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LITHOLOGICAL AND GEOPHYSICAL CHARACTERISTICS OF THE PAKISTAN MINERAL DEVELOPMENT CORPORATION'S THL CORE HOLE: IMPLICATIONS FOR THE COAL RESOURCE POTENTIAL OF THE LOWER AND MIDDLE PART OF THE BARA FORMATION IN THE LAKHRA AREA OF SINDH, PAKISTAN

by

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ABSTRACT

The majority of Sindh Province's known coal resources occur in the Paleocene Bara Formation. This formation is, in places, more than 1000 m thick, but exploration for coal in this unit has been limited to its upper 250 m. None of the shallow exploration holes that have been drilled to date penetrate the entire coal-bearing part of the unit with certainty. Nor is it known if there are additional coal-bearing intervals deeper within the formation.

In 1988, Pakistan Mineral Development Corporation (PMDC) drilled a deep core hole on the Lakhra Anticline. This hole, designated THL, penetrated the upper 565 m of the Bara Formation. It represents the first and only deep core penetration of the Bara Formation. The lithologic and geophysical data from this core hole are reported in this study.

The results indicate that in the Lakhra Anticline area, the coal-bearing part of the formation is limited to the upper 260 m of the unit. The deepest coal bed occurs at 258 m. There are no lower coal bearing intervals in that part of the Formation that has been drilled. The THL deep hole contains one thick coal bed (2.2 m) at 85 m depth. Other significant coal beds include a 1 m thick bed at 141 m, a 0.88 m thick bed at 137 m, and a 0.75 m thick bed at 63 m. All other individual coal beds are less than 0.65 m thick. Laterally, other thick coal beds may be present where partings thin and coal splits join.

BACKGROUND

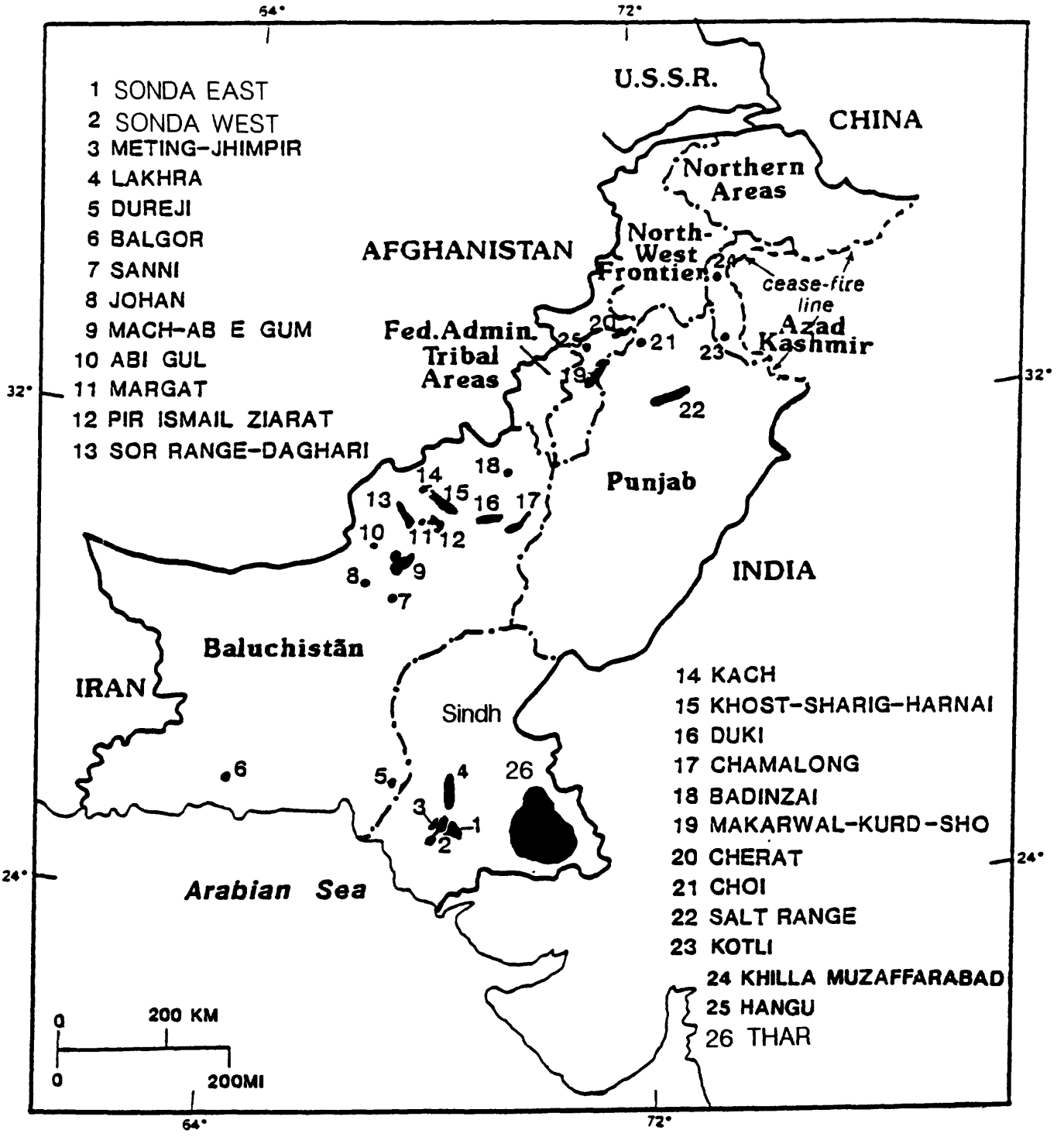
The majority of Pakistan's known coal resources occur in Sindh Province (fig. 1) and as coal utilization becomes increasingly important in Pakistan's economy, Sindh province will expand its dominance as the country's leading coal supplier. Coal deposits occur in two areas within the province: in the west, along the Lakhra Anticline and areas to the south as far as Thatta, and in the east, in the Thar desert (fig. 1).

The thickest and possibly most extensive coal deposits in Pakistan are found in the Thar desert. However, this region is only now beginning to be explored by drilling, so the extent of this potential resource is speculative at this time. For a detailed discussion of the Thar deposits see SanFilipo and others (1992).

Sindh's western coal fields on the Lakhra Anticline produce most of the coal mined in Pakistan. After failed mining attempts in the mid 1800's (Blanford, 1869), commercial coal production began in the late 1950's and early 1960's (Landis, oral communication, 1987) from shallow mines on the axis of the Lakhra Anticline. As successful mining ventures demonstrated the occurrence of economic coal deposits on the anticline, public and private sector coal exploration programs were started in the 1960's. One of the earliest of these was a cooperative drilling program conducted by the Geological Survey of Pakistan (GSP) and the United States Geological Survey (USGS) sponsored by the United States Agency for International Development (USAID). The results of this effort are reported in Ghani and others (1973). Other exploration efforts in Lakhra and in Sonda and Meting-Jhimpir to the south include drilling by GSP, the Pakistan Mineral Development Corporation (PMDC), the Water and Power Development Authority (WAPDA), Japan International Cooperation Agency (JICA),

FIGURE 1: COAL FIELDS OF PAKISTAN

(Modified from SanFilipo and others, 1988)



and USAID (Memon and others, 1976; Japan International Cooperation Agency, 1981; Geologic Associates Inc., 1985; and the John T. Boyd Company, 1985, 1986). These drilling efforts found significant coal resources in Lakhra and the adjoining areas. Beginning in 1985, the GSP/USGS began the USAID sponsored Coal Resource Exploration and Assessment Program (COALREAP) to evaluate more precisely the coal resource potential of Sindh Province. Reports of the COALREAP activities can be found in: Simon and others (1987), Warwick and others (1987), Landis and others (1988), SanFilipo and others (1988,1989,1990, and in press), Schweinfurth and Husain (1988), Thomas, Landis, and Khan (1988), Thomas, Khan, Riaz, and Khan (1988), Thomas and others (1989), Frederiksen (1990), Brouwers and others (1990), Wnuk, Fariduddin, Fatmi, and SanFilipo (1991), Wnuk, SanFilipo, Fatmi, and Fariddudin (1991), Landis and others (1992), and Thomas and Khan (1992).

In addition to the coal exploration programs discussed above, Sindh has been the target of numerous oil and gas exploration efforts. The results of much of this exploration work are proprietary, and information which is available for distribution is often difficult to obtain. Of the drilling records that have been examined, none of the holes were cored in coal-bearing strata. The data available from these exploratory wells consist of geophysical logs, poorly suited for coal exploration studies, and some cursory descriptions of the rock cuttings from the drill holes. Nevertheless, the data, though somewhat ambiguous, do indicate that coal-bearing strata are geographically more widespread in Sindh Province than previously believed and that there are indications of coal occurrence well beyond the areas that have so far been drilled by COALREAP or the other agencies exploring this part of Pakistan (Kazmi and others, 1990).

PURPOSE AND SCOPE

Most of Sindh's known coal resources occur in the Bara Formation (figs. 1 and 2), and most of the coal now being mined in Sindh derives from this unit. The stratigraphically higher Sohnari Formation (as defined by Outerbridge and others, 1991) also contains coal, but the Sohnari beds are typically less than 1 m thick and are currently being mined only in the Meting-Jhimpir coal field (fig. 1).

Petroleum exploration drilling done by the Pak-Hunt Co. in the 1950's indicated that the Bara Formation is approximately 730 m thick in the area of the Lakhra Anticline. Quadri and Shuaib (1986) state that the Ranikot Formation[@] (which consists of the Lakhra, Bara, and Khadro Formations) thickens to more than 1400 m 60 km southwest of the Anticline. More than 1000 m of this thickness belongs to the Bara Formation. But, even though the Bara Formation is thick, exploration for coal in this unit has been limited to the upper 250 m on the assumption that it is not technologically or economically feasible to extract deeper coal beds given the present mining and leasing practices in Pakistan. Since deep formation penetration and exploration has not been an exploration objective, the drilling equipment that has been chosen for the exploration work was mechanically limited to

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@ The stratigraphic nomenclature of the Paleocene strata in Sindh is confused. The Hunting Survey maps do not actually identify a Bara Formation, rather they map the undivided Ranikot Group consisting of, from bottom to top, the Cardita beaumonti beds, the Lower Ranikot Formation, and the Upper Ranikot Formation. Current stratigraphic usage by the Geological Survey of Pakistan is summarized by Cheema and others (1977). They rename the three Hunting subdivisions, from bottom to top, as the Khadro Formation (after Williams, 1959), the Bara Formation, and the Lakhra Formation. Among geologists from the oil industry, the term Ranikot Formation is used by some authors for the Bara Formation only while the Lakhra Formation is correlated to the Dungan Formation of Balochistan (Williams, 1959). Other authors use the term Ranikot Formation to include the Khadro, Bara, and Lakhra Formations (Quadri and Shuaib, 1986).

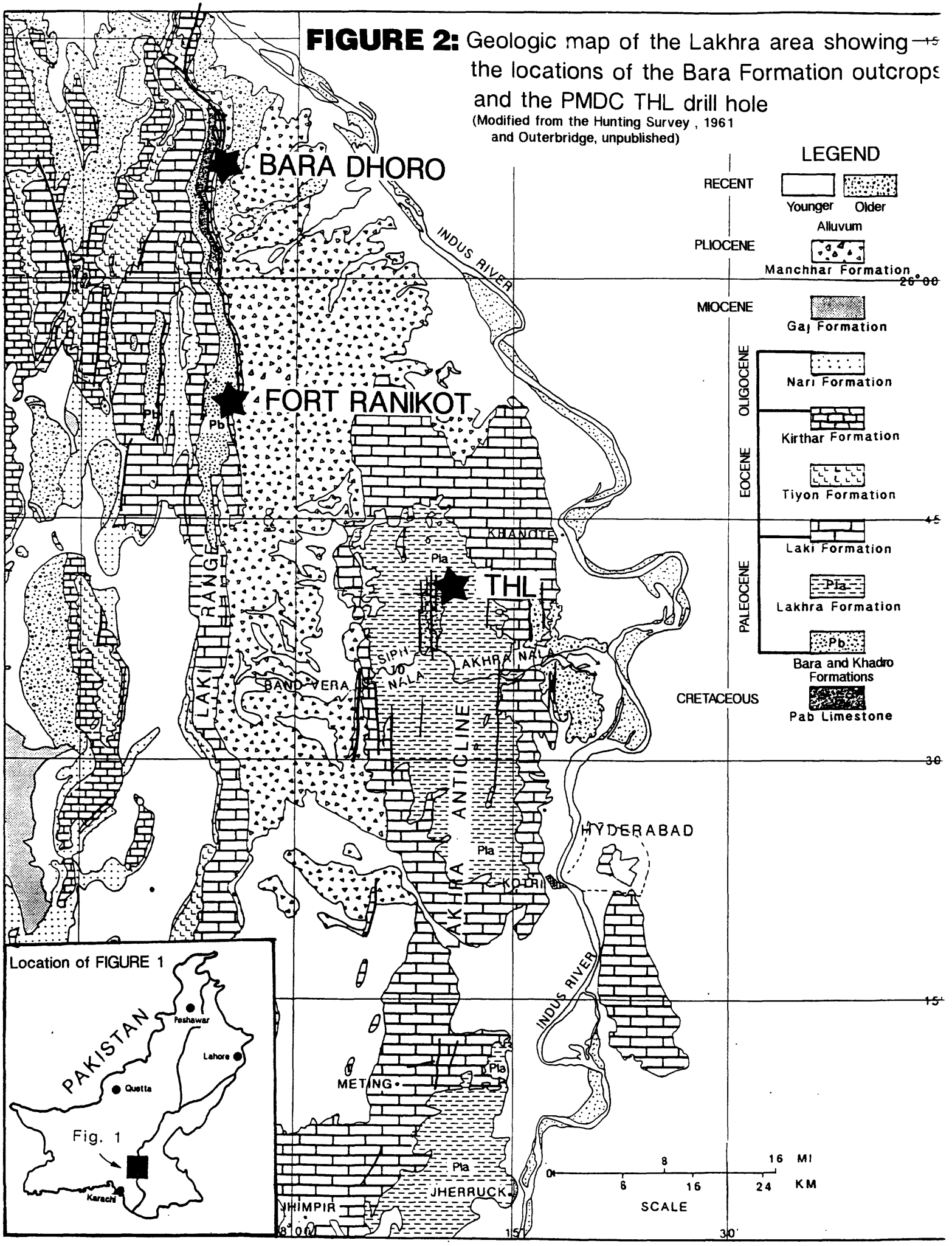


FIGURE 2: Geologic map of the Lakhra area showing the locations of the Bara Formation outcrops and the PMDC THL drill hole
(Modified from the Hunting Survey , 1961 and Outerbridge, unpublished)
BARA DHORO
FORT RANIKOT
THL
INDUS RIVER
LAKI RANGE
BAND VERA
SIPH JO NALA
AKHRA NALA
KHANOTE
AKRA ANTICLINE
KODRI
HYDERABAD
METING
JHERRUCK
JHIMPIR
Pla
Pb
LEGEND
RECENT
Younger
Older
Alluvum
PLIOCENE
Manchhar Formation
MIOCENE
Gaj Formation
OLIGOCENE
Nari Formation
Kirthar Formation
EOCENE
Tiyon Formation
Laki Formation
PALEOCENE
Lakhra Formation
Bara and Khadro Formations
CRETACEOUS
Pab Limestone
26° 00
45
30
15
8° 00
15
30
0
8
16 MI
8
16
24 KM
SCALE
Location of FIGURE 1
PAKISTAN
Peshawar
Lahore
Quetta
Karachi
Fig. 1

penetration capabilities of 400 m or less. COALREAP drilling averaged 177.17 m per hole for 45 drill holes (SanFilipo and others, 1988, Thomas and others, 1990). Some of the drill holes were drilled to depths of 400 m, but in all of these holes, the Bara Formation was deeply buried. The deepest penetration of the Bara Formation was 226 m in drill-hole UAK-5 in the Sonda Coal Field. None of the coal exploration holes drilled into the Bara Formation are unequivocally known to penetrate the entire coal-bearing part of the unit.

The lithologic and geophysical logs from the oil and gas wells that have penetrated the total thickness of the Bara Formation are vague and inconclusive about the depth of the deepest coal. Surface sections measured by GSP in the northern part of the Lakhi Range around Bara Dhoro (fig. 2, where the type section of the Bara Formation is located) are very generalized, and therefore, also inconclusive about the depth to the deepest coal (Abdullah, unpublished; Ahmed and Siddiqui, unpublished). The surface section measured by GSP at the principal reference section of the Bara Formation at Fort Ranikot (fig. 2) suggest that the coal bearing facies may be limited to the upper part of the formation (Ahmed and Siddiqui, unpublished), but Wnuk and others (in press) have found rooted zones and carbonaceous shales in the lower Bara in the fort.

A thorough regional assessment of the coal resources of the Bara Formation must include consideration of the potential for deeper lying coal beds. Though potential deep coal beds may not be commercial under current economic and technologic conditions, they may, in time, prove to be an economic source of coal bed methane or feedstock for underground gasification processes. Therefore, the primary purpose of this paper is to obtain a more complete understanding of coal distribution in the Bara Formation.

METHODS

In order to test the capabilities of recently purchased drilling equipment, PMDC drilled a 601 m deep test hole at Northing 895,600 m and Easting 2,159,700 m (topographic sheet 40 C/2) in the Lakhra Coal Field (see fig. 1 for the location of this drill hole). This hole was rotary drilled to a depth of 26.12 m and then continuously cored to a total depth of 601.04 m. The core was carefully boxed, labeled, and stored in a PMDC core storage facility at the mine office in Lakhra. The PMDC core hole, designated THL, is the deepest and most complete core of the Bara Formation.

With the kind cooperation of the PMDC management, we were given permission to lithologically and geophysically log and sample the PMDC THL drill core. The data obtained from the THL drill hole is supplemented with reconnaissance observations made at the type area of the Bara Formation (Bara Dhoro), and a preliminary measured section at the principle reference section (Fort Ranikot).

RESULTS

The detailed litholigical description of the rock units from THL are provided in Appendix 1. The geophysical logs are shown in Appendix 2.

Much of the formation consists of poorly cemented sandstone that is difficult to recover during coring. Overall core recovery was a low 61% (Table 1) due to the extensive core loss in these sandstones. Core recovery in the clay-rich parts of the section was significantly higher.

The hole was spudded in the Lakhra Formation and a total of 8.96 m of Lakhra Formation sediments were cored from 26.12 m to 35.08 m. The remaining

TABLE 1

Core recovery in the PMDC deep hole THL

DEPTH INTERVAL	THICKNESS OF CORED INTERVAL	CORE LOSS	PERCENT CORE RECOVERY
26.12-35.08 m	8.96 m	0 m	100 %
35.08-258.31 m	223.23 m	56.22 m	75 %
258.31-374.90 m	116.59 m	101.32 m	13 %
374.90-601.04 m	226.14 m	66.67 m	71 %

PLEASE NOTE: The core recoveries reported in this table are based on the core measurements made in the 1989 field season. The figures reported here may not agree with the core losses reported by the PMDC geologists in their field descriptions because the core may have shifted in the boxes during transport and handling.

565.96 m of cored sediments from 35.08 m to 601.04 m were all from the Bara Formation.

The Bara Formation can be divided into 29 fining upward cycles in the THL core hole (see fig. 3 for examples of these cycles). The uppermost 13 of these cycles consist of clean crossbedded sandstones which grade into clean rippled sandstones which, in turn, grade into dirty, rippled, flaser and lenticular bedded sandstones, siltstones, and claystones. Several of the dirty sandstones and many of the siltstones and claystones are rooted and are overlain by coal beds. Wnuk and others (1992) interpreted these sediments as inner-shelf tidal sandwaves grading upward into estuarine sediments followed by intertidal and coastal plain deposits containing coal.

For cycles 14 through 18, the geophysical logs show cyclic patterns similar to the preceding 13 cycles, but the logs do not indicate the presence of coal. There is no lithologic data for cycles 14 through 18 because of the almost complete core loss in this interval.

Geophysically, cycles 19 through 29 are also similar to the first 13 cycles except that transitions between clean sandstones and fine-grained facies are more abrupt (fig. 3). Cycles begin with clean, crossbedded sandstones rich in glauconite-like minerals. The fine grained facies are homogeneous and consist of maroon, green, and variegated, burrowed shales, siltstones, and mudstones. Except for the abundance of the glauconite-like minerals, the lithology and sedimentary structures of the clean sandstones in the lower cycles are identical to the lithology and sedimentary structures of the clean sandstones in the upper cycles. At the Fort Ranikot section, where the top and bottom of the section are exposed, the clean sandstones in the lower part of the Bara Formation have typical tidal sand-wave structures and lithologies (Wnuk and others, in press). On this basis, the lower sandstones

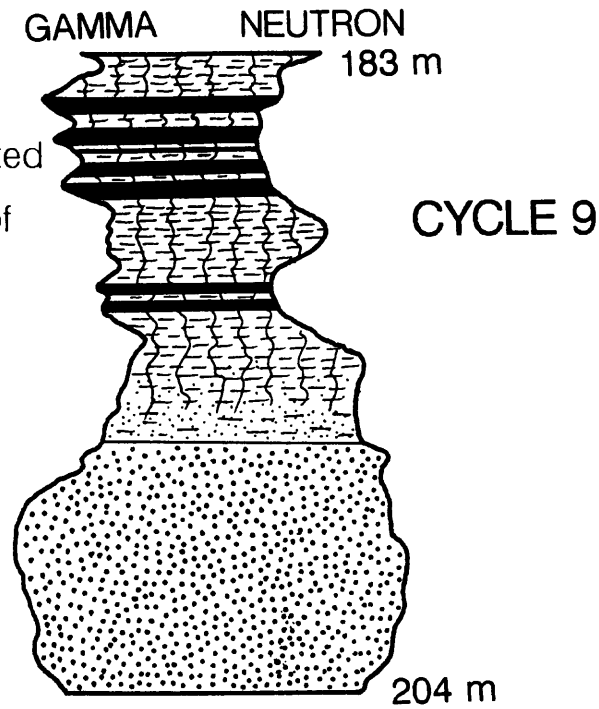
in THL hole are also interpreted to be tidal sand-waves and ridges. However, the intensely bioturbated fine grained facies lack any of the characteristics that would suggest they were deposited in shallow intertidal or supratidal environments thus suggesting that the sandwaves and ridges and the inter-ridge muds were deposited in deeper water, possibly as deep as the middle-shelf.

All of the coal beds, coal zones and rooted intervals that were found in the core are listed in Table 2. There were twenty nine such intervals. The rooted intervals were included because there is a good probability that they were originally covered by organic deposits that were subsequently eroded and replaced by the overlying sediment. Because of the lateral variability observed in Lakhra coal beds, it is possible that the rooted zones can be correlated to coal beds elsewhere in the coal field.

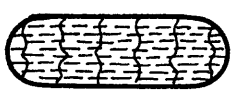
In this report, a coal zone is defined as a sequence of interbedded coal, dirty coal, and/or carbonaceous shale beds in which no consecutive carbonaceous units are separated by more than 1 m of non-carbonaceous claystone, siltstone, or shale parting. Setting the maximum parting thickness at 1 m is a convenient but arbitrary choice. As Table 2 shows, there are only two cases in which the parting thickness approaches 1 meter within a coal zone (0.91 m between unit 114 and 117 and 0.86 m between unit 262 and 264). Typically, coal zones are separated by several meters of interburden and the thinnest interval separating two distinct coal-bearing units is 1.35 m between unit 26 and 29.

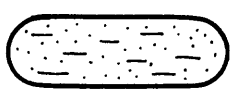
The coal zones defined in this paper generally differ from the coal zones defined by SanFilipo and others (1988). Except in the Lakhra Coal Field, SanFilipo and others (1988) define zones as all of the coal occurring between two clean sandstone units (i.e. all of the coal occurring within a cycle as

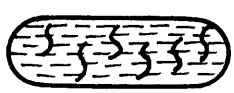
FIGURE 3: Examples of geophysical and lithological characteristics of selected cycles from the upper and lower part of the Bara Formation.

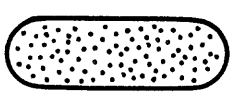



COAL


ROOTED SILTSTONES AND CLAYSTONES


DIRTY SANDSTONES


BIOTURBATED CLAYSTONES SILTSTONES, AND MUDSTONES


CLEAN SANDSTONES

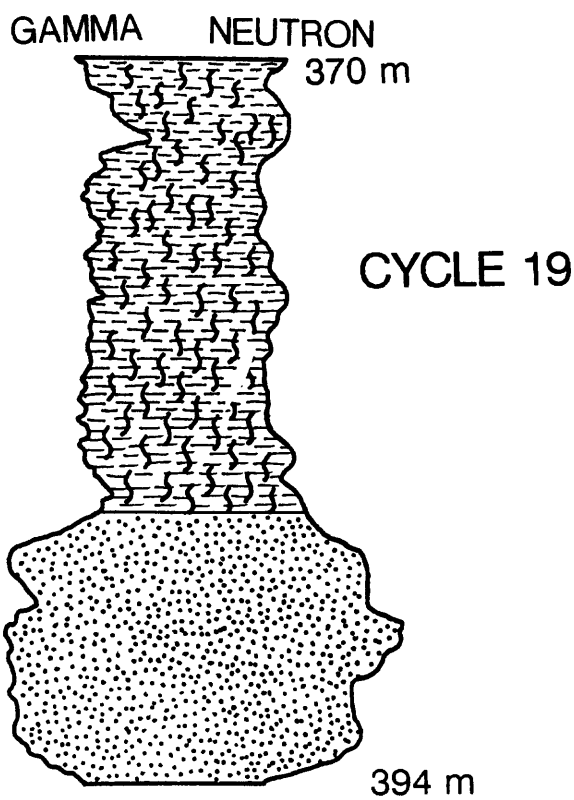


TABLE 2

Coal bed and coal zone thickness and intercepts

COAL_ZONE	UNIT*	LITHOLOGY	BED_THICKNESS	BED_INTERCEPTS
1	26	**COAL**	**0.16 m**	55.45-55.61 m
2	29	**COAL**	**0.25 m**	56.96-57.21 m
3	34	bone coal	0.25 m	62.77-63.02 m
3	35	**COAL**	**0.50 m**	63.02-63.52 m
4	40	rooted claystone	0.75 m	67.40-68.15 m
4	41	rooted claystone	0.17 m	68.15-68.32 m
4	42	carbonaceous shale	0.23 m	68.32-68.55 m
4	43	parting	0.44 m	68.55-68.99 m
4	44	bone coal	0.04 m	68.99-69.03 m
5	57	**COAL**	**2.20 m**	85.69-87.89 m
5	58	carbonaceous shale	0.15 m	87.89-88.04 m
6	69	rooted siltstone	0.21 m	103.63-103.84 m
6	70	bone coal	0.09 m	103.84-103.93 m
6	71	**COAL**	**0.09 m**	103.93-104.02 m
6	72	parting	0.11 m	104.02-104.13 m
6	73	**COAL**	**0.17 m**	104.13-104.30 m
7	93	**COAL**	**0.05 m**	122.70-122.75 m
8	99	bone coal	0.09 m	124.82-124.91 m
8	100	**COAL**	**0.40 m**	124.91-125.31 m
9	106	bone coal	0.19 m	128.35-128.54 m
9	107	parting	0.22 m	128.54-128.76 m
9	108	**COAL**	**0.09 m**	128.76-128.85 m
10	114	**COAL**	**0.28 m**	132.35-132.63 m
10	115,116	parting	0.91 m	132.63-133.54 m
10	117	dirty coal	0.04 m	133.54-133.58 m
10	118	**COAL**	**0.07 m**	133.58-133.65 m
10	119	carbonaceous shale	0.09 m	133.65-133.74 m
11	122	carbonaceous shale	0.13 m	135.62-135.75 m
11	123	parting	0.12 m	135.75-135.87 m
11	124	**COAL**	**0.05 m**	135.87-135.92 m

* The unit numbers in this table refer to the unit numbers in Appendix 1.

TABLE 2: CONTINUED

COAL_ZONE	UNIT*	LITHOLOGY	BED_THICKNESS	BED_INTERCEPTS
11	125	parting	0.10 m	135.92-136.02 m
11	126	**COAL**	**0.07 m**	136.02-136.09 m
11	127	dirty coal	0.14 m	136.09-136.23 m
11	128	carbonaceous mudstone	0.26 m	136.23-136.49 m
11	129	parting	0.45 m	136.49-136.96 m
11	130	dirty coal	0.10 m	136.94-137.04 m
11	131	**COAL**	**0.75 m**	137.04-137.79 m
11	132	dirty coal	0.03 m	137.79-137.82 m
11	133	carbonaceous shale	0.15 m	137.82-137.97 m
11	134	parting	0.14 m	137.97-138.11 m
11	135	dirty coal	0.06 m	138.11-138.17 m
11	136	**COAL**	**0.11 m**	138.17-138.28 m
11	137	dirty coal	0.08 m	138.28-138.36 m
11	138	carbonaceous shale	0.05 m	138.36-138.41 m
12	141	**COAL**	**1.00 m**	140.98-141.98 m
13	145	**COAL**	**0.65 m**	143.76-144.41 m
14	149	**COAL**	**0.23 m**	146.92-147.15 m
15	159	**COAL**	**0.35 m**	160.39-160.74 m
16	164	**COAL**	**0.04 m**	164.99-165.03 m
16	165	carbonaceous shale	0.08 m	165.03-165.11 m
16	166	**COAL**	**0.18 m**	165.11-165.29 m
16	167	interbedded clay, coal	0.06 m	165.29-165.35 m
16	168	pyritized coal	0.06 m	165.35-165.41 m
16	169	**COAL**	**0.16 m**	165.41-165.57 m
17	173	dirty coal	0.22 m	169.89-170.11 m
17	174	**COAL**	**0.14 m**	170.11-170.25 m
17	175	carbonaceous sandstone	0.14 m	170.25-170.39 m
17	176	parting	0.19 m	170.39-170.58 m
17	177	**COAL**	**0.07 m**	170.58-170.65 m
18	182	**COAL**	**0.13 m**	174.44-174.57 m
18	183	dirty coal	0.05 m	174.57-174.62 m
19	189	**COAL**	**0.05 m**	177.65-177.70 m
19	190	carbonaceous shale	0.19 m	177.70-177.89 m
20	197	rooted claystone	0.34 m	185.00-185.34 m
20	198	rooted claystone	0.76 m	185.34-186.10 m
20	199	interbedded sand, clay	0.08 m	186.10-186.18 m
20	200	rooted claystone	0.04 m	186.18-186.22 m

TABLE 2: CONTINUED

COAL_ZONE	UNIT*	LITHOLOGY	BED_THICKNESS	BED_INTERCEPTS
20	201	**COAL**	**0.52 m**	186.22-186.74 m
20	202,203,204	parting	0.57 m	186.74-187.31 m
20	205	dirty coal	0.04 m	187.31-187.35 m
20	206	**COAL**	**0.38 m**	187.35-187.73 m
20	207	parting	0.17 m	187.73-187.90 m
20	208	carbonaceous shale	0.04 m	187.90-187.94 m
20	209	**COAL**	**0.10 m**	187.94-188.04 m
20	210	parting	0.25 m	188.04-188.29 m
20	211	carbonaceous shale	0.39 m	188.29-188.68 m
20	212	parting	0.11 m	188.68-188.79 m
20	213	carbonaceous shale	0.07 m	188.79-188.86 m
20	214	**COAL**	**0.58 m**	188.86-189.44 m
21	219	carbonaceous shale	0.10 m	192.02-192.12 m
21	220	**COAL**	**0.05 m**	192.12-192.17 m
21	221	carbonaceous shale	0.07 m	192.17-192.24 m
21	222	parting	0.67 m	192.24-192.91 m
21	223	**COAL**	**0.22 m**	192.91-193.13 m
22	235	rooted claystone	0.09 m	203.49-203.58 m
22	236	**COAL**	**0.04 m**	203.58-203.62 m
22	237	carbonaceous shale	0.04 m	203.62-203.66 m
23	243	dirty coal	0.01 m	207.61-207.62 m
24	253	carbonaceous shale	0.01 m	212.40-212.41 m
24	254	**COAL**	**0.05 m**	212.41-212.46 m
25	260	carbonaceous shale	0.05 m	216.21-216.26 m
25	261	**COAL**	**0.54 m**	216.26-216.80 m
25	262	carbonaceous shale	0.02 m	216.80-216.82 m
25	263	parting	0.86 m	216.82-217.68 m
25	264	dirty coal	0.19 m	217.68-217.87 m
25	265	parting	0.29 m	217.87-218.16 m
25	266	carbonaceous shale	0.27 m	218.16-218.43 m
26	273	carbonaceous shale	0.03 m	224.79-224.82 m
27	287-294	rooted interval	5.00 m	240.47-245.47 m
28	295	carbonaceous shale	0.05 m	245.47-245.52 m
29	305	carbonaceous shale	0.09 m	257.90-257.99 m
29	306	dirty coal	0.03 m	257.99-258.02 m

defined in this paper). In the Lakhra Coal Field, where the density of data is greater, SanFilipo's coal zones are more closely analogous to those defined in this paper. As stated earlier, this paper defines a coal zone as all of the coal occurring between two 1 m thick non-coal-bearing units. SanFilipo's definition allows only one coal zone per cycle (except in Lakhra), our definition allows for more than one. For the purposes of coal resource calculations, SanFilipo's method is superior since his coal zones are correlatable over longer distances. The zones defined in this paper are more useful for detailed environmental interpretations.

The THL deep hole contains one thick coal bed (2.2 m) at 85 m depth, a 1 m thick bed at 141 m, a 0.88 m thick bed at 137 m, and a 0.75 m thick bed at 63 m. All of the rest of the individual coal beds are less than 0.65 m thick. Laterally, several of the other coal zones could potentially contain thick coals if partings thin and coal splits join. The deepest coal bed, unit 306, occurs at 258 m.

DISCUSSION AND CONCLUSIONS

The results of the COALREAP drilling indicate that coal zones are regionally consistent and correlatable (SanFilipo and others, 1988). Individual coal beds within the Bara Formation, however, tend to be lenticular and discontinuous in their occurrence. Coal beds tend to have multiple shale partings and tend to split, join, and pinch out over very short distances. This unpredictability in coal bed distribution indicates that the results of the THL deep hole drilling need to be interpreted cautiously. Although only one very thick coal bed was encountered in the PMDC hole, multiple thick beds do sometimes occur in other leases on the Lakhra Anticline not far from the

PMDC property. Hence, intervals that appear to have little potential on the PMDC property may have greater potential within the Bara Formation in other parts of the Lakhra coal field.

The PMDC deep hole would suggest that there is little coal potential in the Bara Formation below 260 m of depth. This is confirmed by reconnaissance surveys to the type section of the Bara Formation at Bara Dhoro and to the principal reference section at Fort Ranikot. At Fort Ranikot, only thin carbonaceous shales were found near the base of the Formation. Neither coal nor carbonaceous shales were not found at Bara Dhoro. The results obtained from the PMDC hole are therefore believed to be regionally valid; the Bara Formation below 250 - 300 m is not likely to be coal bearing, at least in the area of the Lakhra Anticline. However, there are numerous facies changes within the Bara Formation. The principal reference section at Fort Ranikot is approximately 30 km away from the PMDC deep hole yet it appears to contain considerably less coal than the PMDC hole. The reference section contains very little of fine grained sediments and appears to be almost entirely sandstone dominated consisting of inner shelf and near shore sediments (Wnuk and others, 1992; Wnuk and others in press) not fluvial sediments as indicated by the Hunting Survey Corporation (1961), Cheema (1977), and Gingerich and others, (1979). The Bara Dhoro type section, 30 km to the north of the principal reference section appears to be lithologically more similar to the PMDC hole, but is barren of coal. Much additional work must be done before these facies relationships can be better understood.

RECOMMENDATIONS

Improved cooperation with agencies such as the Oil and Gas Development

Corporation (OGDC) and others involved with oil and gas drilling in Sindh may help to make additional data about the deeper Bara Formation rocks available to the Coal Reap investigations. This data can help significantly in developing a regional picture of the Bara Formation facies variations and help with coal exploration.

The Bara Formation tends to be well exposed in the Laki Range northwest of the Lakhra Anticline and south of the town of Shewan. There are numerous places here in which a thick, and in some cases a complete Bara section can be measured. Measuring those sections will provide a substantial amount of information about the range of facies variation in the Bara Formation without the expense of drilling.

Two or three well chosen deep stratigraphic test holes south and east of the Lakhra Anticline can provide much needed information about the lower Bara Formation in the areas where the Bara Formation is entirely in the subsurface. At least one of these should be drilled in the area of Mirpur Batoro where the Bara Formation appears to be in the Shallow subsurface according to the figure in Quadri and Shuaib (1986).

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APPENDIX 1

LITHOLOGIC DESCRIPTION OF THE PMDC THL CORE HOLE

Described by: Christopher Wnuk, U.S. Geological Survey
John R. SanFilipo, U.S. Geological Survey
Farah Fatmi, Geological Survey of Pakistan
Shafique Ahmed Khan, Geological Survey of Pakistan
Mohammad Fariduddin, Geological Survey of Pakistan

Location: Survey of Pakistan Topographic Sheet 40 C/2
Northing 895,600 m, Easting 2,159,700 m

Rotary Interval: 0 - 26.12 m

Core Drilling Begins: 26.12 m

Core Drilling Ends: 601.04 m

Total Depth: 601.04 m

LAKHRA FORMATION

1. Sandstone: Very fine-grained, poorly sorted; homogeneous; green-gray; composed of quartz, rare glauconite pellets, very abundant
1.98 m interstitial clay possibly containing a glauconitic
(28.10 m) component, and calcareous cement that becomes more abundant downward; CONTAINS: rare shell fragments and shell molds, shell fragments become slightly more abundant downward; no evidence of bedding or burrows; shale bands at the base; bands of secondary gypsum; grades into:

2. Siltstone: Medium gray; coarsens downward; CONTAINS: irregular fine-grained quartz sand laminations, in places the laminations
0.34 m are composed of fine- to medium-grained quartz sand; sparse
(28.44 m) shell fragments and shell molds; horizontal sand filled burrows along bedding surfaces; grades into:

3. Sandstone: Very fine- to coarse-grained, poorly sorted; homogeneous; medium gray; composed of quartz, glauconite pellets that
0.64 m become larger (up to 7 mm in diameter) and more abundant
(29.08 m) downward, very abundant interstitial clay, and calcareous cement; CONTAINS: gastropods, Turetella, pelecypods, shell fragments and shell molds; rare clay pebbles; no evidence of bedding; grades into:

4. Sandstone: Fine- to coarse-grained, poorly sorted; homogeneous; green-gray; composed of quartz, sparse glauconite pellets,
0.90 m abundant interstitial clay, and calcareous cement; weakly
(29.98 m) cemented; CONTAINS: sparse shell fragments; rare coalified plant fragments; siderite bands and nodules; rare clay bands; no evidence of bedding; grades into:

5. Sandstone: Very fine- to coarse-grained, poorly sorted; homogeneous; yellow-brown; composed of quartz, black altered glauconite
0.78 m pellets, and a small amount of interstitial clay; poorly
(30.76 m cemented, friable; CONTAINS: no evidence of bedding; sharp contact with:

6. Claystone: Medium gray; CONTAINS: very fine-grained quartz sand laminations less than 1 mm thick; laminar bedding; finely
0.10 m comminuted carbonaceous debris on bedding plane surfaces;
(30.86 m) mica flakes? or possibly flakes of secondary gypsum; sharp contact with:

7. Sandstone: Fine- to medium-grained, poorly sorted; medium gray; composed of quartz, altered glauconite pellets, some
0.52 m interstitial clay, and calcareous cement in places; poorly
(31.38 m) cemented, friable; CONTAINS: calcite cemented nodules up to 3 cm in diameter; rare resin blebs in the calcite nodules; grades into:

8. Sandstone: Very fine- to medium-grained, some coarse grains, poorly sorted; green-gray; composed of quartz, very abundant

0.67 m (32.05 m) interstitial clay which may contain a glauconitic component, and calcareous cement; CONTAINS: calcareous clay bands in places, clay bands are up to 7 cm thick; carbonaceous debris on bedding plane surfaces; finely comminuted shell fragments on bedding plane surfaces, shell debris becomes less abundant downward; bands of secondary gypsum; grades into:

9. Sandstone: Very fine-grained, fines downward, poorly sorted; medium gray; composed of quartz, extremely abundant interstitial clay, rare glauconite pellets, and calcareous cement; CONTAINS: finely comminuted carbonaceous debris, coalified wood fragments, carbonaceous remains pyritized in places; rare resin blebs; bedding plane burrows filled with fine- to medium-grained sand; bands of secondary gypsum; clay laminations; siderite nodules; sharp contact with:

1.00 m (33.05 m)

10. Sandstone: Fine-grained, some coarse grains, poorly sorted; green-gray; composed of quartz and abundant interstitial clay that appears to contain some finely disseminated glauconite; CONTAINS: abundant shell fragments, especially bivalves; carbonaceous debris and coalified wood fragments; grades into:

0.20 m (33.25 m)

11. Sandstone: Fine-grained with scattered medium grains, fines to very fine-grained and becomes more argillaceous downward, poorly sorted; massive; homogeneous; green-gray; composed of quartz, abundant interstitial clay that appears to contain finely disseminated glauconite, and calcareous cement; CONTAINS: shale bands and laminations at the base; Turetella, sparse shell fragments; burrows; rare bands of secondary gypsum; grades into:

1.83 m (35.08 m)

BARA FORMATION

12. Sandstone: Fine- to medium-grained, poorly sorted; massive; homogeneous; medium gray; composed of quartz, red altered glauconite pellets, extremely abundant interstitial clay, and calcareous cement; CONTAINS: abundant intact and fragmental bivalves (clams); grades into:

0.51 m (35.59 m)

13. Sandstone: Fine-grained, fines to very fine-grained to silty and becomes more argillaceous downward, poorly sorted; massive; homogeneous; green-gray; composed of quartz, abundant dark minerals, red altered glauconite pellets, abundant interstitial clay that appears to contain finely disseminated glauconite, and a small amount of calcareous cement; CONTAINS: burrows; indistinct shale laminations, laminations become more defined and abundant downward; rare forams and sparse shell fragments; sparse carbonaceous debris; sparse siderite nodules; grades into:

1.47 m (37.06 m)

14. Core loss: Probably occurred in unit 11:

0.17 m
(37.23 m)

15. Siltstone: Medium gray; very slightly calcareous; fines downward; CONTAINS: very fine-grained quartz sand laminations less than 3 mm thick and usually less than 1 mm thick, occasionally fine-grained quartz sand occurs on some laminations, laminations become less abundant downward; sparse, finely comminuted shell fragments associated with sand laminations, on some laminations shell fragments may be abundant; siderite bands and nodules; rare pyrite in places; very rare glauconite pellets; burrows, sometimes filled with concentrations of shell fragments, glauconite pellets, and pyrite and has the appearance of calcarenite; grades into:

3.90 m
(41.13 m)

16. Sandstone: Badly fragmented during drilling; fine- to coarse-grained; homogeneous; medium gray; composed of quartz, rare glauconite pellets, and calcareous cement; CONTAINS: finely comminuted shell fragments; extremely indurated calcite zones; grades into:

2.26 m
(43.39 m)

17. Core loss: Probably in sandstone:

0.26 m
(43.65 m)

18. Sandstone: Very fine- to fine-grained, poorly sorted; dark green-gray; composed of quartz, sparse glauconite pellets, abundant interstitial clay, and calcareous cement; CONTAINS: laminar bedding; rare iron mineralized carbonaceous debris on some bedding plane surfaces; sparse, finely comminuted shell fragments; sparse siderite pellets; grades into:

2.28 m
(45.93 m)

19. Sandstone: Fine-grained, sparse medium and coarse grains in places, well-sorted; homogeneous; light gray; composed of quartz, abundant glauconite pellets, little interstitial clay, and calcareous cement; indurated; CONTAINS: abundant finely comminuted shell fragments; rare coalified wood fragments; no evidence of bedding; sharp contact with:

1.00 m
(46.93 m)

20. Sandstone: Core badly fragmented during drilling; fine-grained, common medium and coarse grains in places, fines downward, poorly sorted; homogeneous; green-gray; composed of quartz, glauconite pellets, abundant interstitial clay, and calcareous cement; weakly cemented; CONTAINS: finely comminuted shell fragments; rare iron mineralized carbonaceous debris, carbonaceous debris becomes more abundant downward; burrows; no evidence of bedding; shale beds and laminations near the base; beds and laminations disturbed by burrowing; siderite nodules; pyrite; grades into:

2.90 m
(49.83 m)

21. Sandstone: Fine-grained, sand beds well-sorted; medium-gray; composed of quartz, some interstitial clay and abundant clay laminations; CONTAINS: abundant clay beds and laminations, laminations become more abundant and thicker downward; abundant carbonaceous debris on shale laminations; rare siderite nodules; rare shell fragments; burrows, burrows parallel bedding surfaces; grades into:

0.36 m
(50.19 m)

22. Siltstone: Dark gray; CONTAINS: very fine- to fine-grained quartz sand laminations less than 1 mm thick, laminations become less abundant downward; vertical sand filled burrows; scattered shell fragments including Pectin; abundant pyritized carbonaceous debris; grades into:

2.63 m
(52.82 m)

23. Sandstone: Fine-grained, poorly sorted; dark gray; composed of quartz and very abundant interstitial clay; CONTAINS: abundant pyritized and coalified organic debris on bedding plane surfaces; laminar bedding; resin blebs; sharp contact with:

0.27 m
(53.09 m)

24. Sandstone: Very fine-grained, poorly sorted; light gray with medium gray clay beds; composed of quartz and extremely abundant interstitial clay; CONTAINS: abundant shale laminations up to 3 mm thick, laminations become more abundant downward; abundant carbonaceous debris on bedding plane surfaces; sparse small burrows; ripple lenses, siderite bands and nodules; grades into:

0.66 m
(53.75 m)

25. Siltstone: Dark gray; fines downward; CONTAINS: abundant very fine-grained flat quartz sand laminations up to 1 mm thick; horizontal sand filled burrows on bedding plane surfaces; vertical burrows; siderite nodules; sparse finely comminuted carbonaceous debris on bedding plane surfaces; sharp contact with:

1.70 m
(55.45 m)

26. Coal: Black; CONTAINS: abundant resin; sharp contact with:

0.16 m
(55.61 m)

27. Claystone: Medium gray; underclay; slickensided; intensely rooted; CONTAINS: finely comminuted carbonized and pyritized plant debris, coalified wood fragments; below 30 cm the unit becomes fissile, pyritized roots; rooted throughout; partially intact plant fossils; grades into:

0.76 m
(56.37 m)

28. Sandstone: Very fine-grained, scattered medium grains, fines downward becomming increasingly argillaceous, poorly sorted; medium gray; composed of quartz and very abundant interstitial clay; CONTAINS: abundant carbonized and pyritized plant debris; resin blebs; sand filled burrows parallel to bedding; siderite nodules; rooted throughout, rooting intensity decreases downward; sharp contact with:

0.59 m
(56.96 m)

29. Coal: Black; sharp contact with:

0.25 m
(57.21 m)

30. Sandstone: Fine-grained, poorly sorted; dark gray; composed of quartz and interstitial clay; CONTAINS: abundant finely comminuted carbonaceous debris and carbonaceous laminations, carbonaceous debris becomes primarily pyritized and less abundant downward; shale laminations become prevalent in the basal part of the unit; sand filled burrows parallel to bedding planes; resin blebs; pyritized roots, unit rooted to a depth of 1.04 m, rooting intensity decreases downward; contact unknown:

1.36 m
(58.57 m)

31. Sandstone: Medium-grained, fines downward to a fine-grained sandstone; well-sorted; light gray; composed of quartz and little interstitial clay; weakly cemented, friable; core badly fragmented by drilling; CONTAINS: scattered heavy minerals; no obvious internal bedding structures, unit homogeneous; contact unknown:

0.42 m
(58.99 m)

32. Core loss: In sandstone:

2.45 m
(61.44 m)

33. Sandstone: Very fine- to fine-grained, fines downward and becomes increasingly clay rich downward, poorly sorted; dark gray; composed of quartz and abundant interstitial clay; CONTAINS: coalified and pyritized plant fragments on bedding surfaces; burrows; siderite bands; rare resin blebs; grades into:

1.33 m
(62.77 m)

34. Bone coal: Black; CONTAINS: very fine-grained quartz sand laminations and lenses up to 9 mm thick, sand lenses intertongue erosively with the coal bed; shale laminations; abundant resin; grades into:

0.25 m
(63.02 m)

35. Coal: Black; CONTAINS: resin; sharp contact with:

0.50 m
(63.52 m)

36. Mudstone: Light gray; fines downward from a primarily silty matrix to a primarily clayey matrix; homogeneous; massive; slickensided; rooted throughout; CONTAINS: carbonized root remains; matrix supported fine-grained quartz grains; sharp contact with:

2.14 m
(65.66 m)

37. Siltstone: Medium gray; rooted throughout; CONTAINS: abundant coalified and pyritized wood fragments, coalified trunks,

1.09 m (66.75 m) and intact plant fossil impressions; lower half contains very fine-grained to silty quartz sand laminations and ripple lenses; sandstone laminations contain finely comminuted carbonaceous debris on bedding surfaces; rare resin blebs; grades into:

38. Sandstone: Very fine-grained with scattered medium grains, fine-grained in places, unit fines downward and becomes increasingly clay rich downward, poorly sorted; medium gray; composed of quartz and interstitial clay; CONTAINS: scattered very fine-grained dark minerals; burrows; siderite nodules, the percentage of siderite increases downward; shale bands and laminations less than 1 mm thick; grades into:

0.50 m (67.25 m)

39. Claystone: Medium gray; CONTAINS: very fine-grained quartz sand laminations; finely comminuted carbonaceous debris on bedding plane surfaces; burrows; pyrite; siderite nodules; sharp contact with:

0.15 m (67.40 m)

40. Claystone: Medium gray, lightens downward to light gray; massive; homogeneous; intensely rooted; slickensided; soapy; hackly; CONTAINS: carbonized roots and abundant carbonaceous debris in the top 20 cm; below 20 cm unit light gray underclay containing sparse carbonized root compressions; grades into:

0.75 m (68.15 m)

41. Claystone: Medium gray; intensely rooted; slickensided underclay; CONTAINS: abundant coalified wood fragments; sharp contact with:

0.17 m (68.32 m)

42. Carbonaceous shale: Dark gray; intensely rooted; slickensided; CONTAINS: abundant coalified plant and wood fragments; pyritized carbonaceous debris; sharp contact with:

0.23 m (68.55 m)

43. Claystone: Medium gray; becomes sandy near the base; massive; homogeneous; moderately rooted; CONTAINS: coalified wood fragments, scattered carbonaceous debris, and intact plant fossils; sharp contact with:

0.44 m (68.99 m)

44. Bone coal: Black; grades into:

0.04 m (69.03 m)

45. Mudstone: Light gray; coarsens downward, becomming increasingly sandy and containing sandstone zones in places; homogeneous; massive; intensely rooted throughout; slickensided in places; CONTAINS: carbonized and pyritized roots; grades into:

2.77 m (71.80 m)

46. Claystone: Light gray; intensely rooted throughout; CONTAINS: carbonized root and plant fragments; partially intact plant
0.45 m fossils; grades into:
(72.25 m)

47. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and abundant interstitial clay; rooted; CONTAINS: shale
0.87 m bands and laminations up to 4 mm thick; abundant finely
(73.12 m) comminuted carbonaceous debris distributed throughout the unit; grades into:

48. Sandstone: Fine-grained, well-sorted; light gray; composed of quartz with little interstitial clay; clay confined to shale bands
0.62 m and laminations; CONTAINS: ripples and flat laminations;
(73.74 m) rare carbonaceous laminations; grades into:

49. Sandstone: Fine- to medium-grained, coarsens downward to medium-grained, slightly argillaceous at the top; well-sorted;
0.92 m light gray; clean, composed of quartz and little
(74.66 m) interstitial clay; poorly cemented, friable; core badly fragmented by drilling; CONTAINS: low-angle cross-beds; rare coalified wood fragments define cross-bed surfaces in places; contact unknown:

50. Core loss: In sandstone:

1.63 m
(76.29 m)

51. Sandstone: Medium-grained, well-sorted; light gray; composed of quartz and no interstitial clay; poorly cemented, friable, core
0.64 m badly broken by drilling; CONTAINS: no indication of
(76.93 m) internal bedding structures; contact unknown:

52. Core loss: In sandstone:

2.56 m
(79.49 m)

53. Sandstone: Medium-grained, well-sorted; light gray; composed of quartz and no interstitial clay; poorly cemented, friable, core
1.22 m badly broken by drilling; CONTAINS: no indication of
(80.71 m) internal bedding structures; contact unknown:

54. Core loss: In sandstone:

1.98 m
(82.69 m)

55. Sandstone: Medium-grained, well-sorted; light gray; composed of quartz and no interstitial clay; poorly cemented, friable, core
0.87 m badly broken by drilling; CONTAINS: thin, well-indurated
(83.56 m) calcite cemented nodules; no indication of internal bedding

structures; contact unknown:

56. Core loss: In sandstone:

2.13 m
(85.69 m)

57. Coal: Black; resinous; grades into:

2.20 m
(87.89 m)

58. Carbonaceous shale: Black; CONTAINS: abundant pyritized and carbonized plant debris; core is disintegrated as a result of the chemical decomposition of the pyrite; grades into:

0.15 m
(88.04 m)

59. Mudstone: Light gray; massive; homogeneous; intensely rooted; CONTAINS: matrix supported fine-grained quartz grains; rare coalified plant fragments; pyritized root remains; sharp contact with:

0.68 m
(88.72 m)

60. Sandstone: Fine-grained, very fine-grained in places, coarsens downward to fine- to medium-grained, poorly sorted; light gray; composed of quartz and interstitial clay; CONTAINS: sparse roots; ripples; flat laminations; sharp contact with:

0.35 m
(89.07 m)

61. Sandstone: Medium-grained, argillaceous at the top becomes clean and well-sorted downward; light gray; composed of quartz and little interstitial clay; poorly cemented, friable; CONTAINS: flat clay laminations less than 1 mm thick at the top of the unit; contact unknown:

0.20 m
(89.27 m)

62. Core loss: In sandstone:

2.32 m
(91.59 m)

63. Sandstone: Medium-grained; well-sorted; light gray; composed of quartz, rare, very fine-grained dark minerals, and no interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds defined by very rare accumulations of coalified wood fragments, bedding structures are difficult to determine because the unit is so clean; contact unknown:

0.96 m
(92.55 m)

64. Core loss: In sandstone:

2.04 m
(94.59 m)

65. Sandstone: Medium-grained, well-sorted; light gray; composed of quartz, rare very fine-grained dark minerals, very rare

3.10 m (97.69 m) glauconite pellets, a small amount of silt in the matrix, and no interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds defined by very rare accumulations of coalified wood fragments, bedding structures are difficult to determine because the unit is so clean; contact unknown:

66. Sandstone: Medium-grained, zones of fine-grained and very fine- to medium-grained sand in places, well-sorted; light gray to white; composed of quartz, rare very fine-grained dark minerals, very rare glauconite pellets, a small amount of silt in the matrix, and no interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds defined by very rare accumulations of coalified wood fragments, bedding structures are difficult to determine because the unit is so clean; contact unknown:

4.17 m (101.86 m)

67. Core loss: In sandstone:

1.73 m (103.59 m)

68. Sandstone: Medium-grained, well-sorted; light gray; composed of quartz, rare very fine-grained dark minerals, very rare glauconite pellets, a small amount of silt in the matrix, and no interstitial clay; poorly cemented, friable; CONTAINS: abundant carbonaceous debris; sharp contact with possibly as a result of core loss:

0.04 m (103.63 m)

69. Siltstone: Dark gray top 5 cm, light gray below; intensely rooted; slickensided; CONTAINS: carbonized and pyritized plant fragments in the dark gray part; pyritized roots in the light gray part; sharp contact with:

0.21 m (103.84 m)

70. Bone coal: Black; grades into:

0.09 m (103.93 m)

71. Coal: Black; sharp contact with:

0.09 m (104.02 m)

72. Claystone: Medium gray; intensely rooted; slickensided; underclay; CONTAINS: coalified roots and plant debris; sharp contact with:

0.11 m (104.13 m)

73. Coal: Black; CONTAINS: slickensided clay lenses in the top 6 cm, clay slicks follow root penetrations from the overlying unit; sharp contact with:

0.17 m (104.30 m)

74. Mudstone: Light gray; massive; homogeneous; intensely rooted; CONTAINS: carbonized root remains; grades into:

0.24 m
(104.54 m)

75. Sandstone: Very fine- to fine-grained, well-sorted; light gray; composed of quartz, rare silt-sized heavy mineral grains, and little interstitial clay; poorly cemented, friable, badly fragmented by drilling; contact unknown:

0.12 m
(104.66 m)

76. Core loss: Probably in sandstone:

1.63 m
(106.29 m)

77. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and some interstitial clay; sparsely rooted throughout; CONTAINS: clean sand laminations up to 0.5 mm thick interbedded with very argillaceous sand laminations up to 5 mm thick; sparse finely comminuted carbonaceous debris on bedding plane surfaces; sharp contact with:

0.65 m
(106.94 m)

78. Sandstone: Very fine-grained, well-sorted; light gray to white; clean, composed of quartz, rare fine-grained dark minerals, and no interstitial clay; poorly cemented, friable; CONTAINS: ripple cross-bedding throughout the unit although the sediment is so clean that internal bedding structures are difficult to identify; flat clay laminations near the base of the unit; contact unknown:

1.54 m
(108.48 m)

79. Core loss: Probably in sandstone:

0.66 m
(109.14 m)

80. Sandstone: Fine-grained, coarsens downward to fine- to medium-grained at the base, well-sorted; light gray to white; clean, composed of quartz, local concentrations of calcareous cement, and no interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds; some cross-beds defined by the accumulation of sparse coalified wood fragments; internal bedding structures difficult to identify because the unit is so clean; contact unknown:

2.90 m
(112.04 m)

81. Core loss: Probably in sandstone:

0.60 m
(112.64 m)

82. Sandstone: Fine-grained, well-sorted; light gray to white; clean, composed of quartz and no interstitial clay; poorly cemented, friable; CONTAINS: internal bedding structures

0.64 m

(113.28 m) difficult to identify because the unit is so clean; contact unknown:

83. Core loss: Probably in sandstone:

0.81 m
(114.09 m)

84. Sandstone: Fine-grained, well-sorted; white; orthoquartzitic, composed of quartz, calcareous cement, and no interstitial clay; 0.30 m dense; very well cemented; CONTAINS: high angle planar (114.39 m) cross-beds; very sparse carbonaceous debris on cross bed surfaces; sharp contact with:

85. Sandstone: Fine-grained, well-sorted; light gray; non-calcareous; clean, composed of quartz and no interstitial clay; poorly 0.34 m cemented, friable; CONTAINS: abundant siderite nodules (114.73 m) throughout; contact unknown:

86. Core loss: In sandstone:

1.65 m
(116.38 m)

87. Sandstone: Medium-grained, well-sorted; light gray; clean, composed of quartz and no interstitial clay; poorly cemented, friable; 0.08 m unit badly fragmented by drilling; contact unknown: (116.46 m)

88. Core loss: In sandstone:

2.13 m
(118.59 m)

89. Sandstone: Fine-grained, coarsens downward to fine- to medium-grained, argillaceous fraction increases slightly downward, well-0.90 m sorted; light gray; clean, composed of quartz, fine-grained (119.49 m) dark minerals, and little interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds; sharp contact with:

90. Siltstone: Medium gray; CONTAINS: flat sand laminations up to 1 mm thick; laminations disturbed by burrowing in the top 50 cm, 1.98 m below 50 cm burrows are confined to bedding plane surfaces (121.47 m) and become less abundant downward, burrows filled with fine-grained quartz sand; scattered finely comminuted carbonaceous debris on bedding plane surfaces, carbonaceous debris pyritized in places and becomes more abundant downward; rare resin blebs; quartz sand becomes increasingly abundant in the basal 50 cm and the unit becomes a sandstone at the base; sharp contact with:

91. Carbonaceous shale: Black; allochthonous; CONTAINS: fine-grained

quartz sand laminations between coalified wood and plant
0.03 m fragments; sharp contact with:
(121.50 m)

92. Siltstone: Medium gray; CONTAINS: abundant very fine-grained quartz sand laminations less than 1 mm thick, laminations become
1.20 m less abundant downward; sparse carbonaceous debris on
(122.70 m) bedding plane surfaces; carbonaceous debris becomes more abundant downward; sand filled burrows on bedding plane surfaces; sharp contact with:

93. Coal: Black; sharp contact with:

0.05 m
(122.75 m)

94. Claystone: Top 5 cm medium gray, then becomes light gray below; massive; homogeneous; intensely rooted; soapy; hackly;
0.26 m CONTAINS: carbonized root remains; grades into:
(123.01 m)

95. Sandstone: Very fine- to fine-grained, coarsens downward from mudstone at the top to fine grained sandstone at the base, poorly
0.85 m sorted; light gray; composed of quartz and extremely
(123.86 m) abundant interstitial clay; massive; homogeneous; intensely rooted throughout; sharp contact with:

96. Mudstone: Light gray; fines downward; homogeneous; massive; rooted throughout; CONTAINS: carbonized and pyritized root
0.48 m traces, many of the pyritized root traces are hollow;
(124.34 m) matrix supported very fine- to fine-grained quartz sand; grades into:

97. Claystone: Light gray; massive; homogeneous; sparsely rooted; CONTAINS: pyritized root traces some of which are hollow;
0.40 m grades into:
(124.74 m)

98. Claystone: Light gray; massive; homogeneous; intensely rooted; slickensided; underclay; grades into:
0.08 m
(124.82 m)

99. Bone coal: Black; rooted; CONTAINS: pyritized carbonaceous debris; resin; grades into:
0.09 m
(124.91 m)

100. Coal: Black; sharp contact with:

0.40 m
(125.31 m)

101. Claystone: Dark gray in the top 4 cm then light gray below; massive; homogeneous; intensely rooted; slickensided; CONTAINS: carbonized root remains: grades into:
0.09 m
(125.40 m)

102. Mudstone: Light gray; massive; homogeneous; intensely rooted, but rooting intensity decreases downward; slickensided in places; CONTAINS: fine-grained, matrix supported quartz sand grains; carbonized root remains; grades into:
1.66 m
(127.06 m)

103. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; massive; homogeneous; rooted; CONTAINS: hollow, pyritized root traces; grades into:
0.59 m
(127.65 m)

104. Claystone: Light gray; massive; homogeneous; rooted; CONTAINS: sparse, hollow, pyritized root traces; sharp contact with:
0.40 m
(128.05 m)

105. Claystone: Light gray darkens to dark gray at the base; massive; homogeneous; intensely rooted; slickensided; CONTAINS: carbonized root traces; grades into:
0.30 m
(128.35 m)

106. Bone coal: Black; sharp contact with:

0.19 m
(128.54 m)

107. Claystone: Medium gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: abundant carbonized and pyritized plant fragments and roots; sharp contact with:
0.22 m
(128.76 m)

108. Coal: Black; sharp contact with:

0.09 m
(128.85 m)

109. Siltstone: Medium gray; massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; grades into:
0.48 m
(129.33 m)

110. Mudstone: Light gray; massive; homogeneous; rooted; CONTAINS: fine-grained matrix supported quartz grains, quartz content increases downward; pyritized root traces; pyrite crystals; grades into:
1.35 m
(130.68 m)

111. Claystone: Light gray; massive; homogeneous; intensely rooted; CONTAINS: hollow pyritized root traces; sharp contact with:
0.68 m

(131.36 m)

112. Claystone: Light gray darkens to medium gray at base; massive; homogeneous; intensely rooted; slickensided; sharp contact with:
0.39 m
(131.75 m)

113. Core loss: Cumulative core loss accumulated within the preceding 15 m of section:
0.60 m
(132.35 m)

114. Coal: Black; CONTAINS: abundant small clay lenses indicating root penetrations from the overlying unit; clay lenses especially common in the basal part of the unit; sharp contact with:
0.28 m
(132.63 m)

115. Claystone: Light gray; silty, coarsens downward to sandy siltstone at the base; massive; homogeneous; sparsely rooted; CONTAINS: sparse coalified root traces; sharp contact with:
0.81 m
(133.44 m)

116. Claystone: Medium gray; massive; homogeneous; intensely rooted; CONTAINS: abundant carbonized root traces and plant fragments; grades into:
0.10 m
(133.54 m)

117. Bone coal: Black; CONTAINS: slickensided clay lenses indicating root penetrations from the overlying unit; grades into:
0.04 m
(133.58 m)

118. Coal: Black; CONTAINS: slickensided clay lenses indicating root penetrations from the overlying unit; grades into:
0.07 m
(133.65 m)

119. Carbonaceous shale: Dark gray; rooted; CONTAINS: abundant coalified plant debris; sharp contact with:
0.09 m
(133.74 m)

120. Claystone: Light gray; massive; homogeneous; intensely rooted; slickensided; hackly; CONTAINS: carbonized root traces; grades into:
0.15 m
(133.89 m)

121. Claystone: Light gray, fines downward and becomes darker gray at the base; massive; homogeneous; rooted; CONTAINS: pyritized and carbonized root traces; sharp contact with:
1.73 m
(135.62 m)

122. Carbonaceous shale: Dark gray to black; rooted; slickensided;

CONTAINS: abundant carbonized and pyritized plant
0.13 m fragments; sharp contact with:
(135.75 m)

123. Claystone: Medium gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: sparse carbonized root traces and
0.12 m plant fragments; sharp contact with:
(135.87 m)

124. Coal: Black; CONTAINS: slickensided clay lenses indicating root penetrations from the overlying unit; sharp contact with:
0.05 m
(135.92 m)

125. Claystone: Medium gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: sparse carbonized root traces and
0.10 m plant fragments; sharp contact with:
(136.02 m)

126. Coal: Black; grades into:

0.07 m
(136.09 m)

127. Bone coal: Black; grades into:

0.14 m
(136.23 m)

128. Carbonaceous mudstone: Black; presumed rooted however roots are not obvious; CONTAINS: fine-grained matrix supported quartz
0.26 m sand grains; abundant pyritized and carbonized plant
(136.49 m) debris; intact plant fossils; grades into:

129. Siltstone: Dark gray; coarsens downward into an extremely argillaceous, fine-grained quartz sandstone at the base;
0.45 m massive; homogeneous; not obviously rooted; CONTAINS:
(136.94 m) sparse finely comminuted carbonaceous debris on bedding plane surfaces; sharp contact with:

130. Bone coal: Black; grades into:

0.10 m
(137.04 m)

131. Coal: Black; resinous; grades into:

0.75 m
(137.79 m)

132. Bone coal: Black; sharp contact with:

0.03 m

(137.82 m)

133. Carbonaceous shale: Black; massive; homogeneous; intensely rooted; slickensided; CONTAINS: carbonized and pyritized wood
0.15 m fragments; grades into:
(137.97 m)

134. Claystone: Medium gray, becomes lighter gray downward; massive; homogeneous; intensely rooted; slickensided; CONTAINS:
0.14 m some carbonized and pyritized plant debris and root traces;
(138.11 m) grades into:

135. Bone coal: Black; CONTAINS: pyritized carbonaceous debris and slickensided clay lenses that indicate root penetration
0.06 m from the overlying unit; grades into:
(138.17 m)

136. Coal: Black; grades into:

0.11 m
(138.28 m)

137. Bone coal: Black; grades into:

0.08 m
(138.36 m)

138. Carbonaceous shale: Medium gray; fissile; rooted; slickensided; CONTAINS: carbonized root traces and plant fragments and
0.05 m coalified wood fragments; grades into:
(138.41 m)

139. Claystone: Light gray; massive; homogeneous; intensely rooted; underclay; CONTAINS: carbonized and pyritized root traces;
0.27 m grades into:
(138.68 m)

140. Claystone: Light gray; siltstone in places, extremely dirty very fine-grained sandstone in places; massive; homogeneous;
2.30 m intensely rooted; medium gray with sparse slickensides in
(140.98 m) the basal 15 cm; CONTAINS: carbonized and pyritized root traces throughout; sharp contact with:

141. Coal: Black; sharp contact with:

1.00 m
(141.98 m)

142. Core loss: Location unknown:

0.41 m
(142.39 m)

143. Siltstone: Light gray; massive; homogeneous; intensely rooted throughout; hackly; CONTAINS: carbonized and pyritized root traces; grades into:
0.82 m
(143.21 m)

144. Claystone: Light gray, becomming medium gray in the basal 10 cm; massive; homogeneous; intensely rooted throughout; slickensided; CONTAINS: carbonized and pyritized root traces; sharp contact with:
0.55 m
(143.76 m)

145. Coal: Black; CONTAINS: slickensided clay lenses in the top 10 cm of the unit, clay lenses indicate root penetrations from the overlying claystone; sharp contact with:
0.65 m
(144.41 m)

146. Siltstone: Light gray; massive; homogeneous; intensely rooted; CONTAINS: carbonized and pyritized root traces; grades into:
1.31 m
(145.72 m)

147. Sandstone: Very fine-grained, poorly sorted; light gray to white; composed of quartz and very abundant interstitial clay; massive; homogeneous; intensely rooted; CONTAINS: carbonized and pyritized root traces; grades into:
0.82 m
(146.54 m)

148. Claystone: Light gray becomming medium gray in the basal 10 cm; massive; homogeneous; rooted; sharp contact with
0.38 m
(146.92 m)

149. Coal: Black; sharp contact with:

0.23 m
(147.15 m)

150. Claystone: Dark gray in the top 5 cm, light gray below; massive; homogeneous; intensely rooted; CONTAINS: carbonized root traces; abundant carbonaceous debris in the top 5 cm; grades into:
0.54 m
(147.69 m)

151. Mudstone: Light gray; massive; homogeneous; rooted throughout; coarsens downward; CONTAINS: fine-grained matrix supported quartz sand grains; pyritized and carbonized root traces; grades into:
1.32 m
(149.01 m)

152. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; massive; homogeneous; rooted throughout, rooting intensity decreases downward; CONTAINS: carbonized and pyritized root traces; grades into:
1.23 m
(150.24 m)

153. Sandstone: Fine-grained, moderately sorted; light gray; composed of quartz and some interstitial clay; CONTAINS: sparse roots

1.13 m (151.37 m) in the top 75 cm; sparse burrows; abundant, finely comminuted carbonaceous debris in the upper part of the unit, carbonaceous debris becomes less abundant downward; ripples and megaripples in places; flat laminations become more abundant toward the base but individual lamina become less distinct downward; grades into:

154. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and abundant interstitial clay; CONTAINS: laminar and wavy bedding as the predominant bed forms; poorly defined low-angle cross-beds in places; zones of small-scale ripples and zones of megaripples in places, the zones containing the megaripples consist of clean friable sandstone; finely comminuted carbonaceous debris defines ripple surfaces; rare internal scour surfaces at the base of ripples; zones of abundant clay and siltstone bands and laminations, siltstone becomes increasingly abundant in the basal meter; zones with finely comminuted, homogeneously distributed carbonaceous debris in places; sharp contact with:

3.35 m (154.72 m)

155. Sandstone: Fine-grained, coarsens downward to fine- to medium-grained in the middle and basal part of the unit, well-sorted; light gray; clean, composed of quartz, scattered, very fine-grained heavy minerals, rare corroded (and therefore presumed to be transported) glauconite grains, and no interstitial clay; poorly cemented, friable; CONTAINS: small scale ripples; internal bedding structures are difficult to discern because the unit is so clean; contact unknown:

1.69 m (156.41 m)

156. Core loss: Location appears to be in unit 155; contact unknown:

0.93 m (157.34 m)

157. Sandstone: Fine- to medium grained, well-sorted; light gray; clean, composed of quartz, scattered, very fine-grained heavy minerals, rare corroded (and therefore presumed to be transported) glauconite grains, and no interstitial clay; poorly cemented, friable; core badly fragmented during drilling; character of the internal bedding structures is unknown because the core is so badly fragmented; contact unknown:

0.30 m (157.64 m)

158. Core loss: Location appears to be in unit 157; contact unknown:

2.75 m (160.39 m)

159. Coal: Black; CONTAINS: abundant pyrite; coal core badly decomposed as a result of pyrite recrystallization; contact unknown:

0.35 m (160.74 m)

160. Sandstone: Fine-grained to granular but predominantly very coarse-grained, poorly sorted; light gray; composed of quartz and
0.22 m no interstitial clay; poorly cemented, friable; core badly
(160.96 m) fragmented during drilling; character of the internal bedding structures is unknown because the core is so badly fragmented; contact unknown:

161. Core loss: Location not certain but presumed to be in unit 160; contact unknown:
2.43 m
(163.39 m)

162. Sandstone: Fine-grained to granular but predominantly very coarse-grained, poorly sorted; light gray; composed of quartz and
0.10 m no interstitial clay; poorly cemented, friable; core badly
(163.49 m) fragmented during drilling; character of the internal bedding structures is unknown because the core is so badly fragmented; contact unknown:

163. Core loss: Location not certain but presumed to be in unit 160; contact unknown
1.50 m
(164.99 m)

164. Coal: Black; sharp contact with:

0.04 m
(165.03 m)

165. Carbonaceous shale: Black; CONTAINS: abundant carbonized and pyritized plant fragments; grades into:
0.08 m
(165.11 m)

166. Coal: Black; CONTAINS: abundant pyrite, coal core badly fragmented as a result of pyrite recrystallization; grades
0.18 m into:
(165.29 m)

167. Interbedded claystone and coal: Black; CONTAINS: coaly laminations, clayey laminations and, in places, medium-grained quartz
0.06 m sand laminations; grades into:
(165.35 m)

168. Coal: Black; CONTAINS: abundant pyrite, coal core badly fragmented as a result of pyrite recrystallization; sharp
0.06 m contact with:
(165.41 m)

169. Coal: Black; sharp contact with:

0.16 m

(165.57 m)

170. Siltstone: Medium gray; sparsely rooted; CONTAINS: carbonaceous debris on bedding plane surfaces; sand filled horizontal burrows on some bedding plane surfaces; pyritized roots, unit rooted to a depth of at least 88 cm; flat laminations composed of a) very fine-grained or medium-grained quartz sand, sand laminations are up to 2 mm thick and become more abundant downward, b) silt laminations up to 5 mm thick, and c) carbonaceous laminations up to 0.5 mm thick; some of the finest grained laminations are sideritized; grades into:

1.20 m
(166.77 m)

171. Sandstone: Very fine-grained, well-sorted; light gray; composed of quartz and little interstitial clay within the individual sandstone beds; CONTAINS: dark gray shale bands and laminations up to 1.5 cm thick, clay bands have flat laminar internal bedding; horizontal sand-filled burrows on bedding plane surfaces; carbonaceous laminations; siderite nodules; small scale ripples in the sandstone interbeds between the shale laminations; grades into:

0.65 m
(167.42 m)

172. Siltstone: Medium gray; CONTAINS: three allochthonous coal beds; the first bed is 5 cm thick and occurs 2 cm below the top of the unit, this coal bed consists of carbonaceous bands interlaminated with clean, fine-grained quartz sandstone; the second coal bed is 2 cm thick and occurs 1.82 m below the top of the unit, and the third coal bed is 2 cm thick and occurs 2.42 m below the top of the unit; the siltstone also contains siderite bands and nodules; flat laminations; abundant carbonaceous laminations sometimes more than 1 mm thick; abundant very fine-grained quartz sand laminations up to 1 mm thick but usually much thinner, large mica flakes are often associated with the sandstone laminations; sparse burrows; sharp contact with:

2.47 m
(169.89 m)

173. Bone coal: Black; CONTAINS: abundant pyrite, coal core badly fragmented as a result of the chemical decomposition of the pyrite; abundant fine-grained quartz sandstone laminations; sharp contact with:

0.22 m
(170.11 m)

174. Coal: Black; sharp contact with:

0.14 m
(170.25 m)

175. Carbonaceous sandstone: Very fine- to medium-grained, poorly sorted; black; composed of quartz and abundant interstitial clay; CONTAINS: interlaminated sand and shaly carbonaceous debris; no evidence of rooting; sharp contact with:

0.14 m
(170.39 m)

176. Sandstone: Medium-grained, coarse-grained in places, well-sorted; light gray; clean, composed of quartz and little

0.19 m (170.58 m) interstitial clay; poorly cemented, friable; CONTAINS: abundant carbonaceous debris, no evidence of rooting; sharp contact with:

177. Coal: Black; sharp contact with unit 179:

0.07 m (170.65 m)

178. Core loss: Location not certain, but loss most likely occurred above unit 177:

1.90 m (172.55 m)

179. Sandstone: Fine-grained, silty at the top, poorly sorted; light gray; composed of quartz and very abundant interstitial clay; 0.79 m (173.34 m) becomes less argillaceous downward; massive; homogeneous; rooted; CONTAINS: pyritized root traces; grades into:

180. Mudstone: Light gray; massive; homogeneous; hackly; intensely rooted; CONTAINS: matrix-supported fine-grained quartz grains; 0.82 m (174.16 m) fine-grained, rounded, black to dark brown matrix-supported ferruginous grains (concretions?); grades into:

181. Claystone: Light gray, becomes dark gray in the basal 10 cm; massive homogeneous; intensely rooted; intensely slickensided; 0.28 m (174.44 m) CONTAINS: carbonized plant fossils in places; sharp contact with:

182. Coal: Black; grades into:

0.13 m (174.57 m)

183. Bone coal: Black; sharp contact with:

0.05 m (174.62 m)

184. Claystone: Dark gray in the top 2 cm then light gray below; massive; homogeneous; intensely rooted; slickensided; CONTAINS: 0.51 m (175.13 m) pyritized root traces; grades into:

185. Siltstone: light gray; massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; grades into:

0.41 m (175.54 m)

186. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; light gray; 1.27 m (176.81 m) massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; grades into:

187. Siltstone: light gray; massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown matrix-supported ferruginous grains (concretions?); grades into:

0.30 m
(177.11 m)

188. Claystone: light gray, medium gray basal 4 cm; massive; homogeneous; hackly; soapy texture; slickensided near the base; CONTAINS: no obvious root traces but the texture is strongly indicative of rooting; sharp contact with:

0.54 m
(177.65 m)

189. Coal: Black; grades into:

0.05 m
(177.70 m)

190. Carbonaceous shale: Black; fissile; rooted; CONTAINS: abundant coalified wood and plant fragments on bedding plane surfaces; sharp contact with:

0.19 m
(177.89 m)

191. Siltstone: Medium gray; coarsens downward becomming increasingly sandy; rooted; CONTAINS: coalified and pyritized plant fragments and whole plant fossils on bedding plane surfaces; grades into:

0.48 m
(178.37 m)

192. Sandstone: Very fine-grained, coarsens downward, poorly sorted; medium gray; composed of quartz and extremely abundant interstitial clay; rooted; CONTAINS: roots to a depth of 1 m below the top of the unit; burrows; relict flat laminations, laminar bedding preserved at the base of the unit; sparse carbonaceous debris on bedding plane surfaces, carbonaceous debris becomes less abundant downward; siderite nodules; grades into:

2.03 m
(180.40 m)

193. Interlaminated sandstone and siltstone: Sandstone is fine-grained, poorly sorted; light gray; composed of quartz, rare concentrations of heavy minerals, and abundant interstitial clay; CONTAINS: flat clay bands and laminations up to 2 cm thick but usually thinner; heavy mineral laminations in places; zones of very fine-grained, very clean sand that contains no heavy mineral grains; Siltstone is medium gray; becomes more abundant toward the bottom; CONTAINS: sand filled burrows on bedding plane surfaces; sharp contact with:

2.15 m
(182.55 m)

194. Sandstone: Very fine- to fine-grained, coarsens downward to medium-grained at the base, poorly sorted; medium gray; composed of quartz and abundant interstitial clay; CONTAINS: abundant coalified debris homogeneously distributed throughout the unit; carbonaceous laminations less than 1 mm thick; shale bands and laminations up to 4 mm thick; grades into:

1.02 m
(183.57 m)

195. Sandstone: Medium-grained, well-sorted; light gray; clean, composed of quartz and no interstitial clay; poorly cemented, friable;
0.23 m CONTAINS: no evidence of internal bedding because the unit
(183.80 m) is so clean; sharp contact with:

196. Core loss: Location believed to be in unit 195:

1.20 m
(185.00 m)

197. Claystone: Light gray to white; massive; homogeneous; CONTAINS: no obvious roots however the texture is indicative of rooting;
0.34 m fine-grained, rounded, black to dark brown, matrix-
(185.34 m) supported ferruginous grains (concretions?); sharp contact with:

198. Claystone: Light gray; massive; homogeneous; rooted throughout; hackly; slickensided; sharp contact with:
0.76 m
(186.10 m)

199. Interbedded sandstone and claystone: Sandstone is fine-grained, poorly sorted; light gray; composed of quartz and abundant
0.08 m interstitial clay; CONTAINS: flat laminations; Claystone
(186.18 m) is medium gray; CONTAINS: carbonaceous debris associated with claystone bedding plane surfaces; sharp contact with:

200. Claystone: Medium gray; massive; homogeneous; slickensided; rooted; sharp contact with:
0.04 m
(186.22 m)

201. Coal: Black; CONTAINS: abundant pyrite, 33 cm from the top of the unit there is a 1 cm thick zone in which the coal is
0.52 m badly disintegrated by pyrite oxidation; sharp contact
(186.74 m) with:

202. Claystone: Medium gray; rooted; CONTAINS: abundant carbonized wood fragments; rare slickensides; grades into:
0.14 m
(186.88 m)

203. Claystone: Light gray; massive; homogeneous; rooted; slickensided; CONTAINS: carbonized and pyritized root traces; grades
0.22 m into:
(187.10 m)

204. Claystone: Light gray, becomming medium gray in the basal 4 cm; massive; homogeneous; hackly; intensely slickensided;
0.21 m rooted; sharp contact with:
(187.31 m)

205. Bone coal: Black; CONTAINS: abundant slickensided clay lenses along root penetrations from the overlying unit; grades into:
0.04 m
(187.35 m)

206. Coal: Black; CONTAINS: abundant slickensided clay lenses in the top 10 cm that follow root penetrations from the overlying unit; a zone 4 cm thick 12 cm below the top of the unit that has been badly disintegrated because of pyrite oxidation; sharp contact with:
0.38 m
(187.73 m)

207. Claystone: Medium gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: abundant finely comminuted carbonaceous debris on bedding plane surfaces; sharp contact with:
0.17 m
(187.90 m)

208. Carbonaceous shale: Dark gray; rooted; slickensided; sharp contact with:
0.04 m
(187.94 m)

209. Coal: Black; sharp contact with:

0.10 m
(188.04 m)

210. Claystone: Medium gray; rooted; CONTAINS: rare slickensides; carbonized and pyritized plant debris; grades into;
0.25 m
(188.29 m)

211. Carbonaceous shale: Black; rooted; CONTAINS: abundant pyritized and carbonized plant debris, becomes increasingly carbonaceous downward and grades into a bone coal at the base; sharp contact with:
0.39 m
(188.68 m)

212. Claystone: Medium gray; intensely rooted; hackly; slickensided; CONTAINS: abundant carbonaceous debris; grades into:
0.11 m
(188.79 m)

213. Carbonaceous shale: Black; CONTAINS: medium gray slickensided clay lenses that follow root penetrations from the overlying unit; slickensides; some pyritized plant debris and abundant coalified carbonaceous debris; sharp contact with:
0.07 m
(188.86 m)

214. Coal: Black; sharp contact with:

0.58 m
(189.44 m)

215. Siltstone: Medium gray in the top 10 cm, light gray throughout the rest of the unit; massive; homogeneous; intensely rooted;

1.12 m (190.56 m) CONTAINS: a thin zone of soapy, slickensided claystone; pyritized root traces; fine-grained, rounded, black to dark brown matrix-supported ferruginous grains, these grains become more abundant downward; grades into:

216. Mudstone: Light gray; fines downward from very argillaceous very fine-grained sandstone at the top to mudstone; massive; 0.66 m (191.22 m) homogeneous; intensely rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains; grades into:

217. Siltstone: Light gray; massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; fine-grained, rounded, 0.50 m (191.72 m) black to dark brown, matrix-supported ferruginous grains; grades into:

218. Claystone: Light gray, becomming medium gray at the base; massive; homogeneous; intensely rooted; slickensided; hackly; 0.30 m (192.02 m) CONTAINS: pyritized root traces; sharp contact with:

219. Carbonaceous shale: Black; slickensided; rooted; becomes increasingly carbonaceous downward; CONTAINS: pyritized carbonaceous 0.10 m (192.12 m) debris; grades into:

220. Coal: Black; grades into:

0.05 m (192.17 m)

221. Carbonaceous shale: Black; fissile; slickensided in places; rooted; CONTAINS: abundant carbonized and pyritized plant debris; 0.07 m (192.24 m) grades into:

222. Claystone: Medium gray in the top 5 cm then light gray below; massive; homogeneous; intensely rooted; intensely slickensided; 0.67 m (192.91 m) soapy and hackly in the basal 14 cm; CONTAINS: pyritized roots; sharp contact with:

223. Coal: Black; sharp contact with:

0.22 m (193.13 m)

224. Claystone: Light gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: pyritized roots; contact unknown:

0.42 m (193.55 m)

225. Core loss: Location unknown; the loss most likely occurred in the coal:

0.79 m
(194.34 m)

226. Siltstone: Light gray; massive; homogeneous; intensely rooted; slickensided; CONTAINS: pyritized roots; grades into:
0.48 m
(194.82 m)

227. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; becomes less argillaceous downward; rooted throughout; grades into:
0.79 m
(195.61 m)

228. Sandstone: Very fine-grained, well-sorted; light gray; composed of quartz, sparse heavy minerals, and little interstitial clay; CONTAINS: sparse roots; shale laminations less than 1 mm thick; rare carbonaceous debris on bedding plane surfaces; very rare carbonaceous laminations; small scale ripples in places; sharp contact with:
1.12 m
(196.73 m)

229. Siltstone: Light gray; CONTAINS: sparse pyritized roots; sparse carbonaceous debris on bedding plane surfaces; rare carbonaceous laminations; scattered silty very fine-grained sandstone lenses up to 5 cm thick; sharp contact with:
0.71 m
(197.44 m)

230. Sandstone: Very fine-grained, coarsens downward to fine-grained at the base; well-sorted; white; very clean, composed of quartz, very fine-grained heavy minerals, and no interstitial clay; friable; CONTAINS: burrows; ripples; nodular texture; internal bedding structures become less apparent downward; contact unknown:
1.27 m
(198.71 m)

231. Core loss: In sandstone (probably unit 230); contact unknown:
1.73 m
(200.44 m)

232. Sandstone: Fine-grained, well-sorted; medium gray; clean, composed of quartz, sparse glauconite pellets, and no interstitial clay; unit extremely indurated but non-calcareous; glauconite pellets appear to be transported, they are frequently corroded and broken; contact unknown:
0.13 m
(200.57 m)

233. Core loss: In sandstone, unit not certain; contact unknown:
2.87 m
(203.44 m)

234. Sandstone: Medium-grained, coarse-grained in places; well-sorted; medium gray; clean, composed of quartz and no interstitial clay; indurated but not calcareous; sharp contact with:
0.05 m
(203.49 m)

235. Claystone: Medium gray; rooted; slickensided; CONTAINS: carbonized and pyritized plant debris; sharp contact with:

0.09 m
(203.58 m)

236. Coal: Black; CONTAINS: abundant slickensided clay lenses along root penetrations from the overlying unit; grades into:

0.04 m
(203.62 m)

237. Carbonaceous shale: Black; rooted; CONTAINS: abundant pyritized and carbonized plant debris; grades into:

0.04 m
(203.66 m)

238. Siltstone: Medium gray in the top 5 cm then light gray below; massive; homogeneous; intensely rooted; CONTAINS: pyritized root traces; grades into unit 240:

0.35 m
(204.01 m)

239. Core loss: Believed to be in sandstone (unit 234);

2.43 m
(206.44 m)

240. Sandstone: Very fine-grained, silty, becomes less argillaceous toward the base, poorly sorted; light gray; composed of quartz and very abundant interstitial clay; massive homogeneous; intensely rooted; CONTAINS: pyritized root traces; grades into:

0.85 m
(207.29 m)

241. Siltstone: Light gray; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains; grades into:

0.08 m
(207.37 m)

242. Claystone: Light gray; massive; homogeneous; rooted; CONTAINS: pyritized root traces; sharp contact with:

0.24 m
(207.61 m)

243. Bone coal: Black; sharp contact with:

0.01 m
(207.62 m)

244. Siltstone: Medium gray; massive; homogeneous; rooted; grades into:

0.15 m
(207.77 m)

245. Siltstone: Light gray; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark

0.52 m (208.29 m) brown, matrix-supported ferruginous grains near the base; grades into:

246. Sandstone: Fine-grained, silty, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains; grades into:
0.74 m (209.03 m)

247. Siltstone: Light gray; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains; grades into:
0.38 m (209.41 m)

248. Claystone: Light gray; massive; homogeneous; rooted; hackly; intensely slickensided; CONTAINS: pyritized root traces; grades into:
0.34 m (209.75 m)

249. Siltstone: Medium gray in the top 20 cm then light gray below; massive; homogeneous; rooted, rooting intensity decreases downward; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains near the base; grades into:
1.28 m (211.03 m)

250. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and very abundant interstitial clay; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains; grades into:
0.82 m (211.85 m)

251. Claystone: Light gray; massive; homogeneous; rooted; hackly; intensely slickensided; CONTAINS: pyritized root traces; grades into:
0.49 m (212.34 m)

252. Claystone: Dark gray; rooted; slickensided; CONTAINS: sparse carbonized plant material, unit becomes increasingly carbonaceous downward; grades into:
0.06 m (212.40 m)

253. Carbonaceous shale: Black; rooted; slickensided; CONTAINS: abundant coalified plant debris; grades into:
0.01 m (212.41 m)

254. Coal: Black; sharp contact with:

0.05 m (212.46 m)

255. Siltstone: Medium gray in the top 4 cm then light gray below; massive; homogeneous; intensely rooted; CONTAINS: sparse coalified

0.68 m (213.14 m) plant remains; pyritized root traces; fine-grained, rounded black to dark brown, matrix-supported ferruginous grains (concretions?), some of these grains appear to have hollow cores, the ferruginous grains are most abundant in the zones where roots are pyritized; grades into:

256. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; becomes 1.36 m (214.50 m) less argillaceous downward; massive; homogeneous; intensely rooted; CONTAINS: sparse coalified plant remains; pyritized root traces; contact unknown:

257. Core loss: Location not certain, presumed to be in the sandstone (unit 256); contact unknown:
0.54 m (215.04 m)

258. Claystone: Light gray; massive; homogeneous; sparsely rooted; intensely slickensided in places; fine-grained, rounded, 0.97 m (216.01 m) black to dark brown; matrix-supported ferruginous grains (concretions?), ferruginous grains are very abundant in some zones; sharp contact with:

259. Claystone: Light gray grading downward to medium gray in the basal 5 cm; massive; homogeneous; intensely rooted; slickensided; 0.20 m (216.21 m) CONTAINS: pyritized root traces; grades into:

260. Carbonaceous shale: Black; fissile; CONTAINS: abundant coalified carbonaceous debris; grades into:
0.05 m (216.26 m)

261. Coal: Black; grades into:
0.54 m (216.80 m)

262. Carbonaceous shale: Black; fissile; CONTAINS: abundant carbonaceous debris; grades into:
0.02 m (216.82 m)

263. Claystone: Medium gray grading into light gray downward and back into medium gray at the base; massive; homogeneous; intensely 0.86 m (217.68 m) rooted; slickensided; hackly texture developed toward the base; CONTAINS: root impressions; grades into:

264. Bone coal: Black; CONTAINS: abundant slickensided clay lenses along root penetrations from the overlying unit; sharp contact 0.19 m (217.87 m) with:

265. Claystone: Medium gray in the top 1 cm grading into light gray below; massive; homogeneous; intensely rooted; sharp contact with:
0.29 m
(218.16 m)

266. Carbonaceous shale: Dark gray; fissile; rooted; CONTAINS: abundant carbonized plant remains on bedding surfaces, becomes increasingly carbonaceous downward; sharp contact with:
0.27 m
(218.43 m)

267. Siltstone: Medium gray; fissile; intensely rooted; CONTAINS: abundant carbonaceous debris on bedding plane surfaces; carbonized and pyritized roots; very fine-grained sandstone laminations less than 1 mm thick and common silt laminations, sand and silt laminations become increasingly abundant downward; rare heavy mineral grains; burrows; roots, rooting intensity decreases downward; grades into:
0.90 m
(219.33 m)

268. Sandstone: Very fine-grained coarsening downward to fine-grained, poorly sorted; medium gray; composed of quartz and very abundant interstitial clay; CONTAINS: abundant carbonaceous laminations and small scale ripples in the upper part of the unit, ripple cross-sets are defined by carbonaceous debris on cross-set surfaces; burrows, in many places the unit is homogenized by burrowing; relict clay laminations; sharp contact with:
0.85 m
(220.18 m)

269. Shale: Dark gray; fissile; appears to be slightly rooted; CONTAINS: rare pyritized root remains; small horizontal bedding plane burrows; thin, irregular, discontinuous very fine-grained sandstone laminations; sparse coalified and carbonized plant debris; grades into:
1.14 m
(221.32 m)

270. Interlaminated sandstone and claystone: Sandstone is very fine-grained, fine-grained in places, well-sorted; light gray; composed of quartz, scattered very fine-grained heavy minerals, and little interstitial clay; non-calcareous; flat-bedded sandstone laminations are up to 1 mm thick, thickness increases downward and sandstone beds up to 3 cm thick can be found toward the basal part of the unit; CONTAINS: rare, finely comminuted shell fragments associated with some sandstone laminations; rare heavy mineral laminations; vertically penetrating burrows in the basal part of the unit; Claystone is dark gray; claystone laminations are up to 3 mm thick though usually thinner; CONTAINS: small horizontal bedding plane burrows on clay laminations; siderite bands toward the basal part of the unit; sharp contact with:
2.95 m
(224.27 m)

271. Sandstone: Medium-grained, coarse-grained in places, well-sorted; white; clean, composed of quartz, sparse heavy minerals, calcareous cement, and little interstitial clay; massive; homogeneous; hard, well-cemented; CONTAINS: no evidence of
0.43 m
(224.70 m)

bedding; pyrite grains up to 4 mm in diameter; nodular texture which may be evidence of burrowing; dark gray zones of sandstone that are not well-cemented; grades into:

272. Conglomeratic sandstone: Very fine-grained to granular, poorly sorted; medium gray; composed of quartz, clay pebbles, and abundant
0.09 m pyrite; sharp contact with:
(224.79 m)

273. Carbonaceous shale: Dark gray; CONTAINS: abundant coalified and carbonized plant debris on bedding plane surfaces; burrows
0.03 m filled with sand from the overlying unit; grades into:
(224.82 m)

274. Siltstone: Medium gray, lightens downward; massive; homogeneous; rooted; CONTAINS: abundant carbonized and pyritized plant
0.56 m debris on bedding plane surfaces, below 26 cm all of the
(225.38 m) carbonaceous remains are pyritized; carbonaceous debris becomes less abundant downward; grades into:

275. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and abundant interstitial clay; CONTAINS: sparse
4.29 m rooting to a depth of 1.6 m; laminar bedding; abundant
(229.67 m) carbonaceous debris on bedding plane surfaces; carbonaceous laminations; burrows parallel to bedding plane surfaces; below the top meter vertical burrows become abundant; siderite bands; sharp contact with:

276. Interlaminated sandstone and claystone: Sandstone is fine- to medium-grained, poorly sorted; light gray; composed of quartz and
1.04 m abundant interstitial clay; laminar bedded; CONTAINS:
(230.71 m) abundant carbonaceous and coaly laminations; abundant vertical burrows; Claystone is medium gray laminations and beds up to 2 cm thick; CONTAINS: laminar bedding; abundant carbonaceous debris on bedding plane surfaces; abundant horizontal bedding plane burrows; siderite bands; pyrite grains; grades into:

277. Sandstone: Fine- to coarse-grained, moderately sorted; pale brown; clean, composed of quartz and little interstitial clay;
0.72 m poorly cemented, friable; CONTAINS: flat laminations and
(231.43 m) ripples; carbonaceous and shale laminations; laminations generally less than 1 mm thick though sometimes as much as 3 mm thick; occasional clay beds up to 4 cm thick, these clay beds contain very fine-grained sandstone laminations and finely comminuted carbonaceous debris on bedding plane surfaces; pyrite grains; sharp contact with:

278. Sandstone: Fine- to coarse-grained, poorly sorted; medium gray with bands of red and yellow-brown; composed of quartz and
0.26 m abundant interstitial clay; CONTAINS: coal fragments;
(231.69 m) appears to be laminar bedded; sharp contact with:

279. Sandstone: Fine-grained, poorly sorted; medium gray; composed of quartz, abundant dark minerals, and interstitial clay;
0.37 m (232.06 m) CONTAINS: abundant clay and carbonaceous laminations, yellow, sulfur-colored staining occurs along some of the carbonaceous laminations; abundant pyrite; small scale ripples; burrows; grades into:

280. Sandstone: Fine-grained, well-sorted; medium gray; clean, composed of quartz, sparse heavy minerals, and little interstitial
0.23 m (232.29 m) clay; poorly cemented, friable; CONTAINS: abundant shaly and carbonaceous laminations; abundant pyrite, core badly fragmented by pyrite oxidation; grades into:

281. Sandstone: Fine-grained, well-sorted; light gray, has an abundant sulfur-yellow efflorescence; clean, composed of quartz,
0.84 m (233.13 m) sparse dark minerals, and little interstitial clay; poorly cemented, friable; CONTAINS: sparse carbonaceous laminations; possibly low angle cross-beds but internal bedding structures are difficult to determine because the sandstone is so clean; contact unknown:

282. Core loss: In sandstone; contact unknown:

3.36 m (236.49 m)

283. Sandstone: Fine-grained, coarsens downward becomming medium- to coarse-grained in places, well-sorted; medium gray;
1.09 m (237.58 m) composed of quartz, rare dark minerals, and a small amount of interstitial clay; poorly cemented, friable; CONTAINS: planar cross beds; ripple cross-beds in the lower half of the unit; a rare zone of carbonaceous laminations in the basal part of the unit, carbonaceous laminations are associated with a yellow sulfur-colored efflorescence; contact unknown;

284. Core loss: In sandstone; contact unknown:

1.01 m (238.59 m)

285. Sandstone: Medium-grained with scattered coarse grains; well-sorted; medium gray, sulfur-yellow colored efflorescence in places;
0.59 m (239.18 m) clean, composed of quartz, rare dark minerals, rare milky quartz grains, and no interstitial clay; poorly cemented, friable; sharp contact with:

286. Core loss: Location not certain; lost interval may include some coal; contact unknown:
1.29 m (240.47 m)

287. Claystone: Light gray; massive; homogeneous; intensely rooted;

coarsens downward; CONTAINS: fine-grained, rounded, black
0.54 m to dark brown; matrix-supported ferruginous grains
(241.01 m) (concretions?); grades into:

288. Sandstone: Fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; becomes less
0.98 m argillaceous downward; massive; homogeneous; rooted;
(241.99 m) CONTAINS: pyritized root traces; contact unknown:

289. Core loss: Location not certain; presumed to be in sandstone; contact unknown:
0.50 m
(242.49 m)

290. Claystone: Light gray; massive; homogeneous; rooted; CONTAINS: fine-grained, rounded, black to dark brown; matrix-supported
0.19 m ferruginous grains (concretions?); in places; grades into:
(242.68 m)

291. Siltstone: Light gray; massive; homogeneous; rooted; fines downward to claystone at the base; CONTAINS: fine-grained, rounded,
0.93 m black to dark brown; matrix-supported ferruginous grains
(243.61 m) (concretions?); grades into:

292. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; massive;
0.37 m homogeneous; rooted; CONTAINS: sparse pyritized root
(243.98 m) traces; grades into:

293. Claystone: Light gray, becomming medium gray toward the base; massive; homogeneous; rooted; slickensided; hackly; CONTAINS:
0.57 m abundant, fine-grained, rounded, black to dark brown;
(244.55 m) matrix-supported ferruginous grains (concretions?), ferruginous grains become less abundant toward the base; grades into:

294. Claystone: Medium gray; fissile; coarsens downward and becomes sandy toward the base; slightly rooted; slickensided; CONTAINS:
0.92 m sparse carbonized and pyritized plant debris; coalified
(245.47 m) wood fragments, carbonaceous debris becomes more abundant downward; grades into:

295. Carbonaceous shale: Black; fissile; rooted; CONTAINS: abundant carbonized and pyritized plant debris on bedding plane
0.05 m surfaces; sharp contact with:
(245.52 m)

296. Claystone: Light gray; silty at the top of the unit; massive; homogeneous; rooted; slickensided; hackly; CONTAINS: sand
1.30 m laminations at the top near the contact with the
(246.82 m) carbonaceous shale; root traces pyritized, some traces are filled with sand in the top 5 cm of the unit; fine-grained, rounded, black to dark brown; matrix-supported ferruginous

grains (concretions?), grades into:

297. Siltstone: Light gray; massive; homogeneous; rooted; slickensided; hackly; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown; matrix-supported ferruginous grains (concretions?), grades into:
0.67 m
(247.49 m)

298. Sandstone: Very fine-grained, poorly sorted; light gray; composed of quartz and extremely abundant interstitial clay; massive; homogeneous; rooted; CONTAINS: pyritized root traces; fine-grained, rounded, black to dark brown; matrix-supported ferruginous grains (concretions?), grades into:
0.18 m
(247.67 m)

299. Sandstone: Very fine-grained, well-sorted; light gray; composed of quartz and little interstitial clay; CONTAINS: very abundant flat carbonaceous laminations less than 0.5 mm thick, the sandstone interbeds between the laminations are less than 2 mm thick; grades into:
1.37 m
(249.04 m)

300. Sandstone: Fine-grained, well-sorted; light gray; composed of quartz, corroded, apparently transported, green glauconite grains, and little interstitial clay; CONTAINS: very abundant carbonaceous laminations less than 0.5 mm thick; carbonaceous laminations become less abundant downward and disappear toward the base of the unit; sandstone interbeds between the carbonaceous laminations are up to 1 cm thick; laminations are inclined so the unit appears to be a single low-angle cross-bed set; contact unknown:
1.15 m
(250.19 m)

301. Core loss: In sandstone; contact unknown:
1.20 m
(251.39 m)

302. Sandstone: Very fine-grained, well-sorted; light gray; very clean, composed of quartz, rare mica flakes, and no interstitial clay; CONTAINS: low angle cross beds defined by abundant carbonaceous laminations less than 0.5 mm thick, sandstone interbeds between the laminations are up to 3 mm thick; the entire unit is a single cross-bed set; sparse mica flakes are associated with the carbonaceous laminations; no burrows; sideritized zones; grades into:
0.73 m
(252.12 m)

303. Sandstone: Fine-grained, well-sorted; light gray; clean, composed of quartz, rare corroded (probably due to transport) glauconite grains, and no interstitial clay; CONTAINS: rare finely comminuted carbonaceous debris; sandstone is so clean that internal bedding structures are difficult to discern, the distribution of the carbonaceous debris suggests that the internal bedding may be dominated by small scale ripples; contact unknown:
2.25 m
(254.37 m)

304. Core loss: In sandstone; contact unknown:

3.53 m
(257.90 m)

305. Carbonaceous shale: Dark gray; rooted; slickensided; CONTAINS: coalified and pyritized wood and plant fragments; becomes
0.09 m increasingly carbonaceous downward; grades into:
(257.99 m)

306. Bone coal: Black; CONTAINS: abundant shale laminations; pyritized root traces and carbonaceous debris; grades into:
0.03 m
(258.02 m)

307. Shale: Medium gray; rooted; coarsens downward to fine-grained, argillaceous quartz sand at the base; CONTAINS: abundant
0.29 m carbonized and pyritized plant debris on bedding plane
(258.31 m) surfaces; becomes less carbonaceous downward; burrows in the lower part of the unit; contact unknown:

308. Core loss: Probably in the basal part of unit 307; contact unknown:

0.33 m
(258.64 m)

309. Sandstone: Fine-grained, fines downward to very fine-grained, poorly sorted; medium gray becomming light gray downward; composed
0.38 m of quartz and extremely abundant interstitial clay;
(259.02 m) massive; homogeneous; rooted; core badly disintegrated by drilling; CONTAINS: pyritized roots; burrows; abundant, fine-grained, rounded, black to dark brown, matrix-supported ferruginous grains (concretions?); contact unknown:

310. Core loss: In sandstone; contact unknown:

0.17 m
(259.19 m)

311. Claystone: Dark gray; massive; homogeneous; sparsely rooted throughout; CONTAINS: abundant coalified wood fragments;
1.30 m rare, whole palm leaf fossils; rare slickensides; sharp
(260.49 m) contact with:

312. Sandstone: Fine- to medium-grained, silty, poorly sorted; medium gray; composed of quartz and abundant interstitial clay;
0.54 m CONTAINS: flat shale laminations visible in the top 5 cm;
(261.03 m) laminations contain abundant carbonaceous debris on their surfaces; ripple cross-beds are locally preserved; scattered coalified plant fragments; abundant burrows, unit homogenized by burrowing; contact unknown:

313. Core loss: In sandstone; contact unknown:

2.46 m
(263.49 m)

314. Sandstone: Medium-grained with some fine and silt grains, moderately well-sorted; light gray; clean, composed of quartz and little interstitial clay; poorly cemented, friable; CONTAINS: possible ripples or megaripples, the unit is so clean that internal bedding structures are difficult to distinguish; contact unknown:
1.24 m
(264.73 m)

315. Core loss: In sandstone; contact unknown:

1.76 m
(266.49 m)

316. Sandstone: Medium-grained with some fine and silt grains, moderately well-sorted; light gray; clean, composed of quartz and little interstitial clay; poorly cemented, friable; CONTAINS: low-angle cross-beds; the unit is so clean that internal bedding structures are difficult to distinguish; sharp contact with:
0.90 m
(267.39 m)

317. Claystone: Medium gray; CONTAINS: abundant carbonized and pyritized plant debris; sand filled burrows; sharp contact with:
0.10 m
(267.49 m)

318. Sandstone: Fine-grained with a small silt-sized fraction, well-sorted; light gray; clean, composed of quartz, rare corroded (presumed transported) glauconite grains, sparse heavy minerals, and no interstitial clay; poorly cemented, friable; CONTAINS: low angle cross-beds defined by carbonaceous debris on bedding plane surfaces; contact unknown:
0.10 m
(267.59 m)

319. Core loss: Probably in sandstone although unit is not certain; contact unknown:
1.90 m
(269.49 m)

320. Sandstone: Fine-grained with thin zones of medium grains, well-sorted; light gray; clean, composed of quartz, rare corroded (presumed transported) glauconite grains, sparse heavy minerals, and little interstitial clay; CONTAINS: sparse carbonaceous debris on bedding surfaces; ripple cross-bedded but unit is so clean that internal bedding structures are difficult to observe; contact unknown:
0.88 m
(270.37 m)

321. Core loss: Probably in sandstone; contact unknown:

1.22 m
(271.59 m)

322. Claystone: Medium gray; homogeneous; CONTAINS: abundant pyrite scattered throughout; rare pyritized carbonaceous debris at the base of the unit; sharp contact with:
0.56 m
(272.15 m)

323. Sandstone: Medium-grained with sparse coarse grains, well-sorted; light gray; clean, composed of quartz, no interstitial clay, and a calcareous cement; CONTAINS: sparse carbonaceous debris; no evidence of internal bedding structures; sharp contact with:
0.10 m
(272.25 m)

324. Sandstone: Medium-grained, scattered coarse and very coarse grains, well-sorted; light gray; clean, composed of quartz, rare rose quartz, rare heavy minerals, and no interstitial clay; poorly cemented, friable, core badly disintegrated near the base; CONTAINS: scattered carbonaceous debris and rare coaly laminations; planar cross-beds up to 10 cm thick; possibly small-scale ripples; internal bedding structures difficult to distinguish because the sandstone is so clean; contact unknown:
1.20 m
(273.45 m)

325. Core loss: In sandstone; contact unknown:
1.14 m
(274.59 m)

326. Sandstone: Medium-grained, well sorted; light gray; clean, composed of quartz, common corroded (presumed transported) glauconite grains, sparse heavy minerals, and no interstitial clay; glauconite becomes more abundant downward; internal bedding structures are difficult to observe because the unit is so clean; contact unknown:
1.30 m
(275.89 m)

327. Core loss: In sandstone; contact unknown:
1.10 m
(276.99 m)

328. Siltstone: Light gray; CONTAINS: burrows filled with clean, well-sorted, very coarse-grained sandstone, sandstone contains rare glauconite pellets; sharp contact with:
0.23 m
(277.22 m)

329. Sandstone: Fine-grained, well-sorted; light gray; clean, composed of quartz, calcareous cement, and no interstitial clay; extremely indurated; CONTAINS: carbonaceous debris on ripple surfaces; sharp contact with:
0.05 m
(277.27 m)

330. Sandstone: Fine-grained, well-sorted; light gray; clean, composed of quartz, sparse heavy minerals, corrodes (and therefore presumed transported) glauconite pellets, and no interstitial clay; poorly cemented, friable; CONTAINS:
0.30 m
(277.57 m)

small scale ripples; contact unknown:

331. Core loss: In sandstone; location not certain; contact unknown:

0.92 m
(278.49 m)

332. Sandstone: Fine-grained, well-sorted; light gray; clean, composed of quartz, sparse heavy minerals, corroded (and therefore presumed transported) glauconite pellets, and no interstitial clay; poorly cemented, friable; CONTAINS: low angle cross beds; contact unknown:
0.60 m
(279.09 m)

333. Core loss: In sandstone; contact unknown:

2.40 m
(281.49 m)

334. Sandstone: Fine-grained, poorly sorted; pale brown; composed of quartz, very abundant glauconite pellets, very abundant interstitial clay, and a small amount of calcareous cement; indurated; CONTAINS: large scale planar cross-beds; rare carbonaceous debris on some cross-bed surfaces; contact unknown:
0.10 m
(281.59 m)

335. Siltstone: Medium gray; CONTAINS: abundant coalified and pyritized plant fragments; no evidence of rooting; grades into:
0.06 m
(281.65 m)

336. Carbonaceous sandstone: Interlaminated black carbonaceous laminations with white, fine-grained quartz sandstone laminations; laminations are all less than 1 mm thick; no evidence of rooting; sharp contact with:
0.03 m
(281.68 m)

337. Siltstone: Medium gray; fissile; CONTAINS: abundant, very fine-grained quartz sandstone laminations; very abundant carbonaceous laminations; pyritized carbonaceous debris; no evidence of rooting; grades into:
0.12 m
(281.80 m)

338. Sandstone: Fine-grained; medium gray; CONTAINS: abundant carbonaceous and silty flat laminations; contact unknown:
0.04 m
(281.84 m)

339. Core loss: Location not known; suspected to occur in sandstone unit 334; contact unknown:
2.65 m
(284.49 m)

340. Sandstone: Very fine- to fine-grained, poorly sorted; medium gray; composed of quartz and abundant interstitial clay; CONTAINS: abundant carbonaceous debris scattered
0.47 m

(284.96 m) throughout; burrows, unit homogenized by burrowing; traces of relict ripples toward the base of the unit; traces of carbonaceous and shaly laminations; contact unknown:

341. Core loss: Location not certain; probably in sandstone; contact unknown:

2.53 m
(287.49 m)

342. Sandstone: Fine-grained, well-sorted; pale brown; composed of quartz, some interstitial clay, and abundant glauconite pellets;
0.07 m well-indurated but non-calcareous; CONTAINS: high angle
(287.56 m) planar cross-beds; contact unknown:

343. Core loss: Location not known; probably in sandstone; contact unknown:

2.93 m
(290.49 m)

344. Sandstone: Very fine- to fine-grained, poorly sorted; medium gray; composed of quartz and abundant interstitial clay;
0.63 m CONTAINS: abundant burrows, unit appears to be homogenized
(291.12 m) by burrowing; traces of relict laminations; homogeneously distributed carbonaceous debris; sharp contact with unit 346:

345. Core loss: Location not certain but is believed to have occurred at the top of unit 344:

1.37 m
(292.49 m)

346. Carbonaceous shale: Black; fissile; CONTAINS: abundant carbonized and pyritized plant debris on bedding plane surfaces;
0.20 m slickensides; has a texture that is typically associated
(292.69 m) with rooting but no definitive roots can be identified; sharp contact with:

347. Interlaminated sandstone and siltstone: Sandstone is very fine- to medium-grained, coarsens downward, moderately well-sorted;
0.42 m light gray; clean, composed of quartz, some dark minerals,
(293.11 m) and little interstitial clay; CONTAINS: irregular flat laminations of medium gray shale and siltstone laminations up to 2 mm thick; burrows, bedding irregularities in the shale laminations probably due to disruption by burrowing; the top of the unit contains a population of burrows that are filled with very coarse- to granular sand grains, burrows parallel bedding plane surfaces; abundant, finely comminuted carbonaceous debris on siltstone bedding plane surfaces; grades into:

348. Sandstone: Very fine- to coarse-grained, coarsens downward to very coarse-grained, poorly sorted; medium gray; composed of
1.68 m quartz, and abundant interstitial clay; CONTAINS: abundant

(294.79 m) burrows, unit homogenized by burrowing; sparse, pyritized carbonaceous debris; contact unknown:

349. Core loss: Location unknown; possibly loss may have occurred at the base of unit 348 or possibly at the top of unit 350;
1.70 m contact unknown:
(296.49 m)

350. Sandstone: Medium-grained to granular though most grains are coarse, moderately well-sorted; light gray; very clean, composed of
0.23 m quartz and no interstitial clay; poorly cemented, friable;
(296.72 m) core badly disintegrated during drilling; no evidence of internal bedding structure is preserved; contact unknown:

351. Core loss: Presumed to be all in sandstone; contact unknown:

23.47 m
(320.19 m)

352. Sandstone: Very fine-grained, well sorted; light gray; composed of quartz, rare dark minerals, some interstitial clay, and
0.23 m calcareous cement; extremely well-indurated; CONTAINS:
(320.42 m) ripples; rare, finely comminuted carbonaceous debris; contact unknown:

353. Core loss: Presumed to be all in sandstone; contact unknown:

39.07 m
(359.49 m)

354. Sandstone: Very fine-grained, well sorted; light gray; composed of quartz, rare dark minerals, some interstitial clay, and
0.30 m calcareous cement; extremely well-indurated; CONTAINS:
(359.79 m) ripples; rare, finely comminuted carbonaceous debris; contact unknown:

355. Core loss: Presumed to be all in sandstone; contact unknown:

14.70 m
(374.49 m)

356. Sandstone: Fine- to medium grained, moderately well-sorted; light gray; composed of quartz, abundant interstitial clay, and
0.04 m calcareous cement; indurated; CONTAINS: ripples; contact
(374.53 m) unknown:

357. Sandstone: Very fine- to fine-grained, poorly sorted; light green; composed of quartz, sparse mica flakes orientated
0.37 m perpendicular to bedding, sparse, very fine-grained dark
(374.90 m) minerals, and very abundant interstitial clay, the clay appears to have a significant glauconitic content; homogeneous, shows no evidence of bedding; contact unknown:

358. Claystone: Light green with brown mottling; massive; homogeneous; slickensided; CONTAINS: pockets of very fine- and fine-grained quartz grains; zones of black ferruginous mineralization; contact unknown:
0.07 m
(374.94 m)

359. Core loss: Location unknown, presumably in sandstone (unit 357); contact unknown:
1.92 m
(376.89 m)

360. Claystone: Mottled light green, purple, red, brown; massive; homogeneous; slickensided; contact unknown:
0.08 m
(376.97 m)

361. Core loss: Location unknown; contact unknown:
1.12 m
(378.09 m)

362. Siltstone: Light gray with red mottling and rare yellow-brown mottling; clayey and slickensided in places; massive; homogeneous; hackly texture; CONTAINS: rare burrows; grades into:
0.47 m
(378.56 m)

363. Mudstone: Mottled red and light gray with rare yellow-brown mottling; mottling has a brecciated appearance; CONTAINS: fine- to very fine-grained matrix-supported quartz grains, sand fraction contains rare dark minerals and mica flakes, sand content increases in abundance toward the middle and then the unit becomes more argillaceous downward; yellow-brown, limonitized (?) burrow traces; burrow traces branch frequently and are less than 1 mm in diameter; contact unknown:
1.74 m
(380.30 m)

364. Core loss: Location not known; contact unknown:
0.19 m
(380.49 m)

365. Claystone: Maroon with light gray mottling; orange hued microbreccia texture; very silty; micaceous; massive; homogeneous; slickensided; hackly texture; CONTAINS: no evidence of bedding; no carbonaceous debris; sparse, indistinct burrows; grades into:
0.25 m
(380.74 m)

366. Siltstone: Maroon with light gray mottling; orange hued microbreccia texture; argillaceous; the light gray mottled rock appears to be slightly more silty than the maroon rock; grades into:
0.27 m
(381.01 m)

367. Claystone: Maroon with light gray mottling; orange hued microbreccia texture; very silty; micaceous; massive; homogeneous;

0.48 m (381.49 m) slickensided; hackly texture; CONTAINS: no evidence of bedding; no carbonaceous debris; sparse, indistinct burrows; contact unknown:

368. Core loss: Location unknown; contact unknown:

0.20 m (381.69 m)

369. Claystone: Light gray with bright red mottling; homogeneous; massive; hackly; slickensided; CONTAINS: round, ferruginous pisoliths; contact unknown:

1.78 m (383.47 m)

370. Core loss: Probably occurred in unit 369; contact unknown:

0.02 m (383.49 m)

371. Claystone: Light gray with chocolate brown to purple mottling; silty in places; homogeneous; massive; slightly hackly; slickensided; CONTAINS: round, ferruginous pisoliths; contact unknown:

2.23 m (385.72 m)

372. Sandstone: Very fine-grained with abundant silt in the matrix, poorly sorted; light green-gray; composed of quartz, sparse dark minerals, and sparse (biotite ?) mica; homogeneous; massive; CONTAINS: no evidence of bedding; contact unknown:

0.62 m (386.34 m)

373. Core loss: Presumably in sandstone (unit 372); contact unknown:

0.15 m (386.49 m)

374. Sandstone: Very fine-grained with abundant silt in the matrix, poorly sorted; light green-gray; composed of quartz, sparse dark minerals, and sparse (biotite ?) mica; homogeneous; massive; CONTAINS: no evidence of bedding; grades into:

0.12 m (386.61 m)

375. Sandstone: Very fine-grained, very silty, poorly sorted; light green-gray; composed of quartz, sparse mica flakes, and abundant interstitial silt and clay; CONTAINS: dark gray silt laminations; laminar bedding; ripples; planar cross-beds (possibly megaripples); vertical burrows, some of the burrows appear to be pyritized; sharp contact with:

1.00 m (387.61 m)

376. Sandstone: Medium- to coarse-grained, poorly sorted; light green-gray; composed of quartz, abundant fine-grained dark minerals, some medium-grained fragmental glauconite pellets, and very abundant interstitial clay; CONTAINS: few observable internal bedding structures; small scale ripples up to 5 cm in amplitude are observed near the base of the unit, cross

1.58 m (389.19 m)

bed surfaces are defined by silty laminations; grades into:

377. Sandstone: Medium- to primarily coarse-grained, poorly sorted; light green-gray; composed of quartz, abundant fine-grained dark
0.70 m minerals, some broken glauconite pellets, and very abundant
(389.89 m) interstitial clay; CONTAINS: ripples throughout the unit, ripple cross-bed surfaces are defined by shale laminations; contact unknown:

378. Core loss: Presumed to occur in unit 377 or the top of 379; contact unknown:
2.30 m
(392.19 m)

379. Sandstone: Medium- to primarily coarse-grained, poorly sorted; light green-gray; composed of quartz, abundant fine-grained dark
0.20 m minerals, some broken glauconite pellets, and very abundant
(392.39 m) interstitial clay; CONTAINS: ripples throughout the unit, ripple cross-bed surfaces are defined by shale laminations; contact unknown:

380. Core loss: Presumed to occur in unit 379; contact unknown:

2.80 m
(395.19 m)

381. Claystone: Mottled light gray and chocolate brown; slickensided; hackly; massive; homogeneous; CONTAINS: micro-brecciated
0.55 m texture; "breccia" fragments are yellow-brown; grades into:
(395.74 m)

382. Siltstone: Green-gray; massive, homogeneous; may contain some glauconite pellets and layers of glauconite rich clays on
0.25 m some surfaces; grades into:
(395.99 m)

383. Sandstone: Very fine-grained, fine-grained in places, poorly sorted; green-gray; composed of quartz and abundant interstitial
0.36 m silt and clay; massive; homogeneous; CONTAINS: no evidence
(396.35 m) of bedding; grades into:

384. Siltstone: Green-gray; massive; homogeneous; fines downward from being sandy at the top to argillaceous at the base; may contain
0.16 m abundant glauconite in the clay fraction; grades into:
(396.51 m)

385. Claystone: Mottled red and gray; slickensided; hackly; massive; homogeneous; CONTAINS: micro-brecciated texture; "breccia"
1.03 m fragments are yellow-brown; grades into:
(397.54 m)

386. Claystone: Gray, mottled red and brown; intensely slickensided; hackly; massive; homogeneous; CONTAINS: a poorly developed

2.00 m "breccia" texture; grades into:
(399.54 m)

387. Siltstone: Gray, mottled red; sandy and slightly micaceous at the top, fines downward; massive; homogeneous; CONTAINS: burrows;
1.05 m slickensided clay laminations possibly along burrow traces;
(400.59 m) no evidence of bedding; grades into:

388. Claystone: Gray with subordinate red mottling; top of the unit is purple; massive; homogeneous; slickensided; soapy texture
3.75 m in places; CONTAINS: sparse matrix-supported, rounded,
(404.34 m) coarse, quartz grains; may contain pyritized carbonaceous debris; grades into:

389. Siltstone: Gray with red mottling; massive; homogeneous; coarsens downward grading into a light green-gray mudstone at the
0.27 m base of the unit; CONTAINS: abundant, very fine-grained
(404.61 m) matrix supported quartz sand grains; no evidence of bedding; grades into:

390. Sandstone: Very fine- to medium-grained with sparse coarse grains, poorly sorted; light green; composed of quartz, very
0.97 m abundant interstitial clay, and possibly glauconite
(405.58 m) disseminated within the matrix; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:

391. Siltstone: Light green at the top darkening to purple with brown mottling at the base; sandy at the top fining downward and
0.83 m becomming argillaceous at the base; massive; homogeneous;
(406.41 m) CONTAINS: sparse slickensides; yellow-brown streaks possibly following burrow traces; grades into:

392. Sandstone: Very fine-grained, poorly sorted; light green-gray; composed of quartz, disseminated glauconite, and very
0.88 m abundant interstitial clay; CONTAINS: no evidence of
(407.29 m) bedding in the upper part of the unit; large scale planar cross-beds occur in the lower part of the unit, cross-beds are defined by silt laminations containing a large percentage of disseminated glauconite; grades into:

393. Sandstone: Very fine-to fine-grained, poorly sorted; light green-gray; composed of quartz, mica flakes, sparse dark minerals,
0.13 m disseminated glauconite, and very abundant interstitial
(407.42 m) silt; core badly fragmented during drilling; CONTAINS: low angle planar cross-beds; contact unknown:

394. Core loss: Presumed to occur in sandstone unit 393; contact unknown:

2.87 m
(410.29 m)

395. Sandstone: Very fine- to fine-grained coarsening downward to fine- to medium grained in the lower half of the unit, poorly

1.90 m (412.19 m) sorted; light green-gray; composed of quartz, abundant dark minerals, detrital glauconite, and abundant interstitial clay; CONTAINS: wavy and laminar bedding throughout, bedding defined by thin laminations of glauconite rich silt, laminations are most abundant at the top of the unit and become less prominent downward; internal bedding structures are indistinct; contact unknown:

396. Core loss: Presumed to be in sandstone unit 395; contact unknown:

1.30 m (413.49 m)

397. Sandstone: Fine- to coarse-grained, poorly sorted; light green-gray; composed of quartz, abundant dark minerals, detrital glauconite, and some interstitial clay; CONTAINS: no evidence of internal bedding; contact unknown:

0.36 m (413.85 m)

398. Core loss: Presumed to be in sandstone unit 397; contact unknown:

2.14 m (415.99 m)

399. Mudstone: Green-gray; coarsens downward becomming increasingly sandy toward the base; CONTAINS: abundant fine- to medium-grained matrix-supported quartz grains; scattered, small glauconite pellets; pyritized plant fragments scattered throughout the upper half of the unit; thin claystone zones that are intensely slickensided; contact unknown:

0.70 m (416.69 m)

400. Core loss: location not certain; may have occurred at the base of unit 397; contact unknown:

2.00 (418.69 m)

401. Claystone: Mottled chocolate-brown and gray; intensely slickensided; hackly texture; appears micro-brecciated, brecciation emphasized by the yellow-brown coloration associated with this texture; CONTAINS: abundant ferruginous "pisoliths", some of these "pisoliths" appear to be filled with chalcopyrite; grades into:

0.75 m (419.44 m)

402. Siltstone: Chocolate-brown with green mottling, unit becomes gray toward the base; unit fines downward becomming a hackly, slickensided claystone toward the middle then coarsens downward becomming sandy toward the base; homogeneous; massive; CONTAINS: no evidence of bedding; sparse, finely comminuted, pyritized carbonaceous debris; mica on some bedding surfaces; burrows; grades into unit 404:

1.34 m (420.78 m)

403. Core loss: Location not known:

0.10 m

(420.88 m)

404. Claystone: Chocolate-brown with gray streaks; massive; homogeneous; slickensided; hackly; grades into:
0.49 m
(421.37 m)

405. Sandstone: Very fine-grained, poorly sorted; light green-gray; composed of quartz, mica, and abundant interstitial clay; unit becomes less argillaceous downward; at places contains zones of siltstone; massive; homogeneous; CONTAINS: evidence of secondary mineralization possibly along burrow traces, mineralization may be chalcedony; no evidence of internal bedding structures; grades into:
1.39 m
(422.76 m)

406. Siltstone: Light green-gray; sandy; massive; homogeneous; slickensided wherever the unit becomes clay rich; CONTAINS: finely comminuted, pyritized plant debris; no evidence of internal bedding structures; grades into:
0.28 m
(423.04 m)

407. Claystone: Light green-gray; coarsens downward to siltstone in the middle part of the unit then fines downward again; massive; homogeneous; intensely slickensided; hackly; CONTAINS: no evidence of internal bedding structures; grades into:
0.42 m
(423.46 m)

408. Claystone: light green-gray; coarsens downward to siltstone; homogeneous; slickensided; hackly; CONTAINS: common coalified plant debris; no evidence of internal bedding; grades into:
0.07 m
(423.53 m)

409. Mudstone: Green-gray; at places grades into sandstone or siltstone; becomes very sandy toward the base; massive; homogeneous; slickensided; CONTAINS: a silt and clay matrix supporting very fine-grained quartz grains; matrix also contains dark brown, medium-grained rounded concretions (pisoliths ?); no evidence of bedding; contact unknown:
0.54 m
(424.07 m)

410. Core loss: Location not known; contact unknown:
0.62 m
(424.69 m)

411. Mudstone: Green-gray; at places grades into sandstone or siltstone; becomes very sandy toward the base; massive; homogeneous; slickensided; CONTAINS: a silt and clay matrix supporting very fine-grained quartz grains; matrix also contains dark brown, medium-grained rounded concretions (pisoliths ?); no evidence of bedding; grades into:
0.44 m
(425.13 m)

412. Sandstone: Very fine- to fine-grained, coarsens downward slightly, poorly sorted; green-gray; composed of quartz, mica flakes, trace of dark minerals, and very abundant interstitial clay; massive; homogeneous; CONTAINS: some convolute
0.75 m
(425.88 m)

bedding however mostly there are no observable internal bedding structures; argillaceous zones with slickensides; grades into:

413. Siltstone: Green-gray; fines downward into olive-gray claystone; slickensided; hackly; CONTAINS: abundant finely comminuted
0.40 m pyritized carbonaceous debris on bedding plane surfaces,
(426.28 m) some debris appears to be unreplaced; carbonaceous debris becomes more abundant downward; no evidence of bedding in the upper part of the unit; the lower part of the unit contains convoluted carbonaceous laminations; grades into:

414. Carbonaceous shale: Gray-brown to black; CONTAINS: abundant coalified and pyritized plant fragments on bedding plane surfaces;
0.29 m unit becomes less carbonaceous downward; grades into:
(426.57 m)

415. Siltstone: Medium gray; CONTAINS: abundant very fine-grained quartz sand laminations; finely comminuted carbonaceous debris on
0.12 m bedding plane surfaces; common large coalified or pyritized
(426.69 m) plant fragments on some bedding plane surfaces; grades into:

416. Sandstone: Very fine-grained, coarsens downward to fine-grained, poorly sorted; light gray; composed of quartz, sparse dark
0.44 m minerals, and very abundant interstitial silt; CONTAINS:
(427.13 m) dark gray, flat, silt laminations throughout the unit; vertical burrows; abundant coalified plant debris on bedding plane surfaces; small scale ripples at the top of the unit; contact unknown:

417. Core loss: Presumed to occur in sandstone, either unit 416 or unit 418; contact unknown:
0.06 m
(427.19 m)

418. Sandstone: Fine- to coarse-grained, poorly sorted; light gray; composed of quartz and little interstitial clay; CONTAINS:
0.11 m shale lenses which may be shale rip-up clasts; abundant
(427.30 m) wavy carbonaceous laminations; contact unknown:

419. Core loss: Presumed to occur in sandstone, either unit 418 or unit 420; contact unknown:
1.19 m
(428.49 m)

420. Sandstone: Fine-grained, well-sorted; light gray; composed of quartz, common glauconite pellets, and little interstitial clay;
0.52 m CONTAINS: dark gray, wavy silt laminations; abundant
(429.01 m) carbonaceous debris on silt lamination surfaces; rare burrows; low angle cross beds; grades into:

421. Sandstone: Fine- to medium-grained, moderately well-sorted; light

gray; composed of quartz, scattered glauconite, and some
0.37 m interstitial clay; CONTAINS: rare, faint, green, clay
(429.38 m) laminations that may define indistinct cross-bed surfaces; contact unknown:

422. Core loss: In sandstone, location unknown; contact unknown:

1.61 m
(430.99 m)

423. Sandstone: Fine- to medium-grained, poorly sorted; green-gray; composed of quartz, common detrital (transported)
0.58 m glauconite pellets, rare, very fine-grained dark minerals,
(431.57 m) and very abundant green, glauconitic, interstitial clay; unit becomes less argillaceous downward; CONTAINS: no evidence of internal bedding structures in the upper part of the unit, but at the base, unit contains large scale planar cross-beds defined by light green clay laminations; a micro-brecciated texture at the base which may represent an accumulation of clay rip-up clasts; contact unknown:

424. Core loss: Probably in sandstone, unit 423; contact unknown:

0.42 m
(431.99 m)

425. Claystone: Gray with red mottling; unit appears to be out of place in the core box and most probably is part of unit 428.
0.06 m
(432.05 m)

426. Sandstone: Fine- to medium-grained, poorly sorted; green-gray; composed of quartz, scattered glauconite pellets, and very
0.34 m abundant interstitial clay; massive; homogeneous;
(432.39 m) CONTAINS: no evidence of bedding; contact unknown:

427. Core loss: Presumed to be in sandstone unit 426; contact unknown:

0.10 m
(432.49 m)

428. Claystone: Light gray at top, medium gray with light gray mottling at the base; silty; sparse slickensides; CONTAINS: scattered
0.27 m medium-grained matrix-supported quartz grains; rare,
(432.76 m) partially pyritized, coalified branch compressions; a light gray microbreccia at the bottom of the unit, this brecciated texture may represent clay rip-up clasts; no evidence of other internal bedding structures; contact unknown:

429. Core loss: Presumed to be in sandstone unit 430; contact unknown:

1.73 m

(434.49 m)

430. Sandstone: Medium-grained, poorly sorted; green-gray; composed of quartz, detrital (transported) glauconite pellets, and
0.04 m abundant interstitial glauconitic clay; massive;
(434.53 m) homogeneous; CONTAINS: a 1 cm thick claystone bed at the top of the unit; claystone contains a large coalified wood fragment; no other evidence of bedding; contact unknown:

431. Core loss: Presumed to occur in sandstone units 430 or 432; contact unknown:
2.96 m
(437.49 m)

432. Sandstone: Fine- to medium-grained, poorly sorted; light green-gray; composed of quartz and extremely abundant interstitial
1.82 m clay; massive; homogeneous; CONTAINS: no evidence of
(439.31 m) internal bedding structures; grades into:

433. Sandstone: Fine- to coarse-grained, fines downward to medium- to fine-grained at the base, poorly sorted; pink-gray with abundant
1.83 m green clay lenses; composed of quartz, glauconite at the
(441.14 m) base, and some interstitial clay; massive; homogeneous; core badly fragmented during drilling; CONTAINS: no evidence of internal bedding structures; contact unknown:

434. Core loss: Presumed to be in sandstone unit 433; contact unknown:

1.79 m
(442.93 m)

435. Mudstone: Green-gray; CONTAINS: fine-grained quartz sand supported in an argillaceous silty matrix; sparse glauconite pellets
0.06 m which may be preferentially distributed on indistinct
(442.99 m) bedding plane surfaces; variable amounts of pyritized carbonaceous debris on many bedding plane surfaces; grades into:

436. Siltstone: Olive-gray; CONTAINS: films of sparse, finely comminuted carbonaceous debris on bedding plane surfaces in the upper
0.20 m part of the unit; carbonaceous debris becomes more abundant
(443.19 m) downward and the unit contains abundant coaly laminations toward the base; large scale slickensides in places; grades into:

437. Mudstone: Light green-gray; CONTAINS: very fine-grained quartz grains supported in a silty, probably glauconitic
0.25 m argillaceous matrix; abundant carbonaceous laminations up
(443.44 m) to 1 mm thick, mudstone interbeds are up to 5 cm thick; laminations define low angle cross-beds; abundant pyritized carbonaceous material, some of the pyritized material appears to be altering to chalcopyrite; grades into:

438. Sandstone: Very fine- to medium-grained, moderately well-sorted; light gray; composed of quartz, abundant glauconite pellets, and some interstitial clay; CONTAINS: faint green clay laminations defining low angle cross-bed surfaces; finely comminuted carbonaceous debris on some bedding plane surfaces; sharp contact with:

0.44 m
(443.88 m)

439. Siltstone: Olive-gray; CONTAINS: abundant finely comminuted carbonaceous debris on bedding plane surfaces; mica; contact questionable, unit may be out of place in the core box:

0.06 m
(443.94 m)

440. Sandstone: Fine- to medium-grained with some coarse grains, moderately well-sorted; light gray; composed of quartz, abundant glauconite, dark minerals, and some interstitial clay; CONTAINS: faint planar laminations; sharp contact with:

0.36 m
(444.30 m)

441. Siltstone: Olive-gray; argillaceous; slickensided in places; CONTAINS: abundant finely comminuted carbonaceous debris along bedding plane surfaces and rare coalified wood fragments; sharp contact with:

0.05 m
(444.35 m)

442. Sandstone: Fine- to medium-grained, becomes coarse-grained in the basal 8 cm, moderately well-sorted; light green-gray; composed of quartz, abundant glauconite, and some interstitial clay; massive; homogeneous; CONTAINS: clay pebbles which may be rip-up clasts; no evidence of bedding; sharp contact but there is a possibility that the core may be out of place within the box:

0.80 m
(445.15 m)

443. Claystone: Grades from green mudstone composed of very fine-grained quartz and dark minerals in an argillaceous matrix to a red-brown, mottled green-gray sandy, silty claystone; hackly; slickensided; homogeneous; CONTAINS: no evidence of bedding; grades into:

0.24 m
(445.39 m)

444. Claystone: Chocolate-brown with light gray mottling; silty at the top, fines downward; hackly; intensely slickensided; CONTAINS: some carbonaceous debris along slickensides; yellow-brown microbrecciation texture in places; grades into:

1.95 m
(447.34 m)

445. Siltstone: Maroon and chocolate-brown with yellow-brown microbrecciation texture in places; CONTAINS: burrows; grades into:

0.43 m
(447.77 m)

446. Sandstone: Very fine-grained, poorly sorted; green-gray with chocolate brown mottling; composed of quartz, mica, and very abundant interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:

0.12 m
(447.89 m)

447. Core loss: Presumed to be in sandstone units 446 or 448; contact unknown:
0.50 m
(448.39 m)

448. Sandstone: Very fine-grained coarsening downward to fine-grained, poorly sorted; green-gray with chocolate brown mottling; composed of quartz, mica, and very abundant interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:
0.95 m
(449.34 m)

449. Core loss: Presumed to be in sandstone units 448 or 450; contact unknown:
2.05 m
(451.39 m)

450. Sandstone: Fine-grained with some medium grains, well sorted; green-gray with chocolate brown mottling; clean, composed of quartz and abundant dark minerals; CONTAINS: planar cross-bedding; sparse carbonaceous debris along cross-bed surfaces; contact presumed to be sharp:
1.10 m
(452.49 m)

451. Siltstone: Olive-gray; argillaceous; slickensided in places; CONTAINS: some sand laminations in the middle part of the unit; finely comminuted carbonaceous debris on some bedding plane surfaces; contact presumed to be sharp:
0.15 m
(452.64 m)

452. Conglomeratic sandstone: Fine- to medium-grained at the top of the unit, fine- to coarse grained at the base, green clay pebbles range in diameter from 3 to 20 mm, pebbles coarsen downward, poorly sorted; light brown; composed of quartz and abundant green clay pebbles; contact presumed to be sharp:
0.20 m
(452.84 m)

453. Siltstone: Light green-gray; CONTAINS: sparse slickensides in places; sparse, randomly orientated, finely comminuted carbonaceous debris; contact unknown:
0.08 m
(452.92 m)

454. Sandstone: Fine- to medium-grained, some coarse grains, poorly sorted; pale brown; composed of quartz and some interstitial clay; CONTAINS: no evidence of bedding, the unit appears massive and homogeneous though it does contain faint bedding defined by greenish clay streaks that are thought to be drilling mud that has been injected into the sandstone; contact unknown:
0.47 m
(453.39 m)

455. Core loss: Presumed to be in sandstone units 454 or 456; contact unknown:
1.00 m
(454.39 m)

456. Sandstone: Fine- to medium-grained, some coarse grains, poorly sorted;

pale brown; composed of quartz and some interstitial clay;
0.48 m CONTAINS: no evidence of bedding, the unit appears massive
(454.87 m) and homogeneous though it does contain faint bedding defined by greenish clay streaks that are thought to be drilling mud that has been injected into the sandstone; contact unknown:

457. Core loss: Presumed to be in sandstone unit 456; contact unknown:

2.25 m
(457.12 m)

458. Claystone: Green-gray with maroon mottling; coarsens downward to siltstone; CONTAINS: brown, ferruginous pisoliths;
0.27 m burrows; brecciated texture, "breccia" consists of angular,
(457.39 m) irregular chocolate-brown siltstone lenses in the claystone matrix; grades into:

459. Siltstone: Red-brown to chocolate-brown with a small amount of light gray mottling; massive; homogeneous; CONTAINS: a light
0.53 m brown, microbrecciated texture in places; no evidence of
(457.92 m) bedding; grades into:

460. Claystone: Red-brown with light gray mottling, becomes light gray with red mottling toward the base; light brown microbreccia
1.53 m texture in places; silty; intensely slickensided; hackly;
(459.45 m) massive; homogeneous; CONTAINS: ferruginous pisoliths in the lower half of the unit; no evidence of bedding; grades into:

461. Siltstone: Light purple, mottled gray and brown; coarsens downward, argillaceous at the top and sandy at the base; massive;
0.90 m homogeneous; CONTAINS: small bifurcating burrow(?) traces
(460.35 m) less than 1 mm in diameter, the burrows appear mineralized possibly with manganese; grades into:

462. Mudstone: Light green-gray with maroon mottling; silty; slickensided in the more argillaceous zones; massive; homogeneous;
0.59 m CONTAINS: fine-grained matrix-supported quartz grains;
(460.94 m) scattered mica (biotite ?) flakes; no evidence of bedding; grades into:

463. Siltstone: Pale green with maroon mottling; sandy at the top of the unit becomming more argillaceous downward; massive;
0.65 m homogeneous; CONTAINS: scattered mica (biotite ?) flakes;
(461.59 m) no evidence of bedding; the lower part of the unit appears to be burrowed, burrows appear as clay filled streaks along bedding plane surfaces; grades into:

464. Sandstone: Very fine-grained, poorly sorted; light green-gray; composed of quartz, mica flakes, and very abundant
0.18 m interstitial clay; CONTAINS: ripples defined by the
(461.77 m) accumulation of dark green-gray clay on cross-bed surfaces;

grades into:

465. Siltstone: Chocolate-brown becomming green-gray toward the base; slickensided; massive; homogeneous; CONTAINS: ferruginous
0.47 m pisoliths; mica flakes; no evidence of bedding; grades
(462.24 m) into:

466. Sandstone: Very fine-grained, poorly sorted; light green-gray, medium gray in the lower half; composed of quartz, mica flakes,
0.18 m and very abundant interstitial clay; CONTAINS: ripples and
(462.42 m) planar laminations defined by the accumulation of clay on the bedding surfaces; scattered, pyritized carbonaceous debris in the upper part of the unit: grades into:

467. Siltstone: Medium gray; sandy in places; massive; homogeneous; slickensided in the more argillaceous zones; CONTAINS:
0.25 m scattered carbonized and pyritized twigs and other plant
(462.67 m) debris; mica flakes; faint, planar very fine-grained quartz sand laminations; sharp contact with:

468. Sandstone: Very fine- to medium-grained, coarsening downward to fine to very coarse-grained; poorly sorted; light pink-gray with
1.40 m faint green laminations; composed of quartz, fragmented,
(464.07 m) detrital (transported) glauconite pellets, and some white interstitial clay; friable; core badly fragmented as a result of drilling; CONTAINS: flat laminations defined by the accumulation of green silt; contact unknown:

469. Core loss: Location presumed to be in sandstone units 468 or 470; contact unknown:
0.42 m
(464.49 m)

470. Sandstone: Fine- to very coarse-grained, poorly sorted; green-gray; composed of quartz, detrital (transported) glauconite
0.99 m grains; and little interstitial clay; CONTAINS: scattered,
(465.48 m) light green clay pebbles; contact unknown:

471. Core loss: Presumed to be in sandstone units 471 or 472; contact unknown:
1.81 m
(467.29 m)

472. Sandstone: Fine- to very coarse-grained, fine-grained and very dirty at the base, poorly sorted; green-gray; composed of quartz,
0.86 m detrital (transported) glauconite grains; and little
(468.15 m) interstitial clay; CONTAINS: abundant light green clay pebbles; faint, large scale low-angle cross laminations, laminations become better defined downward; sharp contact:

473. Siltstone: Mottled maroon and green; sandy; massive; homogeneous; CONTAINS: no evidence of internal bedding; grades into:
0.62 m

(468.77 m)

474. Sandstone: Very fine- to fine-grained, coarsens downward slightly, poorly sorted; pale green; composed of quartz, detrital (transported) glauconite, sparse dark minerals, and very abundant interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:
0.40 m
(469.17 m)

475. Core loss: Presumed to be in sandstone units 474 or 476; contact unknown:
1.12 m
(470.29 m)

476. Sandstone: Very fine- to fine-grained, poorly sorted; light green-gray; composed of quartz and abundant interstitial clay; CONTAINS: planar cross-bedding; flat laminations, laminations are defined by the accumulation of silt; pyritized carbonaceous debris on some bedding plane surfaces; sharp contact with:
0.63 m
(470.92 m)

477. Claystone: Green with chocolate-brown mottling; silty; hackly; slickensided; massive; homogeneous; CONTAINS: ferruginous "pisoliths"; no evidence of bedding; unit is believed to grade into unit 479:
0.58 m
(471.50 m)

478. Core loss: Presumed to occur in sandstone unit 476:
1.79 m
(473.29 m)

479. Claystone: Mottled green and maroon; coarsens downward into siltstone; massive; homogeneous; hackly texture in places; CONTAINS: ferruginous "pisoliths"; no evidence of bedding; grades into:
0.43 m
(473.72 m)

480. Sandstone: Very fine- to medium-grained, poorly sorted; light green-gray; composed of quartz, mica flakes, some dark minerals, possibly some glauconite, and abundant interstitial clay; massive; homogeneous; CONTAINS: slickensided clay beds; ferruginous staining on quartz grains; no evidence of bedding; contact unknown:
2.07 m
(475.79 m)

481. Core loss: In sandstone units 480 or 482; contact unknown:
0.50 m
(476.29 m)

482. Sandstone: Very fine- to fine-grained, moderately well-sorted; light green-gray; composed of quartz, some dark minerals, some detrital (transported) glauconite, and some interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:
0.29 m
(476.58 m)

483. Core loss: In sandstone units 480 or 482; contact unknown:

2.61 m
(479.19 m)

484. Sandstone: Very fine- to medium-grained, coarsens downward, poorly sorted; pink-gray; composed of quartz, broken glauconite pellets, and abundant interstitial clay; CONTAINS: green clay pebbles; scattered, pyritized carbonaceous debris; no evidence of bedding; contact unknown:
0.83 m
(480.02 m)

485. Core loss: Presumed to be in sandstone units 484 or 486; contact unknown:

2.37 m
(482.39 m)

486. Sandstone: Very fine- to medium-grained, coarsens downward, poorly sorted; pink-gray; composed of quartz, broken glauconite pellets, and abundant interstitial clay; CONTAINS: green clay pebbles; scattered, pyritized carbonaceous debris; no evidence of bedding; contact unknown:
0.15 m
(482.54 m)

487. Core loss: Presumed to be in sandstone units 486 or 488; contact unknown:

2.75 m
(485.29 m)

488. Sandstone: Very fine- to medium-grained, coarsens downward, poorly sorted; pink-gray; composed of quartz, broken glauconite pellets, and abundant interstitial clay; CONTAINS: green clay pebbles; scattered, pyritized carbonaceous debris; no evidence of bedding; contact unknown:
0.08 m
(485.37 m)

489. Core loss: Presumed to occur in sandstone unit 488; contact unknown:

2.50 m
(487.87 m)

490. Claystone: Green with red mottling; hackly texture; massive; homogeneous; CONTAINS: burrows with meniscate (concave upward) fills; sparsely developed yellow-brown microbreccia texture; no evidence of bedding; probably no lithological break occurs between units 490 and 492:
0.42 m
(488.29 m)

491. Core loss: Location unknown; most logically loss occurred in sandstone unit 488; contact unknown:

2.58 m
(490.87 m)

492. Claystone: Green with red mottling; hackly texture; massive; homogeneous; CONTAINS: burrows with meniscate (concave upward) fills; sparsely developed yellow-brown microbreccia texture; grades into:
0.12 m
(490.99 m)

493. Siltstone: Green with maroon mottling; coarsens downward becomming more silty toward the base; massive; homogeneous;
0.30 m CONTAINS: abundant slickensides in the more argillaceous
(491.29 m) upper part; clay filled horizontal burrows; no evidence of bedding; grades into:

494. Siltstone: Gray-green; micaceous; CONTAINS: finely comminuted carbonaceous debris on bedding plane surfaces, some of the
1.23 m carbonaceous debris has been pyritized; faint, very fine-
(492.52 m) grained quartz sand laminations at the top of the unit, laminations are flat to slightly wavy, range between 1 and 3 mm in thickness, and become more abundant downward; possibly burrowed; sharp contact with:

495. Sandstone: Very fine- to coarse-grained with a few granules at the top of the unit, poorly sorted; green-gray; composed of quartz
0.77 m and some interstitial clay; poorly cemented, friable; core
(493.29 m) badly fragmented during drilling; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:

496. Core loss: Presumed to occur in sandstone unit 495; contact unknown:

1.00 m
(494.29 m)

497. Siltstone: Pale green-gray; micaceous; in places unit is a very fine- to fine-grained sandstone; CONTAINS:large coalified wood
0.47 m fragments; scattered, finely comminuted carbonaceous debris
(494.76 m) on bedding plane surfaces; grades into:

498. Sandstone: Very fine- to fine-grained coarsening downward to fine- to coarse-grained with some very coarse and granular grains at
1.75 m the base of the unit, poorly sorted; light green-gray;
(496.51 m) moderately clean, composed of quartz, sparse glauconite pellets, and a small amount of interstitial clay; CONTAINS: faint laminations at the top of the unit; clay rip-up clasts; contact unknown:

499. Core loss: Presumed to be in sandstone units 498 or 500; contact unknown:
0.78 m
(497.29 m)

500. Sandstone: Fine- to coarse-grained, poorly sorted; light green-gray; moderately clean, composed of quartz, sparse glauconite
0.70 m pellets, and a small amount of interstitial clay; poorly
(497.99 m) cemented, friable; core badly fragmented during drilling; homogeneous; CONTAINS: no evidence of bedding; contact unknown:

501. Core loss: Presumed to be in sandstone unit 500; contact unknown:

4.60 m

(502.59 m)

502. Siltstone: Yellow-brown with gray and red mottling; core badly fragmented and may be out of place; contact unknown:
0.20 m
(502.79 m)

503. Sandstone: Fine- to coarse-grained, poorly sorted; olive-green-gray; dirty, composed of quartz, scattered broken glauconite pellets, and abundant interstitial clay; massive; homogeneous; CONTAINS: a white coating on the quartz grains which may be kaolinitic; no evidence of bedding; contact unknown:
0.55 m
(503.34 m)

504. Mudstone: Green-gray; silty; massive; homogeneous; hackly texture; core badly fragmented during drilling; CONTAINS: very fine-grained matrix-supported quartz sand; ferruginous pisoliths; grades into:
0.20 m
(503.54 m)

505. Siltstone: Gray with brown mottling; massive; homogeneous; CONTAINS: slickensides surfaces in more clay-rich zones; burrows, some burrows appear to be clay streaks along approximately horizontal surfaces other burrows are vertical traces and are often iron replaced; ferruginous pisoliths; no evidence of bedding; grades into:
1.00 m
(504.54 m)

506. Claystone: Dark gray with sparse red mottling; coarsens downward becomming increasingly silty toward the base; hackly; slickensided; massive; homogeneous; core badly fragmented; CONTAINS: ferruginous pisoliths; no evidence of bedding; grades into:
2.90 m
(507.44 m)

507. Siltstone: Maroon with gray mottling; coarsens toward the middle grading into mudstone then fines to claystone toward the base; massive; homogeneous; CONTAINS: sparse, medium-grained matrix-supported quartz sandstone in places; burrows with concave upward meniscate burrow-fills; slickensides in the more argillaceous zones; no evidence of bedding; grades into:
1.30 m
(508.74 m)

508. Mudstone: Maroon; coarsens downward from sandy claystone at the top of the unit to mudstone containing medium- to coarse-grained matrix-supported quartz sand in a silty, argillaceous matrix; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:
1.39 m
(510.13 m)

509. Sandstone: Fine- to coarse-grained, poorly sorted; pale-green; composed of quartz, sparse dark minerals, and abundant pale-green interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:
1.71 m
(511.84 m)

510. Sandstone: Fine- to coarse-grained, poorly sorted; pale-green; composed of quartz, glauconite pellets; sparse dark

2.38 m (514.22 m) minerals, and some pale-green interstitial clay; CONTAINS: faint, poorly defined large scale planar cross beds; clay pebbles in the middle part of the unit; golden colored quartz grains, color may be due to ferruginous staining; possible burrows on bedding plane surfaces; contact unknown:

511. Core loss: Presumed to occur in sandstone units 510 or 512; contact unknown:

0.62 m (514.84 m)

512. Sandstone: Medium- to coarse-grained fining downward to predominantly medium-grained, moderately well-sorted; pale-green; composed of quartz, glauconite pellets, sparse dark minerals, and little interstitial clay; CONTAINS: clay rip-up clasts along faint, low-angle cross-beds at the top of the unit; a sharp basal contact that appears to be a scour, there are coarse grains and granules at the base; sharp contact with:

1.05 m (515.89 m)

513. Sandstone: Very fine-grained, poorly sorted; light green-gray; composed of quartz, mica flakes and some interstitial clay; CONTAINS: very faint cross-beds in places; wavy laminations; horizontal burrows on bedding plane surfaces; grades into:

0.72 m (516.61 m)

514. Siltstone: Light green with sparse maroon mottling; sandy; CONTAINS: clay filled burrows; flat laminations in places though bedding is mostly indistinct probably because the unit has been homogenized by burrowing; finely comminuted carbonaceous debris on bedding plane surfaces; micaceous; slickensides in places; becomes sandy toward the base; grades into unit 516:

0.85 m (517.46 m)

515. Core loss: Location unknown:

0.28 m (517.74 m)

516. Claystone: Green-gray; coarsens downward to siltstone and then sandy siltstone; rare slickensides; massive; homogeneous; CONTAINS: sparse, finely comminuted carbonaceous debris on some surfaces; sparse mica flakes in the sandy areas; no evidence of bedding; grades into:

0.49 m (518.23 m)

517. Sandstone: Fine-grained, well-sorted; pale green; clean, composed of quartz, sparse glauconite pellets, extremely abundant dark minerals, and little interstitial clay; CONTAINS: low-angle cross-beds; ripples greater than 4 cm in amplitude (megaripples), ripples become smaller scale downward within the unit; in places sand grains appear to be lineated along ripple cross-bed surfaces; dark minerals are most abundant

1.28 m (519.51 m)

in the cross-bedded zone; in places the unit becomes homogeneous with no evidence of bedding; sharp contact with:

518. Claystone: Medium green; slickensided; hackly; massive; homogeneous; CONTAINS: burrows; grades into:
0.28 m
(519.79 m)

519. Claystone: Medium green with maroon mottling; massive; homogeneous; CONTAINS: green halo's around burrow traces; sparse, slickensided, horizontal burrows; no evidence of bedding; grades into:
0.57 m
(520.36 m)

520. Claystone: Medium gray; silty; massive; homogeneous; CONTAINS: scattered finely comminuted carbonaceous debris; rare, whole plant fossils; very fine-grained quartz sand laminations in the basal 30 cm; mica flakes become more abundant downward; sand laminations contain very small scale cross-beds; no evidence of bedding; no burrows; sharp contact with:
0.99 m
(521.35 m)

521. Sandstone: Medium- to coarse-grained, moderately well-sorted; coarsens downward to very coarse-grained to granular at the base; pale green; composed of quartz and some argillaceous matrix; some of the coarse quartz grains appear to be coated with argillaceous material; massive; homogeneous; poorly cemented, friable; CONTAINS: no evidence of bedding; contact unknown:
1.28 m
(522.63 m)

522. Claystone: Light gray; massive; homogeneous; may be out of place; CONTAINS: rare, small horizontal burrows with quartz and possibly glauconite fillings; no evidence of bedding; contact unknown:
0.06 m
(522.69 m)

523. Core loss: Location unknown; loss presumed to occur either in unit 521 or 524; contact unknown:
0.44 m
(523.13 m)

524. Conglomeratic sandstone: Dominantly coarse grained however the unit ranges from medium-grained to pebble size with quartz pebbles up to 9 mm in diameter, poorly sorted; coarsens downward with increasing proportions of coarse, very coarse, and pebble size fractions increasing with depth; light gray; composed of quartz and no interstitial clay; CONTAINS: clay bands; abundant clay pebbles, clay pebbles may be very large or the apparent pebbles may represent clay beds cut and filled by the conglomerate; sharp contact with:
0.39 m
(523.52 m)

525. Sandstone: Medium- to coarse-grained, well-sorted; pale green; clean, composed of quartz grains with an argillaceous coating

0.67 m around the grains and no apparent dark mineral grains;
(524.19 m) massive; homogeneous; poorly cemented, friable; CONTAINS: sparse coalified wood fragments; no evidence of internal bedding; contact unknown:

526. Core loss: Location not certain; loss presumed to occur either in unit 525 or 527; contact unknown:
0.25 m
(524.44 m)

527. Sandstone: Medium- to coarse-grained, fining downward to fine- to medium-grained with scattered coarse grains, moderately
2.09 m well-sorted; pale green; clean, composed of quartz grains
(526.53 m) with an argillaceous coating around the grains and no apparent dark mineral grains; massive; homogeneous; poorly cemented, friable; CONTAINS: planar cross-beds in the upper part of the unit; small scale ripples; in places the unit is massive and homogeneous with no evidence of bedding; carbonaceous debris defines cross-bed surfaces; sparse coalified wood fragments; no evidence of internal bedding; sharp contact with:

528. Conglomeratic sandstone: Medium- to very coarse-grained with scattered quartz and clay pebbles, poorly sorted; light gray;
0.38 m composed of quartz, rare dark minerals, and little
(526.91 m) interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:

529. Core loss: Presumed to occur in sandstone but the exact location is unknown; contact unknown:
0.38 m
(527.29 m)

530. Claystone: Green-gray at the top of the unit grading downward into mottled green, gray, red, yellow-brown, and violet;
0.54 m coarsens downward; massive; homogeneous; hackly;
(527.83 m) slickensided; grades into:

531. Siltstone: Maroon with yellow-brown and gray mottling; coarsens downward; massive; homogeneous; micaceous; slickensided in
0.33 m the more argillaceous zones; CONTAINS: burrows; no
(528.16 m) evidence of bedding; grades into:

532. Mudstone: Maroon with yellow-brown and gray mottling; coarsens downward into sandstone at the base; massive; homogeneous;
0.21 m micaceous; CONTAINS: very fine- to fine-grained matrix-
(528.37 m) supported quartz sand grains; burrows; no evidence of bedding; grades into:

533. Sandstone: Very fine- to fine-grained, poorly sorted; light gray with sparse yellow-brown and maroon mottling; composed of
1.04 m quartz, common dark minerals, mica flakes, interstitial
(529.41 m) clay, and rare glauconite and calcareous cement in the

lower part of the unit; CONTAINS: may have low angle cross-bedding but internal bedding structures may be difficult to discern and the unit may be homogeneous and massive; contact unknown:

534. Core loss: Presumed to occur in sandstone unit 533; contact unknown:

2.78 m
(532.19 m)

535. Siltstone: Maroon; irregularly interbedded with fine-grained sandstone in the top 70 cm, unit fines downward and grades into claystone at the base; sparse slickensides in the more argillaceous part of the unit; CONTAINS: sparse burrows; flat laminations that are difficult to discern; grades into:

0.27 m
(532.46 m)

536. Claystone: Maroon; coarsens downward, percentage of very fine- to fine-grained matrix-supported quartz sand increases downward; massive; homogeneous; hackly; soapy; sparsely slickensided becomming increasingly slickensided downward; grades into:

0.30 m
(532.76 m)

537. Mudstone: Maroon with gray and yellow-brown mottling; coarsens downward; massive; homogeneous; CONTAINS: rare pisoliths; no evidence of bedding; grades into:

0.70 m
(533.46 m)

538. Sandstone: Very fine- to coarse-grained, primarily fine-grained, poorly sorted; light gray with maroon and yellow-brown mottling; composed of quartz and very abundant interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:

0.08 m
(533.54 m)

539. Mudstone: Maroon with gray mottling; fines downward; massive; homogeneous; rare slickensides; CONTAINS: fine- to medium-grained, matrix-supported quartz grains; pisoliths; no evidence of bedding; grades into:

0.36 m
(533.90 m)

540. Siltstone: Maroon with gray mottling; micaceous; massive; homogeneous; CONTAINS: burrows; scattered fine-grained, matrix-supported quartz grains; no evidence of bedding; grades into:

0.85 m
(534.75 m)

541. Claystone: Maroon with gray mottling; coarsens toward the middle becomming silty then fines downward; slickensided; massive; homogeneous; soapy; hackly; CONTAINS: pisoliths up to 3 mm in diameter; no evidence of bedding; grades into:

1.94 m
(536.69 m)

542. Siltstone: Medium gray with red mottling, maroon to red colors become dominant downward; CONTAINS: yellow-brown pisoliths up to 3 mm in diameter that do not have an internal concentric structure; burrows; rare, matrix-supported quartz grains;

0.55 m
(537.24 m)

grades into:

543. Siltstone: Red; fines downward; massive; homogeneous; CONTAINS: scattered pisoliths; scattered silt-sized dark minerals; mica flakes; grades into:
0.68 m
(537.92 m)

544. Claystone: Red at the top of the unit, grades into mottled red and gray in the lower part; silty at the top fines downward; slickensided; massive; homogeneous; CONTAINS: abundant burrows with concave upward meniscate fills, some of the mottling may be related to burrowing; pisoliths in places; grades into:
1.06 m
(538.98 m)

545. Claystone: Maroon with gray mottling; silty; coarsens downward; massive; homogeneous; slickensided in places; hackly; blocky fracture; CONTAINS: pisoliths; lineations suggestive of burrowing; no evidence of bedding; grades into:
0.39 m
(539.37 m)

546. Siltstone: Maroon; fines downward grading into claystone at the base; slickensided in places, slickensides appear to be associated with burrows; massive; homogeneous; CONTAINS: sparse mica flakes; vertical burrows, burrows become more abundant downward; grades into:
0.79 m
(540.16 m)

547. Mudstone: Mottled gray and maroon; coarsens downward; CONTAINS: sparse pisoliths up to 6 mm in diameter; burrows; matrix-supported fine-grained quartz grains; grades into:
0.53 m
(540.69 m)

548. Sandstone: Very fine- to fine-grained, poorly sorted; fines downward; mottled red and gray with yellow-brown staining; composed of quartz and extremely abundant interstitial clay; massive; homogeneous; CONTAINS: pisoliths toward the base of the unit; may contain burrows; no evidence of bedding; grades into:
0.78 m
(541.47 m)

549. Mudstone: Mottled red and gray with yellow-brown staining; massive; homogeneous; CONTAINS: horizontal and vertical burrows up to 17 mm in diameter, burrow walls are lined with slickensided clay; pisoliths; no evidence of bedding; sharp contact with:
0.67 m
(542.14 m)

550. Siltstone: Maroon with gray mottling; coarsens downward; massive; homogeneous; blocky fracture; CONTAINS: sparse, matrix-supported, fine-grained quartz grains; abundant burrows with concave upward meniscate burrow fills; rare pisoliths; rare mica flakes; no evidence of bedding; grades into:
0.96 m
(543.10 m)

551. Mudstone: Maroon with gray mottling; coarsens downward; massive; homogeneous; blocky fracture; CONTAINS: abundant, matrix-supported, fine-grained quartz grains; abundant burrows
0.30 m

(543.40 m) with concave upward meniscate burrow fills; rare pisoliths; rare mica flakes; no evidence of bedding; grades into:

552. Claystone: Maroon with gray mottling, becomes more gray downward; silty; massive; homogeneous; CONTAINS: gray burrows;
0.65 m contact unknown:
(544.05 m)

553. Claystone: Badly fragmented during drilling; believed to have the same lithologic characteristics as the overlying unit; contact
0.85 m unknown:
(544.90 m)

554. Siltstone: Mottled red and gray; massive; homogeneous; micaceous; CONTAINS: rare dark gray fine grained minerals; burrows,
0.41 m slickensides parallel burrow traces; no evidence of
(545.31 m) bedding; sharp contact with:

555. Siltstone: Medium gray becomming light green-gray downward; coarsens downward; micaceous; massive; homogeneous; CONTAINS:
0.36 m sparse sand-filled burrows, slickensides parallel some
(545.67 m) burrow traces; fine-grained, matrix-supported quartz sand grains; contact unknown:

556. Sandstone: Fine-grained, moderately well-sorted; light green-gray; composed of quartz, mica flakes, very fine-grained dark
0.55 m minerals, sparse glauconite pellets, and interstitial clay;
(546.22 m) CONTAINS: sparse, poorly defined shale laminations; small-scale ripple cross-beds; mica flakes occur on cross-bed surfaces; sharp contact with:

557. Claystone: Medium gray; massive; homogeneous; CONTAINS: rare pyritized carbonaceous debris on bedding plane surfaces
1.26 m near the base of the unit; rare slickensides; no evidence
(547.48 m) of burrowing; grades over a short distance into:

558. Sandstone: Medium-grained, moderately well-sorted; coarsens downward into medium- to coarse-grained and then to coarse-grained;
2.08 m light green-gray; composed of quartz, abundant green
(549.56 m) glauconite pellets in places, and interstitial clay; CONTAINS: planar cross-beds but cross-bed surfaces are difficult to discern; appears to be flat laminated near the base of the unit; grades into:

559. Siltstone: Gray; core badly fragmented during drilling; contact unknown:
0.09 m
(549.65 m)

560. Core loss: Location unknown; loss presumed to occur either in units 558 or 561; contact unknown:
1.29 m
(550.94 m)

561. Sandstone: Coarse-grained, well-sorted; white; composed of quartz, scattered glauconite pellets, clay pebbles, calcareous
0.42 m cement, and no interstitial clay; well-cemented; CONTAINS:
(551.36 m) light green clay laminations; planar cross beds; rare carbonized wood fragments; claystone pebbles up to 3 mm in diameter; grades into:

562. Claystone: Light green; CONTAINS: irregular, very coarse-grained quartz sandstone beds that may be burrows or possibly
0.24 m sandstone injected during drilling; grades into:
(551.60 m)

563. Claystone: Light green; intensely slickensided; massive; homogeneous; hackly; CONTAINS: no evidence of bedding; sharp contact
0.18 m with:
(551.78 m)

564. Claystone: Mottled red and gray; coarsens downward becomming silty toward the base; massive; homogeneous; hackly;
0.94 m slickensided; CONTAINS: abundant pisoliths generally up to
(552.72 m) 5 mm in diameter though some are larger; grades into:

565. Siltstone: Maroon with gray and yellow-brown mottling; coarsens downward and contains sparse, matrix-supported quartz
1.15 m grains in the lower part of the unit; massive; homogeneous;
(553.87 m) rare slickensides; hackly in places; CONTAINS: mica flakes on bedding surfaces in the lower part of the unit; burrowed, slickensides follow burrow traces, burrows become more abundant toward the base; glauconite pellets near the basal part of the unit; grades into:

566. Mudstone: Maroon; massive; homogeneous; CONTAINS: common bedding plane burrows less than 1 mm wide; burrows are defined by
0.27 m clay slickensides on bedding plane surfaces; abundant mica
(554.14 m) flakes on bedding plane surfaces; vertically penetrating burrows up to 15 mm in diameter; glauconite pellets; matrix-supported, very fine-grained quartz sand grains; no evidence of bedding; grades into:

567. Sandstone: Very fine-grained coarsening downward slightly, poorly sorted; medium gray with red brown banding and mottling in
0.66 m places; composed of quartz, sparse dark minerals, and
(554.80 m) abundant interstitial clay; CONTAINS: internal bedding structures that are difficult to discern; no burrows; large scale planar cross-beds, small scale ripples, cross-bedding and ripples become smaller scale downward; rare, medium gray clay bands and laminations; sharp contact with:

568. Interlaminated claystone and sandstone: Medium gray; CONTAINS: abundant very fine-grained quartz sand laminations less
0.07 m than 1 mm thick; clay laminations approximately 1 mm thick;
(554.87 m) flat laminations and ripple cross-bedding; finely

comminuted carbonaceous debris and carbonized plant fragments on bedding plane surfaces; mica flakes on bedding plane surfaces; sharp contact with:

569. Sandstone: 2.28 m (557.15 m) Very fine- to fine-grained coarsening downward to fine- to medium-grained and then medium grained toward the base, poorly sorted, unit becomes less argillaceous downward and becomes better sorted downward and is well-sorted at the base; light green, in places light gray; composed of quartz, abundant dark mineral grains, and abundant but decreasing amount of interstitial clay; friable; poorly cemented; CONTAINS: laminar bedded claystone bands that contain internal flat sandstone laminations; ripple cross-beds; low-angle cross-beds; contact unknown:

570. Core loss: 0.29 m (557.44 m) Location not certain but presumed to occur in either unit 569 or 571; contact unknown:

571. Sandstone: 1.78 m (559.22 m) Coarse- to very coarse-grained coarsening downward into conglomeratic sandstone containing chert pebbles in the basal 50 cm, well-sorted; light green, in places light gray; composed of quartz, abundant dark mineral grains that may possibly be composed of basaltic hornblende, and no interstitial clay; friable; poorly cemented; CONTAINS: laminar bedded claystone bands that contain internal flat sandstone laminations; ripple cross-beds; low-angle cross-beds; sharp contact with:

572. Sandstone: 2.76 m (561.98 m) Medium-grained, well-sorted; light green becoming lighter in color downward; composed of quartz, sparse dark minerals that become very rare toward the base, and little interstitial clay; massive homogeneous; internal bedding structures are difficult to discern; sharp contact with:

573. Conglomerate: 0.05 m (562.03 m) Light gray; CONTAINS: rounded, pale green clay pebbles up to 2 cm in diameter in a medium-grained quartz sand matrix; sharp contact with:

574. Sandstone: 1.10 m (563.13 m) Fine- to medium-grained, well sorted; green-white; composed of quartz, abundant dark minerals, and no interstitial clay; friable, poorly cemented; appears to be massive and homogeneous but may contain ripples; internal bedding structures are difficult to discern if any exist; sharp contact with:

575. Claystone: 0.84 m (563.97 m) Light green-gray becomming maroon with gray mottling downward and then uniform maroon; coarsens downward to a silty claystone; massive; homogeneous; hackly; slickensided; CONTAINS: burrows with concave upward meniscate burrow-fills; grades into:

576. Claystone: Maroon and gray; coarsens downward becomming silty toward the base; massive; homogeneous; slickensided; CONTAINS: burrows; pisoliths; grades into:
1.17 m
(565.14 m)

577. Siltstone: Maroon; massive; homogeneous; CONTAINS: burrows with slickensides along the burrow traces; grades into:
0.15 m
(565.29 m)

578. Mudstone: Maroon; massive; homogeneous; CONTAINS: burrows with slickensides along the burrow traces; matrix-supported very fine- and fine-grained quartz grains; abundant mica flakes on bedding plane surfaces; grades into:
0.19 m
(565.48 m)

579. Siltstone: Red with gray mottling; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:
0.15 m
(565.63 m)

580. Claystone: Maroon; becomes more silty downward; massive; homogeneous; slickensided; hackly; CONTAINS: pisoliths; burrows with concave upward meniscate fills; grades into:
0.25 m
(565.88 m)

581. Siltstone: Mottled gray and red, gray predominates in some places, red in others; massive; homogeneous; slickensided; CONTAINS: pisoliths and burrows; no evidence of bedding; grades abruptly into:
1.66 m
(567.54 m)

582. Claystone: Mottled gray and red, gray predominates in some places, red in others; silty; coarsens downward; massive; homogeneous; slickensided; CONTAINS: burrows; no evidence of bedding; grades abruptly into:
0.23 m
(567.77 m)

583. Siltstone: Mottled gray and red, gray predominates in some places, red in others; massive; homogeneous; slickensided; CONTAINS: pisoliths and burrows; no evidence of bedding; grades abruptly into:
0.27 m
(568.04 m)

584. Claystone: Gray with red and yellow-brown pebbles, pebbles are irregular giving the unit a brecciated appearance; silty; massive; homogeneous; CONTAINS: abundant burrows, some burrows have a concave upward meniscate burrow-fill; abundant, decomposed pisoliths, the yellow-brown and red colors are the result of pisolith decomposition; no evidence of bedding; grades into:
1.76 m
(569.80 m)

585. Claystone: Maroon with sparse gray mottling; massive; homogeneous; slickensided; hackly; CONTAINS: rare burrows, burrow traces are slickensided; grades into:
1.02 m
(570.82 m)

586. Claystone: Medium gray with sparse red mottling; silty; massive; homogeneous; CONTAINS: no evidence of bedding; grades into:
0.32 m
(571.14 m)

587. Mudstone: Medium gray; massive; homogeneous; rare slickensides; CONTAINS: abundant fine- and some medium-grained matrix-supported quartz grains; no evidence of bedding; sharp contact with:
0.17 m
(571.31 m)

588. Claystone: Medium gray; massive; homogeneous; rare slickensides; CONTAINS: no evidence of bedding; sharp contact with:
0.08 m
(571.39 m)

589. Claystone: Medium gray with red mottling; silty; massive; homogeneous; slickensided; CONTAINS: pisoliths; grades into:
0.35 m
(571.74 m)

590. Claystone: Medium gray with red mottling; massive; homogeneous; slickensided; core badly fragmented during drilling; CONTAINS: pisoliths; grades into:
0.45 m
(572.19 m)

591. Claystone: Maroon with gray mottling; coarsens downward becomming silty toward the base; massive; homogeneous; slickensided; hackly; CONTAINS: burrows, gray mottling defines burrow traces; grades into:
0.70 m
(572.89 m)

592. Claystone: Mottled red and gray; coarsens downward becomming increasingly silty toward the base; massive; homogeneous; hackly; slickensided; core badly fragmented in the top 70 cm; grades into:
1.16 m
(574.05 m)

593. Siltstone: Maroon with gray mottling, violet mottling toward the base of the unit; massive; homogeneous; CONTAINS: burrows, burrows defined by slickensides along burrow traces; mica flakes, some of the flakes look like biotite; no evidence of bedding; grades into:
0.34 m
(574.39 m)

594. Claystone: Mottled red and gray; silty; massive; homogeneous; hackly; slickensided; grades into:
0.17 m
(574.56 m)

595. Claystone: Mottled red and gray; silty; massive; homogeneous; extremely hackly; intensely slickensided; core badly fragmented during drilling; sharp contact with:
0.14 m
(574.70 m)

596. Siltstone: Maroon with gray and violet mottling; CONTAINS: burrows,

burrow traces are slickensided and defined by violet
0.34 m mottling; rare pisoliths; mica flakes, some of the mica may
(575.04 m) be biotite; grades into:

597. Claystone: Mottled maroon and gray; silty; massive; homogeneous; slickensided in places; grades into:
0.09 m
(575.13 m)

598. Claystone: Mottled maroon and gray; coarsens downward becomming increasingly silty toward the base; massive; homogeneous;
0.24 m slickensided in places; grades into:
(575.37 m)

599. Siltstone: Mottled violet, gray, and brown; coarsens downward becomming increasingly sandy toward the base; CONTAINS:
0.20 m vertical and horizontal burrows; sparse, matrix-supported,
(575.57 m) fine-grained quartz grains; no evidence of bedding; grades into:

600. Sandstone: Very fine- to fine-grained with some medium grains, poorly sorted; mottled violet and yellow-brown; composed of
0.47 m quartz, mica flakes, and extremely abundant interstitial
(576.04 m) clay; CONTAINS: irregular clay bands and laminations, the bands may actually be clay rip-up clasts; sharp contact with:

601. Siltstone: Mottled maroon, gray, and yellow-brown at the top of the unit, intensity of the mottling decreases downward and the
1.34 m unit becomes increasingly maroon; fines downward grading
(577.38 m) into a silty claystone at the base of the unit; massive; homogeneous; CONTAINS: sand filled burrows, burrowing intensity decreases downward; slickensides define burrow traces; grades into:

602. Claystone: Maroon; coarsens downward becomming increasingly silty toward the base; massive; homogeneous; CONTAINS: rare
0.79 m burrows, burrows defined by slickensides along burrow
(578.17 m) traces; mica flakes; rare fine-grained, matrix-supported quartz grains; sharp contact with:

603. Claystone: Medium gray with red mottling; silty; massive; homogeneous; hackly; slickensided; CONTAINS: rare, scattered fine-
0.71 m grained, matrix-supported quartz grains; traces of
(578.88 m) mineralized finely comminuted carbonaceous debris; pisoliths; sharp contact with:

604. Mudstone: Medium gray, red and yellow-brown mottling in places; fines abruptly in the basal 20 cm; massive; homogeneous;
1.83 m CONTAINS: abundant very fine- to medium-grained matrix-
(580.71 m) supported quartz grains, coarse quartz grains become more abundant downward in the unit; pisoliths that become less abundant downward and disappear at the base of the unit;

sparse carbonaceous debris near the base of the unit; micaceous; grades into:

605. Siltstone: Mottled medium gray, red, purple, and yellow-brown; massive; homogeneous; rare slickensides; CONTAINS: burrows; abundant mica flakes, much of the mica appears to be biotite; vertical burrows; small, branching, horizontal burrows up to 2 mm in diameter; some of the burrows are sand-filled; sharp contact with:

0.52 m
(581.23 m)

606. Sandstone: Fine-grained with scattered medium grains, unit coarsens downward to medium-grained and medium- to coarse-grained in places, unit contains scattered clay pebbles in places and quartz granules, poorly sorted; light green-gray; composed of quartz, abundant dark minerals, traces of glauconite pellets, rare rose quartz, and some interstitial clay; massive; homogeneous; CONTAINS: heavy mineral laminations, heavy mineral content decreases downward; internal bedding structures are difficult to discern, unit may possibly contain low-angle cross-bedding in places; contact unknown, a small amount of core loss is suspected at the base of the unit, if there has been no loss the contact is sharp:

4.02 m
(585.25 m)

607. Siltstone: Light green-gray; massive; homogeneous; rare slickensides; CONTAINS: pisoliths in places; no evidence of bedding; sharp contact with:

0.24 m
(585.49 m)

608. Claystone: Medium gray with red and yellow-brown mottling; slickensided; massive; homogeneous; hackly; core badly fragmented during drilling; CONTAINS: no evidence of bedding; grades over a short distance into:

0.55 m
(586.04 m)

609. Mudstone: Medium gray with red and yellow-brown mottling; becomes increasingly argillaceous downward; slickensided in places, slickensides become more abundant downward; becomes hackly and badly fragmented toward the base; CONTAINS: very abundant pisoliths; very fine- to coarse-grained, matrix-supported quartz grains, coarser sized fractions become less abundant downward; sharp contact with:

2.20 m
(588.24 m)

610. Sandstone: Very fine- to fine-grained, coarsens downward, fine- to medium-grained by 1.30 m, zones of coarse and very coarse grains in places, poorly sorted; medium green-gray with red mottling in places, the mottled zone is argillaceous and slickensided; composed of quartz, mica flakes, common very fine-grained heavy mineral grains, rare glauconite toward the base of the unit, and extremely abundant interstitial clay though the clay content becomes less abundant downward; CONTAINS: no evidence of bedding in the upper part of the unit, massive and homogeneous; zone of flat laminations, laminations are covered with sparse, finely comminuted iron mineralized carbonaceous debris; large mica

3.00 m
(591.24 m)

flakes are associated with the carbonaceous debris; the laminated zones are significantly finer grained than the rest of the unit; small scale ripples in places, carbonaceous debris defines cross-bed surfaces; zones with fine- to medium-grained sand interlaminated with fine- to very coarse-grained sand; sharp contact with:

611. Conglomeratic sandstone: Coarse- to very coarse-grained with abundant clay pebbles up to 5 mm in diameter, poorly sorted; pale
0.07 m brown; composed of quartz, glauconite pellets, and some
(591.31 m) interstitial clay; sharp contact with:

612. Sandstone: Coarse-grained, fines downward grading into medium- to coarse-grained sandstone and then into fine- to medium-
1.24 m grained sandstone, moderately well-sorted; pale brown;
(592.55 m) composed of quartz, abundant glauconite pellets, and some interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:

613. Core loss: location unknown, loss presumed to occur either in unit 611, 612, or 614; contact unknown:
0.49 m
(593.04 m)

614. Sandstone: Fine- to medium-grained sandstone, moderately well-sorted; pale brown; composed of quartz, abundant glauconite
0.49 m pellets, and some interstitial clay; massive; homogeneous;
(593.53 m) CONTAINS: no evidence of bedding; contact unknown:

615. Conglomeratic sandstone: Very fine-grained to granular, poorly sorted; light gray; composed of quartz, rare rose quartz, and clay
0.10 m pebbles; CONTAINS: no evidence of bedding; clay bands;
(593.63 m) unit turns yellow when reacted with HCl; sharp contact with:

616. Interbedded conglomeratic sandstone and claystone: Conglomeratic fraction ranges from medium-grained quartz sand to quartz
0.26 m pebbles up to 13 mm in diameter, poorly sorted; light gray
(593.89 m) to white; composed of quartz in a white kaolinite-like matrix; Claystone is medium gray; occurs in irregular beds up to 3 cm in thickness; claystone becomes more abundant downward; CONTAINS: sparse carbonaceous debris on some bedding plane surfaces; sharp contact with:

617. Sandstone: Medium- to coarse-grained, well-sorted; light brown; composed of quartz, glauconite pellets, rare dark minerals,
0.57 m and a small amount of interstitial clay; massive;
(594.46 m) homogeneous; friable; poorly cemented; CONTAINS: no evidence of bedding; contact unknown:

618. Core loss: Loss presumed to occur in unit 617; contact unknown:

1.43 m

(595.89 m)

619. Siltstone: Medium green-gray with maroon mottling in the lower part of the unit; coarsens downward; massive; homogeneous; intensely slickensided; hackly; CONTAINS: common, matrix-supported fine-grained quartz sand; grades into:
0.42 m
(596.31 m)

620. Mudstone: Medium green-gray with maroon mottling in the lower part of the unit; coarsens downward, sand becomes increasingly abundant toward the base; massive; homogeneous; intensely slickensided; hackly; CONTAINS: common, matrix-supported fine-grained quartz sand; sparse coaly debris; pisoliths; grades into:
0.59 m
(596.90 m)

621. Sandstone: Medium-grained, poorly sorted; light green-gray; composed of quartz, rare heavy minerals, and abundant interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; contact unknown:
1.90 m
(598.80 m)

622. Core loss: Loss presumed to occur either in unit 621 or 623; contact unknown:
0.20 m
(599.00 m)

623. Sandstone: Medium- to coarse-grained, moderately well-sorted; light green-gray; composed of quartz, very rare glauconite pellets, dark minerals, some calcareous cement, and some interstitial clay; massive; homogeneous; CONTAINS: no evidence of bedding; sharp contact with:
1.45 m
(600.45 m)

624. Sandstone: Medium- to very coarse-grained with occasional quartz pebbles, fines downward slightly, poorly sorted; medium green-gray; composed of quartz, rose quartz, chert, glauconite pellets, and some interstitial kaolinite-like clay; contact unknown:
0.59 m
(601.04 m)

END OF CORE

APPENDIX 2

GEOPHYSICAL LOGS OF THE PMDC THL CORE HOLE

Logged by: Mujeeb Ahmad, Geological Survey of Pakistan
Mehtab-ur-Rahman, Geological Survey of Pakistan

Date: March 21, 1988

Location: Survey of Pakistan Topographic Sheet 40 C/2
Northing 895,600 m, Easting 2,159,700 m

Rotary Interval: 0 - 26.12 m

Core Drilling Begins: 26.12 m

Core Drilling Ends: 601.04 m

Total Depth: 601.04 m

GEOPHYSICAL LOGS RUN:

1) Gamma, Neutron, and Resistivity
2) 4-Pi Density
3) 3 Arm Caliper

1) Gamma, Neutron, and Resistivity

GEOSCIENCE ASSOCIATES

HOLE NUMBER: PMDC. Test Drill Hole

DATE: 21st MARCH, 1988.

LOCATION

STATE/COUNTY SIND PAKISTAN
REGION LAKHRA.
PROJECT
PROSPECT
SEC. TWP. RNG.

TYPE	GAM		Neutron	
LOGGED DEPTH	597.1m		599.1m	
RANGE (f.s.)	200		1K	
%STD DEV	3%		1%	
PAPER SPEED	1-1		1-1	
LOG SPEED	6-1		6-1	
BKGND. COUNT				
PROBE NO.	GN-1		GN-1	
SIZE (dia.)	13/8"		13/8"	
K-FACTOR				
DEAD TIME	2		2	
STANDARD				

DIGITAL DATA

PRINT INTERVAL				
TIMEBASE				

DENSITY CALIBRATION

ALUMINUM				
LUCITE				

HOLE DATA

DEPTH DRILLED: 600m
DEPTH LOGGED: 599.1m
COLLAR ELEV.
DIA. See FROM TO
DIA. Caliper FROM TO
DIA. Log FROM TO
BOREHOLE MEDIUM H_2O+Mud
FLUID LEVEL 68.1m

CASING DATA

WALL SIZE 1/4"
I.D. HW = 4" I.D. PW = 5"
CASED FROM 0 TO 153m
CASING TYPE HW and PW

SAMPLE DATA

NON-CORED HOLE ☐ CORED HOLE ☒

SAMPLED INTERVAL	SAMPLE TYPE

REMARKS

Open Hole

CLIENT

CLIENT U.S.G.S - G.S.P.
GEOLOGIST:

UNIT OPERATOR MUJIB-NEMIAS
UNIT NO. PL-1 OFFICE BOULDER COLORADO U.S.A.

ELECTRIC

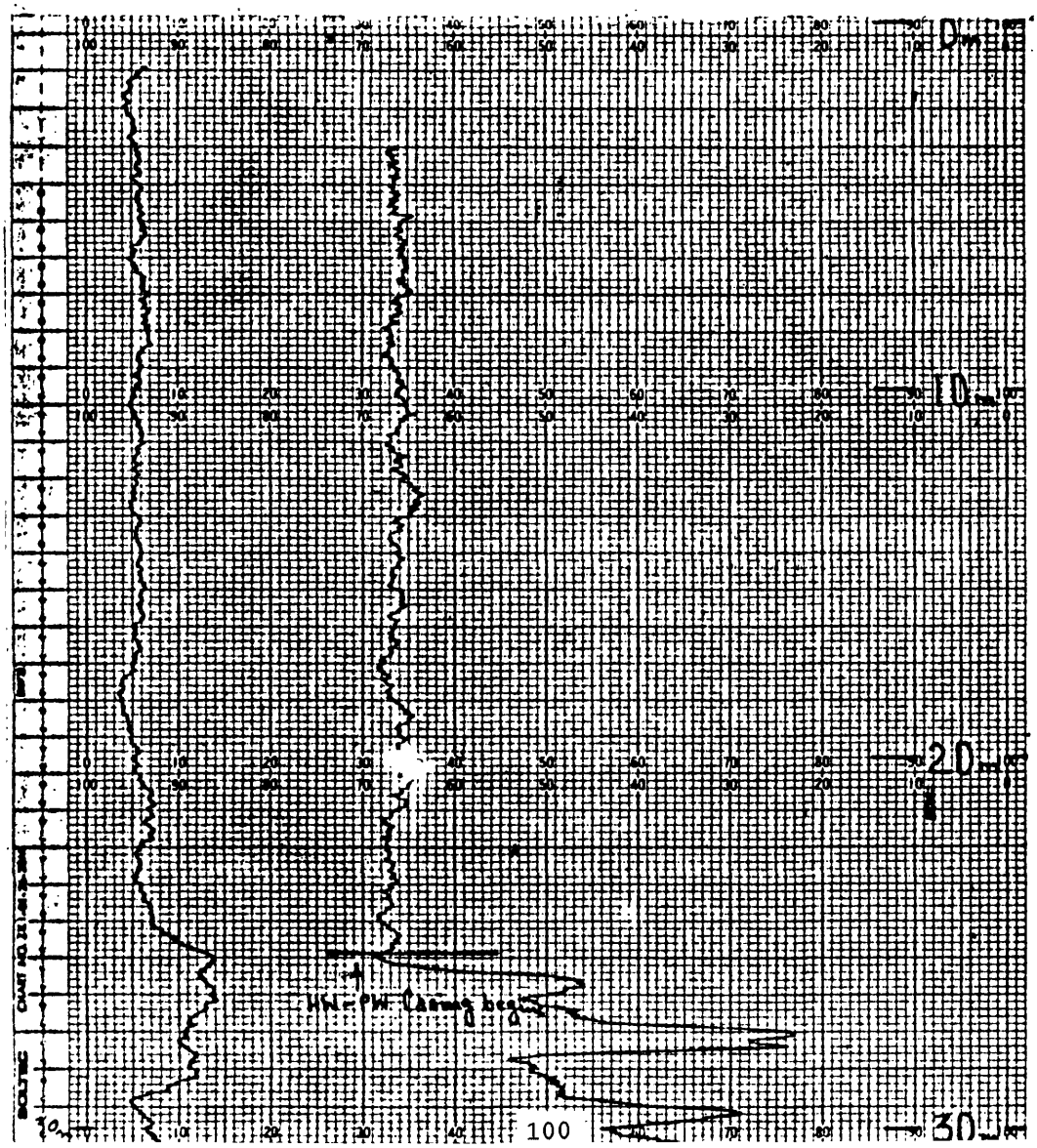
TYPE	RESIST	S.P.
LOGGED DEPTH	597.1m	FT.
SCALE	10	
PAPER SPEED	1-1	
LOG SPEED	6-1	
FINE ADJ.	500 Bias.	

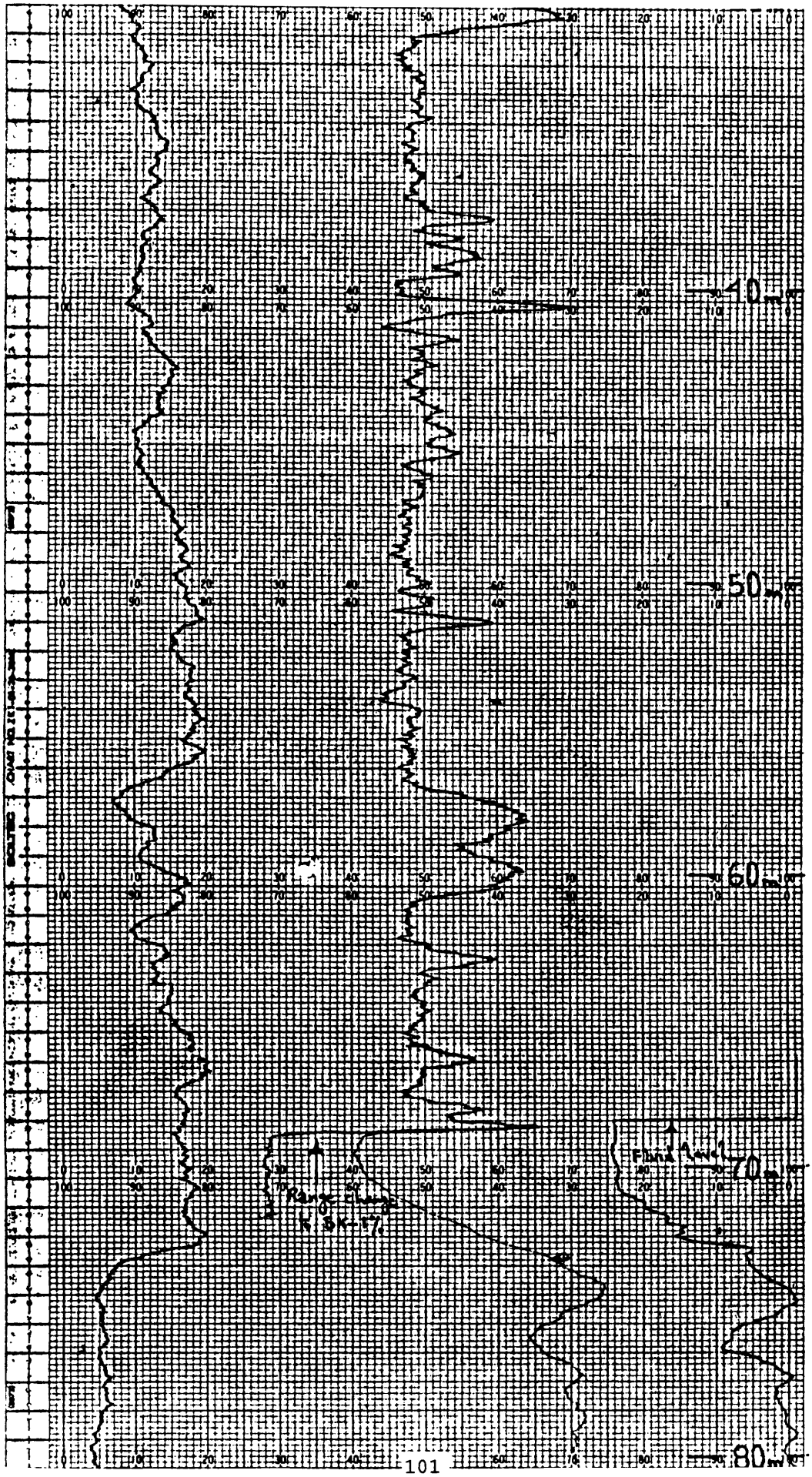
CALIPER

LOGGED DEPTH	FT.
SCALE	
PAPER SPEED	
LOG SPEED	
ARM LENGTH	IN
MAX DEP.	IN

VERTICAL DEV.

DEPTH					
INCLIN.					
BEARING					

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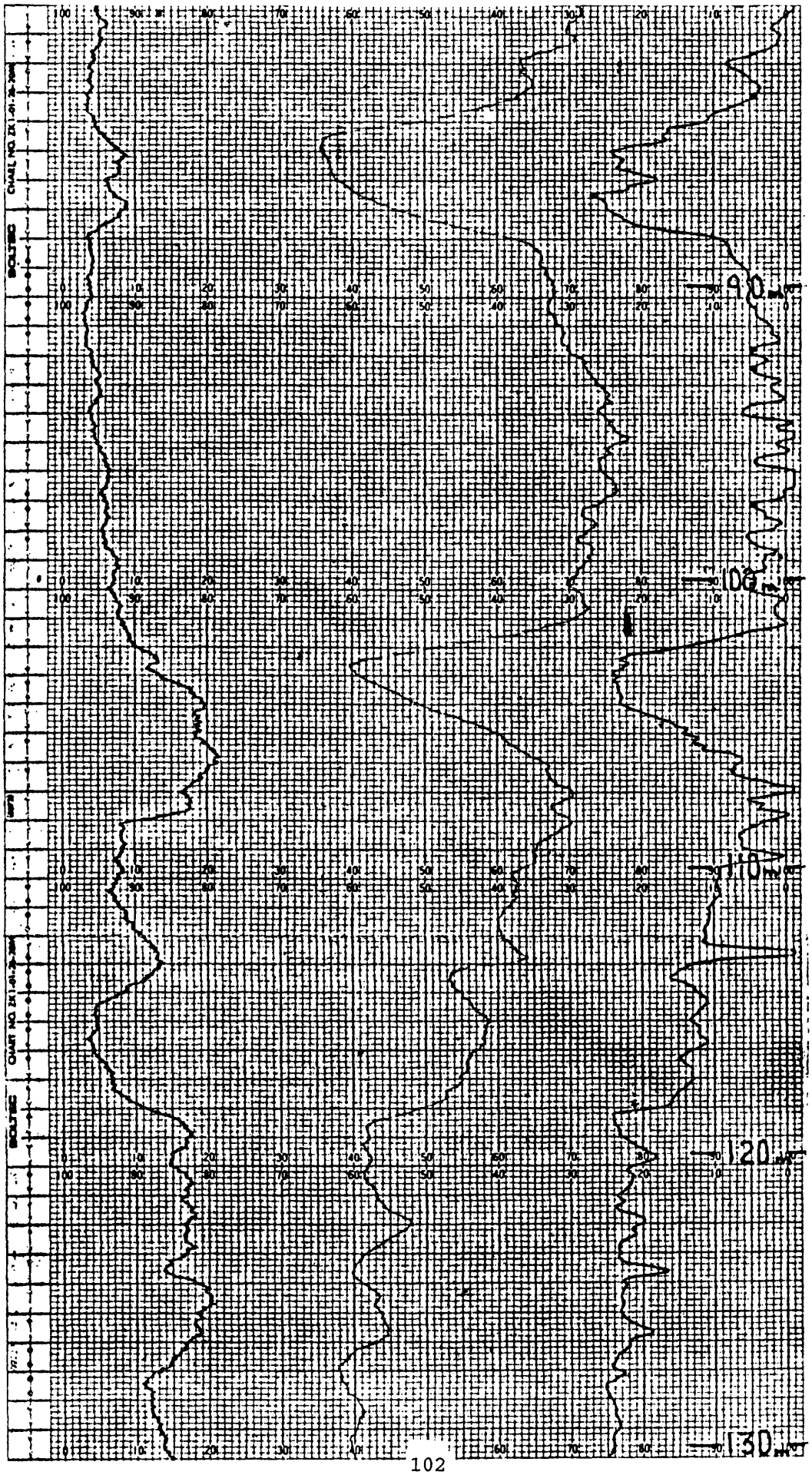
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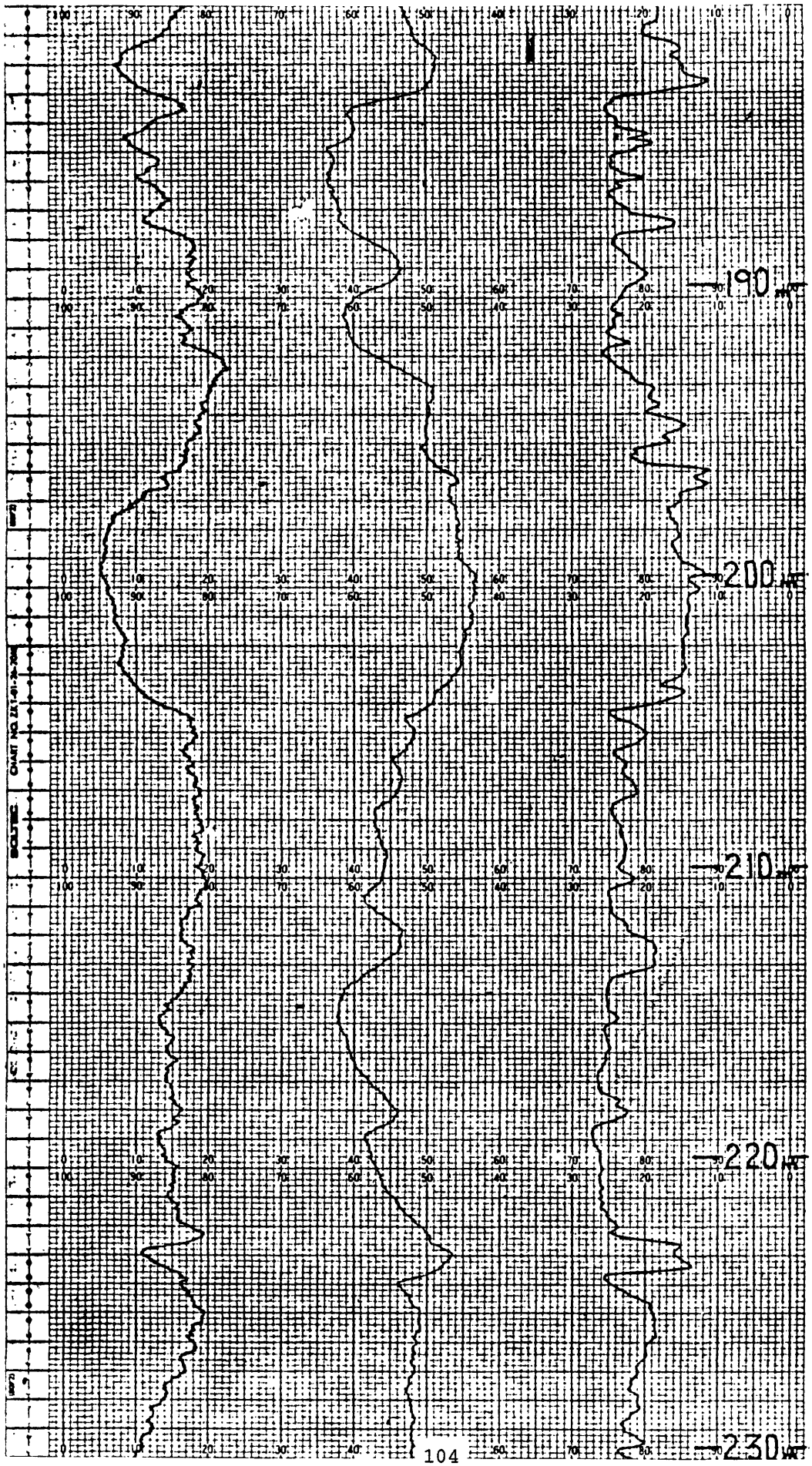
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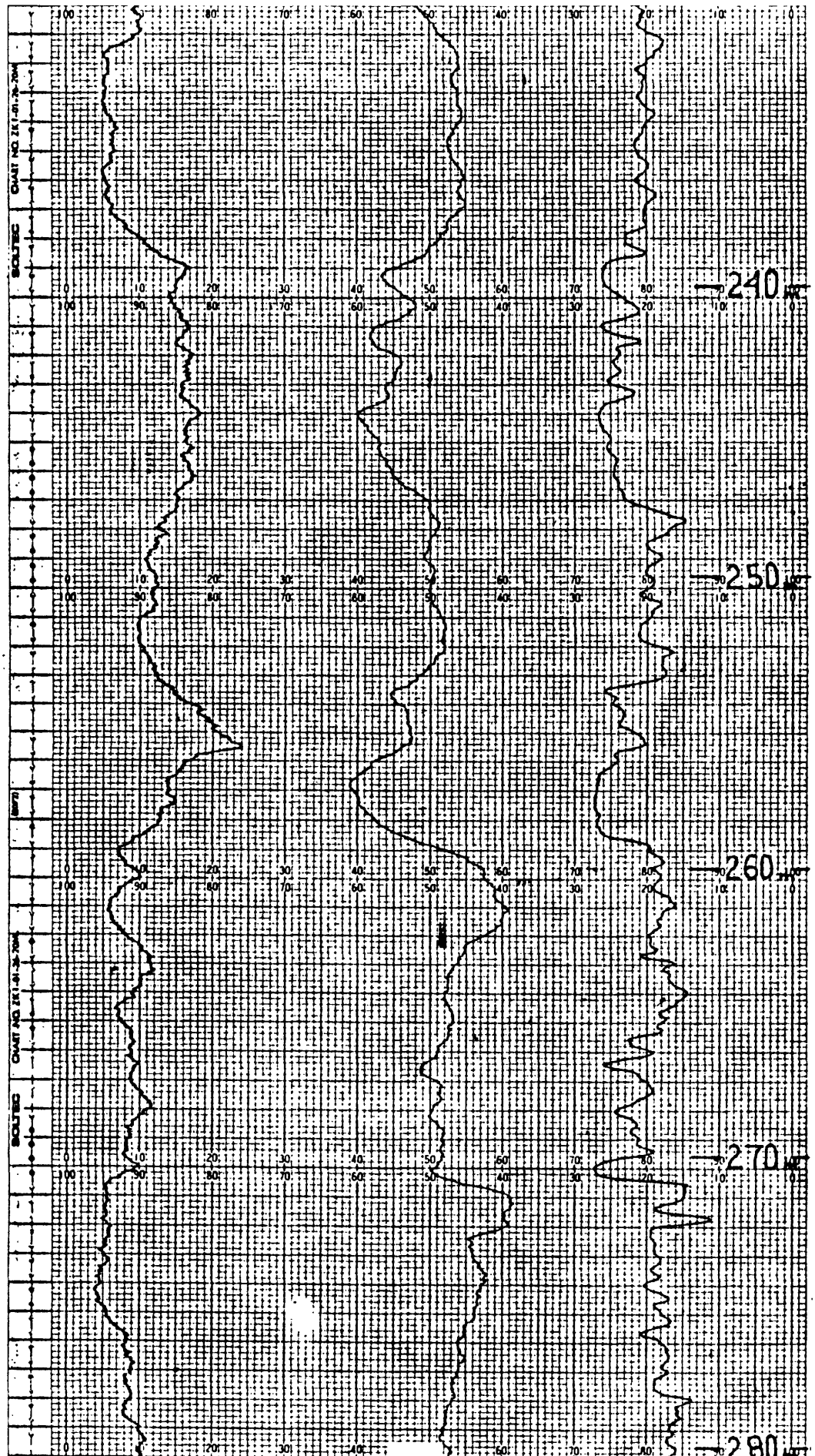
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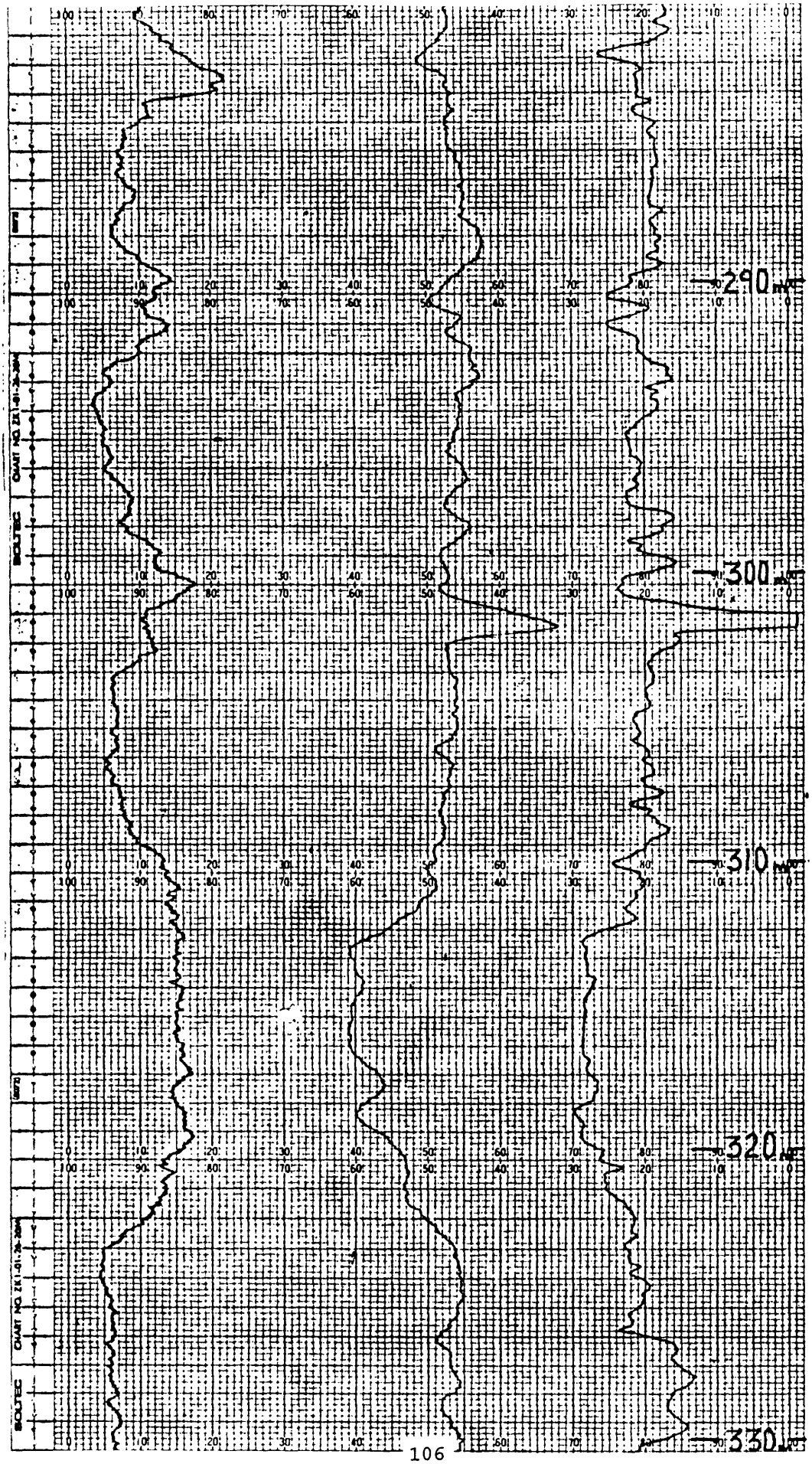
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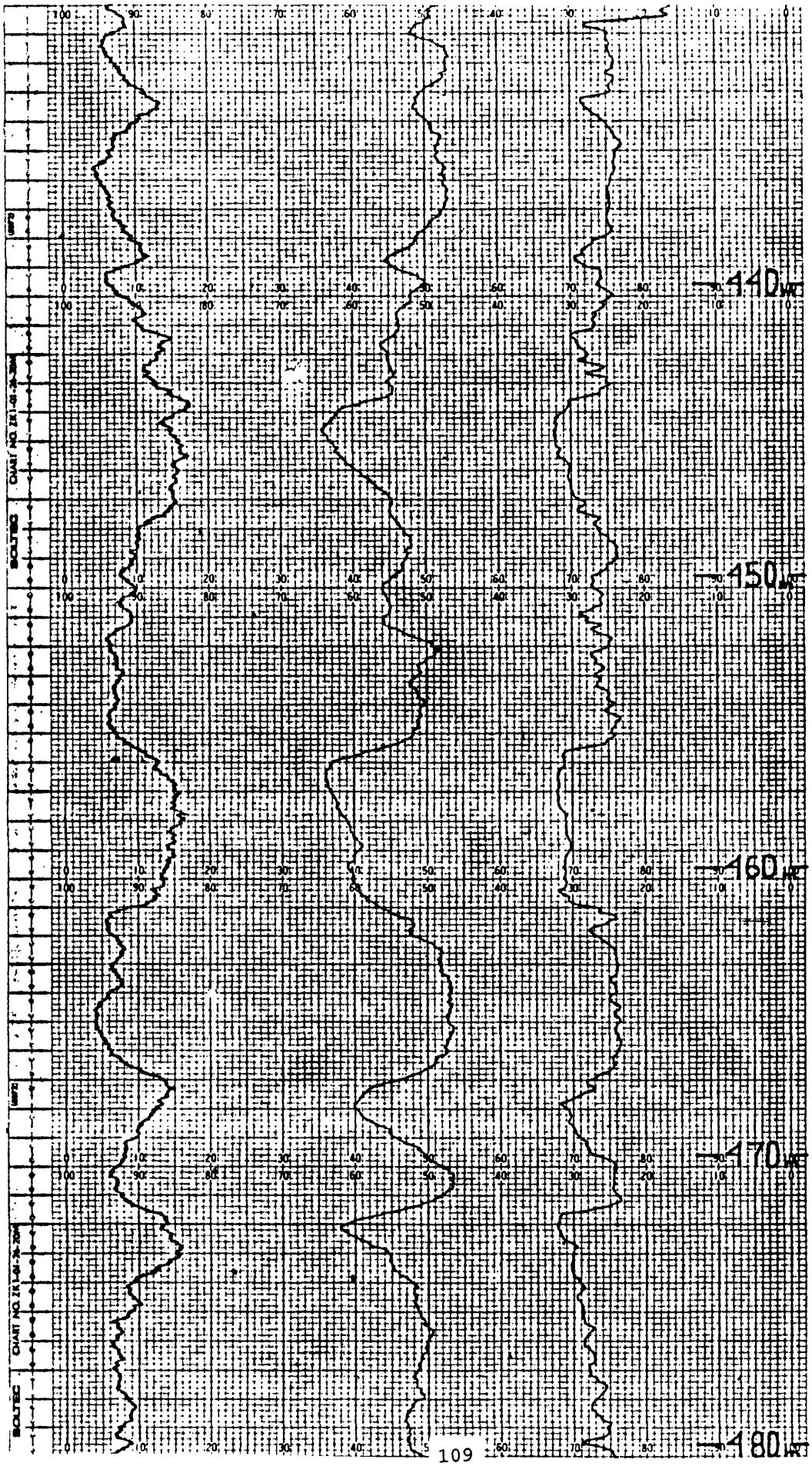
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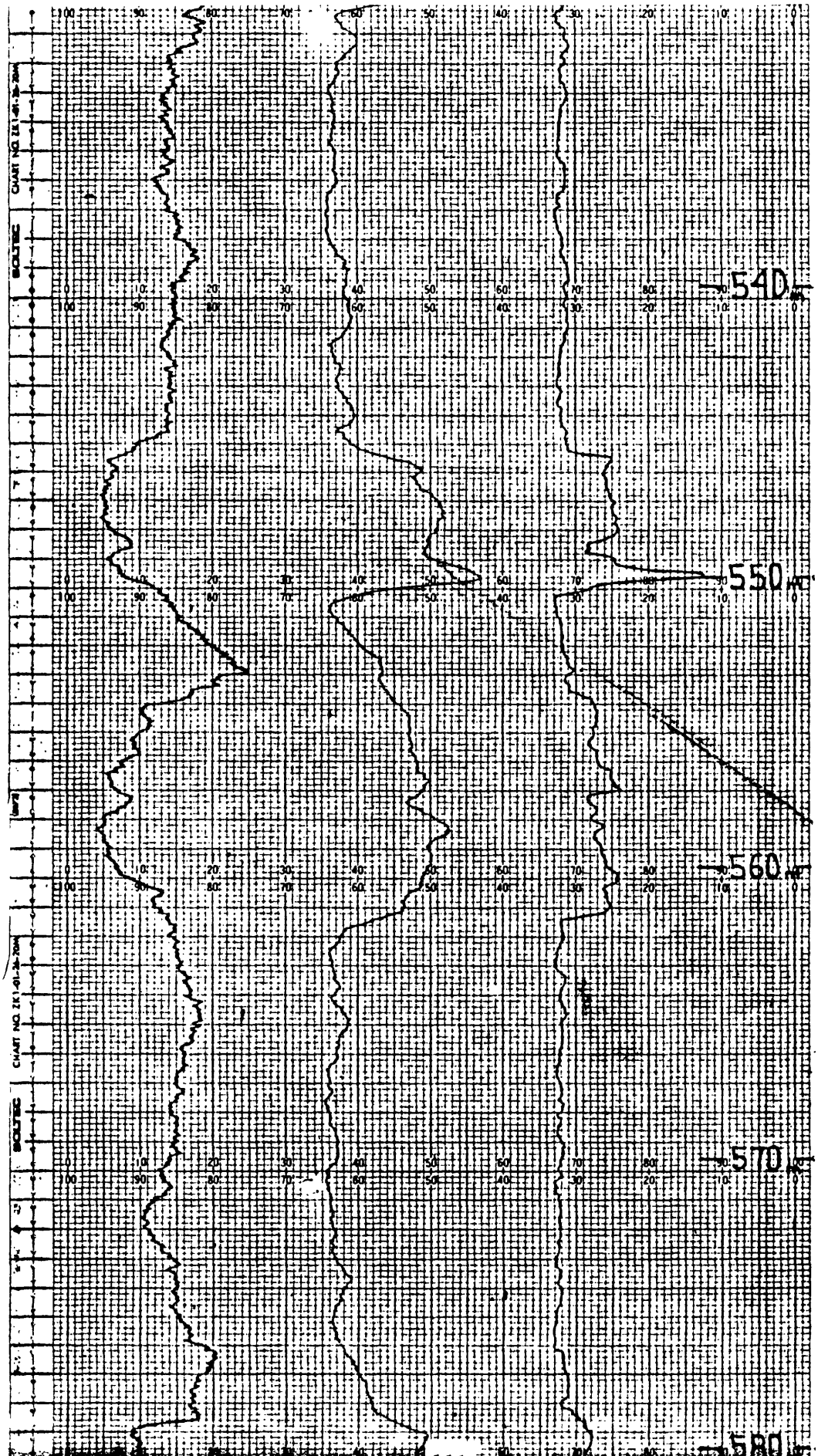
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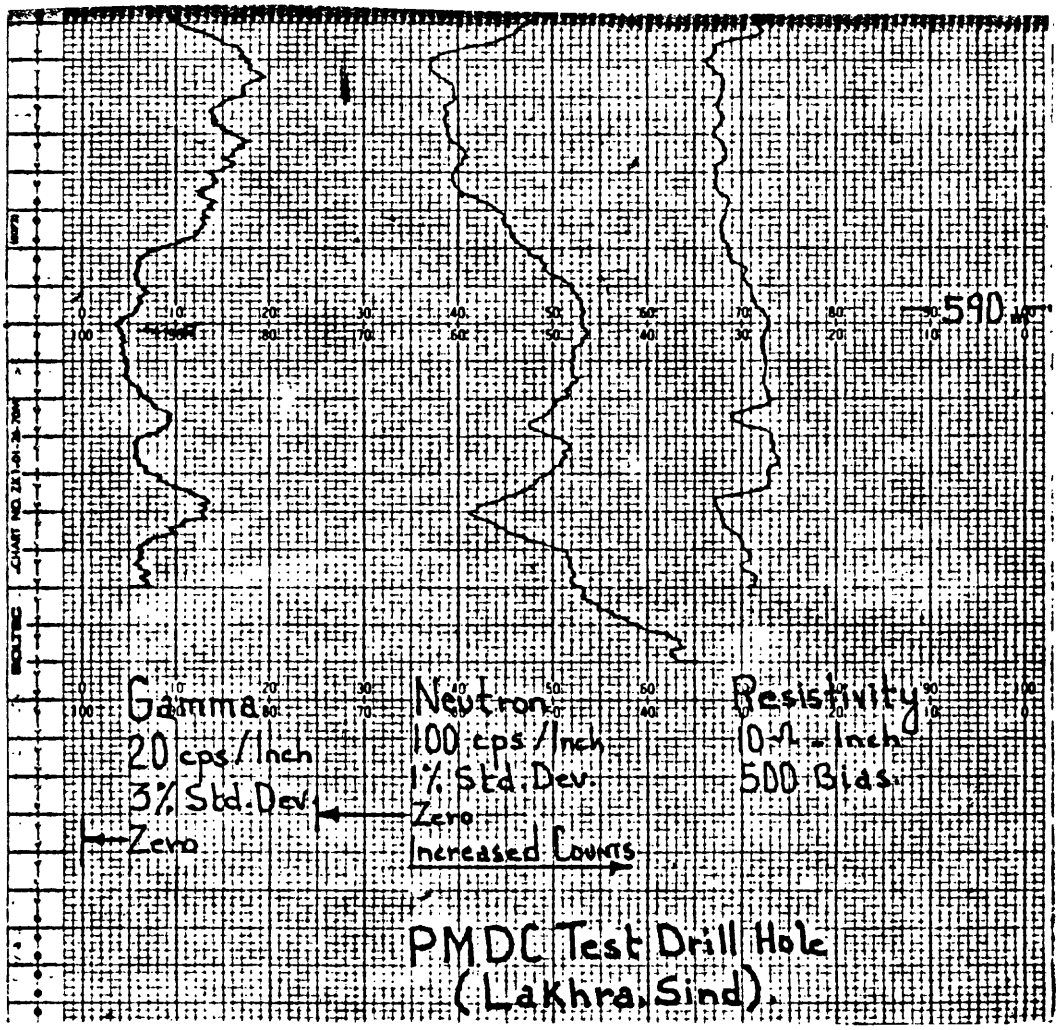

590
Gamma
20 cps/Inch
3% Std. Dev.
Zero
Neutron
100 cps/Inch
1% Std. Dev.
Zero
Increased Counts
Resistivity
0-4-Inch
500 Bias
PMDC Test Drill Hole
(Lakhra, Sind).

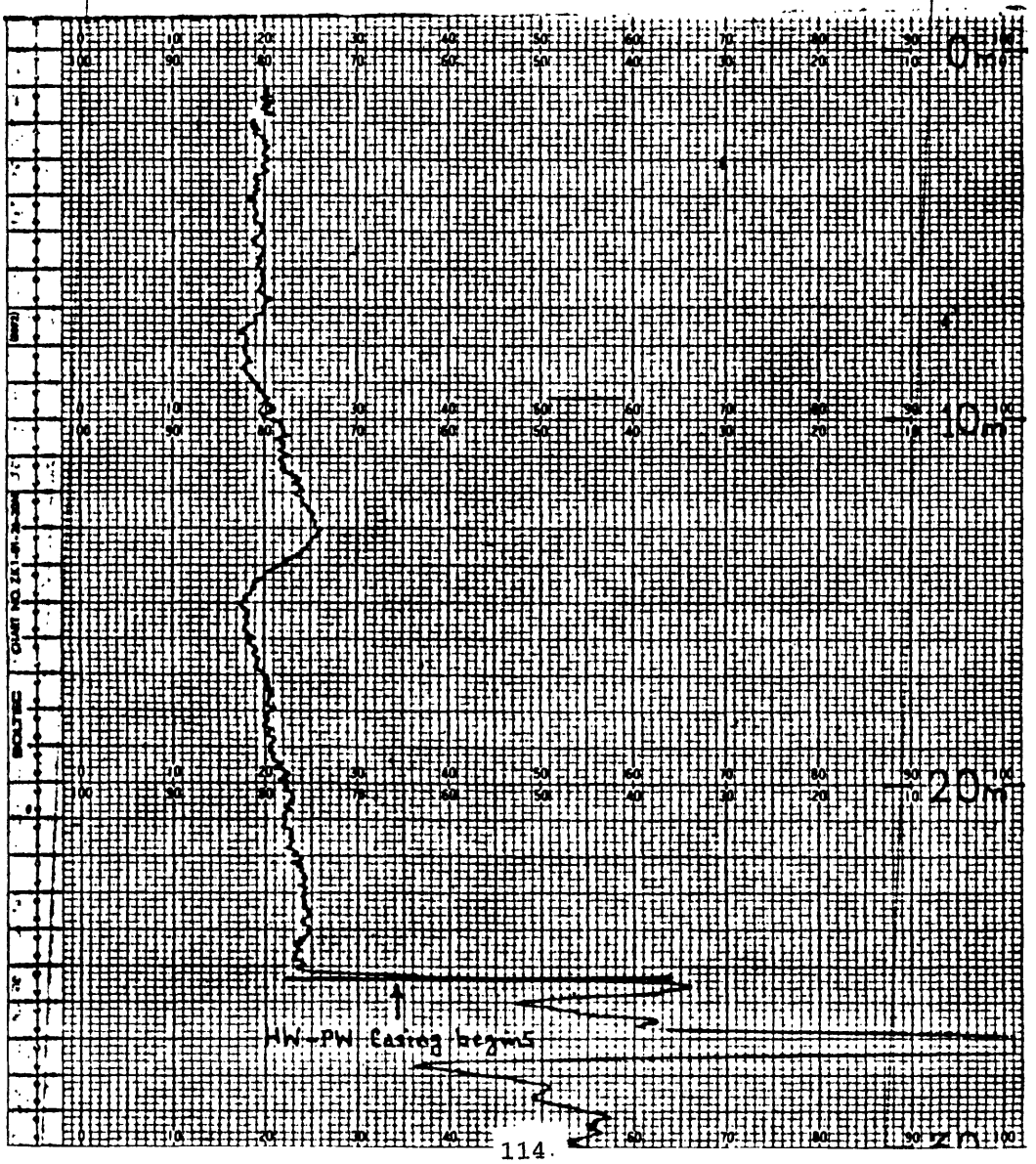
2) 4-Pi Density

GEOSCIENCE ASSOCIATES

HOLE NUMBER: – PMDC Test Drill Hole

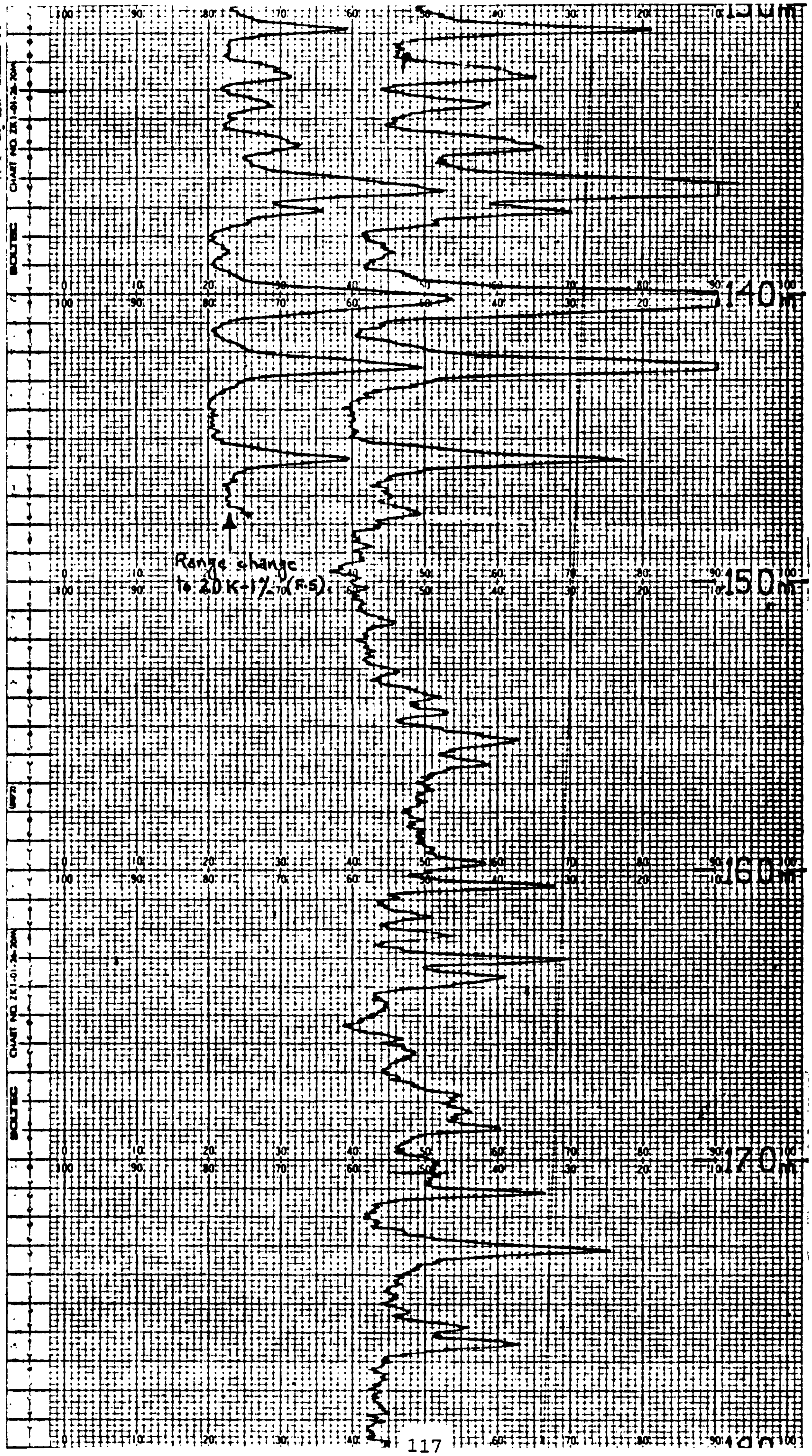
DATE: 21st MARCH, 1988.

LOCATION					HOLE DATA		CLIENT			
STATE/COUNTY SIND PAKISTAN					DEPTH DRILLED: 600 m		CLIENT U.S.G.S – G.S.P.			
REGION LAKHRA.					DEPTH LOGGED: 598m		GEOLOGIST:			
PROJECT					COLLAR ELEV.					
PROSPECT					DIA. Gee FROM TO		UNIT OPERATOR MENTAB-MWB			
SEC. TWP. RNG.					DIA. Caliper FROM TO		UNIT NO. PL-2 OFFICE			
					DIA. log FROM TO		BOULDER COLORADO U.S.A.			
TYPE	GAM		4 Pi Density		BOREHOLE MEDIUM H₂O+Mud.		ELECTRIC			
LOGGED DEPTH			598m		FLUID LEVEL 64.3 m		TYPE	RESIST	S.P.	
RANGE (f.s.)			10K		CASING DATA		LOGGED DEPTH	FT.		FT.
%STD DEV			1%		WALL SIZE 1/4"		SCALE			
PAPER SPEED			1–1		I.D. HW=4" PW = 5"		PAPER SPEED			
LOG SPEED			6–1		CASED FROM 0 TO 25.3m		LOG SPEED			
BKGND. COUNT					CASING TYPE HW and PW.		FINE ADJ.			
PROBE NO.			6D-1		SAMPLE DATA					
SIZE (dia.)			13/4"		NON-CORED HOLE ☐ CORED HOLE ☒					
K-FACTOR					SAMPLED INTERVAL	SAMPLE TYPE				
DEAD TIME			2.				CALIPER			
STANDARD					REMARKS		LOGGED DEPTH			FT.
DIGITAL DATA					Open Hole		SCALE			
PRINT INTERVAL							PAPER SPEED			
TIMEBASE							LOG SPEED			
							ARM LENGTH			IN
							MAX DEP.			IN
DENSITY CALIBRATION							VERTICAL DEV.			
ALUMINUM							DEPTH			
LUCITE							INCLIN.			
							BEARING			



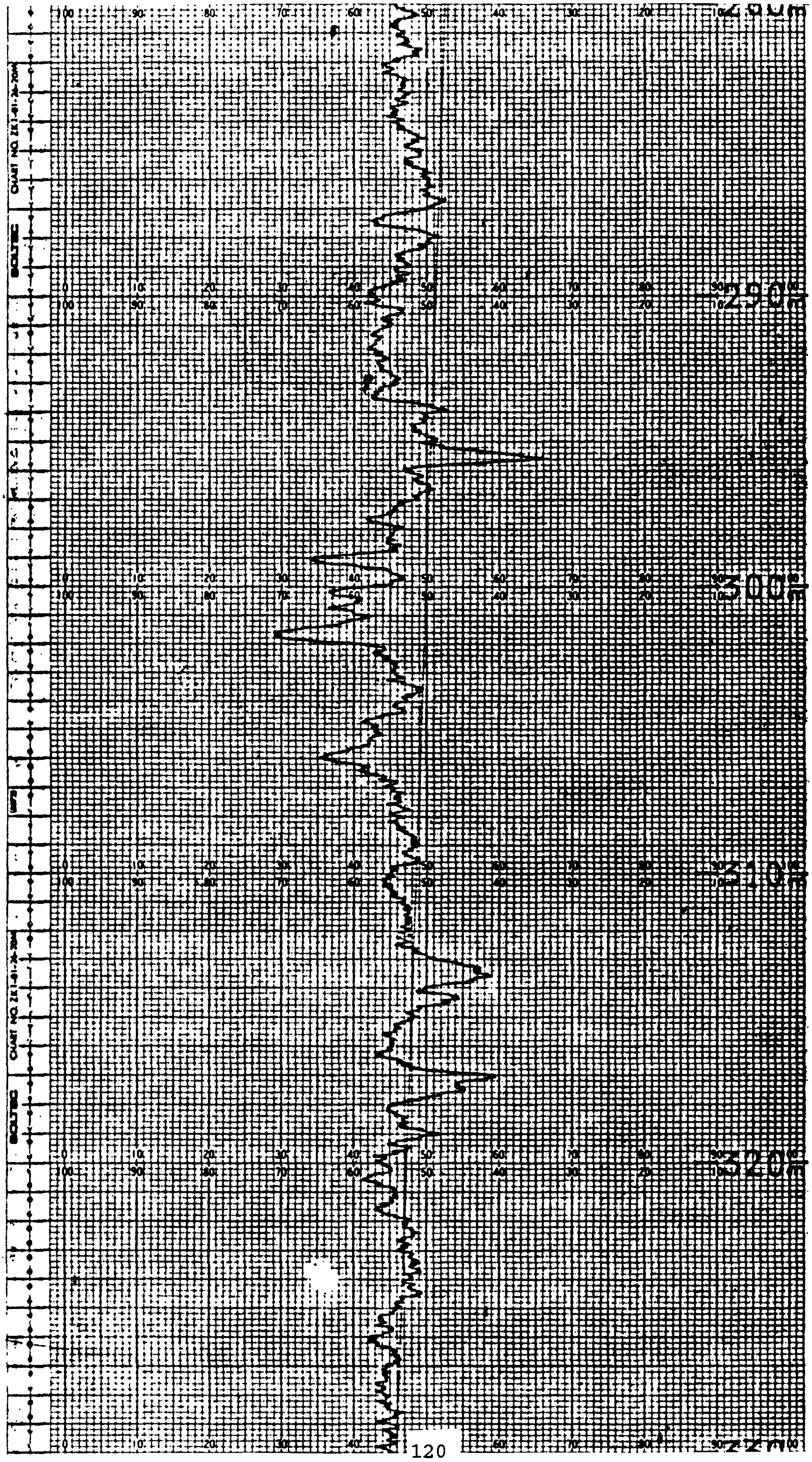
40m
50m
60m
Fluid level
20m

90m
100m
110m
120m


140m
150m
160m
170m
Range change
to 20K-1%(F.S).
SOLTEC CHART NO. ZK1-01-26-20M

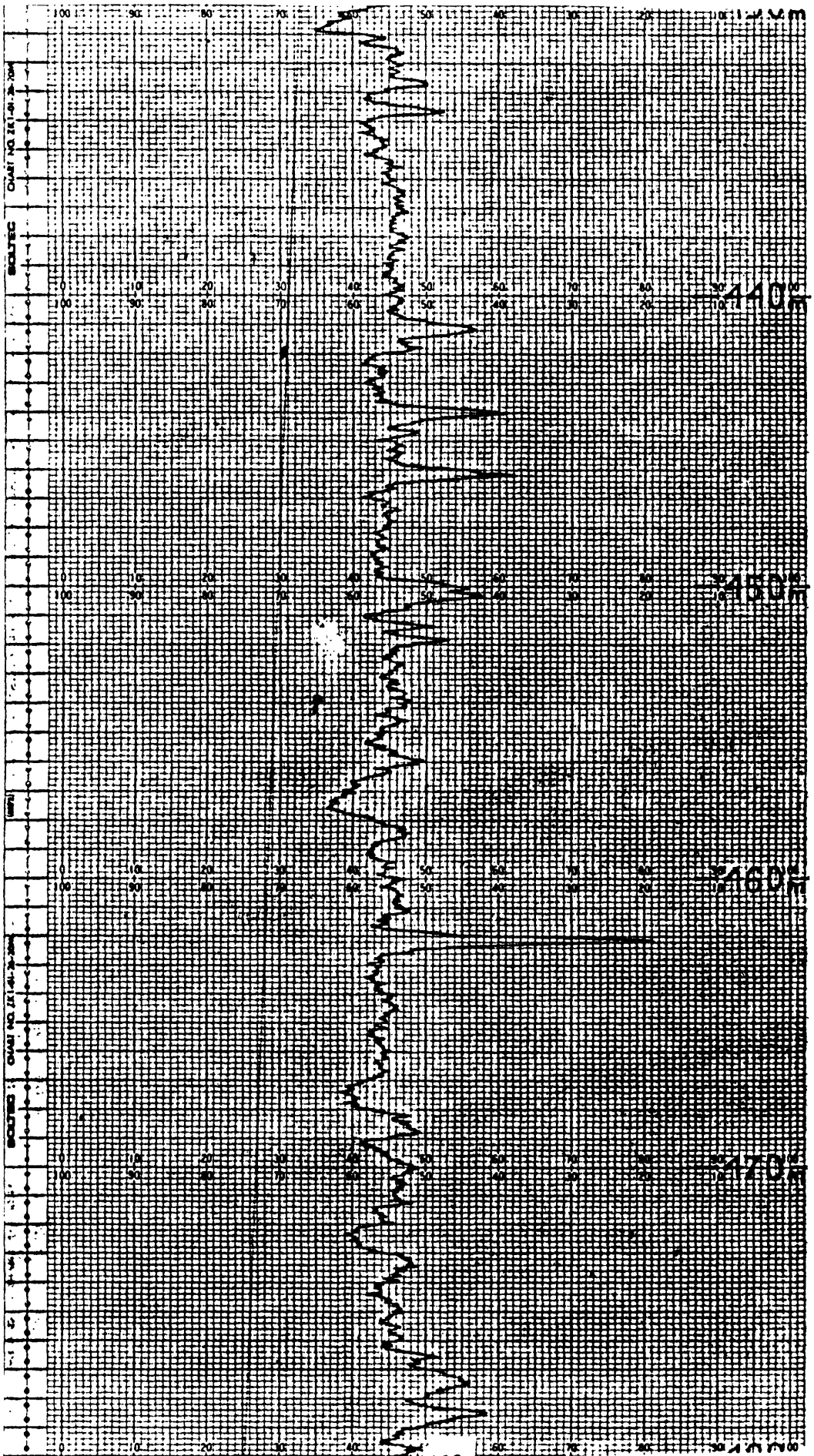
190m
200m
210m
220m

2400
2500
2600
2700

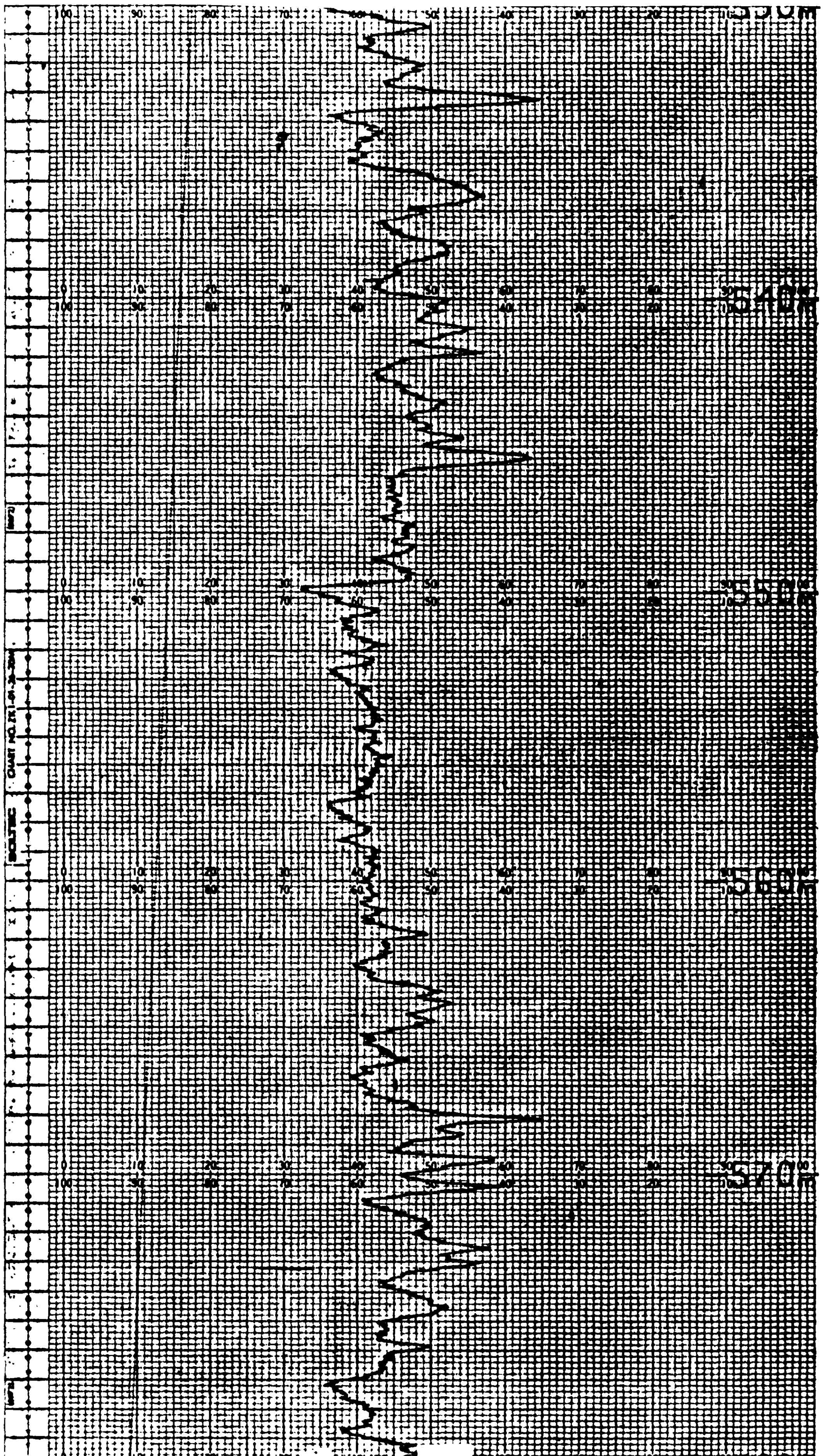

290m
300m
310m
320m

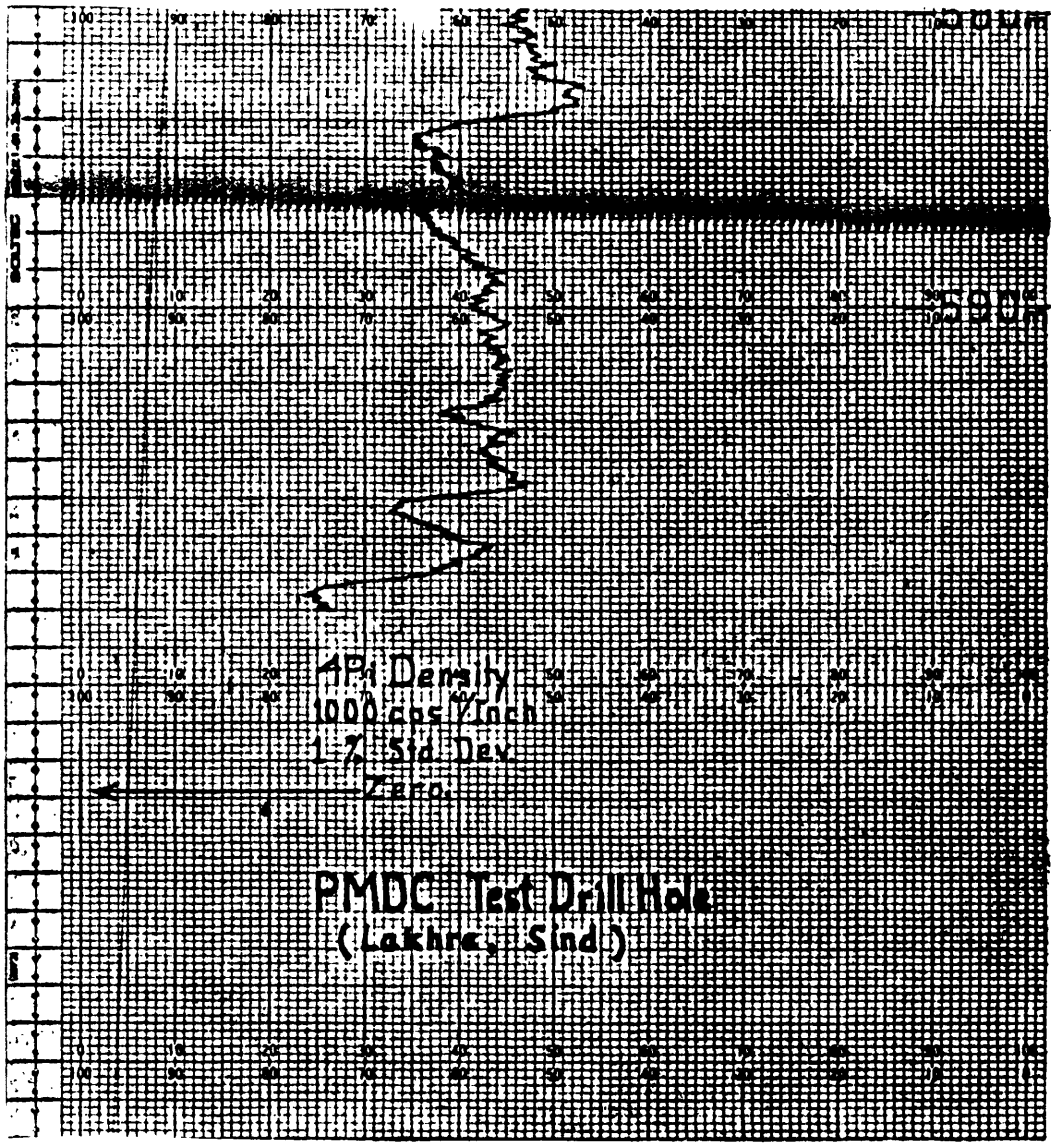
340m
350m
360m
370m

390m
400m
410m
420m


SOLTEC
440m
450m
460m
470m

490m
500m
510m
520m


540m
550m
560m
570m
CHART NO.


API Density
1000 cps/Inch
1/2 Std Dev.
Zero
PMDC Test Drill Hole
(Lakhra, Sind)

3) 3 Arm Caliper

GEOSCIENCE ASSOCIATES

HOLE NUMBER: PMDC Test Drill Hole

DATE: 21st MARCH, 1988.

LOCATION

STATE/COUNTY SIND PAKISTAN
REGION LAKHRA.
PROJECT
PROSPECT
SEC TWP RNG

TYPE	GAM			
LOGGED DEPTH				
RANGE (f s.)				
%STD DEV				
PAPER SPEED				
LOG SPEED				
BKGND COUNT				
PROBE NO.				
SIZE (dia.)				
K FACTOR				
DEAD TIME				
STANDARD				

DIGITAL DATA

PRINT INTERVAL				
TIMEBASE				

DENSITY CALIBRATION

ALUMINUM				
LUCITE				

HOLE DATA

DEPTH DRILLED: 600 m
DEPTH LOGGED: 442 m
COLLAR ELEV
DIA FROM TO
DIA FROM TO
DIA FROM TO
BOREHOLE MEDIUM H.O + Mud.
FLUID LEVEL

CASING DATA

WALL SIZE 1/4"
I.D. HW = 4" I.D. PW = 5"
CASED FROM 0 TO 253m
CASING TYPE HW and PW.

SAMPLE DATA

NON-CORED HOLE ☐ CORED HOLE ☒

SAMPLED INTERVAL	SAMPLE TYPE

REMARKS

CLIENT

CLIENT U.S.G.S - G.S.P.
GEOLOGIST:
UNIT OPERATOR MUJIB-MEHTAB
UNIT NO. PL-2 OFFICE BOULDER COLORADO U.S.A.

ELECTRIC

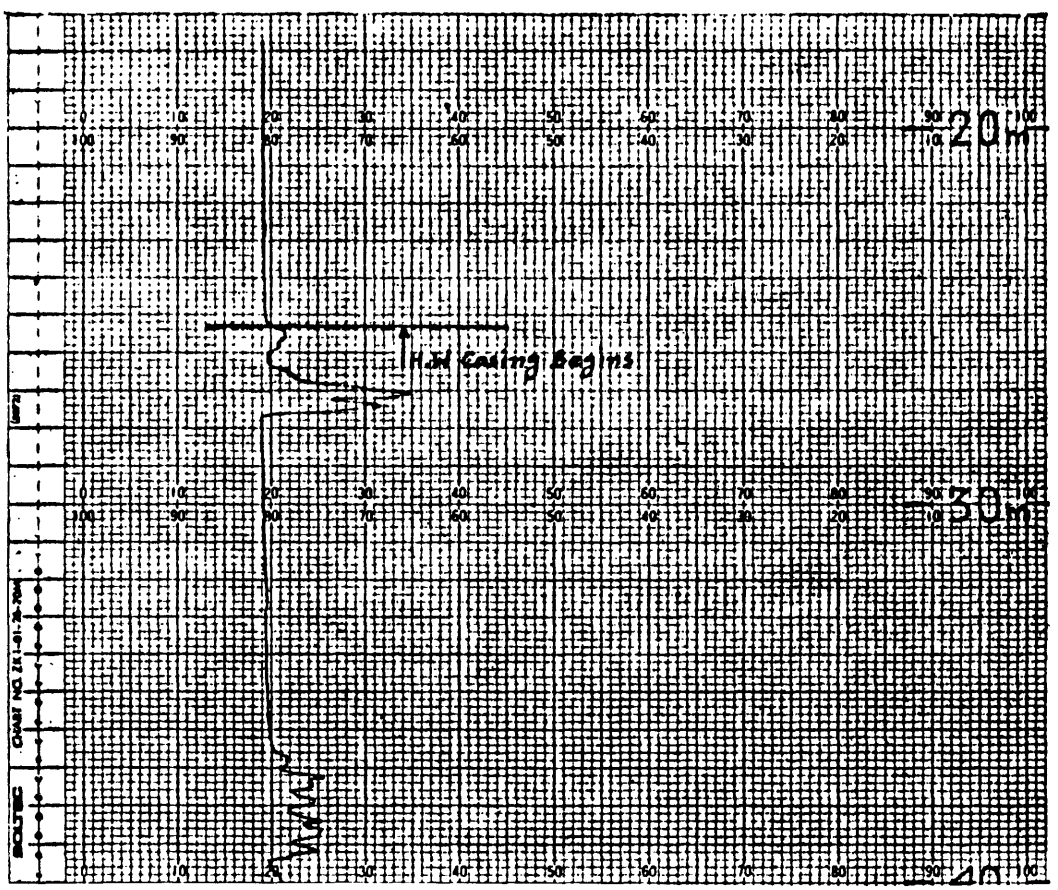
TYPE	RESIST	S.P.
LOGGED DEPTH	FT.	FT.
SCALE		
PAPER SPEED		
LOG SPEED		
FINE ADJ		

3 ARM CALIPER

LOGGED DEPTH 442 m FT.
SCALE 1" Deflection = 1" Dia -
PAPER SPEED 1-1 m
LOG SPEED 6-1
ARM LENGTH 12 IN
MAX DEF 29 IN

VERTICAL DEV.

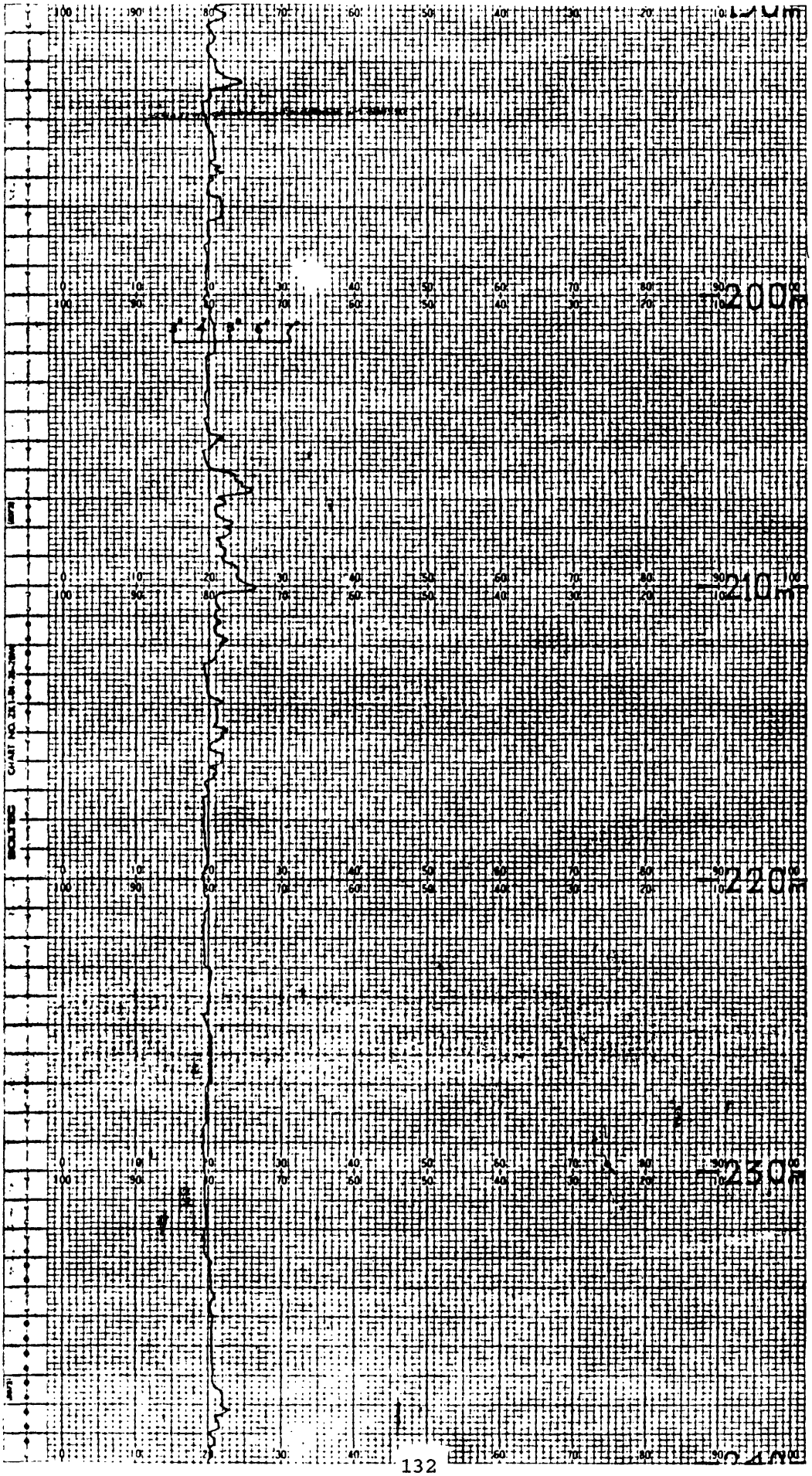
DEPTH					
INCLIN.					
BEARING					



50m
60m
70m
80m

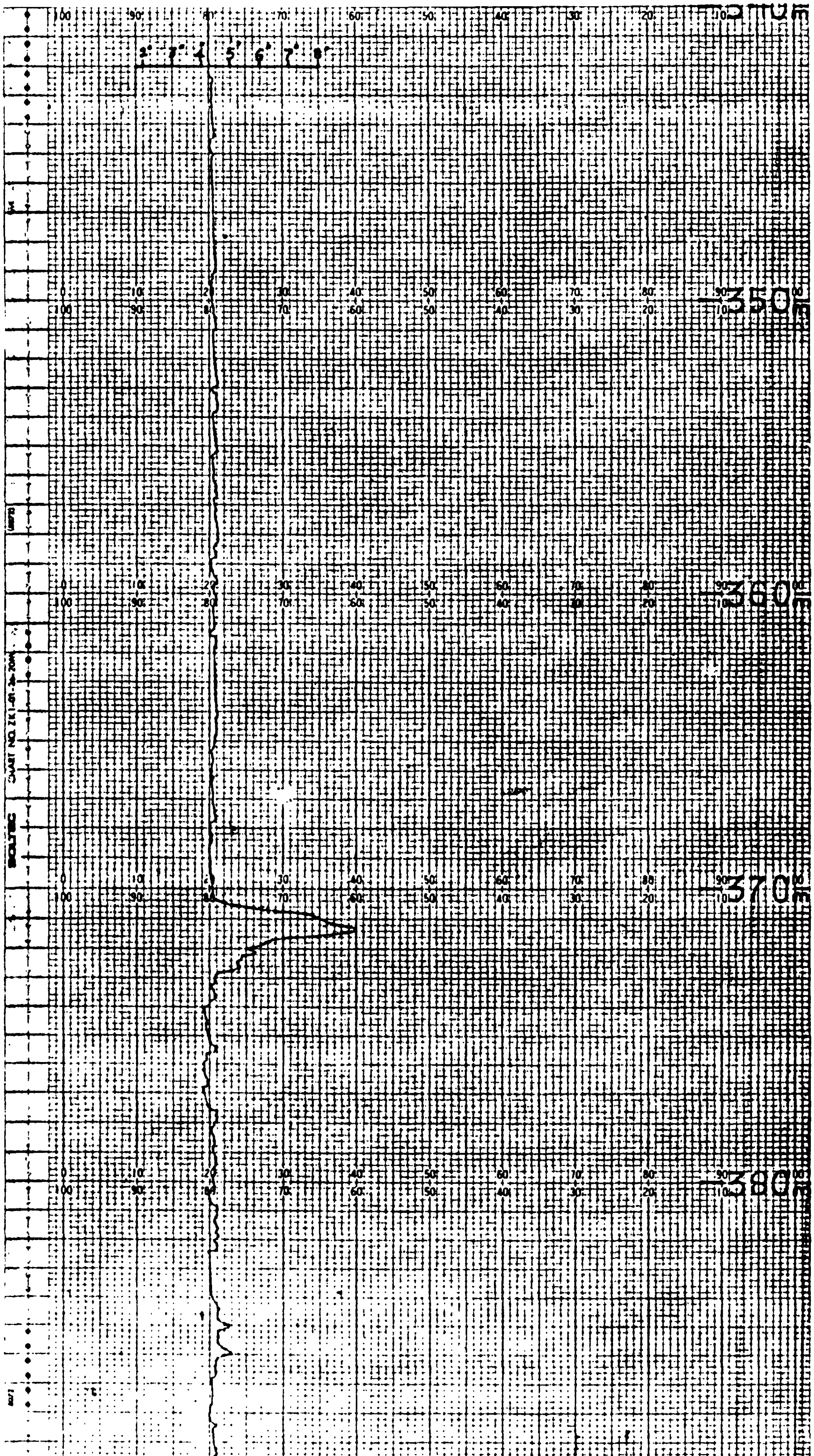
SOLTEC
CHART NO. ZA1-01-28-20M
100 m
110 m
120 m
130 m

BIOLTEC
CHART NO 2K1-01-26-70M
150m
160m
170m
180m

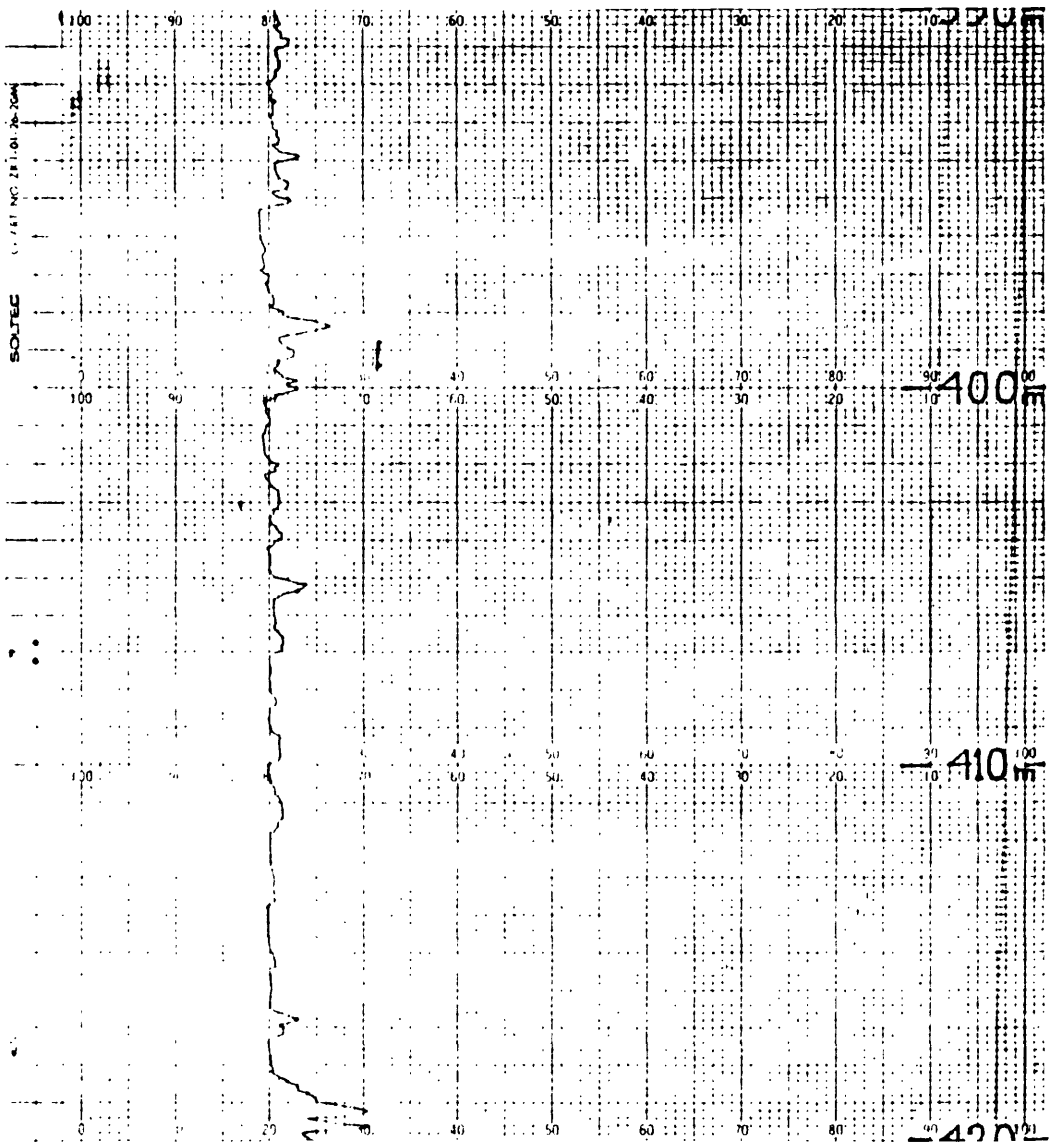

200m
210m
220m
250m

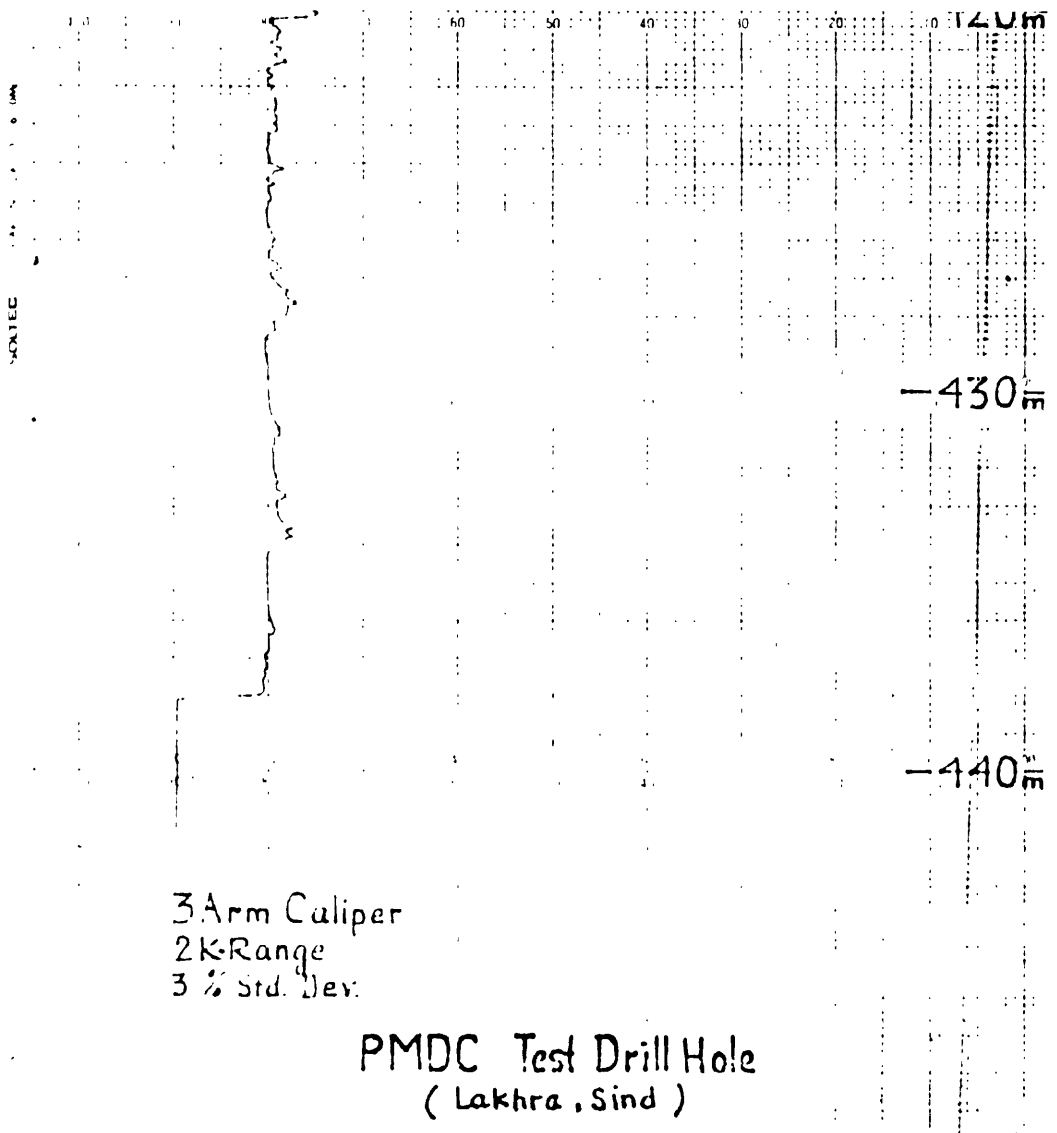
250
260
270
280

300
310
320
330



350m
360m
370m
380m


SOLTEC
400 m
410 m


60
50
40
30
20
10
0
120m
430m
440m
3 Arm Caliper
2 K-Range
3 % Std. Dev.
PMDC Test Drill Hole
(Lakhra , Sind)