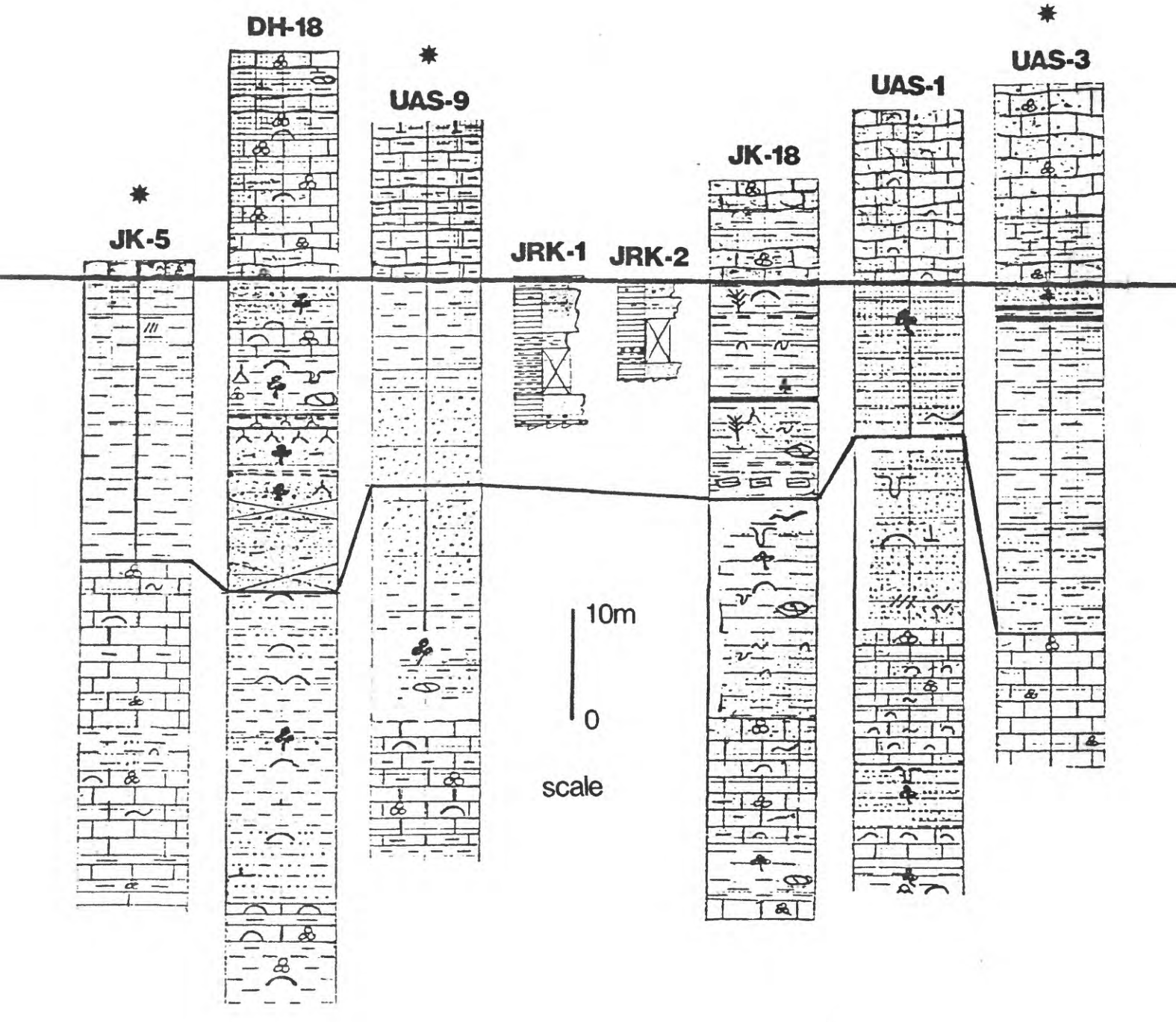


FIGURE 2C

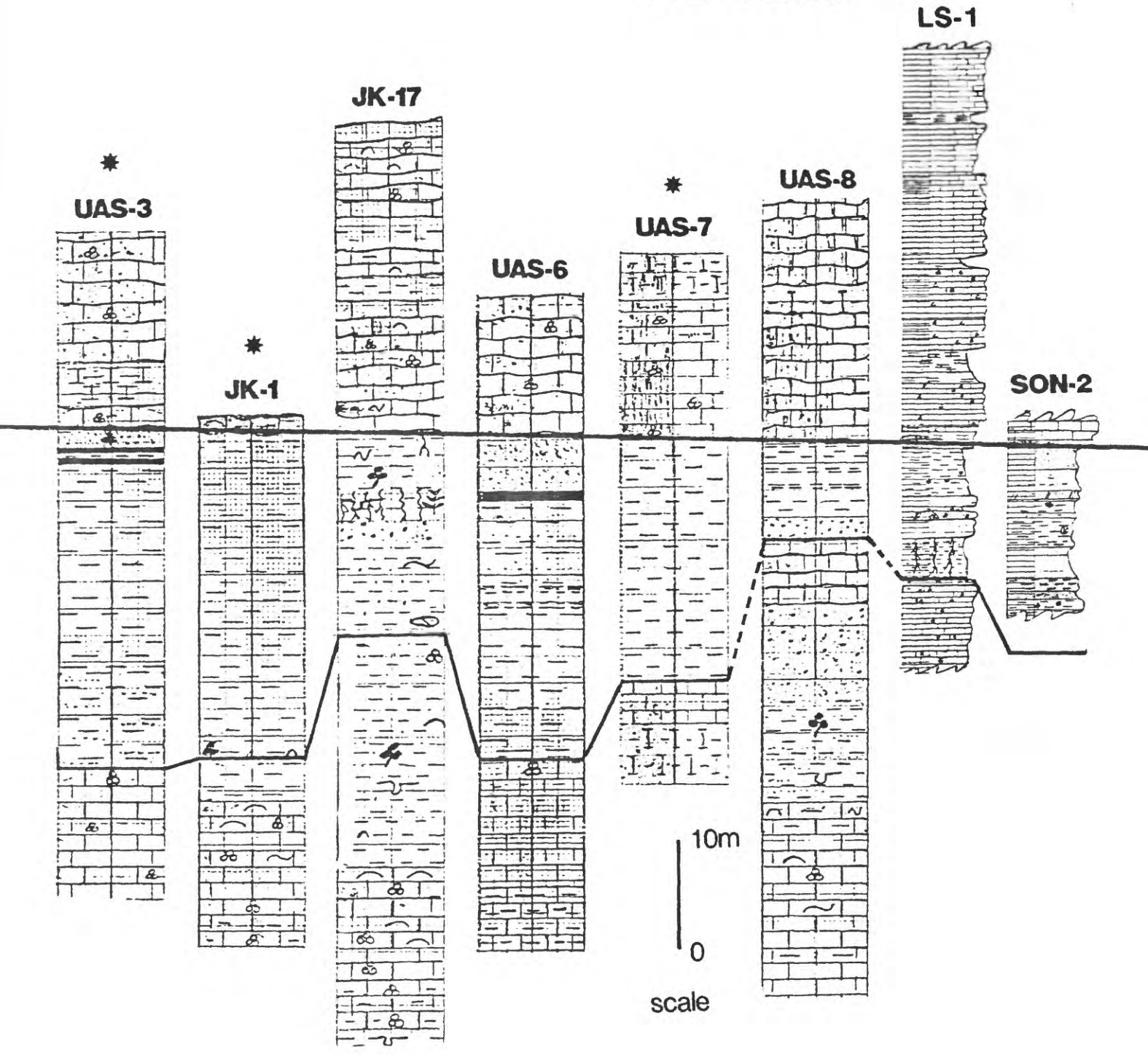


FIGURE 2D

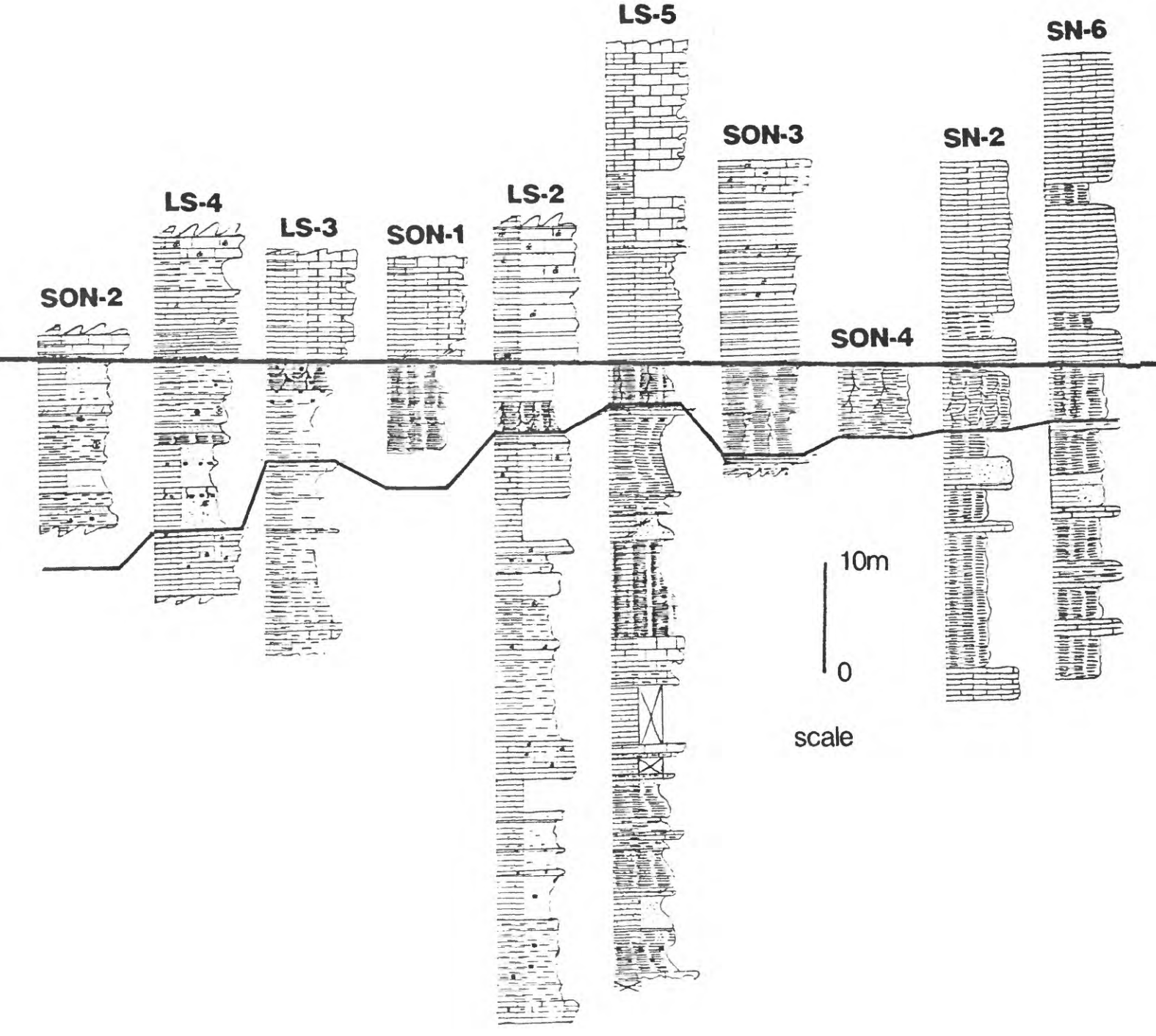


FIGURE 2E

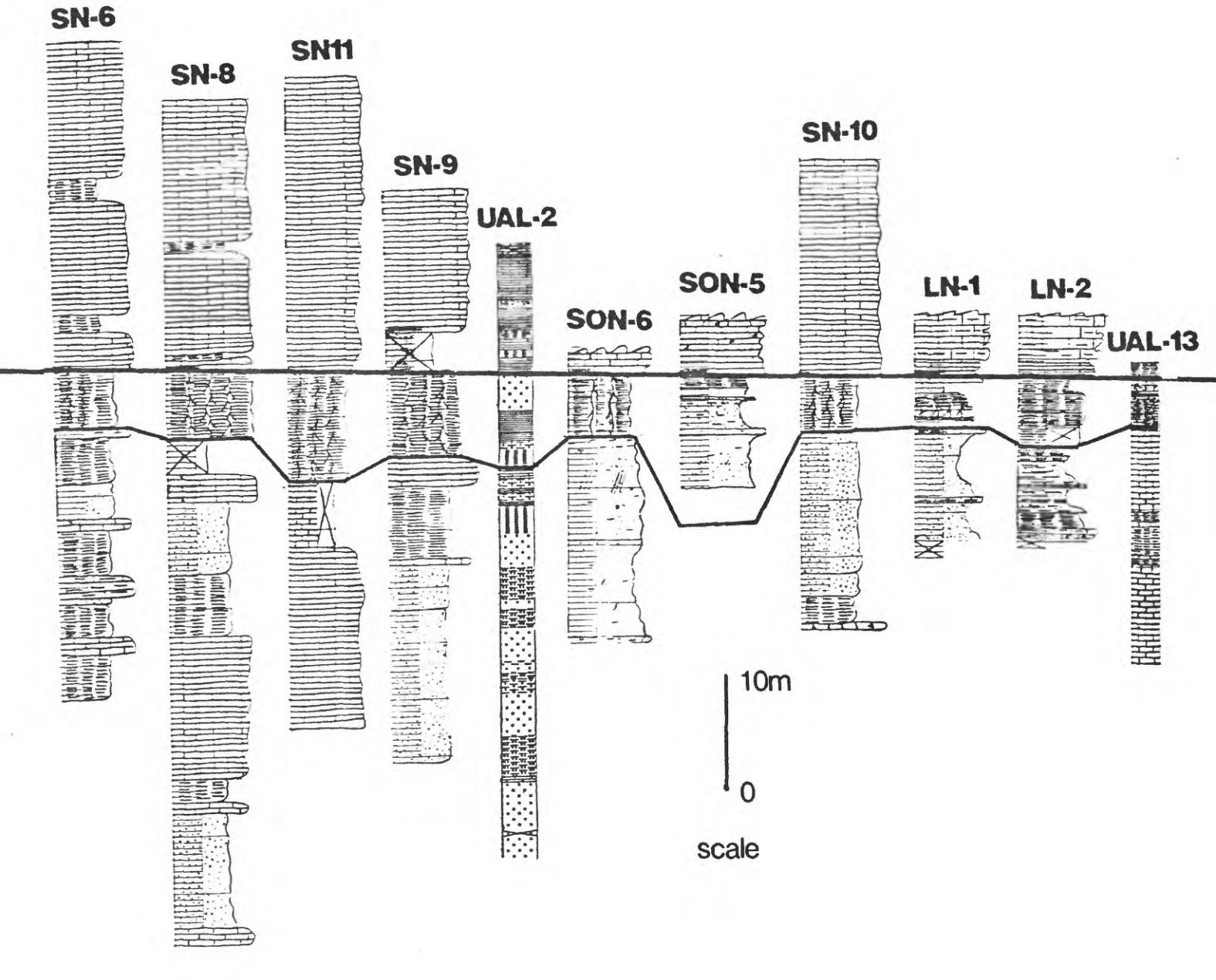
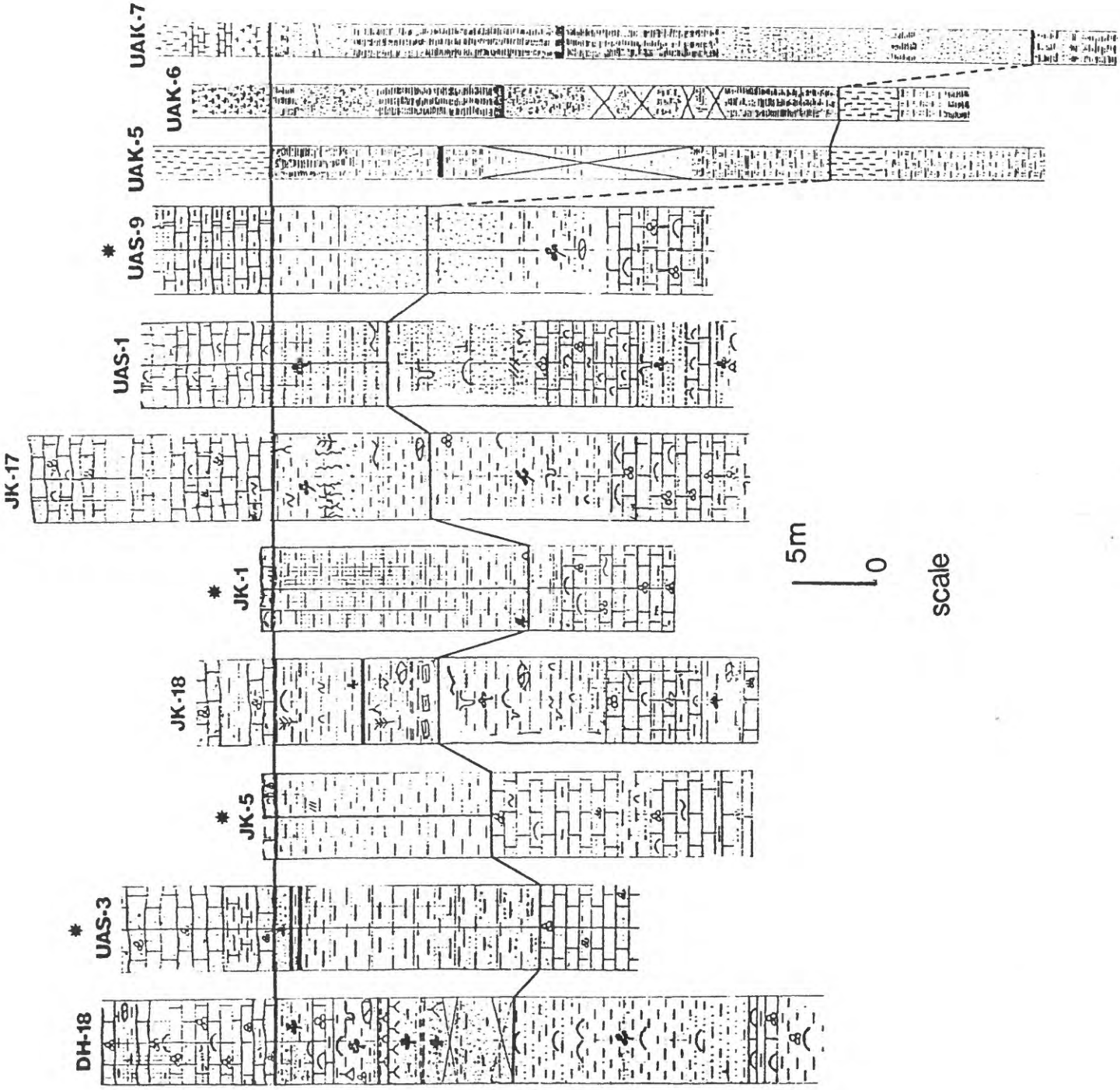


FIGURE 3


UAK-7
UAK-6
UAK-5
UAS-9
UAS-1
JK-17
JK-1
JK-18
JK-5
UAS-3
DH-18
5m
0
scale

with minor percentages of siltstone (6%), mudstone (1%) and conglomerate (1%). Approximately 6% of the cumulative thickness of the Sohnari strata was covered.

The shale/claystone component contains two lithologic types. Volumetrically dominant are the rooted clays. North of approximately Northing 865,000 m, the rooted clays comprise 100% of the thickness of the Sohnari section. These clays are bright red, extremely indurated, massive, homogeneous, and have a blocky fracture. Many outcrops are mined for ochre. South of Northing 865,000 m, the rooted clays are light gray but otherwise identical to the red clays. The gray clays are extensively mined as pottery clay. Also south of Northing 865,000 m, clays with sand laminations become a major part of the section. These clays are fissile, may contain sparse to abundant carbonaceous debris, sometimes contain siderite nodules or their oxidized remains and always contain thin, very fine-grained quartz sand laminations that are typically less than 1 mm thick. Thin ripple lenses may sometimes be found as well. These clays may be brown, red, violet, maroon, or variegated, and are sometimes sparsely rooted. Siltstones in the section are identical to these laminated clays except for their slightly coarser grain size.

South of Northing 865,000 m, sandstones comprise a significant part of the thickness of the Sohnari Member. Sandstones again become prominent north of approximately Northing 900,000 m. Several lithologically distinct sandstone types are present. All of the sandstones in the section are fine- to medium-grained and some beds may contain a small fraction of coarse grains. Well sorted, dirty sandstones containing abundant clay bands and laminations less than 1 mm thick and rare ripples are the most common type of sandstone. These sandstones are gray or green-gray in core, are weathered to brown or yellow-brown at the outcrop, contain abundant

interstitial clay and a sand fraction composed almost exclusively of sub-rounded to sub-angular quartz grains. The dirty sands can be further divided into two groups: those that contain abundant carbonaceous debris, sometimes even containing carbonaceous laminations, and those that contain glauconite, sparse to abundant shells and shell fragments, a small amount of calcareous cement, and sparse carbonaceous debris. The sandstones with abundant carbonaceous debris tend to be located around coals and the rooted horizons; the sandstones with the glauconite and shell debris nearer to the base and top of the Sohnari section.

Less common within the section are the massive sandstones. These may be clean but are more typically dirty. They are fine- to medium-grained, well sorted, and the sand fraction is composed almost exclusively of quartz. Most of these beds appear to have been homogenized by burrowing (burrows resembling Ophiomorpha are common) though some beds have been homogenized by rooting.

Very much rarer within the section are thin beds (less than 1m) of clean sandstone. These are fine- to medium-grained sandstones that are well sorted and contain no interstitial clay. They contain high-energy bedforms like mega-ripples and low-angle cross-beds.

Conglomerates are extremely uncommon and are of two types. The first type consists of rounded to tabular, calcareous and non-calcareous clay pebbles (up to 10 cm long along the longest axis) in a medium to coarse grained sand matrix. These conglomerates weather yellow-brown, and may contain glauconite and shell debris. The other type of conglomerate consists of rounded clay pebbles in a clay matrix.

Coal was never preserved in any of the outcrop sections. Analysis of the COALREAP drill holes and data from Sohnari coal mine sections in the

Meting-Jhimpir Coal Field indicate that coal and carbonaceous shales can range from 0% up to about 5% of the thickness of the Sohnari at any one locality. Coal is discussed in greater detail in the "Coal" section.

Depositional Environments

Outerbridge and others (in press) state that Sohnari strata were deposited in mainly non-marine to brackish water (estuarine) environments. Much of the Sohnari is characterized by slightly bioturbated claystone beds that contain very thin sand laminations. These units are identical to laminated claystones deposited in neritic tidal flat environments (Breyer and McCabe, 1986), and are interpreted to have been deposited under similar conditions.

Stratigraphy

This report conforms to the stratigraphic usage and nomenclature defined in Cheema and others (1977) and accepted by the Geological Survey of Pakistan. This usage is not universally accepted and alternative interpretations can be found in Blanford (1869, 1878, 1880), Williams (1959), and Outerbridge and others (in press) among others.

The Sohnari Member has been differentiated from the overlying and underlying strata on the basis of its more terrestrial aspect (i.e. the fact that it contains coal and rooted zones). The overlying Meting Limestone and Shale Member (of the Laki Formation) consists predominantly of nodular marine limestones and lesser amounts of calcareous shales. The underlying Lakhra Formation consists of intercalated glauconitic marine clastics and foraminiferal limestones. The contact between the Sohnari Member and the Meting Limestone and Shale Member is sharp and consistently identified in lithologic and geophysical logs. The lower contact of the Sohnari Member with the Lakhra Formation is gradational.

Outerbridge and others (in press) report that the Sohnari Member can be as thick as 70 m within the confines of the study area. In comparison to the Sohnari thicknesses measured in this study, the thicknesses reported by Outerbridge and others (in press) are anomalously thick. The greatest part of this discrepancy is caused by differences in the interpretation of the position of the contact between the Sohnari Member and the Lakhra Formation made by Outerbridge an his co-workers versus the interpretation used in this report. These differences are elaborated below. A second significant contributing factor to the thickness discrepancies between Outerbridge and others and this report is the result of differences in the interpretation of the geophysical logs.

The difficulty in assigning a thickness to the Sohnari strata is due to the gradational nature of the contact between the Sohnari Member and the Lakhra Formation. There is no single identifiable horizon that can be consistently used as a boundary between the two units. As a matter of convenience, the Sohnari strata are typically defined as the interval between the lowest Meting limestone bed and the highest Lakhra limestone bed. This is the definition used by Outerbridge and others (in press). Outerbridge and his co-workers group the more distinctly marine facies containing abundant shell faunas in a non-carbonate matrix with Sohnari strata rather than with Lakhra strata, even though these rocks are identical to equivalent clastic facies below the highest Lakhra limestone and very dissimilar to the facies within the more terrestrial parts of the Sohnari Member. Furthermore, Wnuk, Fariduddin, Fatmi, and SanFilipo, (in press, Figures 3 and 4) have shown that limestone beds in the Lakhra Formation are discontinuous, so the basal limestone beds that define Outerbridge's sections are not necessarily correlable. In order to understand regional stratigraphic and facies trends we feel that it is more

appropriate to group similar facies into the same stratigraphic unit. In many sections, particularly north of Northing 865,000 m, our definition and Outerbridge's definition of the location of the contact coincide.

Comparison of Lithology Between the Sohnari and Lakhra Strata

The Sohnari differs from the Lakhra formation in that the Lakhra Formation is composed predominantly of shallow-marine clastic sediments. Lakhra strata consist of approximately 40 percent claystone and siltstone and 40 percent argillaceous, fine-grained sandstone. Limestone is subordinate, usually accounting for less than 20 percent of the formation thickness. In some drill holes, however, over 70% of the section may be composed of carbonates. The sandstone and claystone beds are weakly cemented and form slopes. They typically contain abundant glauconite and are green to olive gray when fresh but weather to yellow brown or yellow orange. The sandstones may contain sparse, poorly preserved shell fragments; the claystones commonly contain shell fragments in addition to well-preserved microfaunas (Amin, 1967; Usmani, 1983; Usmani and Ahmed, 1986a,b, 1987). The sandstone beds are uniformly massive and appear to have been homogenized by burrowing, though relict planar beds and ripples are preserved in places.

Limestones and coarse-grained or conglomeratic sandstones compose approximately 25 percent of the Lakhra Formation thickness. Both lithologies are well cemented ledge formers. The coarse-grained sandstones are thin (usually less than 0.5 m thick). They are intensely burrowed and abundantly fossiliferous. Often the sandstones contain intraformational clay and sandstone clasts and glauconite that weathers to a yellow-brown color. The coarse-grained sandstone beds tend to be most abundant in the lower half of the unit. The limestone beds are usually more than 1 m thick;

beds more than 15 m have been measured in outcrop. They are abundantly fossiliferous and some beds are foraminiferal coquinas. The limestones are argillaceous, sometimes arenaceous, nodular in places, glauconitic in places, and yellowish-brown where weathered. The limestone beds are most common in the top half of the unit.

Distinction between Sohnari and Lakhra beds is based on several rather imprecise characteristics. In core the Lakhra beds tend to have a greenish cast and tend to weather yellow-brown in outcrop because of high concentrations of glauconite disseminated through the matrix or in pellets. In contrast, the Sohnari sandstone beds ocourring below the coal beds and rooted zones are light to medium gray in core and white, gray, red, purple, brown, and variegated in outcrop. Yellow-brown colors also occur but are not common. Sohnari sandstones above the highest coal bed or rooted zone are very much Lakhra-like in their appearance. Carbonaceous debris is very abundant in the Sohnari and tends to be sparse in the Lakhra clastics. Conversely, whole shells and shell fragments that are quite abundant in some beds of the upper Lakhra clastics tend to be uncommon or completely absent in the Sohnari. Shell remains become abundant again above the highest coal or rooted zone of the Sohnari.

Coals and Rooted Zones

Table 2 lists the location and thickness of the Sohnari coals measured in this study and the thicknesses of the coals encountered in the COALREAP drilling (reported in Sanfilipo, Khan, and Khan, 1988). The thickest Sohnari coals found in the COALREAP drill holes are 0.90 m; the thickest Sohnari coal currently mined in the Meting Jhimpir Coal Field is on the National Mines lease in mine NA-15. The coal is 1.32 m thick in places. Coals as thick as 1.78 m have been reported by PMDC from this field (SanFilipo and others, 1988). Coals as thin as 0.60 m are currently

TABLE 2

Sohnari coal thickness and depth.

LOCATION	THICKNESS	DEPTH
DRILL HOLES		
UAL-2	0.25 m	45.48 m
UAL-13	0.15 m	57.09 m
DH-18	0.15 m	41.15 m
DH-23	0.30 m	11.89 m
UAJ-1	0.40 m	119.90 m
"	0.30 m	121.62 m
"	0.05 m	124.40 m
"	0.40 m	150.32 m
UAS-1	?	38.00 m
UAS-3	1.03 m	45.00 m
UAS-6	0.90 m	37.30 m
UAS-8	0.30 m ?	79.00 m
"	0.60 m ?	80.50 m
"	0.60 m ?	82.50 m
UAS-9	?	57.00 m
UAT-3	0.65 m	64.90 m
UAR-4	0.45 m	120.00 m
UAK-5	0.38 m	102.50 m
UAK-6	0.65 m	153.80 m
UAK-7	0.60 m	216.00 m
MINES		
AMN-35	0.60 m	21.70 m
NA-15	1.32 m	30.22 m

economic in the Meting-Jhimpir Field.

Overall, 67% (14 of 21) of the COALREAP drill holes contain coal. Among the holes that were completely penetrated the Sohnari, 83% (10 of 12) contain coal. This percentage improves to 91% if UAT-9 is disqualified because the cored sediments are so severely deteriorated by surficial weathering processes that the core is difficult to recover and coal and roots cannot be accurately identified.

On the basis of geophysical logs, coal has been positively identified in 33% (3 of 9) of the non-core drill holes and tentatively identified in 3 other non-core drill holes. Thus, a total of 67% of the non-core holes appear to contain coal. The fact that coal is more frequently found in cored holes suggests that the occurrence of coal is significantly underestimated in the rotary holes. These apparent underestimates can be explained by the fact that the condition of the rotaried holes is often less than optimal for accurate geophysical surveys. The walls are extensively caved, and often, the holes must be logged through the drill pipe. Under these conditions, even thick coal beds may be difficult to identify on the resulting geophysical logs.

Most drill holes contain one coal bed. However, multiple beds are found in UAJ-1 (3 or possibly 4) and UAS-8 (possibly 2 or 3 depending on the accuracy of the geophysical interpretations). Two of three PMDC drill holes listed in the table of coal thicknesses in SanFilipo and others (1988) also contain multiple coal beds. Both holes (MT-2 and MT-5) contain three coal beds.

Rooted zones or lithologic textures indicative of rooting (massive, blocky, indurated, brecciated claystones) occur in 75% (18 of 24) of the measured outcrop sections. One of the six unrooted sections (SON-1) contains claystones with textural characteristics suggestive of rooting,

but the claystone is near a fault and the texture may be the result of deformation attendant to faulting. Another 3 of the 6 unrooted sections are incomplete (JRK-1, JRK-2, and SON-2). The basal parts of these sections are not exposed, and it is possible that the rooted zones were not uncovered. Rooting appears to be completely absent in sections SON-5 and LN-2, though both of these sections are extremely weathered and it is possible that rooting was masked as a result. Multiple rooted horizons are rare in outcrop sections and have been observed only at section LS-4.

For the most part, the GSP field geologists did not record the presence of rooted zones, but we are assuming that all of the coals overlie rooted zones. In addition, several holes which have no coals are known to contain rooted zones (UAK-16 and JK-17; UAT-9 is too badly weathered to identify rooting but correlative nearby outcrops are known to be rooted). Rooted zones occur in at least 86% (18 Of 21) of all of the drill holes and 100% of the core holes. Besides the two holes which contain more than 1 coal, at least 5 other holes are known to contain multiple rooted horizons (DH-18, UAK-5, UAK-7, UAK-16, and UAL-13). We suspect that reexamination of other Sohnari cores will reveal that multiple rooted zones are commonplace. All of the drill holes and surface sections with multiple coals or rooted zones are south of Northing 865,000 m or north of Northing 900,000 m. Also, all of the holes containing marine sediments are between these two Northings.

At this time we are unable to determine the percentage of rooted zones that are overlain by coal. Experience with the stratigraphically deeper coal-bearing Bara Formation (which is lithologically very similar to the Sohnari Member) suggests that a high percentage of the rooted zones should be overlain by coal. In one Bara Formation core hole examined by Wnuk,

SanFilipo, Fatmi, Khan, and Fariduddin (in press), 24 of the 29 rooted horizons (83%) were overlain by coal beds. The 5 rooted zones that were not topped with a coal all appear to have scour contacts with the overlying sediments (usually sandstone). Given the similarity between the Bara and Sohnari sediments (see the descriptions of the Bara Formation in Wnuk, SanFilipo, Fatmi, Khan, and Fariduddin, in press) it is believed that a comparable association exists between rooted zones and coal in the Sohnari Member as well, at least south of Northing 865,000 m where the Sohnari is relatively thick. North of Northing 865,000 m, there is insufficient core-hole information to consider this issue.

Regional Stratigraphic and Lithologic Trends

The idea that the Sohnari Member is in some way associated with an unconformity is deeply entrenched in the literature (Nuttall, 1925; Hunting Survey Corporation, 1961; Cheema, 1977; Farshori, unpublished). All of these investigators maintain that there is an unconformity between the base of the Sohnari Member and the underlying Lakhra Formation, and they place the Paleocene/Eocene contact at the base of the Sohnari Member. This conclusion is based on the mistaken identification of the Sohnari Member as a fossil laterite because of its tendency to weather to a distinctive bright red color in outcrop (see the discussion in Outerbridge and others (in Press) regarding this subject). However, Ghani and others (1973) showed that the bright red coloration of the Sohnari strata did not extend into the sub-surface and they concluded that the Sohnari was not a fossil laterite. Subsequent paleontological investigations by Usmani (1983) and Frederiksen (1990) indicate that the Sohnari is more likely Paleocene rather than Eocene in age.

Outerbridge and others (in press) conclude that both the upper and lower contacts of the Sohnari are transitional between the overlying and

underlying strata. We concur with Outerbridge's interpretation of the transitional nature of the lower contact with the Lakhra Formation. However, we see no evidence of a transitional upper contact. The clastics above the coal beds often contain shell debris and glauconite, and may even be slightly calcareous, but there is a pronounced lithologic discontinuity between the upper Sohnari marine clastics and the Meting limestone. The upper Sohnari contains no limestones; the Meting is generally more than 90% carbonate. Comparisons between the shaly beds within the Meting limestone and the shales in the marine part of the Sohnari also indicate pronounced lithologic differences. The shales in the Meting unit contain significantly more glauconite, are much more calcareous, and are generally barren of carbonaceous debris compared to the upper Sohnari. The abrupt change in lithology between the Sohnari and Meting strata suggests that there is a hiatus of some kind between the two units.

Analysis of surface section and drill hole UAL-13 data indicates that, throughout the region, 47% of the total thickness of the Sohnari has been disturbed by rooting. However, the absolute percentage of the total unit disturbed by rooting appears to increase toward the north. Between Northings 873,000 m and 896,000 most sections are 100% root bioturbated. North of Northing 896,000 m, fewer of the sections are root turbated, and additional study is needed in this area to determine the causes of this apparent decrease in rooting intensity. Likewise, to the south, a re-evaluation of the drill hole data is needed to determine the degree to which the percentage of rooting decreases.

The data presented in this report indicate that the Sohnari thickens toward the south. The amount of this thickening is difficult to determine because the drill hole data has not yet been reevaluated. Most of this

thickening appears to be related to the increasing amount of marine clastics above the coal and/or rooted horizons toward the south.

Over most of the length of the study area, the east-west width of the exploration belt is too narrow to meaningfully evaluate east-west thickness trends. In the area between Meting and Tando Muhammad Khan, where both the east and west sides of the Indus River have been explored, the Sohnari appears to be more or less uniform in thickness on the west side of the Indus but thickens dramatically on the east side. The cause of this thickening is unknown at this time.

We also do not have the necessary information to correlate the coals and rooted zones between the drill holes and to then extend these correlations to the outcrop sections. It is unclear at this time whether individual coal beds are correlable across the extent of the basin, or whether they are discontinuous lenses. It is also unclear how consistently root horizons can be correlated laterally to coal beds. The ability to correlate coal beds and rooted zones across the basin is an essential prerequisite to addressing questions about the nature of the hiatus between the Meting and the Sohnari, and to determining the cause of the observed thinning of the Sohnari.

Stratigraphic Anomalies

The definition of the Sohnari Member used in this report excludes limestones from the lithology of Sohnari rocks. This definition works well throughout most of the study area. However, there are two drill holes, UAJ-1 and UAS-8, in which the contacts of the Sohnari strata are very difficult to define. In both of these, it is possible that the lower part of the Sohnari may include limestone.

The descriptions of the clastic strata below the highest Lakhra-like limestone in UAS-8 are imprecise in the field notes. The lithologic

characteristics appear more similar to Lakhra clastics, but the possibility that these are Sohnari beds cannot be excluded at this time. In Figure 2, the Lakhra/Sohnari contact is drawn on the top of the highest limestone, but the placement of that contact results in a Sohnari unit that unusually thin compared to the member's thickness in adjacent areas.

In UAJ-1, the stratigraphic problem is more complicated, because there is a coal 5 m below the highest "Lakhra" limestone, and the clastics above and below the limestone appear lithologically very similar. If the Lakhra/Sohnari contact is drawn at the top of this limestone, then we must conclude either that the Lakhra contains coal (a unique occurrence), or that the lower coal is in the Bara Formation and Lakhra is extraordinarily thin in this area compared to immediately adjacent areas. Alternatively, if the limestone is included in the Sohnari, then the Sohnari is more than 65 m thick in UAJ-1. This makes UAJ-1 the thickest occurrence of the Sohnari in the study area.

The limestone bed itself can be correlated between UAT-3, TA-1, UAT-9, and UAJ-1 as shown in Fig. 2A. It is unclear whether to draw the base of the Sohnari at the top of the limestone at this time. The interval between the top of this limestone and the top of the next highest limestone bed is probably the 120 ft (36.6 m) included in the Lakhra Formation as Nuttall's (1932) "Section Near Hilaia Trigonometric Section". For the tine being, we have also included this interval in the Lakhra Formation.

We do not have sufficient data at the present time to choose among the alternative stratigraphic interpretations for the Sohnari in UAS-8 and UAJ-1. Re-study of the core from both of these holes and from UAT-9, and perhaps consideration of new data, will be necessary to resolve these stratigraphic problems.

CONCLUSIONS AND RECOMMENDATIONS

Coals comparable in thickness to the coals being mined in the Meting-Jhimpir Coal Field are documented to occur well beyond the boundaries of Meting-Jhimpir area. The Sohnari may possibly be coal-bearing throughout the region around the Lakhra Anticline. The formation should be considered as a potential exploration target wherever it occurs in the shallow subsurface, because there is the potential to discover other thick pods of coal like those being mined in the Meting-Jhimpir area.

At the north end of the Lakhra Anticline, where the Sohnari Member and, coincidentally, the Lakhra Formation are thinnest, Bara Formation coals were found to be anomalously shallow. Understanding the stratigraphic and depositional trends in the Sohnari (and the Lakhra), will help to predict if other areas also have anomalously shallow coal occurrences, and should be preferentially targeted for exploration. Consequently, additional data must be collected to determine the nature of the depositional hiatus between the Meting and the Sohnari and the degree and the cause of the thinning of the Sohnari. This data collection should take the form of continued reevaluation of existing drill hole data and selected new drilling in areas where there are significant data gaps.

ACKNOWLEDGEMENTS

This study was funded through project 391-0478: Energy Planning and Development Project, Coal Resource Assessment Component 2A; Participating Agency Service Agreement (PASA) IPK-0478-P-IC-5068-00. We would like to express our gratitude to Director General A.H. Kazmi of the Geological Survey of Pakistan for his generous support and encouragement of this project. We would also like to thank our many colleagues at the Geological Survey of Pakistan and the U.S. Geological Survey who contributed valuable

suggestions during the preparation of this manuscript. We must also acknowledge the assistance of the USAID support staff in Karachi and especially in Hyderabad. Without them this study would have been logistically impossible.

REFERENCES

Amin, S.M., 1967, The occurrence of coccoliths and related forms in the Laki and Ranikot Formations from Sari, West Pakistan: The Geological Bulletin of the Panjab University, v. 6, p. 45-54.

Blanford, W.T., 1869, Note on the geology of the neighborhood of Lynyan and Runneekote, north-west of Kotree, in Sind: Memoirs of the Geological Survey of India, v. 6, p. 1-16.

Blanford, W.T., 1878, On the geology of Sind, Records of the Geological Survey of India, v. 11, p. 161-173.

Blanford, W.T., 1880, The geology of western Sind: Memoirs of the Geological Survey of India, v. 17, p. 1-196.

Boyd Company, John, T., 1985, Technical Report, Field Studies Program, Lakhra Coal Project, Sind Province, Pakistan: Report No. 1800, Vol. 3A,B.

Boyd Company, John, T., 1986, Field Studies Program - Phase II, Lakhra Coal Project, Sind Province, Pakistan: Report NO. 1800, Vol. 3C.

Breyer, J.A., and McCabe, P.J., 1986, Coals associated with tidal sediments in the Wilcox Group (Paleogene), South Texas: Journal of Sedimentary Petrology, v. 56, p. 510-519.

Cheema, M.R., Raza, S.M., and Ahmad, H., 1977, Cainozoic, in Shah, S. M. Ibrahim, ed., Stratigraphy of Pakistan: Memoirs of the Geological Survey of Pakistan, Vol. 12, 138 p.

Farshori, M.Z., The geology of Sind: Hyderabad, Sind University, unpublished, 81 p.

Frederiksen, N.O., 1990, Palynological contribution to geologic mapping of Upper Paleocene rocks in the lower Indus coal region, Pakistan: U.S. Geological Survey Open-File Report 90-243, Reston, Virginia, U.S. Geological Survey.

Geologic Associates Inc., 1985, Completion Report, USAID Project NO. 391-0487, Interim drilling program, Lakhra Coal Project, Sind, Pakistan, GA Project No. 84-474F.

Ghani, M.A., Harbour, R.L., Landis, E.R., and Kebblish, W., 1973, Geology and coal resources of the Lakhra Coal Field, Hyderabad area, Pakistan: U.S. Geological Survey Open-File Report 75-553, (also released as U.S. Geological Survey Project Report (IR) PK-55).

Hunting Survey Corporation, Limited, 1961, Reconnaissance geology of part of West Pakistan: Colombo Plan Cooperative Project, published for the Government of Pakistan by the Government of Canada, Oshawa, Maracle Press, 550 p.

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, C., Durrani, N.A., Khan, Rafiq, A., Shah, A.A., 1988, Report on coal resource exploration and assessment program drilling and related activities, September 1987 to February 1988 conducted in the Indus East coal area, southern Sind Province, Pakistan: U.S. Geological Survey Open-File Report 88-543-A,B,C, Reston, Virginia, U.S. Geological Survey.

Memon, A.S., Alam, S., Mohiuddin, M., and Wahid, A., 1976, Geologic report on part of the Lakhra coal field near Khanot, District Dadu, Sind: Pakistan Mineral Development Corporation, Hyderabad, Pakistan, 44 p.

Nuttall, W.L.F., 1925, The stratigraphy of the Laki Series (Lower Eocene) of parts of Sind and Baluchistan (India); with a description of the larger foraminifera contained in those beds: Geological Society of London Quarterly Journal, v. 81, p. 417-453.

Nuttall, W.L.F., 1932, The stratigraphy of the upper Ranikot series (lower Eocene) of Sind, India: Geological Survey of India, Records, v. 65, p. 306-313.

Outerbridge, W.F., Frederiksen, N.O., Khan, M. Riaz, Khan, Rafiq A., Qureshi, H.J., Khan, M. Zameer, Niamatullah, Khan, Shafique A., in press, The Sohnari Formation in southern Pakistan, in Stratigraphic Notes, 1989, U.S. Geological Survey Bulletin 1935.

SanFilipo, J.R., Khan, Rafiq, A., and Khan, Shafique, A., 1988, Geology and coal resources of the Lakhra and Sonda coal fields, with recommendations for future coal assessment work, Part II, Chapter 2, In Schweinfurth, S.P., and Husain, F., eds., 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, Vol. I-VI.

SanFilipo, J.R., Chandio, A.H., Khan, Shafique A., and Khan, Rafiq A., 1989, Results of COALREAP drilling from January 1988 to February 1989, Jherruck area, Sonda Coal Field, Sind Province, Pakistan: U.S. Geological Survey Pakistan Project Report (IR) PK-85.

SanFilipo, J.R., Khan, Rafiq A., Khan, Shafique A., 1990, Coal resources and the geologic controls of the Lakhra and Sonda Coal Fields, Sind Province, Pakistan, in Kazmi, A.H., ed. Proceedings of the workshop on the significance of coal resources of Pakistan, February 8-9, 1989, Karachi, Pakistan: Geological Survey of Pakistan, Quetta.

SanFilipo, J.R., Wnuk, C., Fariduddin, M., Ahmad, M., Khan, S.A., Metab-ur-Rahman, Chandio, A.H., and Khan, R.A., in press, Potential for the occurrence of thick lignite deposits in the Thar Desert and Lower Indus Plain, Sind Province, Pakistan: Geological Survey of Pakistan Project Report (IR) PK-.

Schweinfurth, S.P., and Husain, F., 1988, 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, Vol. I-VI.

Usmani, P., 1983, Planktonic foraminifera from the Ranikot and Basal Laki Formations (Paleocene and Early Eocene) of the Lakhra area, Sind, Pakistan: Neues Jahrbuch fur Geologie und Palaontologie Monatshefte, No. 7, p. 429-447.

Usmani, P., and Ahmed, M.R., 1986a, Paleoecology of Paleocene benthonic smaller foraminifera from the Lakhra area, Sind, Pakistan: Neues Jahrbuch fur Geologie und Palaontologie Monatshefte, No. 8, p. 479-488.

Usmani, P., and Ahmed, M.R., 1986b, Probable new species of smaller benthonic foraminifera from the Lakhra area, Sind, Pakistan: Neues Jahrbuch fur Geologie und Palaontologie Monatshefte, No. 9, p. 570-576.

Usmani, P., and Ahmed, M.R., 1987, Investigation of Lower Paleocene benthonic foraminifera of the superfamily Miliolicea from the Lakhra area, Sind, Pakistan: Sind University Research Journal, v. 19, p. 89-106..

Williams, M.D., 1959, Stratigraphy of the lower Indus Basin, West Pakistan: Fifth World Petroleum Congress, New York, 1959, Section 1, Paper 19, 15 p.

Wnuk, C., Fariduddin, M., Fatmi, S.F., and SanFilipo, J.R., in press, The stratigraphy and geometry of the Lakhra Formation in the Lakhra Coal Field area and Implications for the coal resource potential north of Lakhra, Sind Province, Pakistan: A progress report: U.S. Geological Survey Open File Report, 104 p.

Wnuk, C., SanFilipo, J.R., Fatmi, S.F., Khan, S.A., and Fariduddin, M., in press, The coal resource potential of the lower and middle part of the

Bara Formation in Sind, Pakistan: A progress report: U.S. Geological Survey Open File Report, 91 p.

APPENDIX 1

DESCRIPTIONS OF MEASURED OUTCROP SECTIONS

SECTION TA-1

METING LIMESTONE

1.	Limestone: 2.40 m (2.40 m)	Pale yellow, weathers white; massive; nodular; indurated, ledge former; CONTAINS: abundant Alveolina and other forams; contact unknown:
2.	Covered: 1.60 m (4.00 m)	Slope former; slope wash is light yellow-brown consequently the covered interval is presumed to be an argillaceous limestone or possibly a shale; contact unknown:
3.	Limestone: 0.55 m (4.55 m)	Argillaceous, yellow-brown; weakly indurated, slope former; CONTAINS: abundant Alveolina; contact unknown:
4.	Covered: 3.25 m (7.80 m)	Slope former; presumed to be argillaceous limestone: sharp contact with:
5.	Limestone: 0.45 m (8.25 m)	Argillaceous, yellow-brown; indurated, ledge former; CONTAINS: abundant Alveolina and other forams; sharp contact with:
6.	Marl: 1.80 m (10.05 m)	Dark yellow; clay fraction becomes increasingly abundant upward, top 15 cm is a calcareous shale; arenaceous; weakly cemented, slope former; CONTAINS: very fine- to medium-grained matrix supported quartz sand; Alveolina and other forams; grades into:
7.	Limestone: 11.25 m (21.30 m)	Pale yellow, weathers white; indurated, ledge former; CONTAINS: Alveolina and other forams; grades into:
8.	Limestone: 3.30 m (24.60 m)	Calcarenite; very argillaceous; yellow-brown; quartz grains present locally; weakly indurated, slope former; CONTAINS: abundant gastropods; very abundant Alveolina and other forams, Alveolina becomes more abundant upward, other foram types become less prominent; grades into:

9. Limestone: Calcarenite; very argillaceous; yellow-brown; indurated, ledge former; CONTAINS: abundant fine-grained quartz sand; glauconite pellets; burrows, echinoderms, Alveolina and other foram types; grades into:
0.25 m
(24.85 m)

SOHNARI FORMATION

10. Sandstone: Medium- to coarse-grained, poorly sorted; yellow-brown with red and gray mottling; composed of quartz, abundant interstitial clay, and, in the upper part of the unit, calcareous cement; poorly cemented, slope former; CONTAINS: sparse burrows; planar cross-beds; discoidal forams at the top; abundant red iron concretions at the top; this sandstone is extremely variable laterally; 300 m away the sandstone is white orthoquartzite composed of 100 percent quartz with silica cement; CONTAINS: planar cross-beds up to 20 cm thick; in-drift and in-phase climbing ripples; low-angle cross-beds; laminar bedding in places; in places the orthoquartzite appears to be pale yellow, slightly argillaceous and more weakly cemented; sharp contact with:
1.35 m
(26.20 m)

11. Shale: Variegated, red, gray, purple, yellow-brown, the unit is olive-brown where it is unweathered, fissile; slope former; CONTAINS: fine-grained quartz sand laminae and zones of sandy shale; sharp contact with:
2.90 m
(29.10 m)

12. Ironstone: Dark red to black; hard; nodular; sandy in places; has texture of an ironstone ground mass around ironstone nodules; indurated, ledge former; CONTAINS: small rounded pellets that may be replaced glauconite; sharp undulating contact with:
0.15 m
(29.25 m)

13. Mudstone: Red at base, gray at the top; sand content increases upward and the unit grades into a very fine- to medium-grained poorly sorted, argillaceous sandstone at the top; poorly cemented, slope former; CONTAINS: iron rich concretions; grades into:
0.40 m
(29.65 m)

14. Sandstone: Very fine- to fine-grained, poorly sorted; yellow-brown; composed of quartz and abundant interstitial clay; poorly cemented, slope former; CONTAINS: iron rich concretions and a thin hematite cemented layer at the top of the unit; grades into:
0.45 m
(30.10 m)

15. Mudstone: Variegated red, white, yellow-brown, red at the top, common lateral color changes; clay at base and clay bands in places; slope former; CONTAINS: matrix supported quartz sand grains; no evidence of rooting; grades into:
1.10 m
(31.20 m)

16. Sandstone: Very fine- to fine-grained, poorly sorted; yellow-brown, mottled pink and purple; composed of quartz and very abundant interstitial clay; unit fines upward, clay content increases upward; poorly cemented, slope former; CONTAINS:
2.65 m
(33.85 m)

abundant roots, no evidence of original bedding, unit homogenized by rooting; kaolinite nodules scattered throughout; sharp contact with:

17. Sandstone: Very fine- to fine-grained; purple-red; indurated, ledge former; extensive iron and possibly manganese
0.25 m mineralization, unit appears to be a mineralized alteration
(34.10 m) product of the overlying unit where that unit is in contact with an impermeable barrier to ground water movement; unit varies from 25 to 50 cm in thickness; indurated, ledge former; CONTAINS: abundant roots; grades into:

18. Claystone: Variegated red, gray, purple, black, yellow-brown; coarsens upward to siltstone and then to sandy siltstone; massive;
2.50 m blocky; soapy feel at base; slope former; CONTAINS: abundant
(36.60 m) roots; quartz sand grains appear to parallel root traces; some original laminar bedding preserved; contact not exposed:

19. Claystone: Variegated red, purple, white, gray, black, yellow-brown; very hard and indurated; has the appearance of flint clay;
0.50 m has flaky, exfoliating weathering texture; CONTAINS:
(37.10 m) roots?; very fine-grained sandstone beds at the base of the unit; grades into:

20. Sandstone: Very fine- to medium-grained, poorly sorted; dark red, black in places; porous, has the appearance of clinker; composed of
0.70 m quartz and iron oxide cement; indurated, ledge former;
(37.80 m) CONTAINS: burrows; contact unknown:

21. Covered: Possibly sandstone; contact unknown:

0.40 m
(38.20 m)

22. Sandstone: Very fine- to fine-grained at the base, fines upward to very fine-grained at the top, poorly sorted; yellow-brown, medium
3.50 m gray in places, red hematite banding at the top of the unit;
(41.70 m) composed of quartz and abundant interstitial clay; poorly cemented, slope former; approximately one meter is covered; CONTAINS: abundant fragmental forams at the base; abundant burrows; sharp contact with:

LAKHRA FORMATION

23. Limestone: Crystalline; argillaceous; yellow-brown; indurated, ledge former; CONTAINS: scattered quartz grains in the uppermost
1.40 m part of the unit; gastropods, shell fragments, and various
(43.10 m) foram types; the unit is laterally variable; 800 m to the north the unit thickens to 3.5 m and develops a pebble sized nodular texture, the nodules are irregularly branching, rounded, microcrystalline calcite throughout; the limestone is argillaceous, contains clay pockets that have included quartz grains in places; the unit is massive, homogeneous, and has the appearance of a conglomerate; the pebble texture disappears in the top 50 cm; CONTAINS: corals, gastropods,

pelecypods, and forams; sharp contact with:

24. Sandstone: Fine- to coarse-grained, poorly sorted; purple, yellow-brown, and bands of white kaolinite; composed of quartz and
2.95 m abundant interstitial clay; poorly cemented, slope former;
(46.05 m) CONTAINS: kaolinite beds throughout; no evidence of bedding, unit homogeneous; sharp, irregular contact with:

25. Siltstone: White, mottled with purple and yellow-brown; slightly fissile; sandy in places; CONTAINS: plant fragments; grades
0.45 m into:
(46.50 m)

26. Sandstone: Medium- to very coarse-grained, poorly sorted; yellow-brown basal half, purple upper half; composed of quartz and
6.55 m interstitial clay; poorly cemented, slope former; CONTAINS:
(53.05 m) large scale planar cross-beds up to 1 m thick; abundant burrows above 1.5 m, unit homogenized by burrowing; scour contact with:

27. Sandstone: Fine- to coarse-grained, poorly sorted; white with purple banding and red mottling in places; composed of quartz and
0.30 m very abundant interstitial clay; poorly cemented, slope
(53.35 m) former; CONTAINS: thin black bands of iron mineralization; grades into:

28. Claystone: Sandy, contains abundant matrix supported sand grains, the matrix supported texture suggests rooting but there is no
1.65 m unequivocal evidence for rooting; bottom half variegated
(55.00 m) red, white, and yellow-brown, top half white with red mottling; grades into:

29. Sandstone: Fine-grained, very fine- to medium-grained in places, poorly sorted; white, yellow-brown, and purple; composed of quartz
2.10 m and abundant interstitial clay; poorly cemented, slope
(57.10 m) former; CONTAINS: numerous white kaolinite bands scattered throughout; sharp contact with:

30. Sandstone: Medium-grained, moderately sorted; pink; composed of quartz and some interstitial clay; poorly cemented, slope former;
0.70 m CONTAINS: large scale planar cross-beds; possible burrows;
(57.80 m) kaolinite intertongues at the base; intertonguing contact with:

31. Kaolinite: White, yellow-brown clay approximately 5 cm thick occurs at the base and top of the unit; low density; poorly indurated,
0.35 m slope former; CONTAINS: lenticular sand bodies in places;
(58.15 m) bands of black iron or manganese stain; sharp contact with:

32. Sandstone: Medium- to coarse-grained, poorly sorted; pink; composed of quartz and some interstitial clay; poorly cemented, slope
0.80 m former; CONTAINS: intense burrowing, in places the unit is
(58.95 m) homogenized by burrowing; large scale planar cross-beds; scour contact with:

33. Kaolinite: White; very low density; poorly indurated, slope former; CONTAINS: bands of black manganese or iron mineralization; sharp contact with:
0.20 m
(59.15 m)

34. Sandstone: Medium- to coarse-grained, moderately sorted; light gray, red mottling in places; composed of quartz and some interstitial clay; poorly cemented, slope former; CONTAINS: eastward dipping planar cross-bed sets; scour contact with:
0.40 m
(59.55 m)

35. Sandstone: Fine-grained, medium-grained in places, poorly sorted; white, yellow-brown, red, and black; composed of quartz and abundant interstitial clay; poorly cemented, slope former; CONTAINS: internal scour contacts; white kaolinite bands at the base and scattered throughout the unit, kaolinite of very low density and contains matrix supported quartz sand grains, some kaolinite has an internal vertical structure as if it were dewatered gypsum or a kaolinitic replacement of secondary gypsum veins; sharp contact with:
1.35 m
(60.90 m)

36. Sandstone: Very fine- to fine-grained, poorly sorted; red, purple, yellow-brown, and white, composed of quartz and abundant interstitial clay; poorly cemented, slope former; CONTAINS: kaolinite bands at the base; bands of claystone, siltstone, fine-grained and very fine-grained sandstone; grades into:
0.70 m
(61.60 m)

37. Claystone: Olive-brown, the top part of the unit is (bleached?) white; massive; blocky; coarsens upward, siltstone bands and very fine- to fine-grained quartz sand laminae become more prominent upward; slope former; CONTAINS: siderite nodules in the basal part of the unit; bands of red and purple iron mineralization in the upper third of the unit, mineralization appeared to occur preferentially along siltstone bands.
7.70 m
(69.30 m)

END OF SECTION

SECTION SMJ-1

METING LIMESTONE

1. Limestone: White to buff; argillaceous; nodular; crystalline in places; indurated, ledge former; CONTAINS: laminar bedding; 11.50 m (11.50 m) echinoderms, corals, pelecypods, gastropods, burrows, abundant Alveolina forams; sharp contact with:

SOHNARI FORMATION

2. Sandstone: Fine- to medium-grained, poorly sorted; dark yellow-brown; composed of quartz and abundant interstitial clay; poorly 2.10 m (13.60 m) cemented, slope former; top meter is covered but inferred to be of same lithology; CONTAINS: low-angle cross-beds; abundant vertical and horizontal burrows; sharp contact with:

3. Conglomeratic sandstone: Medium- to coarse-grained, poorly sorted; yellow-brown; composed of quartz, weathered glauconite, 0.45 m abundant interstitial clay, and calcareous clay pebbles; (14.05 m) indurated, ledge former; CONTAINS: scattered oyster shells; tabular clay pebbles orientated parallel to bedding, clay pebbles range in size from 1x2x3 cm to 3x4x10 cm, pebble content and size increases upward within the unit; sharp contact with:

4. Claystone: brown; grading upward into sandy mudstone, sand fraction consists of very fine to medium quartz grains and some 0.15 m (secondary?) dark minerals; slope former; sharp contact (14.20 m) with:

5. Carbonaceous shale: Black; possibly a weathered coal; slope former; CONTAINS: a black ironstone band at the top of the unit; 0.14 m sharp contact with: (14.34 m)

6. Shale: Chocolate-brown; fissile; slope former; CONTAINS: scattered carbonaceous debris; possible slickensides but no definitive 0.55 m evidence of rooting; sharp contact with: (14.89 m)

7. Sandstone: Fine- to medium-grained, poorly sorted; yellow-brown with red shale bands; composed of quartz and abundant 1.35 m interstitial clay; poorly cemented, slope former; the unit (16.24 m) thickens laterally to as much as 3.2 m and contains well preserved root traces in its lower part; CONTAINS: clay laminae up to 2 mm thick; molds of corals and shell fragments; botryoidal hematite at the top of the unit; burrows; no evidence of bedding, unit homogeneous; sharp contact with:

8. Claystone: Light gray, medium gray at the base; massive; homogeneous; feels soapy at the top; unit shows lateral thickness 3.00 m variations, measured thicknesses vary from 3.00 to 3.80 m;

(19.24 m) slope former; CONTAINS: slickensides, unit intensely rooted throughout although rooting intensity diminishes downward; ironstone concretions in the basal 60 cm; grades into:

9. Mudstone: Banded, red, white, and yellow-brown; CONTAINS: fine-grained, matrix supported quartz grains; abundant iron
0.19 m cement and botryoidal iron precipitation; sharp contact
(19.43 m) with:

10. Sandstone: Very fine-grained, contains some fine and medium grains; poorly sorted; fissile; coarsens upward, percentage of clay
1.95 m decreases upward within the unit; brown at the base, grades
(21.38 m) upward into light gray variegated with red and yellow-brown at the top of the unit; composed of quartz and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: apparent biotite flakes in the base; iron replaced carbonaceous debris, carbonaceous debris flat lying on bedding plane surfaces; ironstone nodules; grades into:

11. Shale: Chocolate brown, yellow-brown banding throughout, red mottling prevalent toward the base; fissile; coarsens upward
1.95 m becomming sandy toward the top; contact unknown:
(23.33 m)

12. Covered: Appears to consist mostly of red and brown shales; the shales appear to have been extensively reworked by mining
5.70 m for either gypsum, ocher, or kaolinite; sharp contact
(29.03 m) inferred:

LAKHRA FORMATION

13. Limestone: Crystalline; argillaceous; yellow-brown; vuggy; indurated, ledge former; CONTAINS: abundant forams, Turritella.
0.20 m
(29.23 m)

END OF SECTION

SECTION JRK-1

METING LIMESTONE

1. Limestone: Sparry; crystalline; yellow-brown; indurated, ledge former; CONTAINS: glauconite pellets; shell fragments, coral fragments, echinoderms, and abundant forams including Alveolina and other types; ripples; sharp contact with:
   0.20 m
   (0.20 m)

SOHNARI FORMATION

2. Shale: Olive-brown, red in places; slope former; deeply weathered, appears to be sandy at the base; sharp contact with:
   0.95 m
   (1.15 m)

3. Sandstone: Very fine- to medium-grained, poorly sorted; yellow-brown; clean, composed of quartz, abundant glauconite, and little interstitial clay; weakly indurated (case hardened), ledge former; CONTAINS: abundant burrows, unit homogenized by burrowing; grades into:
   1.20 m
   (2.35 m)

4. Sandstone: Very fine- to fine-grained, some medium grains, poorly sorted; yellow-brown; composed of quartz, abundant glauconite, and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: burrows; bands of limonitic precipitate near the top of the unit; grades into:
   2.65 m
   (5.00 m)

5. Shale: Yellow-brown; fissile; coarsens upward; CONTAINS: fine-grained quartz sand laminae, sand content increases upward; contact unknown:
   1.55 m
   (6.55 m)

6. Covered: Several test pits suggest that the unit is an olive-brown and gray shale that may fine toward the middle and then coarsen upward; contact unknown:
   4.10 m
   (10.65 m)

7. Sandstone: Very fine-grained, poorly sorted; fissile; chocolate brown with bands of hardened yellow-brown and dark-brown layers; composed of quartz and extremely abundant interstitial clay; almost a mudstone; surface of the unit covered with an ironstone concretion deflation lag; sharp contact with:
   2.05 m
   (12.70 m)

8. Ironstone: Layer of red to black concretionary ironstone nodules, internally the nodules contain concentric red, black, and yellow-brown banding.
   0.20 m
   (12.90 m)

END OF SECTION

SECTION JRK-2

SOHNARI FORMATION

1. Shale: Highest bed of the Sonhari Formation; fissile; gray; absolute thickness not determined but the contact with the basal Meting Limestone is believed to be less than 1 meter above the uppermost part of the Sonhari Formation observed here; sharp contact with:

1.60 m
(1.60 m)

2. Sandstone: Very fine- to medium-grained, poorly sorted; yellow-brown; clean, composed of quartz, abundant glauconite, and little interstitial clay; weakly indurated (case hardened), ledge former; CONTAINS: abundant burrows, unit homogenized by burrowing; grades into:

1.20 m
(2.80 m)

3. Sandstone: Very fine- to fine-grained, some medium grains, poorly sorted; yellow-brown; composed of quartz, abundant glauconite, and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: burrows; bands of limonitic precipitate near the top of the unit; contact unknown:

0.50 m
(3.30 m)

4. Covered: Sandstone occurs at the top of the unit, shale occurs at the base of the unit; contact unknown:

4.00 m
(7.30 m)

5. Sandstone: Fine- to medium-grained, poorly sorted; pale purple; composed of quartz and some interstitial clay; poorly cemented, slope former; CONTAINS: 10 cm of iron cemented sandstone at the top that is identical to the uncemented underlying material; base not exposed.

1.30 m
(8.60 m)

BASE OF SECTION

SECTION JRK-3

METING LIMESTONE

1. Limestone: Pale yellow; fine-grained calcarenite; thin bedded, beds on the order of 5 to 10 cm thick; indurated, ledge former; CONTAINS: large scale planar cross-beds to 50 cm thick; low-angle cross-beds in places; ripples; cross-bed directions are unidirectional toward the west; Alveolina and other foram types occur on some bedding plane surfaces; cross-bedded units are composed entirely of forams and are foram coquinas, rippled beds consist of calcarenite; burrows; contact unknown:
   6.00 m
   (6.00 m)

2. Covered: Slope former; the yellow color weathering from the slope suggests that much of the interval may be a weathered argillaceous limestone; contact unknown:
   3.10 m
   (9.10 m)

3. Limestone: Very argillaceous, arenaceous; reacts weakly with acid; sugary; yellow-brown; indurated in places, slope former; CONTAINS: shell fragments; glauconite, unit contains abundant vugs where glauconite may have weathered out; sharp contact with:
   0.65 m
   (9.75 m)

4. Limestone: White; nodular; massive; CONTAINS: burrows; abundant Alveolina; extremely abundant echinoderms up to 4 cm in length; grades into:
   2.80 m
   (12.55 m)

5. Limestone: Calcarenite; pale yellow, weathers light yellow-brown; slightly argillaceous; becomes soft when weathered; slope former; CONTAINS: very argillaceous nodules in places; platy bedding, with beds up to 5 cm thick; zones of ripple cross-beds up to 5 cm thick; beds of Alveolina coquinas up to 5 cm thick; quartz grains sometimes occur in the foram beds; abundant burrows; very few fossil remains; laterally, about a kilometer away, this unit contains large scale planar cross-beds in the basal part of the unit; contact unknown:
   4.40 m
   (16.95 m)

6. Covered: Slope former; slope wash suggests the presence of a shaly interval; laterally, about a kilometer away, this covered interval is the same lithology as the underlying unit; contact unknown:
   1.05 m
   (18.00 m)

7. Marl: Fissile; light yellow-brown; argillaceous; platy bedding; slope former; CONTAINS: shaly bands; no obvious macro-fossils; sharp contact with:
   0.23 m
   (18.23 m)

SOHNARI FORMATION

8. Shale: Olive-brown, yellow-brown, becomes gray with red mottling toward the top of the unit; slope former; CONTAINS: thin,

2.10 m (20.33 m) very fine-grained quartz sand laminae that become less abundant upward; no evidence of rooting; sharp contact with:

9. Sandstone: Very fine- to fine-grained, poorly sorted; yellow-brown; composed of quartz and interstitial clay; poorly cemented at base, becomes better cemented upward; slope former; CONTAINS: planar cross-beds; iron concretions with concentric banding; presumed burrowed; correlates to unit 3 of JRK-1; grades into:
1.30 m (21.63 m)

10. Sandstone: Very fine- to medium-grained, poorly sorted, unit coarsens upward, clay becomes less abundant upward; yellow-brown; Composed of quartz and extremely abundant clay in matrix; almost a mudstone; poorly cemented, slope former; CONTAINS: olive-gray clay beds and laminae toward the base; grades into:
1.10 m (22.73 m)

11. Claystone: Gray with red streaks; coarsens upward; intensely weathered; slope former; CONTAINS: fine-grained quartz sand laminae that become more abundant upward; rooting, if present, has been obscured by weathering; grades into:
3.10 m (25.83 m)

12. Claystone: Red and gray; massive; blocky; CONTAINS: very abundant roots; abundant iron mineralization; a bed of hard iron mineralization at the top of the unit.
1.00 m (26.83 m)

END OF SECTION

SECTION LS-1

METING LIMESTONE

1. Limestone: White; massive; indurated, ledge former; CONTAINS: burrows; abundant Alveolina but no other fossils observed; small scattered lenses of calcarenite near the top of the unit; sharp contact with:
   6.80 m
   (6.80 m)

2. Limestone: White; calcarenite; indurated, ledge former; CONTAINS: ripples; Alveolina; sharp contact with:
   0.80 m
   (7.60 m)

3. Limestone: Pale yellow; massive; calcarenite; weakly cemented, slope former; CONTAINS: very abundant Alveolina; sharp contact with:
   4.75 m
   (12.35 m)

4. Marl: Yellow-brown; extremely argillaceous; slope former; sharp contact with:
   1.10 m
   (13.45 m)

5. Limestone: White; calcarenite; indurated, ledge former; CONTAINS: burrows; shell fragments; forams, Orbitolites and very abundant Alveolina, Alveolina become less prominent upward; sharp contact with:
   5.90 m
   (19.35 m)

6. Covered: Slope former; contains yellow fissile material exposed at the top of the interval that appears to consist of limestone nodules surrounded by more clayey sediment; nodules are argillaceous calcarenites containing shell fragments; contact unknown:
   3.00 m
   (22.35 m)

7. Limestone: White; calcarenite; indurated, ledge former; CONTAINS: burrows; Orbitolites and abundant Alveolina forams; contact unknown:
   3.30 m
   (25.65 m)

8. Covered: Slope former; yellow, fissile shale found in slope wash at the base of the unit; contact unknown:
   3.10 m
   (28.75 m)

9. Limestone: Pale yellow, weathers white; nodular; calcarenite; indurated, ledge former; CONTAINS: abundant Alveolina but other fossil remains are rare; sharp contact with:
   7.30 m
   (36.05 m)

SOHNARI FORMATION

10. Sandstone: Fine-grained, poorly sorted; gray, purple, yellow-brown; composed of quartz and extremely abundant interstitial clay; poorly cemented, slope former; CONTAINS: shale bands and
    1.00 m

(37.05 m) laminae; sharp contact with:

11. Sandstone: Fine- to medium-grained, some coarse grains, poorly sorted; yellow-brown; composed of quartz, abundant glauconite, some
0.75 m interstitial clay and calcareous cement; indurated, ledge
(37.80 m) former; CONTAINS: oyster fragments, burrows on bedding plane surfaces, abundant forams including Assilina, Alveolina, and Orbitolites; cross-beds; ripples; interference ripples; grades into:

12. Sandstone: Fine-grained, poorly sorted; yellow-brown; composed of quartz, abundant interstitial clay, some glauconite, and
0.55 m some calcareous cement; poorly cemented but becomes more
(38.35 m) indurated upward, slope former; CONTAINS: clay laminae; some forams; sharp contact with:

13. Sandstone: Very fine-grained, poorly sorted; yellow-brown; composed of quartz, abundant interstitial clay, and some calcareous
0.30 m cement; indurated, ledge former; CONTAINS: small scale
(38.65 m) ripples throughout, interference ripples; a variety of burrow types; sharp contact with:

14. Sandstone: Very fine-grained, poorly sorted; yellow-brown; composed of quartz, very abundant interstitial clay, and calcareous
0.70 m cement; fissile; poorly cemented, slope former; sharp
(39.35 m) contact with:

15. Shale: Brown; fissile; slope former; CONTAINS: abundant very fine- to fine-grained quartz sand laminae, laminae become
4.30 m more abundant toward the top; bands of yellow-brown iron
(43.65 m) mineralization; grades into:

16. Sandstone: Very fine-grained, poorly sorted; white with red mottling; composed of quartz and interstitial clay; poorly cemented,
1.70 m slope former; CONTAINS: bands of finer grained material
(45.35 m) that weathers yellow; laminar bedding; small scale ripples; an ironstone band at the top of the unit; unit varies in thickness between 10 cm to over 1.70 m and the unit appears to truncate the underlying mudstone though the lithological change appears gradational:

17. Mudstone: White, brown, yellow-brown, and purple; fissile at base becomming blocky at the top; coarsens upward, sand and silt
3.80 m content increases toward the top of the unit; slope former;
(49.15 m) CONTAINS: fine sand laminae toward the base and occasionally some sandstone ripples; abundant roots, the unit is apparently rooted throughout but rooting is most evident and intense in the uppermost part of the unit; basal part of the unit is being mined for clay; grades into:

18. Interbedded gypsum and iron stone: Altered Lakhra Formation limestone; red, white, and maroon; some ironstone bands contain foram
0.40 m ghosts; indurated, ledge former; grades into marly limestone
(49.55 m) at the base that contains ironstone laminae; sharp contact with:

LAKHRA FORMATION

19. Limestone: Yellow; massive; fine-grained calcarenite and calcisiltite; argillaceous; indurated, ledge former; CONTAINS:
7.90 m (57.45 m) gastropods, echinoderms, extremely abundant forams, foraminiferal limestone, Alveolina, Operculina, and abundant Discocyclina and Assilina; randomly orientated forams and homogeneous bedding are presumed to be indicative of burrowing.

END OF SECTION

SECTION LS-3

METING LIMESTONE

1. Limestone: Weathers white; marly in the basal meter; fine to medium grained calcarenite; indurated, ledge former; CONTAINS: wavy and laminar bedding; thickness not measured; sharp contact with:

SOHNARI FORMATION

2. Claystone: Red; blocky; massive; deeply weathered but appears to have the appearance of typical "brecciated" Sonhari Formation
2.45 m claystone from the Lakhra area; slope former; CONTAINS: no
(2.45 m) direct evidence of rooting though the brecciated texture is thought to have been caused by roots; kaolinite pods near the contact with the Meting Limestone; a 3 mm thick band of black (manganese?) mineralization that separates the Sonhari Formation from the Meting Limestone; sharp contact with:

3. Ironstone: Black; dense; sharp contact with:

0.03 m
(2.48 m)

LAKHRA FORMATION

4. Sandstone: May possibly belong in the Sonhari Formation; very fine-grained, poorly sorted; yellow-brown, top 1.5 m purple and
6.60 m red with gray zones; composed of quartz and extremely
(9.08 m) abundant interstitial clay; percentage of interstitial clay varies throughout the unit; poorly cemented, slope former; unit deeply weathered and poorly exposed; CONTAINS: red or gray shale bands; sharp contact with:

5. Limestone: Yellow; argillaceous; fine- to medium-grained calcarenite; massive; laterally variable in thickness; indurated, ledge
1.00 m former; CONTAINS: abundant forams including Assilina,
(10.08 m) Operculina and other forms; homogeneous bedding, unit presumed to be burrowed; sharp contact with:

6. Sandstone: Fine-grained, poorly sorted; coarsens upward slightly, clay becomes less abundant upward; yellow-brown, with red and
5.30 m gray shale beds 10 to 15 cm thick near the top of the unit;
(15.38 m) composed of quartz and very abundant interstitial clay; poorly cemented, slope former; bands of botryoidal iron precipitation with gypsum filling fractures in the iron precipitate; grades into:

7. Mudstone: Yellow-brown; non-calcareous; indurated, ledge former; CONTAINS: matrix supported fine-grained quartz sand in
0.45 m places; very abundant glauconite pellets; abundant shell
(15.83 m) fragments and foram tests; burrows, unit homogenized by burrowing; grades into:

8. Sandstone: Fine-grained, poorly sorted; red-brown; composed of quartz, some dark minerals (probably oxidizing iron bearing
4.50 m minerals), and very abundant interstitial clay; poorly
(20.33 m) cemented, slope former; CONTAINS: abundant shale bands and laminae; laminar bedding; burrows; grades into:

9. Shale: Olive-brown, red bands at the top of the unit, yellow-brown bands at the base of the unit; fissile; slope former;
4.00 m CONTAINS: very fine-grained quartz sand laminae,
(24.33 m) laminae become more abundant upward, some laminae contain glauconite pellets and shell fragments on them; laminar bedding; sharp contact with:

10. Limestone: Yellow-brown; very argillaceous; fine- to medium-grained calcarenite; indurated, ledge former; CONTAINS: , corals,
1.50 m pelecypods, gastropods, Turritella, oysters, some forams,
(25.83 m) Operculina and other types; grades into:

11. Sandstone: Fine- to medium-grained, poorly sorted; yellow-brown; non-calcareous; composed of quartz and very abundant
1.35 m interstitial clay; poorly cemented though it becomes more
(27.18 m) indurated upward, slope former; CONTAINS: shells and shell fragments in the upper part of the unit; bands of sideritic clay; a 40 cm thick, laminar bedded silty shale zone containing sand laminae; burrows, the sand above and below the shaly zone has been homogenized by burrowing.

END OF SECTION

SECTION LS-4

METING LIMESTONE

1. Limestone: White; massive; nodular; homogeneous; sugary texture (recrystallized calcarenitic texture ?); indurated, ledge former; CONTAINS: burrows, gastropods, pelecypods, and abundant Alveolina throughout; contact unknown:
   2.00 m
   (2.00 m)

2. Covered: Slope former; fissile, yellow-brown shale weathering in situ in the basal 10 cm; sharp contact with:
   2.70 m
   (4.70 m)

3. Limestone: Pale yellow; fine-grained calcarenite; thin bedded, bedding generally less than 10 cm thick though bedding becomes thicker, more homogenized and nodular upward; indurated, ledge former; CONTAINS: rare, scattered yellow-brown argillaceous zones up to 30 cm thick; laminated bedding; rare small scale ripples in places; abundant horizontal and vertical burrows; sparse Alveolina and other foram types on bedding surfaces in the lower part of the unit, more homogeneously distributed in the upper part of the unit; rare echinoderms; sharp contact with:
   6.45 m
   (11.15 m)

4. Altered limestone: Black, yellow-brown; interlaminated iron mineralization and secondary gypsum; laminae up to 2 cm thick; sharp contact with:
   0.20 m
   (11.35 m)

SOHNARI FORMATION

5. Siltstone: Yellow-brown; non-calcareous; slope former; CONTAINS: very fine-grained quartz sand laminae; grades into:
   1.75 m
   (13.10 m)

6. Shale: Olive-brown with red and yellow-brown mottling, laterally weathers to a uniform bright red color; fissile; slope former; CONTAINS: fine sand laminae; iron cemented burrows; white kaolinite nodules in places; may contain sparse, oxidized carbonaceous debris; sharp contact with:
   1.10 m
   (14.20 m)

7. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and very abundant interstitial clay; poorly cemented, slope former; sharp contact with:
   0.60 m
   (14.80 m)

8. Shale: Olive-brown with red and yellow-brown mottling, laterally weathers to a uniform bright red color; fissile; slope former; CONTAINS: fine sand laminae; iron cemented burrows; white kaolinite nodules in places; may contain sparse, oxidized carbonaceous debris; sharp contact with:
   2.30 m
   (17.10 m)

9. Sandstone: Medium-grained, some coarse grains, well sorted; orange-

brown; composed of quartz, abundant glauconite, and little
0.60 m interstitial clay; unit highly variable in thickness, ranges
(17.70 m) from 20 to 60 cm in thickness at the outcrop and cannot be traced to the opposite ridge 300 m away; indurated, ledge former; CONTAINS: planar cross-beds up to 20 cm thick, cross beds dip 30 degrees east of north (one measurement); rare burrows; a 5 cm thick clay pebble conglomerate at the base of the unit, rounded pebbles are up to 1 cm long in the long axis, tabular pebbles up to 5 cm long in the longest direction and up to 5 mm thick; sharp contact with:

10. Claystone: Red; massive; blocky; brecciated/conglomeratic texture; indurated, ledge former; CONTAINS: uncommon iron replaced
0.85 m burrows; no obvious rooting although the brecciated texture
(18.55 m) is presumed to be caused by rooting; appears to contain iron replaced wood fragments; sharp contact with:

11. Sandstone: Very fine-grained, poorly sorted; gray-brown with red, purple, and yellow-brown mottling; composed of quartz and
0.75 m extremely abundant interstitial clay; fissile; poorly
(19.30 m) cemented, slope former; CONTAINS: abundant oxidized carbonaceous debris; no evidence of rooting; grades into:

12. Siltstone: Light brown, light gray, red, yellow, purple; fissile; shaly at base, coarsens upward; weakly indurated, slope former;
4.20 m CONTAINS: abundant carbonized wood fragments; oxidized
(23.50 m) carbonaceous debris on some bedding plane surfaces; apparent, sparse rooting in the basal meter, rooting does not disturb fissility; fine-grained quartz sand laminae on bedding plane surfaces; scattered white kaolinite bands and nodules; sparse bivalve shell molds belonging to several species; grades into:

13. Sandstone: Fine-grained, fining upward because of an increasing percentage of interstitial clay, poorly sorted; fissile;
2.85 m light gray, purple, yellow-brown, red; composed of quartz
(26.35 m) and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: laminar bedding; abundant shale laminae; zones of sandstone in which the percentage of interstitial clay is especially high; bands of yellow nodules; no evidence of bedding, unit homogeneous; sharp contact with:

LAKHRA FORMATION

14. Altered limestone: Red and black interlaminated bands of iron mineralization and secondary gypsum mineralization;
0.10 m indurated, ledge former; sharp contact with:
(26.45 m)

15. Limestone: Yellow-brown; argillaceous; indurated, ledge former; CONTAINS: burrows, unit homogenized by burrowing; rare
6.00 m gastropods, extremely abundant forams including Operculina,
(32.45 m) and Assilina, forams randomly orientated, foraminiferal limestone. **END OF SECTION**

SECTION LN-1

METING LIMESTONE

1. Limestone: Yellow-brown; argillaceous; massive; homogeneous; indurated, ledge former; CONTAINS: abundant quartz grains; burrows, unit homogenized by burrowing; small clams, ostracodes, forams including Assilina, Alveolina, and Orbitolites, however forams only occur in the upper part of the unit and there is no trace of forams near to the contact; sharp contact with:

5.30 m
(5.30 m)

SOHNARI FORMATION

2. Sandstone: Fine-grained, well-sorted; brown-yellow; clean; composed of quartz and little interstitial clay; poorly cemented, slope former; CONTAINS: uncommon, scattered clay pebbles up to a few millimeters in diameter; rare dark ferruginous minerals; no evidence of bedding; contact unknown:

0.80 m
(6.10 m)

3. Covered: probably sandstone; contact unknown:

1.00 m
(7.10 m)

4. Claystone: Deeply weathered; fissile; sandy in places, contains quartz sand that ranges from fine- to coarse-grained; red, gray, and yellow-brown banding; red bands tend to be more quartz rich; CONTAINS: no evidence of rooting but rooting may be obscured by the intense weathering; sharp contact with:

1.15 m
(8.25 m)

5. Sandstone: Fine-grained with some medium grains, poorly sorted; maroon; composed of quartz, some interstitial clay, and ferruginous cement; indurated, ledge former; CONTAINS: roots; sharp contact with:

0.25 m
(8.50 m)

6. Sandstone: Very fine- to coarse-grained, fines upward to fine-grained sandstone with the percentage of interstitial clay increasing upward slightly, poorly sorted; maroon, becomes yellow-brown upward; composed of quartz and some interstitial clay; poorly cemented, slope former; CONTAINS: intense rooting in the upper part; LATERALLY: a clay bed up to 10 cm thick may occur at the contact between the sandstone and the overlying unit; sharp contact with:

1.30 m
(9.80 m)

7. Claystone: White; massive; slope former; CONTAINS: abundant coarse and very coarse angular quartz grains and, in places, quartz granules supported in a white, kaolinitic matrix; in places, kaolinitic clay pebbles may be surrounded by a quartz-containing clay matrix; clay pebbles are sometimes red and the unit has a somewhat brecciated texture that may be due to rooting; sharp contact with:

0.20 m
(10.00 m)

LAKHRA FORMATION

8. Sandstone: Fine- to medium-grained, well-sorted; maroon; composed of

quartz and little interstitial clay; poorly cemented, slope
0.70 m former; CONTAINS: burrows; sharp contact with:
(10.70 m)

9. Limestone: Yellow-brown; calcarenite with a calcisiltite matrix; argillaceous; arenaceous, containing abundant medium- to
0.80 m very coarse-grained quartz sand; unit is almost a calcareous
(11.50 m) sandstone; becomes more sandy upward; indurated, ledge former; CONTAINS: abundant glauconite; corals, gastropods, Turritella, shell fragments and abundant forams including Assilina; LATERALLY: toward the north the unit thins to 30 cm and becomes a calcareous sandstone; sharp contact with:

10. Sandstone: Very fine- to fine-grained with medium-grained sand in some zones, poorly sorted; red and maroon; composed of quartz and
5.60 m interstitial clay; near to the contact with the overlying
(17.10 m) limestone unit there are irregularly occurring pods of sandstone cemented by white and maroon, calcareous, kaolinitic clay; overall the unit is poorly cemented, slope former; CONTAINS: well-cemented ferruginous bands containing shell molds; no evidence of bedding, unit homogeneous; sharp contact with:

11. Sandstone: Fine-grained, poorly sorted; yellow-brown; composed of quartz, abundant interstitial clay, and calcareous cement;
0.50 m indurated, ledge former; CONTAINS: abundant burrows, unit
(17.60 m) homogenized by burrowing; sharp contact with:

12. Sandstone: Fine-grained, very fine-grained in places, poorly sorted; maroon, very fine-grained zones are yellow-brown; composed
3.00 m of quartz, abundant interstitial clay, and ferruginous
(20.60 m) cement; CONTAINS: no evidence of bedding, unit homogeneous and presumed to be burrowed.

END OF SECTION

SECTION LN-1A

The top of unit 3 in section LN-1A begins at the same stratigraphic horizon as the top of unit 9 in section LN-1 but is 0.5 km south of section LN-1. The 4.90 m of rocks that overlie unit 3 in section LN-1A are not present in section LN-1. Furthermore, since the top of unit 1 is eroded, it is possible that the total thickness of Lakhra section that overlies unit 1 at section LN-1A is considerably thicker than 4.90 m.

LAKHRA FORMATION

1. Limestone: Yellow-brown; argillaceous; indurated, ledge former; CONTAINS: abundant Operculina, some Assilina, Nautilus.
   0.70 m
   (0.70 m)

2. Covered: Believed to be a burrowed, cross-bedded sandstone; sharp contact with:
   4.20 m
   (4.90 m)

3. Limestone: same as unit 9 in section LN-1; sharp contact with:

   not
   measured

END OF SECTION

SECTION LN-2

METING LIMESTONE

1. Limestone: Pale buff, weathers white; nodular; massive; calcarenite; indurated, ledge former; CONTAINS: abundant burrows, unit homogenized by burrowing; abundant forams including Alveolina and Orbitolites; gastropods; grades into:
   3.80 m (3.80 m)

2. Limestone: Yellow; massive; arenaceous; fine-grained calcarenite; indurated, ledge former; CONTAINS: sparse fine- to coarse-grained quartz grains; abundant burrows, unit homogenized by burrowing; laminar bedding in places; ostracodes, Nautilus in float, Alveolina and Assilina forams; sharp contact with:
   1.75 m (5.55 m)

3. Shale: Yellow-brown; fissile; calcareous; slope former; CONTAINS: a 5 cm thick bed of red and gray non-calcareous shale about 30 cm below the top of the unit; shell fragments; burrows; unit may belong in the Sonhari Formation; sharp contact with:
   1.40 m (6.95 m)

SOHNARI FORMATION

4. Claystone: Purple, red, pink, yellow-brown, white, gray; original lithologies difficult to distinguish, unit extremely altered by secondary gypsum crystallization; indurated, ledge former; CONTAINS: ironstone bands; possible foram replacements in some of the yellow-brown zones; thick gypsum bands and gypsiferous clays in the top 40 cm; contact unknown:
   2.80 m (9.75 m)

5. Covered: Lakhra-Sonhari contact is believed to occur in this covered interval; contact unknown:
   1.90 m (11.65 m)

LAKHRA FORMATION

6. Shale: Red and gray; fissile; slope former; CONTAINS: white kaolinite at the top 10 cm of the unit; sharp contact with:
   0.80 m (12.45 m)

7. Claystone: Red; massive; slope former; CONTAINS: gastropod and foram molds; very abundant glauconite; grades into:
   0.40 m (12.85 m)

8. Sandstone: Very fine-grained, poorly sorted; yellow-brown; composed of quartz, glauconite, and very abundant interstitial clay; poorly cemented, slope former; sharp contact with:
   2.15 m (15.00 m)

9. Sandstone: Fine-grained, poorly sorted; yellow-brown; composed of quartz, interstitial clay, glauconite, and calcareous

0.20 m (15.20 m) cement; indurated, ledge former; CONTAINS: forams including Assilina, pelecypods, gastropods, Turritella, shell fragments, and crab fragments; abundant burrows, unit homogenized by burrowing; sharp contact with:

10. Sandstone: Very fine-grained, poorly sorted; yellow-brown, red in places; composed of quartz and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: olive-brown shale beds and laminae up to several millimeters thick; yellow-brown limonitic nodules in the top 50 cm; grades into:

2.20 m (17.40 m)

11. Shale: Olive-brown; fissile; slope former; CONTAINS: possible very fine-grained quartz sand laminae; sharp contact with:

1.20 m (18.60 m)

12. Limestone: Yellow-brown; extremely argillaceous; arenaceous; fine-grained calcarenite; massive; weakly indurated, slope former; CONTAINS: abundant glauconite; abundant medium- to coarse-grained quartz grains; corals, shell fragments, pelecypods, Turritella, Conus, forams including Assilina, abundant gastropods; no evidence of bedding, unit appears to be burrowed.

0.90 m (19.50 m)

END OF SECTION

SECTION SON-1

METING LIMESTONE

1. Limestone: White; fissile and platy when weathered; laminated and wavy bedded; calcarenite; indurated, ledge former; thickness not measured; sharp contact with:

2. Limestone: Yellow; fine-grained calcarenite; indurated, ledge former; CONTAINS: ripples; planar cross-beds; sharp contact with:
   0.50 m
   (0.50 m)

3. Conglomerate: Yellow-brown; indurated, ledge former; CONTAINS: forams and abundant non-calcareous clay pebbles in a non-calcareous clay matrix; sharp contact with:
   0.70 m
   (1.20 m)

SOHNARI FORMATION

4. Claystone: Yellow-brown; fissile; slope former; sharp contact with:

   0.03 m
   (1.23 m)

5. Claystone: Conglomeratic texture, consists of irregular rounded red clay pebbles in a white clay matrix, red pebbles are the dominant constituent; contains uncommon yellow-brown pebbles, the top 30 cm is a yellow-brown clay pebble conglomerate and is separated from the underlying red and white conglomerate by an iron stone band; weakly indurated, slope former; CONTAINS: possible iron replaced wood fragments; no evidence of rooting; sharp contact with:
   4.40 m
   (5.63 m)

6. Claystone: White, gray, yellow-brown, red; somewhat fissile; slope former; CONTAINS: zones of silt and fine sand; may contain oxidized carbonaceous debris; grades into:
   1.30 m
   (6.93 m)

7. Claystone: Gray with purple, red, and yellow-brown iron mineralization along fractures; silty in places; massive; blocky; iron stained and indurated at the top of the unit; slope former; CONTAINS: white kaolinite nodules; no obvious roots, however the bed has been extensively fractured and disturbed by movement on a nearby fault; contact unknown:
   2.40 m
   (9.33 m

8. Covered: Interval to contact with the Lakhra Formation is unknown, but appears to be no more than 2 to 3 m.

END OF SECTION

SECTION SON-2

METING LIMESTONE

1. Limestone: Light yellow-brown; argillaceous; fine-grained calcarenite; massive; homogeneous; nodular; indurated, ledge former; CONTAINS: abundant Alveolina; no traces of quartz sand; thickness not measured; sharp contact with:

SOHNARI FORMATION

2. Sandstone: Formation break based on lithology, this unit may actually be part of the Meting Limestone; fine-grained, poorly
2.00 m sorted; yellow-brown; composed of quartz, some interstitial
(2.00 m) clay, and some calcareous cement; poorly cemented, becomes more indurated upward, slope former; CONTAINS: sparse Alveolina forams at the top of the unit; no evidence of bedding, unit homogeneous, but also no evidence of burrows; sharp contact with:

3. Sandstone: Fine- to very fine-grained, poorly sorted; yellow-brown; composed of quartz, interstitial clay, and some calcareous
1.95 m cement; indurated, ledge former; CONTAINS: abundant
(3.95 m) bedding surface burrows; laminar, wavy, and ripple bedding; shale interlaminae less than 1 mm thick; sharp contact with:

4. Altered sandstone: Calcareous sandstone interbedded with secondary gypsum; unit extremely disrupted by crystallization of
0.70 m secondary gypsum; yellow-brown, red, and black; poorly
(4.65 m) cemented, slope former; sharp contact with:

5. Claystone: At the base the unit consists of light brown silty shale; fissile; slope former; CONTAINS: abundant carbonaceous
1.10 m debris and bands and pods of a sulfur-yellow alteration
(5.75 m) product (clay?); at the top the unit appears to be a red claystone which also contains pods of the sulfur-yellow alteration product; the upper part of the unit is severely disrupted by the formation of secondary gypsum; the interval between is covered but presumed to be a claystone also; sharp contact with:

6. Altered clay: Sulfur-yellow; powdery; slope former; sharp contact with:

0.03 m
(5.78 m)

7. Carbonaceous shale: Dark brown; intensely weathered; possible weathered coal?; slope former; sharp contact with:
0.05 m
(5.83 m)

8. Shale: Light brown; fissile; slope former; CONTAINS: plant fossil fragments and abundant oxidized carbonaceous debris; no
0.40 m evidence of rooting; sharp contact with:

(6.23 m)

9. Sandstone: Fine-grained, poorly sorted; white with red and yellow-brown bands; composed of quartz and some interstitial clay; poorly cemented, slope former; CONTAINS: laminated bedding; grades into:
   2.70 m
   (8.93 m)

10. Shale: Olive-brown when fresh, weathers violet and, in places, red; fissile; slope former; CONTAINS: abundant very fine-grained quartz sand laminae less than 1 mm thick; yellow sulfur-colored clay? bands; kaolinite bands near the top that are being mined; abundant red oxidized carbonaceous debris; sharp contact with:
   2.15 m
   (11.08 m)

11. Sandstone: Fine-grained, poorly sorted; brown-gray; composed of quartz and very abundant interstitial clay; poorly cemented, slope former; CONTAINS: yellow sulfur-colored clay? bands that approximately parallel bedding; no evidence of bedding, unit homogeneous; sharp contact with:
   0.75 m
   (11.83 m)

12. Shale: Olive-brown with red and yellow-brown laminae along bedding surfaces; fissile; slope former; CONTAINS: yellow sulfur-colored clay-like material filling fractures; sharp contact with:
   1.00 m
   (12.83 m)

13. Sandstone: Fine-grained, poorly sorted; gray-brown; composed of quartz and very abundant interstitial clay; non-calcareous; poorly cemented, slope former; CONTAINS: no evidence of bedding, unit homogeneous; sharp contact with:
   0.65 m
   (13.48 m)

14. Shale: Olive-brown with yellow-brown mottling; fissile; slope former; CONTAINS: abundant oxidized carbonaceous debris; red, hematite rich nodules; laminated bedding; bands of yellow sulfur-colored clay-like material; contact unknown:
   1.10 m
   (14.58 m)

15. Covered: Base of the Sonhari Formation is covered; there is at least 2 to 3 m of unexposed Sonhari above the highest Lakhra limestone.

END OF SECTION

SECTION SON-3

METING LIMESTONE

1. Limestone: White; nodular; crystalline; massive; indurated, ledge former; CONTAINS: oysters, gastropods, abundant echinoderms; abundant forams including Nummulites, Orbitolites, and abundant Alveolina; grades into:
   3.00 m
   (3.00 m)

2. Limestone: Yellow; fine-grained calcarenite; nodular; appears thin bedded though much of the unit is covered by talus; less well-indurated, slope former; CONTAINS: dirty or dolomitic bands that react weakly with acid; burrows, unit homogenized by burrowing; sharp contact with:
   6.10 m
   (9.10 m)

3. Coquina: White with yellow-brown flecks; foram coquina with sparry and calcarenitic matrix; indurated, ledge former; CONTAINS: low-angle cross-beds; sharp contact with:
   0.90 m
   (10.00 m)

4. Limestone: Light yellow-brown; fine-grained calcarenite; thin-bedded, beds typically 10 cm or less in thickness; nodular texture in some of the individual beds; indurated, slope former; CONTAINS: beds of crystalline limestone; laminar bedding; rare ripples; numerous argillaceous zones; medium quartz grains in places; Alveolina on bedding planes in some places though fossils are generally rare; forams become more abundant upward; abundant burrows; sharp contact with:
   9.00 m
   (19.00 m)

SOHNARI FORMATION

5. Claystone: Light gray with purple mottling in places and yellow-brown staining along fractures; fissile; low-density; top 3 m badly weathered and decomposed by the crystallization of secondary gypsum; slope former; sharp contact with:
   4.25 m
   (23.25 m)

6. Claystone: Light gray; conglomeratic texture, rounded gray clay pebbles in a gray ground mass, along fractures and in zones parallel to bedding the pebbles sometimes turn red or purple while the ground mass remains gray; no evidence for rooting has been observed; slope former; sharp contact with:
   4.00 m
   (27.25 m)

LAKHRA FORMATION

7. Limestone: Yellow-brown; very argillaceous; homogeneous; massive; indurated ledge former; CONTAINS: echinoderm fragments, oyster fragments, rare gastropods, and very abundant forams including Assilina, Operculina, and Discocyclina, foraminiferal limestone; sharp contact with;
   1.00 m
   (28.25 m)

8. Siltstone: Purple, red with gray mottling in places; blocky; massive; low-density; poorly cemented, slope former.
   1.30 m
   (29.55 m)

END OF SECTION

SECTION SON-4

METING LIMESTONE

1. Limestone: Yellow-brown; crystalline; thin bedded, beds up to 20 cm in thickness; indurated ledge former; CONTAINS: weathered glauconite; abundant Nummulites, some Alveolina, Orbitolites, gastropods; shell remains replaced by iron near the contact. LATERALLY: 200 m away there is approximately 1 m of additional section below the crystalline limestone; the additional section is an argillaceous calcarenite; CONTAINS: burrows; laminar and ripple bedding; no fossil remains; all basal limestones are in sharp contact with:

not measured

SOHNARI FORMATION

2. Claystone: Bright, intense red; brecciated texture in the upper two-thirds of the unit, surficial weathering enhances the appearance of the brecciated texture but this texture disappears in the basal third of the unit; the basal meter consists of a red, fissile shale; unit indurated and is a ledge former in places; CONTAINS: irregular cylindrical vertical penetrations in the top meter, these penetrations may be roots but may also be burrows; some more definitive root-like structures in the top part of the unit; apparent burrows near the base of the unit; in some places near the base there is extensive iron mineralization of the sediment; sharp contact with:

6.65 m (6.65 m)

LAKHRA FORMATION

3. Limestone: Yellow-brown; argillaceous.

not measured

END OF SECTION

SECTION SON-5

METING LIMESTONE

1. Limestone: Yellow-brown; crystalline; argillaceous; reacts weakly with HCl, possibly dolomitic; indurated, ledge former; CONTAINS: Alveolina and abundant gastropods; grades into:
   0.45 m
   (0.45 m)

2. Limestone: Yellow; argillaceous; nodular; massive; indurated, ledge former; CONTAINS: abundant Alveolina in places; abundant burrows, unit homogenized by burrowing; sharp contact with:
   4.20 m
   (4.65 m)

SOHNARI FORMATION

3. Claystone: White, purple, red, yellow-brown; silty at base; non-calcareous; low-density; poorly indurated, slope former; CONTAINS: sand-sized iron nodules; abundant secondary gypsum; sharp contact with:
   1.00 m
   (5.65 m)

4. Sandstone: Fine-grained, poorly sorted; purple and white; composed of quartz, abundant interstitial clay, and calcareous cement; massive; homogeneous, no evidence of bedding; sharp contact with:
   0.60 m
   (6.25 m)

5. Sandstone: Fine-grained, moderately sorted; purple-black; composed of quartz, some interstitial clay, and calcareous cement; indurated, ledge former; CONTAINS: no evidence of bedding, unit homogeneous; sharp contact with:
   0.30 m
   (6.55 m)

6. Sandstone: Fine- to medium-grained at base, fines upward to fine-grained at the top, poorly sorted; maroon at base, pale brown at top, abundant dark minerals where unit is pale, no dark where unit is maroon; composed of quartz and abundant interstitial clay; poorly cemented, slope former; CONTAINS: no evidence of bedding, unit homogeneous; unit presumed to be homogenized by burrowing though no distinct burrows could be identified; sharp contact with:
   2.50 m
   (9.05 m)

7. Sandstone: Fine- to medium-grained, some coarse grains, poorly sorted; maroon; composed of quartz, some interstitial clay, ferruginous cement, and some calcite cement, calcite cement may be secondary in origin; moderately well cemented, local ledge former; CONTAINS: no evidence of bedding, unit homogeneous; sharp contact with:
   0.60 m
   (9.65 m)

8. Sandstone: Fine-grained, moderately sorted; red, pink, violet; composed of quartz and some interstitial clay; poorly cemented, slope former; CONTAINS: some dark ferruginous minerals that disappear as the unit becomes redder; burrows, unit homogenized by burrowing.
   4.60 m
   (14.25 m)

END OF SECTION

SECTION SON-6

METING LIMESTONE

1. Limestone: Pale yellow; nodular; fine grained calcarenite; indurated, ledge former; CONTAINS: abundant Alveolina in places; sharp contact with:
not measured

SOHNARI FORMATION

2. Claystone: Red; silty at base, fines upward; massive; blocky; brecciated texture, brecciation is not well developed in the basal part of the unit but the texture becomes more intense upward; indurated, ledge former in places; sharp contact with:
5.50 m (5.50 m)

LAKHRA FORMATION

3. Sandstone: Fine- to medium-grained, fines upward, becomes increasingly clay rich upward, poorly sorted; yellow-brown, becomming increasingly red upward; composed of quartz, abundant interstitial clay, abundant altered glauconite, and some calcareous cement; poorly cemented, slope former; CONTAINS: ripples; platy bedding; planar cross-beds up to 10 cm thick; burrows, burrowing intensity increases upward; ferruginous cement in places at the top contact; grades into:
8.00 m (13.50 m)

4. Sandstone: Fine-grained, poorly sorted; yellow-brown; massive; composed of quartz, abundant interstitial clay, calcareous cement that is probably of secondary origin, and dark minerals that are probably derived from altered glauconite; case hardened, ledge former in places; CONTAINS: abundant burrows, unit homogenized by burrowing in most places; traces of planar cross-sets preserved locally; contact unknown:
8.35 m (21.85 m)

5. Covered: presumed to be the same as the overlying material; appears to grade into:
3.20 m (25.05 m)

6. Sandstone: Fine-grained, poorly sorted; yellow-brown; composed of quartz, abundant interstitial clay, glauconite apparently altered to limonite, and calcareous cement; indurated, ledge former; CONTAINS: Turritella, pelecypods, shell fragments, abundant oysters; burrows, unit homogenized by burrowing.
0.40 m (25.45 m)

END OF SECTION

AUTHORS' NOTE: Aerial photographs indicate that a small fault may have been crossed in the basal part of the section. As a result, some of the sandstone may be repeated.

DESCRIPTION OF MEASURED MINE SECTIONS

METING-JHIMPIR COAL FIELD

National Mines, Meting-Jhimpir Coal Field, NA-15

Total depth of mine: 31.54 m
Thickness of measured section: 31.54 m

METING LIMESTONE

1. Limestone: White; massive; nodular; calcarenite; appears recrystallized; indurated; CONTAINS: abundant Alveolina, in
   6.00 m places may be considered an Alveolina limestone; grades
   (6.00 m) into:

2. Limestone: Light gray with yellow weathering colors; argillaceous at the base; massive; homogeneous; calcarenite; becomes nodular
   7.90 m toward the top, brown marl surrounds nodules; indurated;
   (13.90 m) CONTAINS: abundant burrows; sparse Alveolina and other foram types, forams become more abundant toward the top; sharp contact with:

3. Marl: Light brown; fissile; weakly indurated; CONTAINS: a band of calcarenite 60 cm from base; no obvious fossils; sharp
   0.90 m contact with:
   (14.80 m)

4. Limestone: Light brown; massive; homogeneous; argillaceous; calcarenite; indurated; CONTAINS: sparse Alveolina,
   0.55 m Assilina, and other discoidal forams; homogeneous texture
   (15.35 m) presumed to be caused by burrowing though individual burrows are not obvious; sharp contact with:

5. Shale: Pale brown; fissile; reacts weakly with HCl; CONTAINS: abundant Assilina and sparse Alveolina in the top 5 cm;
   0.95 m sharp contact with:
   (16.30 m)

6. Limestone: Light gray; massive; homogeneous; indurated; CONTAINS: abundant burrows, unit homogenized by burrowing; sparse
   1.80 m Alveolina and some discoidal forams, Alveolina becomes
   (18.10 m) larger and more abundant upward; sparse echinoderms; sharp contact with:

7. Limestone: Light gray, yellow-brown weathering colors; thin bedded, beds range in thickness between 3 and 10 cm; individual
   1.60 m limestone beds are separated by as much a 4 cm of marl;
   (19.70 m) calcarenitic?, sugary texture; sparse, very small Alveolina; sharp contact with:

8. Limestone: Light gray, top 1.80 m weathered pale yellow-brown; massive; nodular, medium gray marl surrounds nodules; indurated;
   2.30 m CONTAINS: burrows; abundant Alveolina; echinoderms and high

(22.00 m) spired gastropods at the top of the unit; grades into:

9. Limestone: Light gray; nodular, medium gray marl surrounds nodules; indurated; CONTAINS: very sparse Alveolina; burrows; grades into:
1.35 m
(23.35 m)

10. Limestone: Light gray; massive at base, becomes thinner bedded upward; nodular, light gray nodules surrounded by medium gray marl; indurated; CONTAINS: burrows; abundant Alveolina and other foram types but contains no other shell remains, forams become less abundant upward; sharp contact with:
1.00 m
(24.35 m)

11. Limestone: White; marly; thin bedded; some beds nodular, nodules surrounded by light gray-brown marl; petroliferous odor when limestone reacted with HCl; indurated; CONTAINS: abundant burrows; sparse Alveolina and Assilina forams; grades into:
1.15 m
(25.50 m)

12. Limestone: Medium gray; nodular, light gray nodules surrounded by medium gray marl; indurated; CONTAINS: irregular wavy bedding; abundant burrows; some Alveolina; grades into:
0.75 m
(26.25 m)

13. Limestone: Light gray mottled light brown; massive; homogeneous; nodular; indurated; CONTAINS: shale pebbles in the base that appear to have been churned into the limestone by burrowing; pyrite concentrations developed around the pebbles; pelecypods and abundant Alveolina; sharp contact with:
3.85 m
(30.10 m)

SONHARI FORMATION

14. Claystone: Medium gray; coarsens downward, silty at base; indurated; CONTAINS: thin sand laminae less than 1 mm thick; slickensides in places, unit appears to have sparse rooting throughout; limestone filled burrows containing Alveolina; pyrite on some bedding surfaces; some pyrite replaces carbonaceous debris; sharp contact with:
0.77 m
(30.87 m)

15. Coal: Black; CONTAINS: resin lenses and pyrite bands and lenses especially in the top 20 cm; base not exposed.
0.67 m
(31.54 m)

BASE OF INCLINE

SECTION NA-15A

This partial section was measured about 75 m from the section at the incline.

METING LIMESTONE

1. Limestone: White; indurated; CONTAINS: abundant Alveolina; sharp contact with:

not measured

SONHARI FORMATION

2. Claystone: Medium gray; indurated; CONTAINS: abundant flat sand laminae throughout; slickensided in places; shell filled burrows throughout but burrow penetrations are most abundant in the upper half of the unit, burrow fillings contain Alveolina; siderite bands in places; sharp contact with:

0.76 m (0.76 m)

3. Sandstone: Fine-grained, medium- to coarse-grained sand in shell hash layers, poorly sorted; medium green-gray; composed of quartz, abundant glauconite pellets throughout, and abundant interstitial clay; indurated; CONTAINS: burrows; resin; abundant shell fragments; abundant carbonaceous debris; wavy and laminar bedding; discontinuous shale laminae up to 2 mm thick; local concentrations of shell hash up to 4 cm thick at the top of the unit; glauconite filled foram tests; sharp contact with:

0.50 m (1.26 m)

4. Coal: Black; CONTAINS: resin bands; sand lenses in the top 28 cm, the sand is composed of quartz, some interstitial clay, and glauconite; sand lenses are isolated ripple lenses in some places and, in other places, the lenses are tabular, up to 10 cm long and 1 cm thick, and are laminar bedded; occasional burrow penetrations into the coal from the overlying unit; convoluted bedding in places probably due to peat compaction.

1.32 m (2.58 m)

END OF SECTION

Amin Mines, Meting-Jhimpir Coal Field, Mine AMN-35

Total depth of mine: 22.30 m
Thickness of measured section: 22.30 m

METING LIMESTONE

1. Limestone: Pale brown; sugary, possibly calcarenite; nodular; argillaceous; indurated; CONTAINS: sparse fossils; calcite fracture-fill; sharp contact with:
   0.85 m
   (0.85 m)

2. Limestone: Pale yellow; medium bedded; sugary texture; sparry; indurated; CONTAINS: abundant forams, especially Alveolina and less abundant Orbitolites and Nummulites, Alveolina and Nummulites, have been compressed; burrows; sharp contact with:
   0.25 m
   (1.10 m)

3. Limestone: White; massive; homogeneous; nodular, white nodules are surrounded by brown marl, nodules become more calcarenitic upward; argillaceous, becomes more argillaceous upward; indurated; CONTAINS: burrows, pelecypods, forams, forams become more abundant upward; sharp contact with:
   2.50 m
   (3.60 m)

4. Limestone: Pinkish-white; massive; homogeneous; weathers platy; sugary matrix which appears to be a recrystallized calcarenite; indurated; CONTAINS: abundant Alveolina; zones barren of fossils; sharp contact with:
   1.00 m
   (4.60 m)

5. Limestone: White to pale yellow-brown; laminar bedded; calcarenite; indurated; CONTAINS: sparse Alveolina; grades into:
   1.00 m
   (5.60 m)

6. Limestone: White; weathers chalky; massive; homogeneous; nodular; calcarenite; indurated; CONTAINS: randomly orientated echinoids; rare pelecypods; abundant Alveolina; sharp contact with:
   1.30 m
   (6.90 m)

7. Limestone: Pale pink-gray; biosparite (packstone); sugary texture; appears recrystallized; foraminiferal limestone; indurated; CONTAINS: burrows, very abundant Alveolina, some Nummulites, some echinoids, and shell fragments; shell fragments occur at the base of the unit and parallel bedding; sharp contact with:
   0.60 m
   (7.50 m)

8. Limestone: Pale yellow; calcarenite; massive; homogeneous; nodular, marly coating on nodules; indurated; CONTAINS: sparse Alveolina homogeneously distributed throughout the unit; some Nummulites and echinoderms; abundant burrows, unit homogenized by burrowing; grades into:
   4.10 m
   (11.60 m)

9. Limestone: Yellow-brown at base becomming white upward, incipient alteration of the basal 5 cm, limestone gypsiferous and deep red at contact; argillaceous; massive; nodular; calcarenite;
   2.95 m

(14.55 m) indurated; CONTAINS: abundant burrows; gastropod at lower contact stained a red-brown color; forams including Nummulites and especially abundant Alveolina; fossils become less abundant upward; sharp contact with:

SONHARI FORMATION

10. Siltstone: Medium gray, upper 1.5 m weathered reddish brown; CONTAINS: carbonaceous debris on bedding surfaces; resin blebs; secondary gypsum bands that become more abundant upward; rare burrows; sharp contact with:
3.10 m
(17.65 m)

11. Claystone: Medium gray; coarsens upward; CONTAINS: burrows; finely comminuted carbonaceous debris and scattered coalified plant fragments on bedding surfaces, carbonaceous debris becomes more abundant upward; very fine-grained quartz sand laminae, laminae disappear upward; scattered secondary gypsum bands; intensely rooted, slickensided, unit homogenized by rooting in the upper part of the unit; grades into:
2.00 m
(19.65 m)

12. Interbedded claystone and sandstone: Sandstone very fine- to fine-grained, poorly sorted; medium green-gray; composed of quartz and very abundant interstitial clay; claystone is medium to dark gray; laminated; CONTAINS: resin blebs associated with clay laminae; finely comminuted carbonaceous debris on some bedding surfaces; abundant burrows; grades into:
0.95 m
(20.60 m)

13. Claystone: Medium gray; laminar bedded; CONTAINS: sand laminae up to 15 mm thick, sand laminae become more abundant upward and are primarily laminar bedded, ripple bedded in places; scattered burrows, burrows become more abundant upward; siderite nodules, nodules become more abundant upward; resin blebs; some bands of secondary gypsum; grades into:
0.60 m
(21.20 m)

14. Claystone: Medium gray; laminar bedded; CONTAINS: abundant sand laminae up to 3 mm in thickness, sand laminae are flat and ripple bedded, also sand ripple lenses up to 3 cm thick occur in places; yellow-brown siderite nodules and bands; burrows scattered throughout but tend to be concentrated in certain zones; foraminiferal fragments occur associated with sand laminae and sometimes as burrow fillings; sharp contact with:
0.50 m
(21.70 m)

15. Coal: Black; top 2 cm contains claystone-filled horizontal burrows penetrating from the overlying unit; sharp contact with:
0.60 m
(22.30 m)

16. Carbonaceous shale: Black; silty; base not exposed.

not measured

END OF SECTION