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OUTCROP GAMMA-RAY ANALYSIS OF THE CRETACEOUS MESAVERDE GROUP: JICARILLA APACHE INDIAN RESERVATION, NEW MEXICO

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By:
Jennie Ridgley
Robyn Wright Dunbar

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Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Ginny Weyland, Project Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by
U.S. Geological Survey
MS 939 Box 25046 DFC
Denver, CO 80225

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Abstract

This study, designed to accompany the 1999 report, *Outcrop Analysis of the Cretaceous Mesaverde Group: Jicarilla Apache Reservation, New Mexico,* presents the results of an outcrop gamma-ray survey of six selected measured sections included in the original report. The primary objective of this second study is to provide a baseline to correlate from the outcrop and reservoir model into Mesaverde strata in the San Juan Basin subsurface. Outcrop logs were generated using a GAD-6 gamma-ray spectrometer that simultaneously recorded total counts, potassium, uranium, and thorium data.

Taken together, the sections selected for outcrop gamma-ray analysis display the full lateral and vertical range of sequence stratigraphic and reservoir relationships seen in the field study. Facies represented include vertically stacked marine shoreface parasequences (Point Lookout Sandstone), a variety of nearshore estuarine and fluvial strata (Point Lookout Sandstone and Menefee Formation), and shelf sandstone (Cliff House Sandstone). These units reflect deposition within the highstand and lowstand/transgressive systems tracts of two major depositional sequences near the seaward Mesaverde Group pinchout. A roughly west-northwest trending line projected into the basin subsurface will help to distinguish two distinctly different outcrop log profile patterns. South of this line, complete coarsening-upward shoreface log signatures may be expected. Reservoir geometry will be most influenced by shore-parallel (shoreface) stratigraphic elements. North of this line, incomplete, or truncated, shoreface log signatures signal the presence of one or more sequence boundaries within the section. Reservoir elements will include both shore-parallel trends (shoreface) and complex shore-perpendicular trends (incised valleys).

Purpose

This study, designed to accompany the 1999 report, *Outcrop Analysis of the Cretaceous Mesaverde Group: Jicarilla Apache Reservation, New Mexico,* presents the results of an outcrop gamma-ray survey of six selected measured sections included in the original report. The primary objective of this second study is to provide a baseline to correlate from the outcrop and reservoir model into Mesaverde strata in the San Juan Basin subsurface.

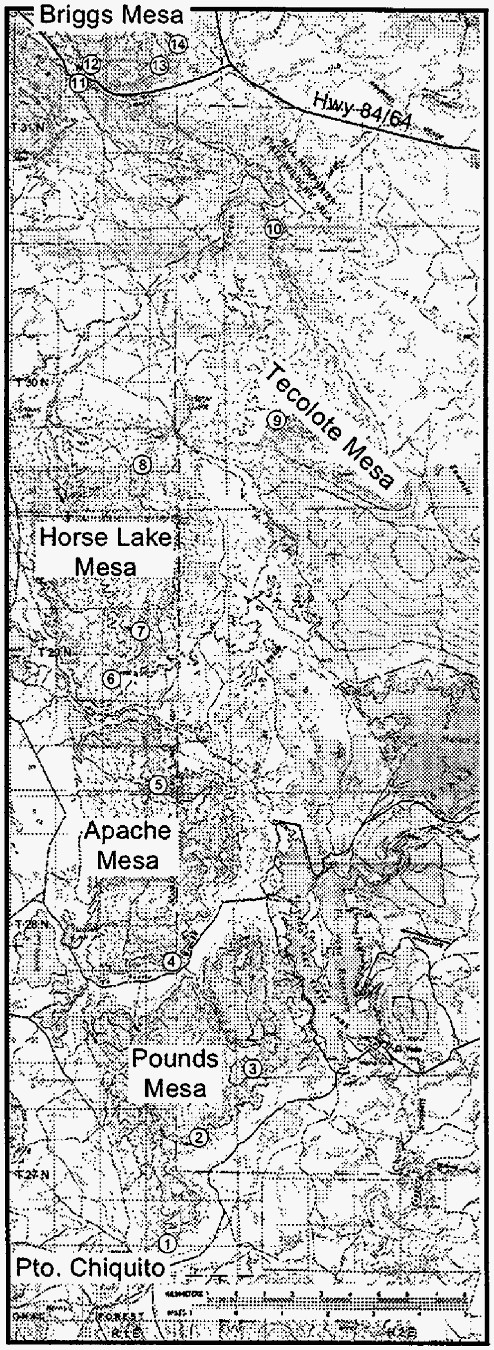
Methods

Six of the original fifteen measured sections were selected for outcrop gamma-ray survey (Fig. 1) based upon the range of reservoir units represented, location within the study area, and accessibility with respect to the somewhat cumbersome equipment. In terms of sequence stratigraphic relationships, these six sections reflect deposition within the highstand and lowstand/transgressive systems tracts of two major depositional sequences. Facies represented include vertically stacked marine shoreface parasequences (Point Lookout Sandstone), a variety of nearshore estuarine and fluvial strata (Point Lookout Sandstone and Menefee Formation), and shelf sandstone (Cliff House Sandstone). Details of these units and their correlations are found in the main report.

The U. S. Geological Survey supplied a GAD-6 gamma-ray spectrometer, which simultaneously collected total count (TC), potassium (K), uranium (U), and thorium (Th) data at each site. Sampling interval was every 2.5 feet, with deviations from that due to accessibility, cover, or local facies variability.

Figure 1: (right) Base map of the study area from 1:100,000 Chama New Mexico-Colorado map showing major geographic localities and locations of measured sections 1 through 14 (circles).

Outcrop gamma-ray data reported in this study are from measured sections 2, 4, 7, 9, 11, and 12.



Count duration per sample was 90 seconds. Outcrop and background data are reported as raw counts for this study (Appendix 1). To calculate %K, ppm eU, and ppm eTh from these raw counts, a set of calibration equations unique to this spectrometer must be applied:

$$K = 0.001113*(Ck-85) - 0.001004*(Cu-44) - 0.0000706*(Cth-27)$$
$$eU = 0.011773*(Cu-44) - 0.008183*(Cth-27)$$
$$eTh = 0.030313*(Cth-27)$$

where: Ck, Cu, Cth are the total counts recorded in the K, U, and Th windows respectively and x* are the predetermined calibration and stripping constants

Results

This section compares vertical gamma-ray trends to observed lithofacies and interpreted depositional environments for each of the six measured sections. Figure 2 is a general legend for all symbols used in this report. Figures 3-8 are composite diagrams that compare individual K, U, Th, and TC profiles to interpreted depositional environment. These figures are especially useful for viewing an entire vertical section in compressed format. Detailed measured section data in Appendix 2 allows specific comparison of total count profiles to rock type, grain size, and sedimentary structures, as well as to interpreted depositional environment. Individual beaches mentioned below and in the accompanying figures (i.e. North Llaves Beach, Pounds Mesa Beach, etc.) are those defined and described in the main report. Plates 1 and 2 from that document show the relative relationships and correlations of these beaches throughout the study area.

DEPOSITIONAL ENVIRONMENTS

nonmarine/transitional	OB	overbank
	SW	swamp
	CH	channel
	EST	estuarine
	TF	tidal flat
marine	FS	foreshore
	USF	upper shoreface
	MSF	middle shoreface
	LSF	lower shoreface
	OT	offshore transition

(gap) = data missing due to cover or inaccessibility

SB1 = sequence boundary 1

SB2 = sequence boundary 2

FS/SB1 = combined flooding surface and sequence boundary

Figure 2: Symbols and terminology used in figures 3-8 and appendices.

Measured Section 2 (Pounds Canyon): Vertically stacked, coarsening-upward beach deposits dominate this section, which shoaled upward to the level of the North Llaves and (lower) Puerto Chiquito beaches. The section displays a full range of intertonguing offshore transition and shoreface lithofacies. Composite gamma-ray data (Fig. 3) display this relationship as a general upward trend (0-180 ft) of decreasing count values and increasing "blockiness", or uniformity, particularly evident in the TC, Th, and U profiles. Individual coarsening-upward shoreface cycles (parasequences) separated from one another by marine flooding surfaces are also resolvable within this general trend at a smaller-scale (best viewed in detailed section data; Appendix 2). A channel/estuarine unit (192-220 ft), that aggraded during local base level rise and was overstepped by foreshore deposits of the lower Pounds Mesa Beach, caps the shoreface package with an interval of subtly increasing count values, again best displayed by the total count, Th and U profiles. This increase in count values corresponds to an overall subtle fining-upward trend in the channel-to-foreshore depositional unit.

This measured section displays all of the major attributes of the highstand systems tract prograding shoreface complex in which individual beaches are stacked vertically and intertongued with both offshore mudrocks (below) and non-marine fluvial strata (above). The gamma-ray signature between 0 and 230 ft captures these attributes and would be useful for recognizing these relationships in the subsurface. It is important to note also that this complete gamma-ray

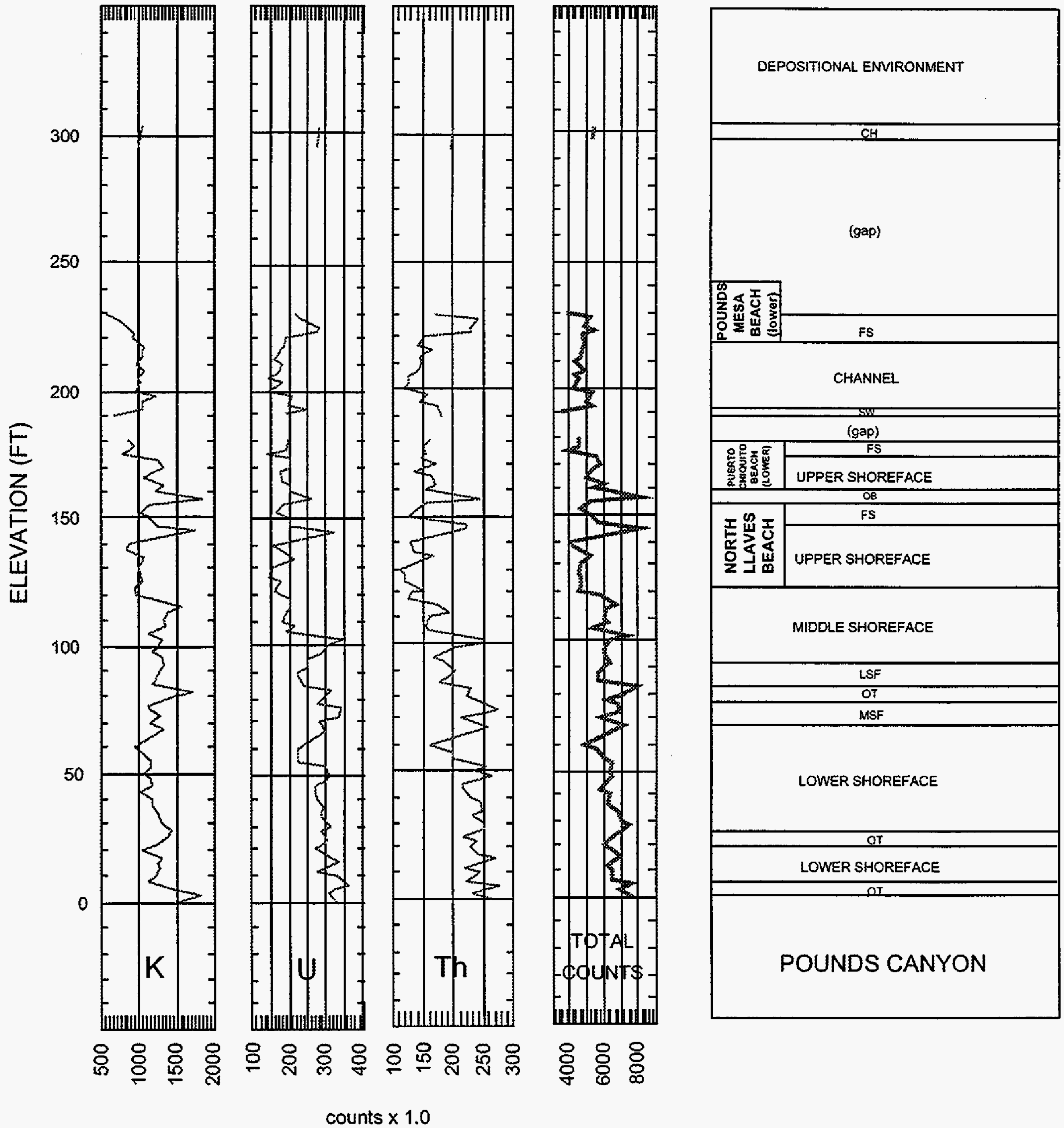


Figure 3: Composite GAD-6 gamma-ray spectrometer data for section 2: Pounds Canyon.

signature will serve as a model to identify *missing* components, as well. Sections at which this signature is incomplete (for instance, where the blocky upper packet is lacking) may be strong candidates to contain erosional sequence boundaries (discussed in more detail for sections 4, 9, 11, and 12.)

Measured Section 4 (Apache Mesa South): Located down depositional dip from measured section 2, the section at Apache Mesa is also dominated by vertically stacked coarsening-upward shoreface deposits. Here, however, much of the sand-rich shoreface interval from measured section 2 has undergone transition to more offshore, mud-rich facies and new beaches (upper Puerto Chiquito Beach, Pounds Mesa Beach, and Stinking Lake Beach) dominate the section. Composite gamma-ray data (Fig. 4) for the lower 150 ft of the section record this offshore increase in mud-dominated facies as a generally consistent trend in average values (seen in total count, Th, U, and K) marked by pronounced high-count spikes. A strong correspondence exists between these high gamma-ray deflections and the mudrock flooding surfaces that bound thin (approximately 10-15 ft thick) offshore transition to lower shoreface parasequences (Appendix 2).

Unfortunately, the massive shoreface cliff (approx. 148-195 ft) at this section was inaccessible and no gamma-ray data exist for this interval. Presumably an upward trend of decreasing count values and increasing "blockiness" (similar to that seen between 80-200 ft at measured section 2) characterizes the zone, culminating in the data for the Stinking Lake Beach upper shoreface (195-235 ft).

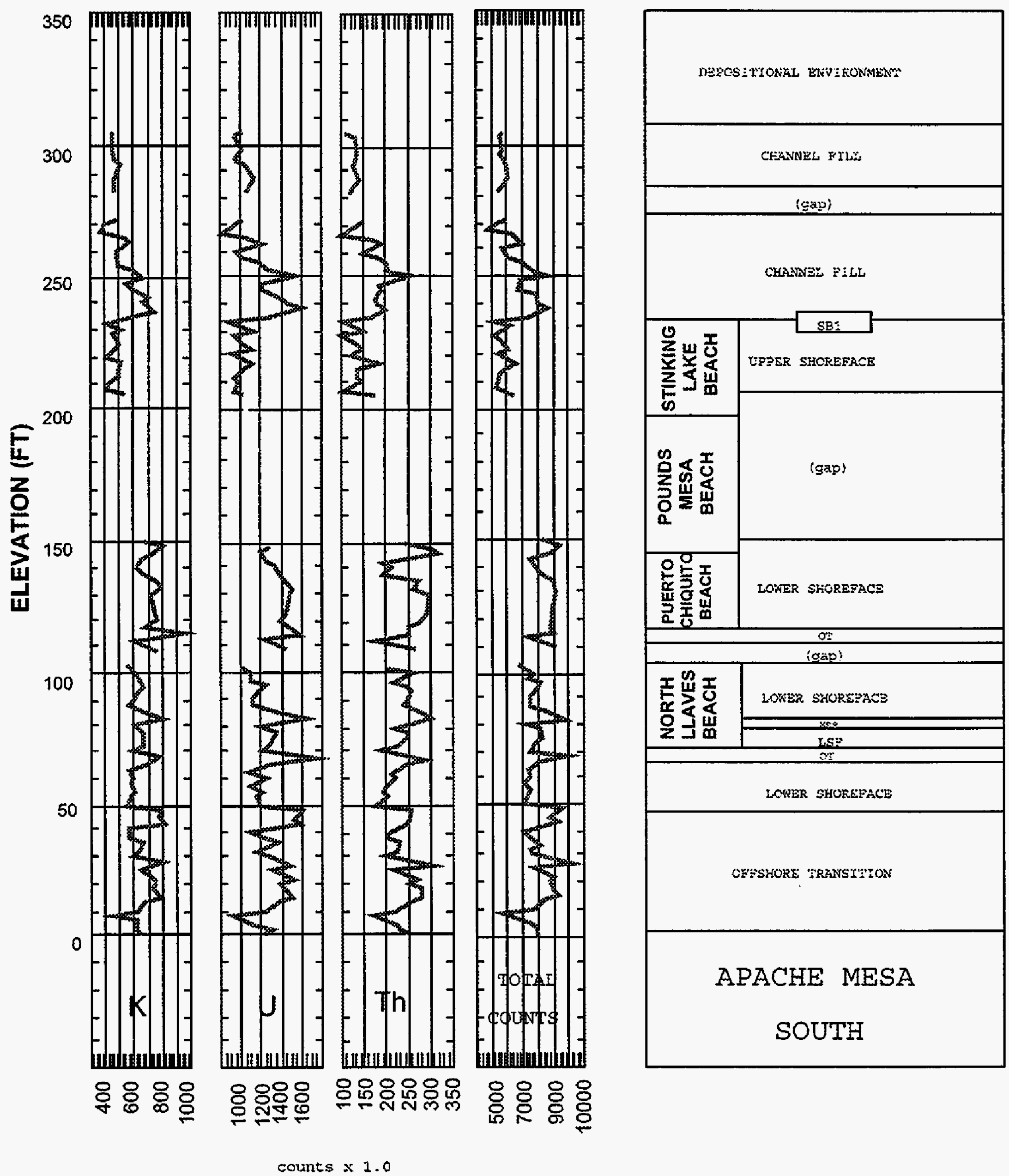


Figure 4: Composite GAD-6 gamma-ray spectrometer data for section 4: Apache Mesa South.

Sequence boundary SB1 separates Stinking Lake upper shoreface sandstone from overlying fluvial channel deposits at about 235 ft. A dramatic positive deflection in total counts, Th, U, and K accompanies this contact. The fluvial sandstone package is much less massive and displays greater bedding variability than the underlying shoreface deposits. The gamma-ray signature (235-270 ft) for this channel fill package is a stacked series of thin (10-15 ft) packets that together constitute an upward trend of decreasing total count, Th, U, and K values. This log signature might be confused with that of a coarsening-upward shoreface profile, although these fluvial outcrops lack corresponding coarsening-upward textural trends and are more variably bedded than a typical shoreface unit. Because proper recognition of this sequence boundary is critical to mapping incised valley reservoir trends into the subsurface, careful consideration should be given to the possibility that an unconformity might "hide" in what superficially appears to be a new shoreface package.

Measured section 7 (Horse Lake Mesa NE): Continuing down depositional dip from sections 2 and 4, measured section 7 contains non-marine strata that lie completely above the SB1 sequence boundary. (The SB2 sequence boundary may lie within the section, but was not correlated into this part of the field area.) The dominant facies in this section are fluvial channel sandstones and organic-rich, heterolithic floodplain deposits. Textural trends in these fine-to-medium grained sandstones are subtle, as are the corresponding trends in the gamma-ray logs (Fig. 5). The interval 0-35 ft contains several fining-upward amalgamated channel scours whose corresponding gamma-ray signatures also exhibit subtle

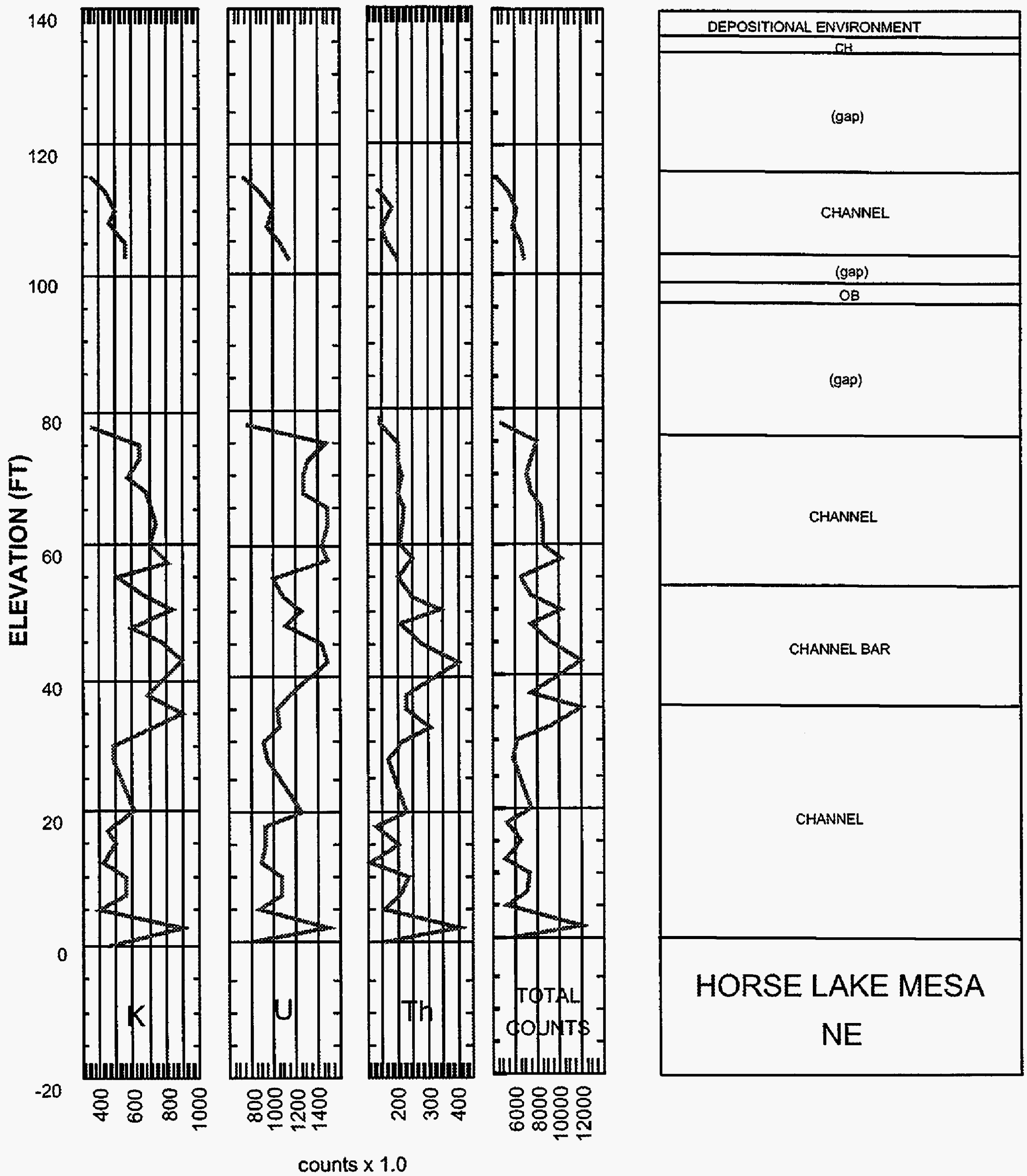


Figure 5: Composite GAD-6 gamma-ray spectrometer data for section 7: Horse Lake Mesa NE.

count increases. Dramatic spikes in total count, K, U, and Th characterize the heterolithic, organic-rich floodplain rocks above 35 ft. Fluvial sandstones above 55 ft display slightly coarsening to uniform textural trends and the corresponding gamma logs reflect this situation with vertically decreasing to uniform total count, K, U and Th signals.

Measured section 9 (Sulphur Canyon): Features present at Sulphur Canyon include a set of shoaling-upward stacked offshore and shoreface parasequences (0-188 ft) that culminate in the lower to middle shoreface sandstones of the Stinking Lake and Stone Lake beaches. Sequence boundary SB1 dissects the Stone Lake shoreface (at 188 ft) and is itself overlain by sand-rich estuarine (bayhead delta) deposits (188-240 ft). The upper 150 ft of the section is floodplain mudrock containing isolated channel sandstone.

Large swings in the total count, Th, U, and K data (fig. 6, Appendix 2) characterize the lower 70 ft of the section (data gap from 70 – 87 ft), where a higher proportion of mudrocks and muddy sandstones are among the data points. As relative sandstone content and grainsize increase upward (90-188 ft), the log signatures lose these extreme excursions, yet still display the thin, jagged character of stacked distal shoreface packets seen at sections 2 and 4. Significantly, however, gamma-ray profiles at measured section 9 never quite achieve the thicker, blocky pattern typical of upper shoreface and foreshore units. *This observation is critical to accurate subsurface correlation.* Upper shoreface deposits are missing at section 9, having been removed by erosion at the SB1 sequence boundary. The "complete" coarsening-upward gamma profile (such

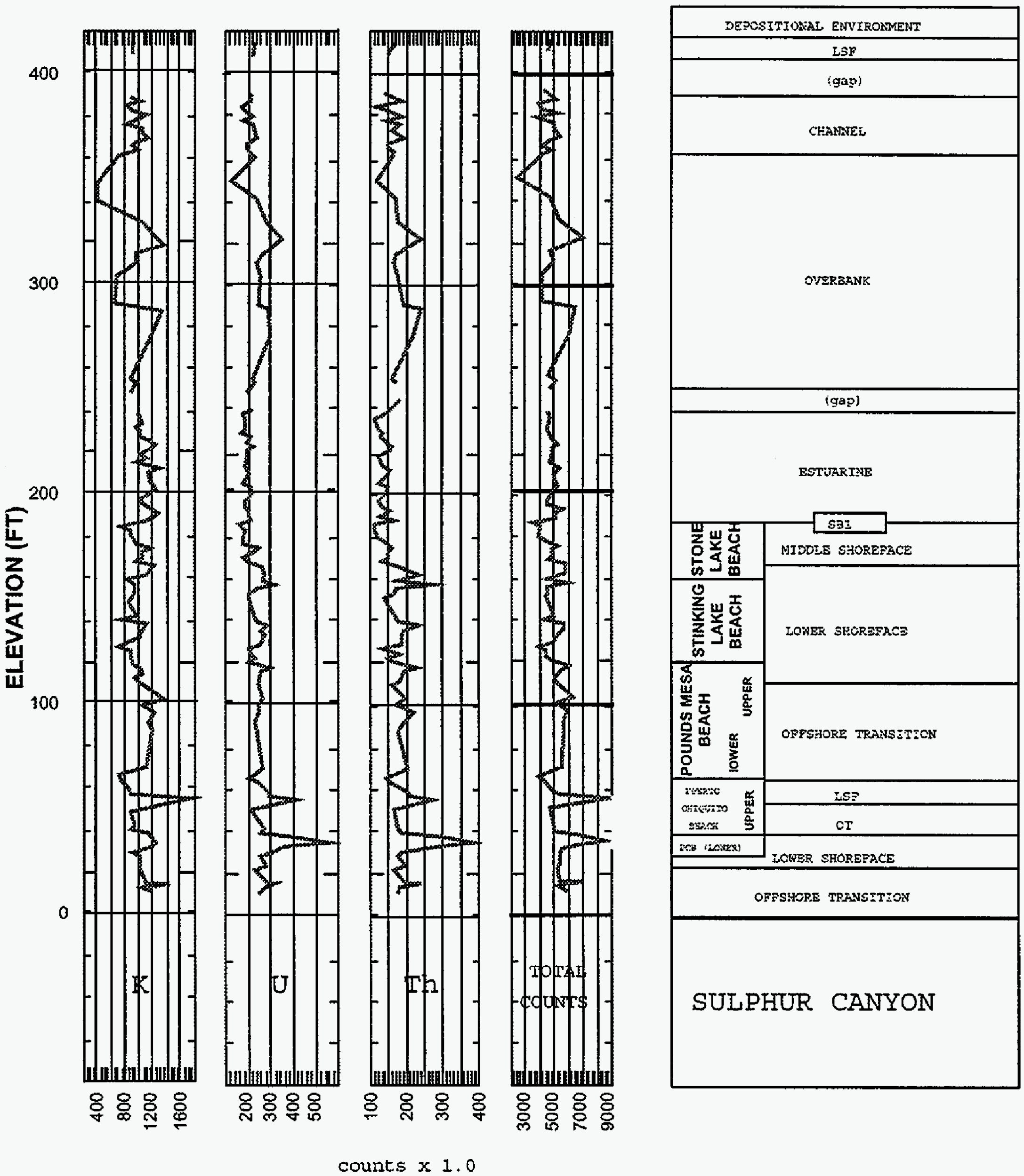


Figure 6: Composite GAD-6 gamma-ray spectrometer data for section 9: Sulphur Canyon.

as that seen in measured section 2) is not present. Instead, estuarine strata directly overlie the middle shoreface, interrupting the standard profile with an unexpected log signature. Outcrops at 188 ft show an abrupt increase in grain size and a dramatic change in bedding character toward thin-bedded, scour and fill surfaces. This change is accompanied in the gamma logs by a deflection toward higher values. Total count, Th, U, and K profiles in the overlying estuarine strata (188 – 240 ft) display a more narrow range of values (i.e. more uniform vertical profile) than underlying shoreface units.

Overlying the estuarine deposits is a 150 ft thick vertical sequence of organic floodplain mudrock and thin fluvial sandstones with significant covered intervals and sparsely distributed gamma-ray data points. This interval was measured strictly for the purpose of reaching the overlying Lewis transgressive surface datum, and does not yield a gamma-ray data set suitable for detailed interpretation.

Measured sections 11 and 12 (Monero Beach Roadcut and Monero Beach North): These two sections are immediately adjacent to one another (Fig 1), with the Monero Beach North section being substantially thicker. Both gamma-ray data sets are provided (Fig. 7, 8, Appendix 2), however this description is based upon the more complete information in section 12, Monero Beach North.

Facies present at Monero Beach North include a set of shoaling-upward shoreface parasequences (0-75 ft) that include, in ascending order, the Stone Lake, Horse Lake and Monero Canyon beaches. Gamma-ray logs for the three shoreface units display subtle decreasing-upward to uniform vertical counts,

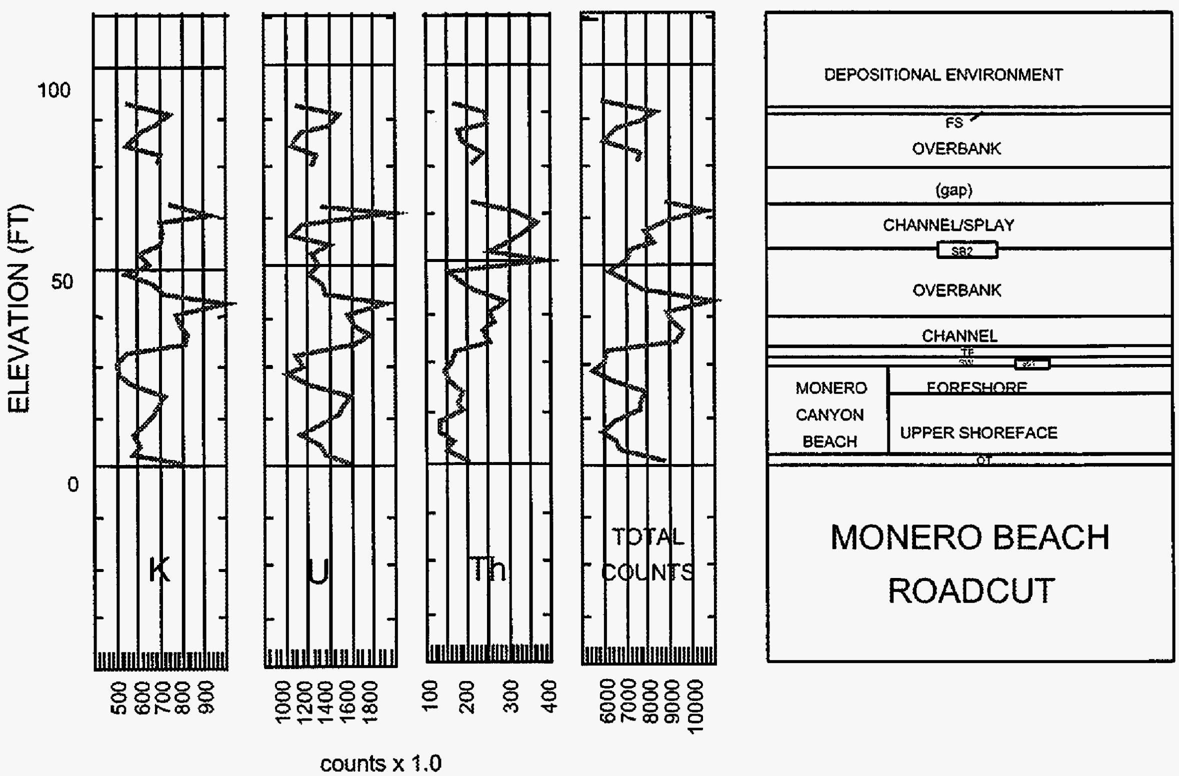


Figure 7: Composite GAD-6 gamma-ray spectrometer data for section 11: Monero Beach Roadcut.

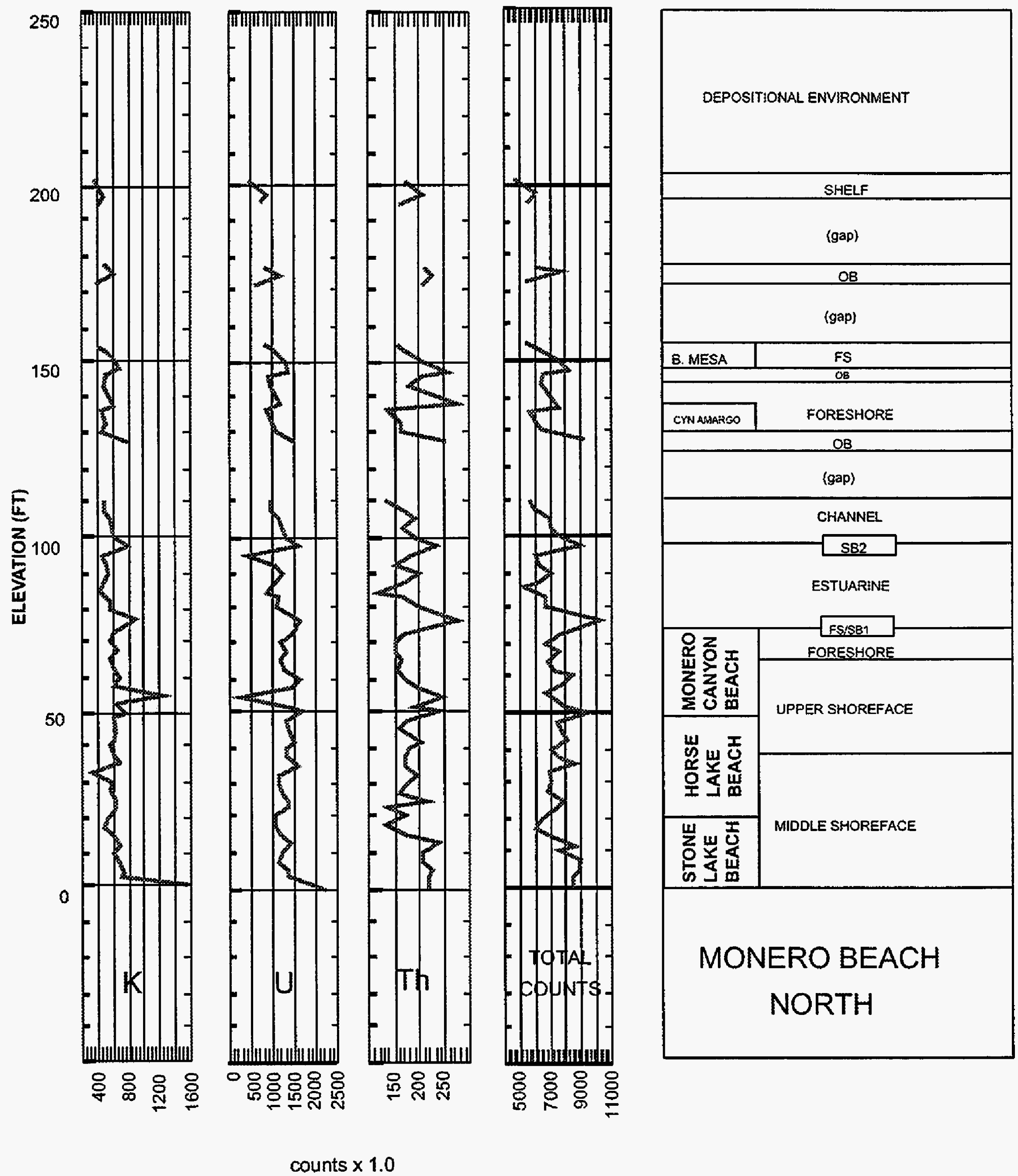


Figure 8: Composite GAD-6 gamma-ray spectrometer data for section 12: Monero Beach North.

which correspond well to the textural trends in the sandstones. Sequence boundary SB1 caps the Monero Canyon beach (at 75 ft) and is itself overlain by both fine-grained and sand-rich estuarine deposits (75-100 ft). Sequence boundary SB2 (at 100 ft) truncates the estuarine package and is overlain by fluvial channel deposits and organic floodplain mudrocks. Strong positive deflections in total count, Th, U, and K mark the base of each sequence boundary. Fluvial and estuarine sandstones display a range of gamma-ray signatures, including both uniform and decreasing-upward count values.

The section above 110 ft is dominated by floodplain deposits, but contains the backstepping, landward limits of two new beaches, Canon Amargo and Briggs Mesa (at 128 ft and 173 ft, respectively). Based upon gamma-ray data only, these thin, backstepping foreshore deposits would be extremely difficult to distinguish from fluvial channels. Just as was the case in outcrop, careful lateral correlation of these units would be required to confidently identify them as new beaches.

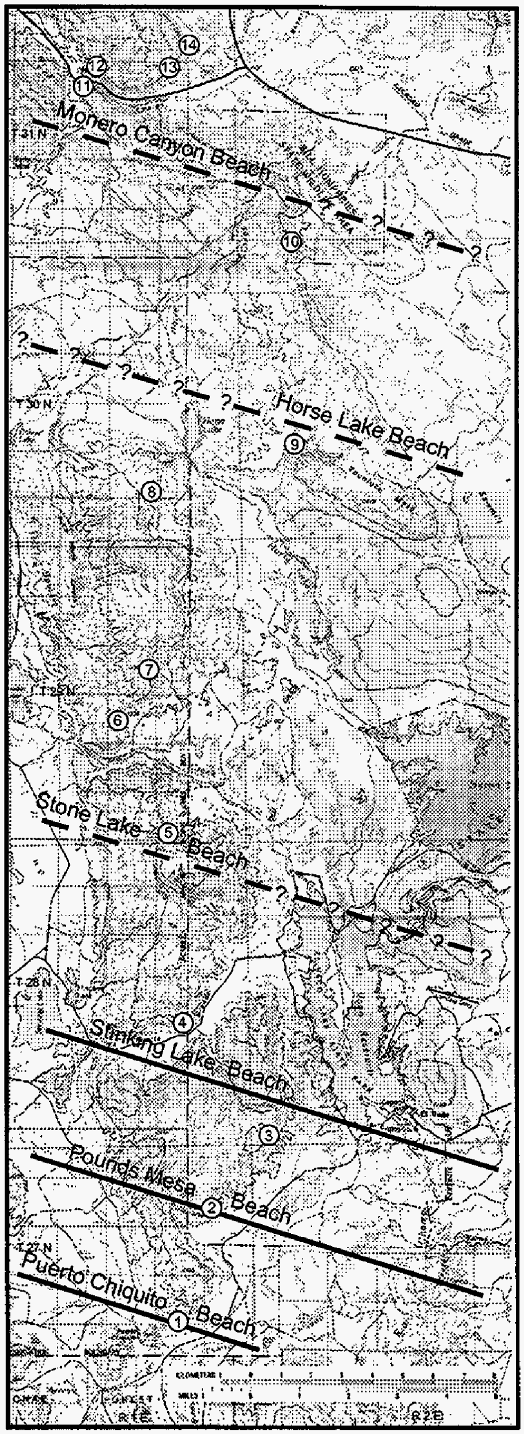
Summary

Outcrop gamma-ray data for the six sections reported in this study provide an initial baseline to link the Mesaverde outcrop model to equivalent strata in the subsurface. While these rocks have long been recognized to record complex intertonguing of marine and non-marine sub-environments, a major result of the outcrop study was to place these strata within an organized sequence stratigraphic framework with the power to predict subsurface stacking patterns and reservoir trends. Recognition of sequence bounding unconformities (SB1, SB2) and the complex juxtaposition of facies above and below will be critical to the successful application of this model to the subsurface.

A reasonable starting point from outcrop would be to project the *approximate* trend of the Stinking Lake beach (Fig. 9) into the basin subsurface. To the south-southwest of this line, more complete shoreface log signatures (similar to that in measured section 2) may be expected and reservoir geometry will be most influenced by shore-parallel (shoreface) stratigraphic elements. To the north-northeast of this line, the likelihood of intersecting a sequence boundary at the top of the Point Lookout increases dramatically. Rocks overlying this boundary may be fine-grained or sand-rich, fluvial or estuarine, so that no "typical " log signature exists for this situation. Rather it will be important to recognize missing shoreface units, such as documented at sections 4 and, more clearly at 9. Reservoir elements will include both shore-parallel trends (below the sequence boundary) and shore-perpendicular (incised valleys) above.

Figure 9: Location of individual beach parasequences in the study area. Foreshore deposits constrain the location of the Puerto Chiquito, Pounds Mesa, and Stinking Lake shorelines. (Foreshore positon of North Llaves beach is located somewhere to the south of the study area, and is therefore not shown.) Position for Stone Lake, Horse Lake, and Monero Canyon beaches is inferred due to later erosion of foreshore and upper shoreface by the SB1 surface.
A line extending the Stinking Lake beach trend into the subsurface will approximately separate two different sequence stratigraphic packages and predicted log pattern signatures. South of this line, complete coarsening-upward shoreface log signatures will dominate. North of this line, coarsening upward shoreface signatures may be truncated by erosion at the SB1 sequence boundary.

See text for details.



Appendix 1

Outcrop gamma-ray data for measured sections described in this study. Data collected using a U.S. Geological Survey GAS-6 gamma-ray spectrometer which simultaneously records total counts, potassium, uranium, and thorium. See text for details.

Measured Section 2: Pounds Canyon

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	7637	1494	333	266	sandy mud	offshore transition
2.5	6904	1827	309	229	ss	offshore transition
5	7591	1459	325	278	sandy mud	offshore transition
7.5	6422	1118	361	222	ss	lower shoreface
10	6490	1219	333	243	ss	lower shoreface
recalib						
12.5	6256	1267	278	217	ss	lower shoreface
15	6901	1239	338	273	ss	lower shoreface
17.5	6586	1297	315	239	ss	lower shoreface
20	5954	1056	272	228	ss	lower shoreface
recalib						
22.5	6301	1244	293	238	sandy mud	offshore transition
25	6670	1392	306	216	ss	offshore transition
27.5	7378	1422	286	254	ss	lower shoreface
30	7033	1312	313	253	ss	lower shoreface
32.5	6687	1281	289	230	ss	lower shoreface
35	6528	1240	290	247	ss	lower shoreface
37.5	6209	1184	292	242	ss	lower shoreface
40	6324	1162	277	227	ss	lower shoreface
42.5	5773	1021	270	215	ss	lower shoreface
45	6243	1174	269	216	sandy mud	offshore transition
47.5	6430	1150	305	266	ss	lower shoreface
50	6395	1075	307	234	ss	lower shoreface
52.5	6508	1157	301	257	ss	lower shoreface
55	5919	1151	224	197	ss	lower shoreface
57.5	5475	1059	221	197	ss	lower shoreface
60	4914	951	224	161	ss	lower shoreface
gap						
67.5	7130	1334	299	258	ss	lower shoreface
recalib						
70	5763	1140	283	211	ss	middle shoreface
72.5	6931	1273	334	245	ss	middle shoreface
75	6700	1141	341	274	ss	middle shoreface
77	6065	1129	276	238	ss	middle shoreface
80	7107	1489	288	222	sandy mud	offshore transition
82.5	7976	1729	312	228	sandy mud	offshore transition
85	5700	1178	239	175	ss	lower shoreface
87.5	5690	1227	224	195	ss	lower shoreface
recalib						
90	5989	1276	221	202	ss	lower shoreface

92.5	6274	1319	252	184	ss	lower shoreface
95	5942	1290	249	166	ss	middle shoreface
97.5	5876	1183	290	203	ss	middle shoreface
100	6398	1241	305	244	ss	middle shoreface
102.5	7290	1312	344	254	ss	middle shoreface
105	5310	1129	193	158	ss	middle shoreface
107.5	6227	1347	214	153	ss	middle shoreface
110	5986	1318	183	159	ss	middle shoreface
112.5	6027	1388	193	192	ss	middle shoreface
115	6607	1573	200	173	ss	middle shoreface
117.5	5832	1353	204	125	ss	middle shoreface
120	4499	974	173	131	ss	middle shoreface
121.5	4596	949	158	150	ss	middle shoreface
125	4545	1052	175	120	ss w/mudrips	upper shoreface
127.5	4448	1010	143	120	ss	upper shoreface
130	4631	988	156	114	ss	upper shoreface
recalib						
135	5146	1083	213	166	ss	upper shoreface
137	4182	848	173	134	ss	upper shoreface
140	4130	862	155	129	ss	upper shoreface
145	8068	1737	323	220	ss	upper shoreface
147	5646	1252	203	220	ss	upper shoreface
150	5096	1124	201	124	ss	foreshore
152.5	4627	1026	163	139	ss	foreshore
155	5125	1160	180	154	ss	foreshore
157	8021	1852	262	244	muddy sand	overbank
160	5450	1237	200	155	ss	upper shoreface
162	5887	1333	201	170	ss	upper shoreface
165	5064	1062	180	164	ss	upper shoreface
167	5313	1195	175	135	ss	upper shoreface
170	5813	1341	201	169	ss	upper shoreface
172.5	5548	1253	204	147	ss	upper shoreface
175	3741	787	137	153	ss	foreshore
177.5	4444	935	192	151	ss	foreshore
180	4462	868	198	162	ss	foreshore
gap						
190	3496	676	189	180	coal	swamp
192.5	5302	1039	250	173	org. ss	swamp
195	5020	1032	199	144	ss	channel
197.5	5321	1225	210	157	ss	channel
200	4240	969	143	118	ss	channel
202.5	4530	1007	178	127	ss	channel
205	4382	987	141	124	ss	channel

207.5	4917	1083	170	143	ss	channel
210	4306	969	179	147	ss	channel
212.5	4595	1035	160	146	ss	channel
215	4773	1032	174	165	ss	channel
217.5	4938	1082	186	140	ss	channel
220	4686	924	189	153	ss	foreshore
222.5	5348	947	277	228	ss	foreshore
225	4939	834	282	226	ss	foreshore
227.5	5081	722	230	239	ss	foreshore
230	3791	527	219	170	ss	foreshore
gap						
302	5450	1036	280	200	ss	channel
	4450	809	208	170		BACKGROUND

Measured Section 4: Apache Mesa South

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	8066	646	1230	251	sandy mud	offshore transition
2.5	7946	626	1304	231	sandy mud	offshore transition
5	7546	621	1142	225	ss	offshore transition
8	5750	458	911	170	ss	offshore transition
10	7754	627	1258	221	ss	offshore transition
recalib						
12.5	8440	681	1372	259	sandy mud	offshore transition
14.5	9381	788	1511	279	mud	offshore transition
17.5	9002	733	1438	280	sandy mud	offshore transition
20	8828	753	1398	256	ss	offshore transition
21.5	9115	746	1524	271	sandy mud	offshore transition
25	7799	648	1310	218	ss	offshore transition
27.5	10168	811	1489	309	sandy mud	offshore transition
30	7632	591	1263	202	ss	offshore transition
recalib						
32.5	7549	632	1155	224	sandy mud	offshore transition
35	8092	660	1374	229	sandy mud	offshore transition
37.5	7380	572	1228	205	sandy mud	offshore transition
40	7061	564	1093	203	ss	offshore transition
42.5	9313	812	1593	244	sandy mud	offshore transition
45	8816	781	1518	253	sandy mud	offshore transition
47.5	9608	792	1606	258	sandy mud	offshore transition
50	7271	558	1202	177	ss	offshore transition
52.5	7198	577	1148	203	ss	lower shoreface
55	7476	615	1209	190	ss	lower shoreface
57.5	7176	576	1090	201	ss	lower shoreface
60	7535	595	1261	219	ss	lower shoreface
62.5	7316	568	1070	213	ss	lower shoreface
65	7969	698	1292	248	ss	lower shoreface
67.5	9977	782	1750	289	sandy mud	offshore transition
70	7444	588	1214	187	ss	lower shoreface
72.5	7832	660	1265	225	ss	lower shoreface
recalib						
75	8244	662	1338	244	ss	lower shoreface
77.5	8140	665	1346	245	ss	lower shoreface
80	7191	609	1194	222	ss	middle shoreface
82	9898	805	1638	302	mud	lower shoreface
85	8365	650	1371	287	mud	lower shoreface
87.5	7494	572	1116	239	ss	lower shoreface
90	7480	595	1117	246	ss	lower shoreface
92.5	7801	643	1174	258	ss	lower shoreface

95	8199	663	1249	246	ss	lower shoreface
97.5	7312	633	1099	218	ss	lower shoreface
100	7782	604	1088	264	ss	lower shoreface
102.5	6664	549	989	203	ss	lower shoreface
gap						
109	9186	768	1445	265	shale	offshore transition
112.5	7414	612	1224	176	ss	offshore transition
recalib						
115	9067	963	1580	250	mud	offshore transition
117.5	8802	681	1443	252	ss	lower shoreface
120	8891	759	1396	276	ss	lower shoreface
122.5	8868	755	1442	292	ss	lower shoreface
gap						
130	9247	723	1484	294	ss	lower shoreface
132.5	9086	797	1515	261	ss	lower shoreface
135	9114	762	1432	276	ss	lower shoreface
137.5	8189	663	1387	191	ss w/mudrips	lower shoreface
140	7839	617	1338	211	ss	lower shoreface
142.5	7492	646	1246	192	ss	lower shoreface
145.5	8783	736	1193	323	muddy org. ss	lower shoreface
147.5	9405	801	1292	307	ss	lower shoreface
150	8296	684	1272	243	ss	lower shoreface
gap						
205	6418	538	1063	176	ss	upper shoreface
207.5	5243	417	934	105	ss	upper shoreface
210	5412	433	985	143	ss	upper shoreface
212.5	5528	492	935	135	ss	upper shoreface
215	6086	493	1059	133	ss	upper shoreface
217.5	6633	515	1114	185	ss	upper shoreface
220	5479	416	909	123	ss	upper shoreface
222.5	6068	477	1119	142	ss	upper shoreface
225	5584	491	1024	136	ss	upper shoreface
227.5	5190	448	932	102	ss	upper shoreface
230	6224	516	1137	151	ss	upper shoreface
232.5	5165	413	876	103	ss	upper shoreface
235	7356	620	1281	168	shale	nm channel fill
237.5	8620	746	1607	195	muddy ss	nm channel fill
240	8068	670	1477	180	muddy ss	nm channel fill
242.5	7846	707	1398	176	ss	nm channel fill
245	6669	581	1216	187	ss	nm channel fill
recalib						
247.5	6845	552	1204	184	ss	nm channel fill
250	8664	663	1537	259	ss	nm channel fill
252.5	7733	595	1273	210	ss	nm channel fill

255	6982	501	1178	194	ss	nm channel fill
257.5	6118	477	1019	181	ss	nm channel fill
260	5718	482	961	149	ss	nm channel fill
262.5	7045	573	1210	187	ss	nm channel fill
265	6364	535	1047	168	ss	nm channel fill
267	4812	368	824	101	ss	nm channel fill
270	5308	404	957	132	ss	nm channel fill
272	5928	481	1015	152	ss	nm channel fill
gap						
282.5	5428	474	1052	117	ss	nm channel fill
287.5	6117	466	1131	136	ss	nm channel fill
292.5	5901	508	1044	125	ss	nm channel fill
295	5507	469	937	131	ss	nm channel fill
297.5	5654	452	1007	135	ss	nm channel fill
302.5	5583	455	945	129	ss	nm channel fill
305	5654	459	1020	110	ss	nm channel fill

Measured Section 7: Horse Lake Mesa NE

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	5583	455	801	155	ss	channel
2.5	13770 *	1049**	1609***	518****	ss	channel
5	5256	402	875	154	ss	channel
7.5	7091	564	1079	206	ss	channel
10	7223	560	1075	235	ss	channel
12.5	5061	433	899	107	ss	channel
15	6498	495	929	202	ss	channel
17.5	5368	452	930	125	ss	channel
20	7525	605	1260	230	ss	channel
gap						
27.5	5808	490	951	166	ss	channel
30	6140	481	912	212	ss	channel
32.5	9283	713	1054	310	ss	channel
35	24381 *	1455**	1040	227	ss	channel
37.5	7401	691	1139	230	mud	channel bar
42.5	21682 *	1279**	2229***	897****	sandy mud	channel bar
45	9258	784	1436	280	mud	channel bar
47.5	7520	601	1106	211	ss	channel bar
50	10145	835	1259	340	mud	channel bar
52	7401	670	1085	250	ss	channel bar
recalib						
55	6521	507	1002	199	ss	channel
57.5	10132	811	1741***	247	ss	channel
60	8518	702	1438	205	ss	channel
62.5	8514	738	1505***	214	ss	channel
65	8456	719	1488	223	ss	channel
67.5	7514	684	1281	201	ss	channel
70	7140	569	1275	216	ss	channel
72.5	7531	642	1305	199	ss	channel
75	7966	643	1469	198	ss	channel
77.5	4668	352	764	140	ss	channel
gap						
95	6736	356	1190	187	ss	overbank
gap						
102.5	6944	560	1143	204	ss	channel
105	6511	561	1058	162	ss	channel
107.5	5879	461	955	145	ss	channel
110	6252	495	995	182	ss	channel
112.5	5407	441	877	135	ss	channel
115	4424	360	722	123	ss	channel

gap						
135	5853	479	971	158	ss	channel

* values over 12 000 are artifically assigned a value of 12000 to avoid flattening of data on well log plots

**values over 900 are artificially assigned a value of 900 to avoid flattening of data on well log plots

***values over 1500 are artificially assigned a value of 1500 to avoid flattening of data on well plots

****values over 400 are artificially assigned a value of 400 to avoid flattening of data on well plots

Measured Section 9: Sulphur Canyon

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
11	5970	1111	240	176	ss	offshore transition
12.5	5178	1007	266	179	ss	offshore transition
14.5	6922	1362	303	241	mud	offshore transition
15.5	5390	1034	282	198	ss	offshore transition
gap						
21.5	5185	985	224	165	ss	offshore transition
24	5315	974	270	196	ss	offshore transition
27.5	5328	957	252	176	ss	lower shoreface
30	5496	846	293	185	muddy ss	lower shoreface
32.5	6691	1116	345	288	muddy ss	lower shoreface
35	8603	1171	540	386	muddy ss	lower shoreface
37.5	6769	1053	376	301	ss	lower shoreface
40	4905	804	252	188	ss	lower shoreface
42.5	4901	864	265	176	muddy ss	offshore transition
gap						
50	4642	823	196	162	muddy ss	offshore transition
54.5	8830	1684	404	271	muddy ss	offshore transition
57.5	5349	820	281	207	ss	lower shoreface
60	4815	772	278	200	ss	lower shoreface
63	4294	681	243	152	ss	lower shoreface
65	3895	678	190	144	ss	lower shoreface
70	5449	1045	253	200	shale	offshore transition
gap						
87.5	5662	1133	229	176	sandy mud	offshore transition
91	5695	1076	227	193	ss	offshore transition
96.5	5893	1156	241	217	sandy mud	offshore transition
recalib						
100	5143	1004	243	169	ss	offshore transition
102.5	6345	1310	260	195	sandy mud	offshore transition
gap						
110	5203	944	241	161	ss	offshore transition
112.5	4924	869	237	182	ss	lower shoreface
115	5527	1009	248	192	ss	lower shoreface
117.5	6003	979	291	231	sandy mud	lower shoreface
120	4840	855	190	162	ss	lower shoreface
122.5	4390	810	214	146	sandy mud	offshore transition
125	4470	814	199	181	ss	lower shoreface
127.5	3919	670	192	135	ss	lower shoreface
130	4779	823	252	188	ss	lower shoreface
132.5	5408	978	263	187	ss	lower shoreface

135	5628	969	249	192	ss	lower shoreface
137.5	5708	1042	270	236	ss	lower shoreface
140	4314	689	229	177	ss	lower shoreface
142.5	4962	904	219	168	ss	lower shoreface
gap						
150	4397	800	193	137	ss	lower shoreface
152.5	4600	870	189	163	ss	lower shoreface
155	4579	865	234	170	ss	lower shoreface
157.5	5947	867	307	269	ss	lower shoreface
160	4537	742	259	174	muddy ss	lower shoreface
162.5	5765	1028	268	234	ss	lower shoreface
165	5709	1145	255	181	ss	lower shoreface
167.5	4553	913	179	132	ss	lower shoreface
170	4869	1009	167	146	ss	middle shoreface
172.5	4858	1006	195	148	ss	middle shoreface
175	5291	1095	237	161	ss	middle shoreface
177.5	4506	894	170	147	ss	middle shoreface
180	3942	809	163	123	ss	middle shoreface
182.5	3981	827	172	113	ss	middle shoreface
185	3452	695	150	109	ss	middle shoreface
187.5	5154	1027	201	165	ss	middle shoreface
190	5066	1155	187	129	ss	estuarine
192.5	5607	1228	193	154	ss	estuarine
195	4561	1003	172	131	ss	estuarine
197.5	4518	972	173	124	ss	estuarine
200	4920	1046	211	145	ss	estuarine
202.5	5242	1176	196	148	ss	estuarine
205	5126	1147	166	120	ss	estuarine
207.5	4988	1102	173	130	ss	estuarine
210	5153	1061	187	147	ss	estuarine
212.5	5432	1249	179	154	ss	estuarine
215	4643	921	174	131	ss	estuarine
217.5	4897	1039	185	124	ss	estuarine
220	4868	983	183	156	ss	estuarine
222.5	5222	1176	203	158	ss	estuarine
225	4855	1104	186	144	ss	estuarine
227.5	4660	957	199	128	ss	estuarine
230	4560	986	154	134	ss	estuarine
232.5	4622	916	176	124	ss	estuarine
235	4653	1012	173	109	ss	estuarine
237.5	4592	947	170	142	ss	estuarine
240	4681	921	203	156	ss	estuarine
gap						
250	4667	812	183	181	ss	overbank

252.5	5047	917	219	170	shale	overbank
255	4509	803	210	160	ss	overbank
gap						
275	6021	1097	288	219	coal	overbank
gap						
287.5	6461	1272	284	238	shale	overbank
291	4120	606	240	190	muddy coal	overbank
gap						
304	4182	618	246	175	coaly ss	overbank
gap						
310	5019	913	231	167	ss w/mudrips	overbank
315	4752	911	257	172	ss	overbank
320	6985	1317	335	237	mud	overbank
gap						
330	5389	1016	269	176	mud	overbank
gap						
340	4747	346	233	168	coaly mud	overbank
gap						
350	2396	354	118	116	coal	overbank
gap						
361	4094	658	226	159	coal	overbank
363	4890	926	193	165	ss	channel
365	4211	857	182	150	ss	channel
367.5	4731	921	185	151	ss	channel
370	5397	1057	231	193	ss	channel
372.5	4997	993	227	158	ss	channel
375	4999	1013	208	178	ss	channel
377.5	3818	748	164	142	ss	channel
380	5243	1034	207	187	sandy mud	channel
382.5	4178	840	178	147	ss	channel
385	3829	745	159	118	ss	channel
387.5	5135	963	201	188	ss	channel
390	4240	828	198	139	ss	channel
gap						

Measured Section 11: Monero Beach Roadcut

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	8740	747	1455	206	mud	offshore transition
2.5	6768	519	1239	147	ss	upper shoreface
5	6501	542	1185	166	ss	upper shoreface
7.5	5962	512	1015	135	ss	upper shoreface
10	6533	565	1179	133	ss	upper shoreface
12.5	7600	606	1357	190	ss	upper shoreface
15	7662	637	1406	177	ss	upper shoreface
17.5	7819	654	1466	189	ss	upper shoreface
20	6342	517	1084	154	ss	foreshore
22.5	5561	452	893	144	ss	foreshore
25	6015	443	1033	158	ss	foreshore
27.5	6132	485	971	172	coal	swamp
30	9296	752	1512	255	mud	tidal flat
32.5	9543	766	1641	236	ss	channel
35	9123	728	1513	262	ss	channel
37.5	8902	710	1450	252	ss	channel
40	10926	934	1795	290	sandy mud	overbank
42.5	7705	663	1239	215	muddy sand	overbank
45	7031	592	1217	186	muddy sand	overbank
47.5	6192	480	1093	153	ss	overbank
50	7050	588	1168	392	mud	overbank
52.5	7226	544	1109	252	ss	overbank
55	8287	640	1267	297	coaly shale	overbank
57.5	7840	651	931	341	ss	channel/splay
60	8926	635	1026	370	ss	channel/splay
62.5	10607	869	1829	314	mud	channel/splay
65	8754	684	1199	212	ss	channel/splay
gap						
75	7534	631	1118	211	mud	overbank
77.5	7647	642	1146	234	ss	overbank
80	6023	485	920	189	mud	overbank
83	6581	545	1015	179	ss	overbank
85	7691	631	1274	249	mud	overbank
87.5	8398	684	1360	244	mud	overbank
90	5963	486	958	166	ss	foreshore(?)
	5977	460	1009	157		BACKGROUND

Measured Section 12: Monero Beach North

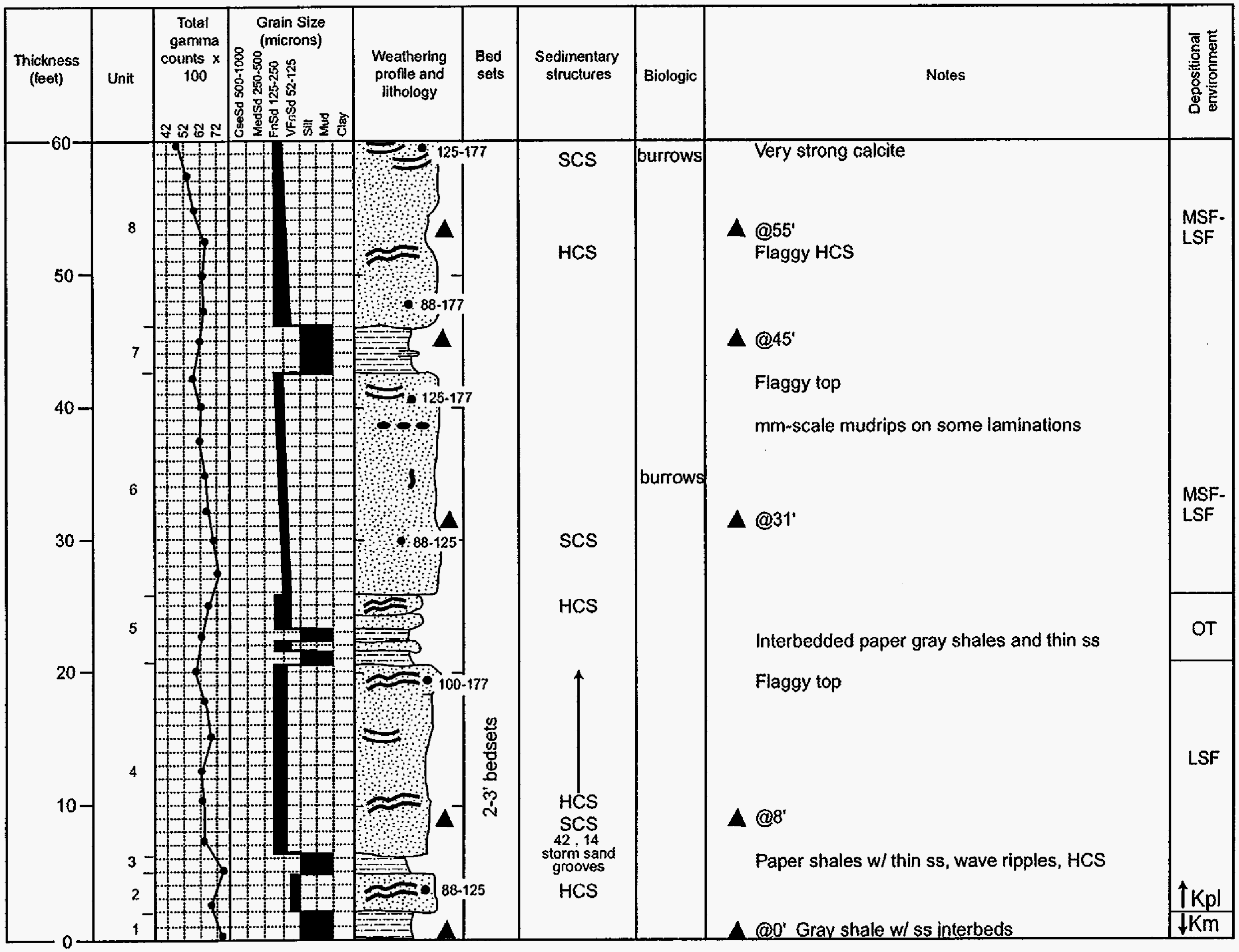
Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	20109 **	1570	2229	842	ss	middle shoreface
3	8408	708	1382	221	ss	middle shoreface
5	8814	734	1376	227	ss	middle shoreface
7.5	9002	696	1129	208	ss	middle shoreface
10	7539	605	1207	207	ss	middle shoreface
12.5	8582	684	1393	238	ss	middle shoreface
15	6998	601	1190	171	ss	middle shoreface
17.5	6070	490	1052	136	ss	middle shoreface
20	6399	529	1025	172	muddy sand	middle shoreface
22.5	7321	622	1376	137	ss	middle shoreface
25	7833	636	1356	217	ss	middle shoreface
27.5	6824	555	1208	158	ss	middle shoreface
30	7091	593	1155	177	ss	middle shoreface
32.5	6970	328	1145	194	ss	middle shoreface
35	8524	691	1581	174	muddy sand	middle shoreface
37.5	7506	609	1318	171	ss	middle shoreface
40	7035	549	1307	183	ss	upper shoreface
42	8043	602	1511	204	ss	upper shoreface
45	7653	627	1387	161	ss	upper shoreface
48	7429	602	1311	178	ss	upper shoreface
50	9538	770	1686	240	silty sand	upper shoreface
52	7926	635	1351	188	ss	upper shoreface
55	6694	1246	295	243	ss	upper shoreface
57.5	7734	597	1476	194	ss	upper shoreface
60	8408	696	1631	174	ss	upper shoreface
62.5	7323	611	1280	155	ss	upper shoreface
65	6860	570	1201	164	ss	upper shoreface
67.5	7609	653	1337	150	ss	foreshore
70	6643	565	1180	150	ss	foreshore
72.5	7665	616	1448	167	ss	foreshore
77	10248	883	1642	273	silt	overbank
80	6617	546	1079	197	ss	channel
82.5	6721	553	1149	169	ss	channel
85	5307	441	860	119	ss	channel
87.5	6109	478	1035	170	ss	channel
90	7023	525	1223	199	ss	channel
92.5	6257	502	1026	152	ss	channel
95	6031	467	401	187	ss	channel
97.5	9029	779	1600	233	ss	channel
100	7587	604	1305	188	ss	channel

102.5	7021	582	1245	168	ss	channel
105	6947	567	1155	190	ss	channel
107.5	5931	470	947	168	ss	channel
110	5638	483	965	135	ss	channel
gap/recalib						
127.5	9258	779	1493	253	shale	overbank
130	6375	456	1073	163	ss	foreshore
132.5	5993	508	1005	162	ss	foreshore
136	5621	465	866	137	ss	foreshore
137.5	7581	620	1198	274	ss	foreshore
143	6469	493	959	179	ss	foreshore
146	6523	518	903	208	shale	overbank
147.5	8198	690	1357	257	silty sand	overbank
150	7621	641	1319	211	ss	foreshore(?)
153	6372	518	980	164	ss	foreshore(?)
155	5402	415	838	157	ss	foreshore(?)
gap						
172	5442	368	579	206	coal	overbank
175	7653	610	1169	227	ss	overbank
177	6198	476	803	210	ss	overbank
gap						
195	5490	398	748	161	ss	shelf
197.5	6050	476	852	205	ss	shelf
202	4662	357	458	172	ss	shelf
	6925	586	1112	174		BACKGROUND

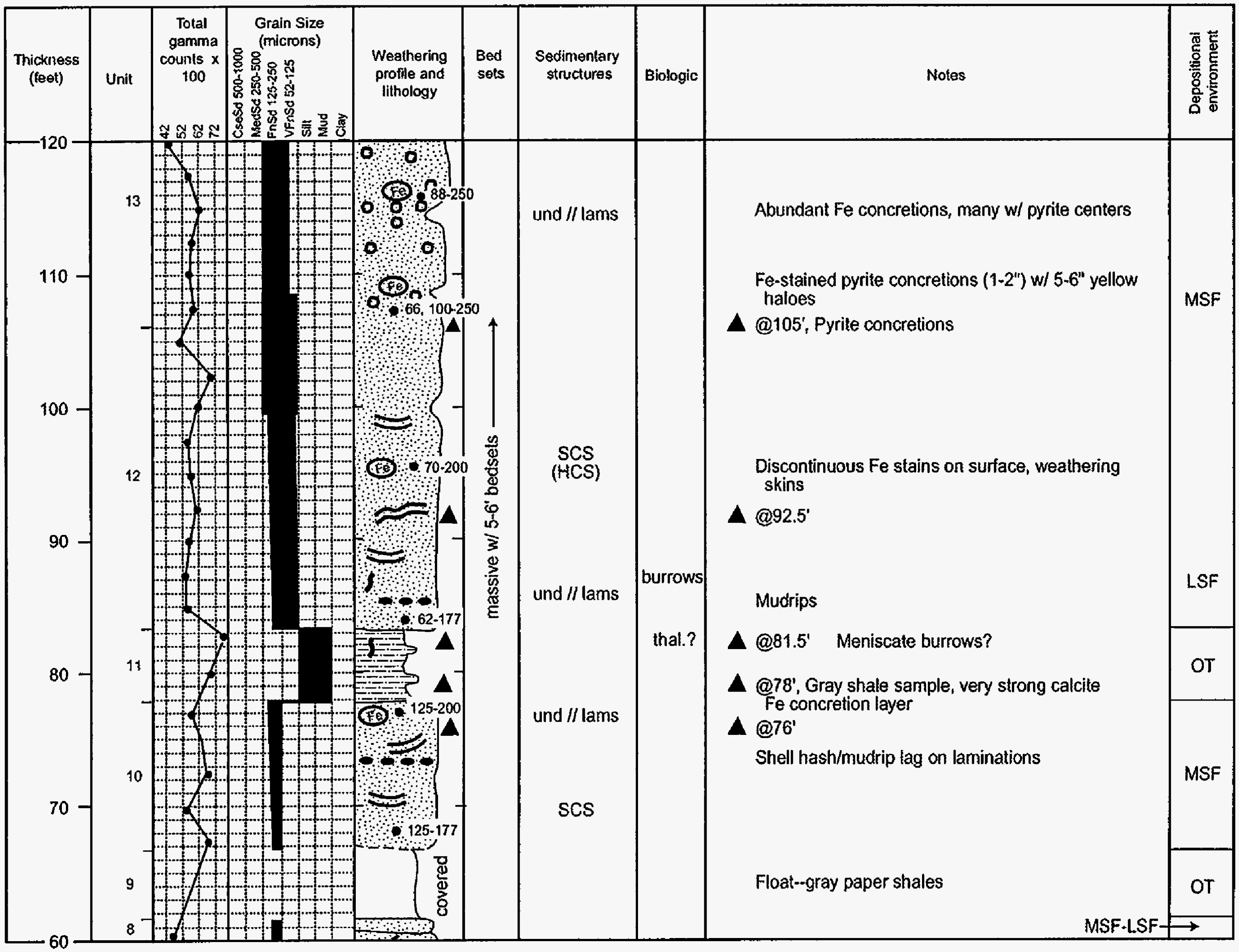
** values over 12 000 are artificially assigned a value of 12 000 to avoid flattening of the data on well log plots

Appendix 2

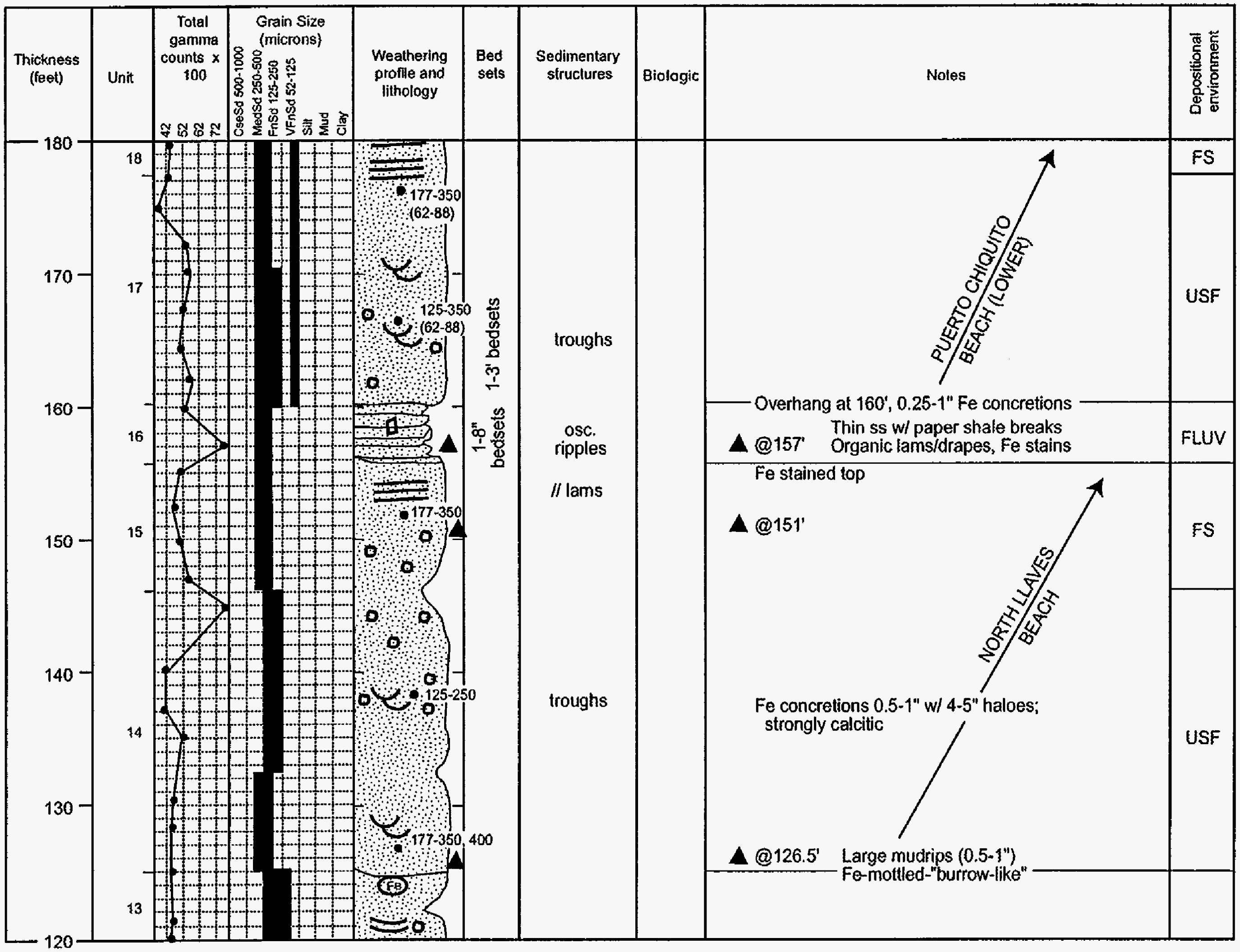
Detailed measured section data for the sections discussed in this study. Gamma-ray data are presented as total count profiles with each data point represented by a solid circle.



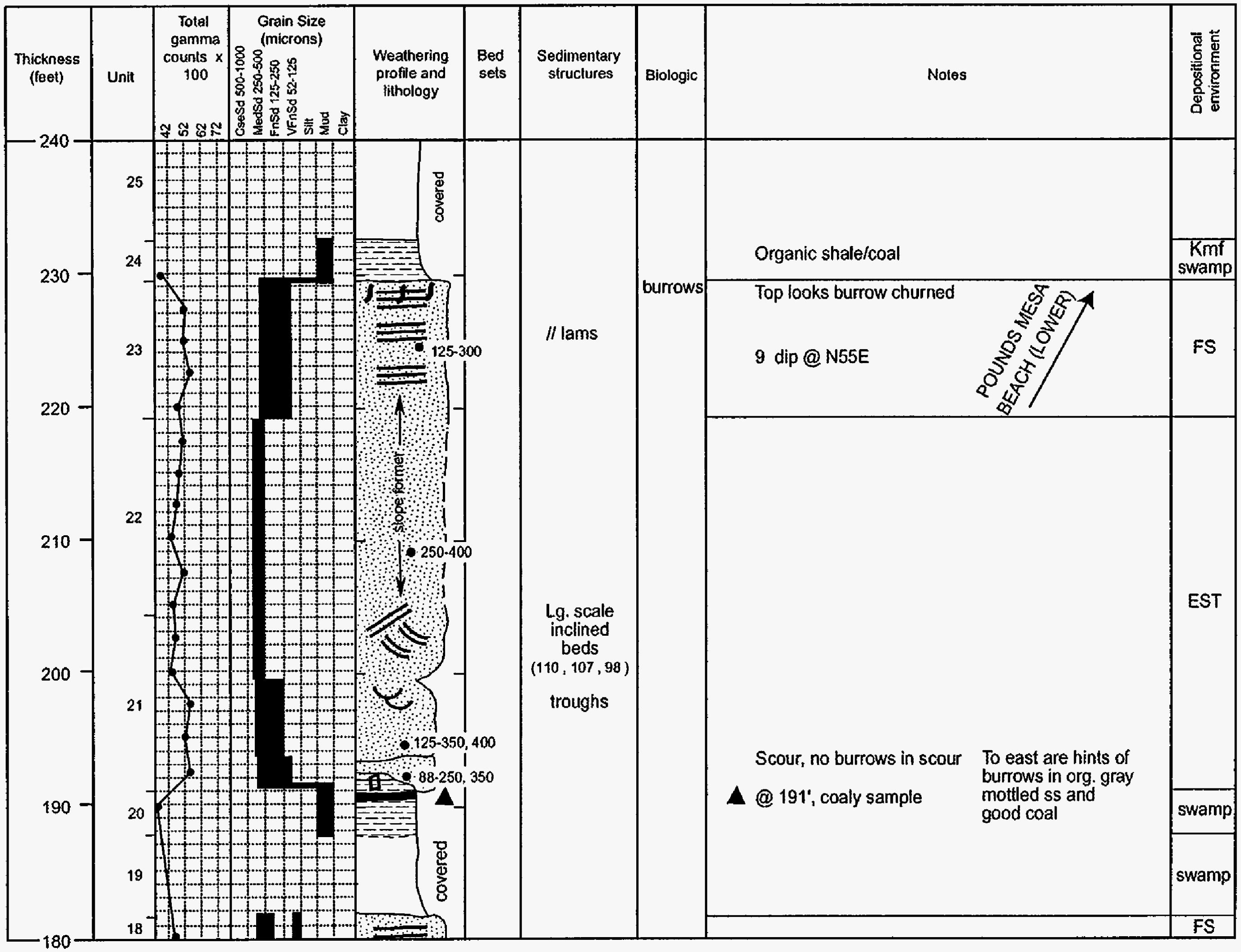
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



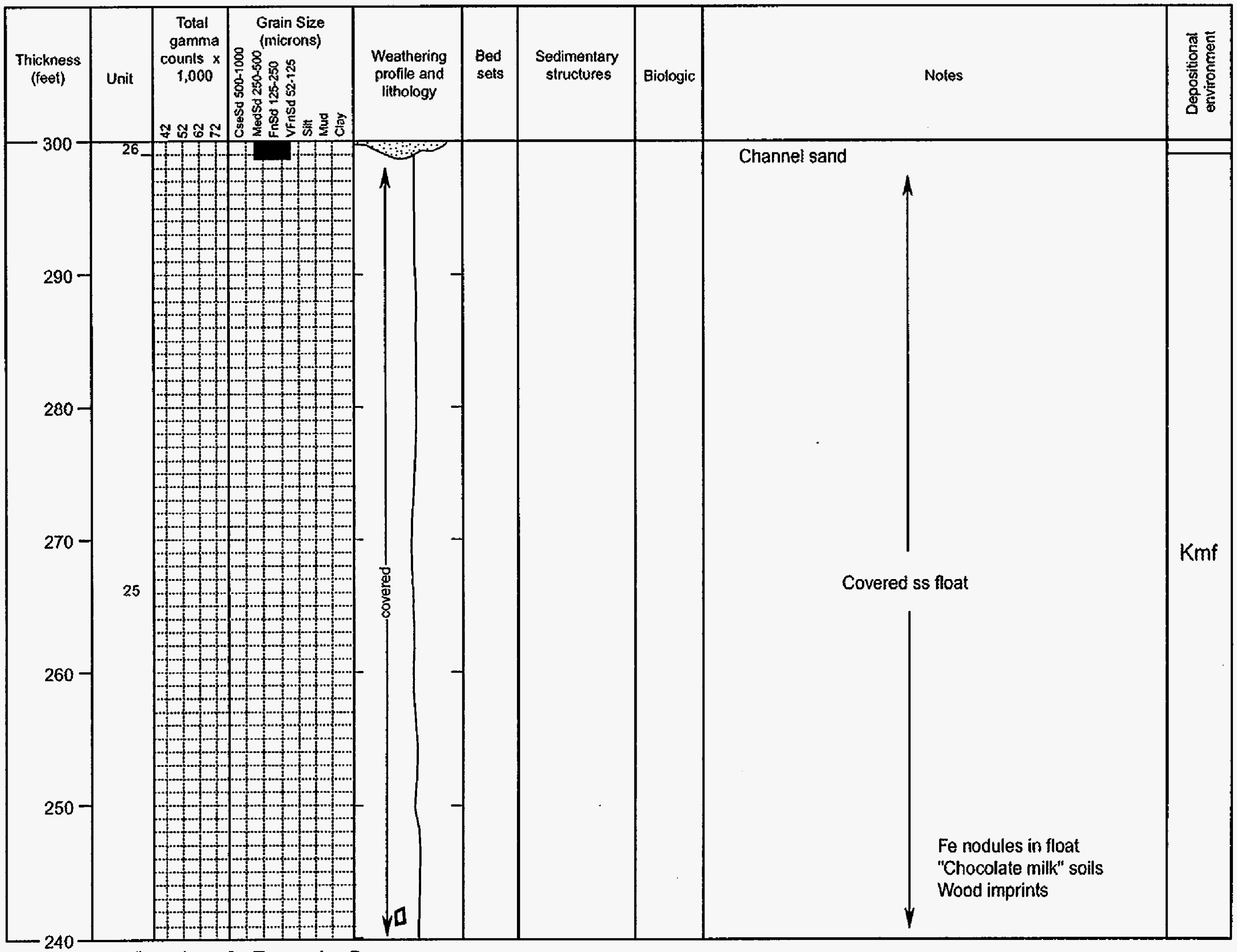
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



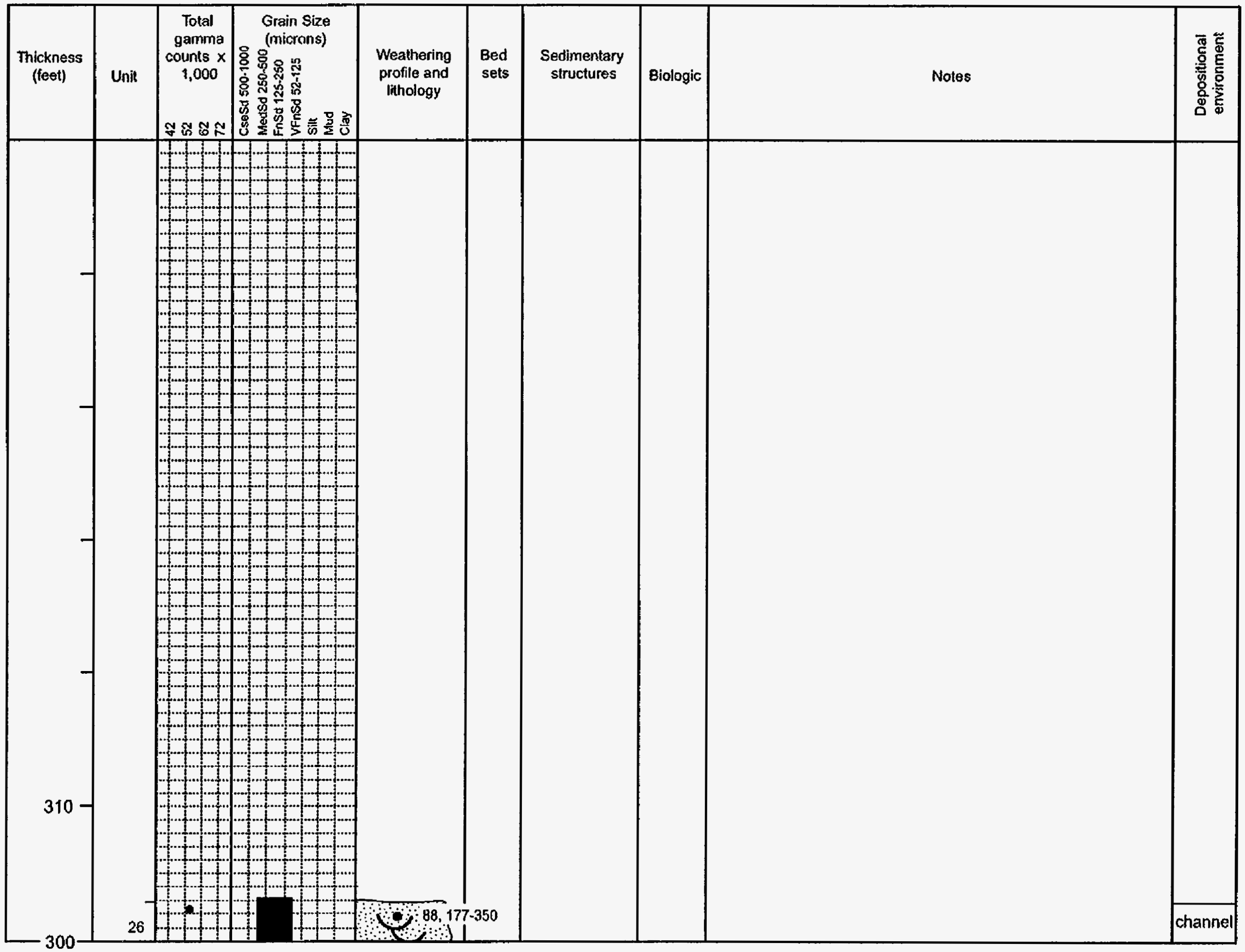
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



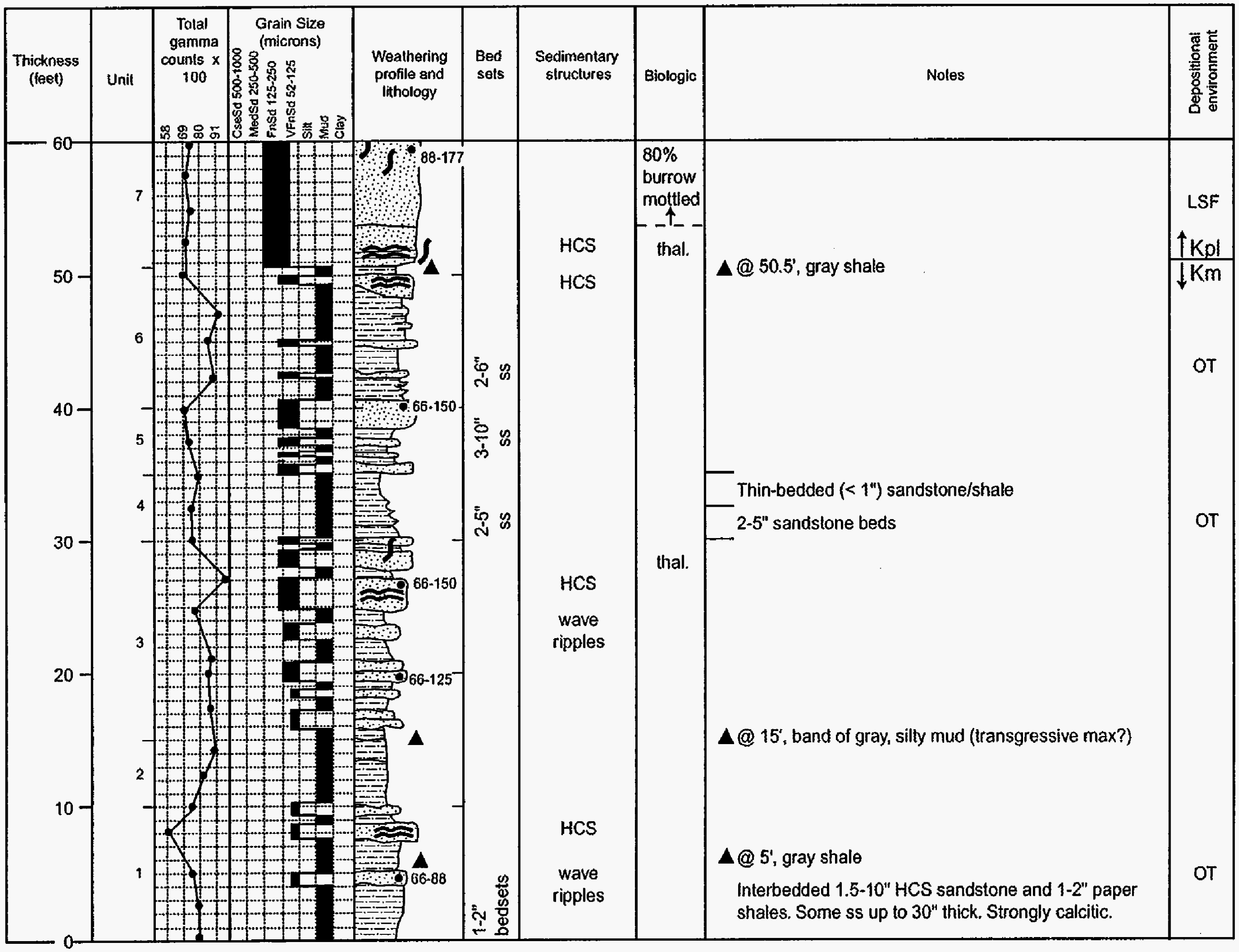
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



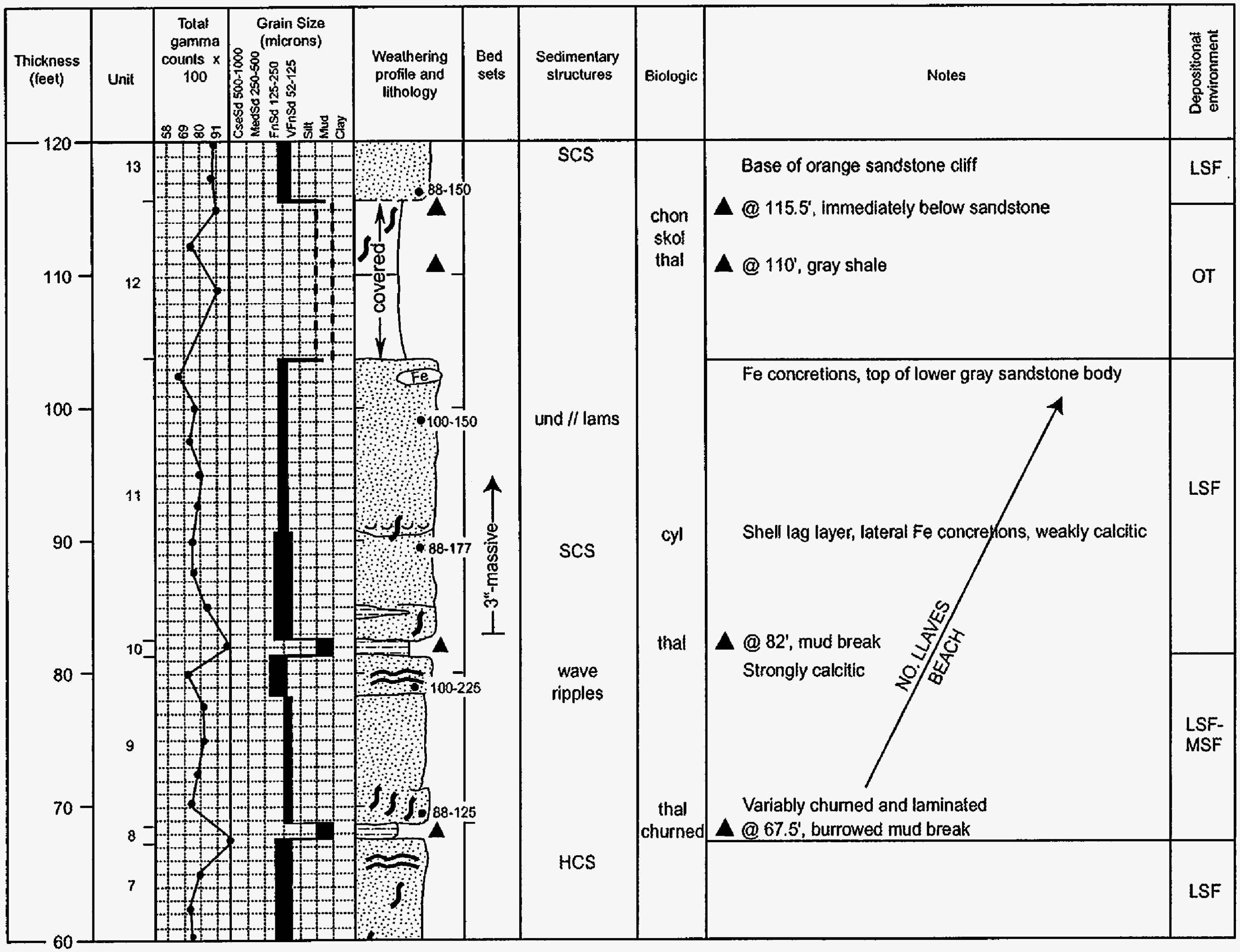
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



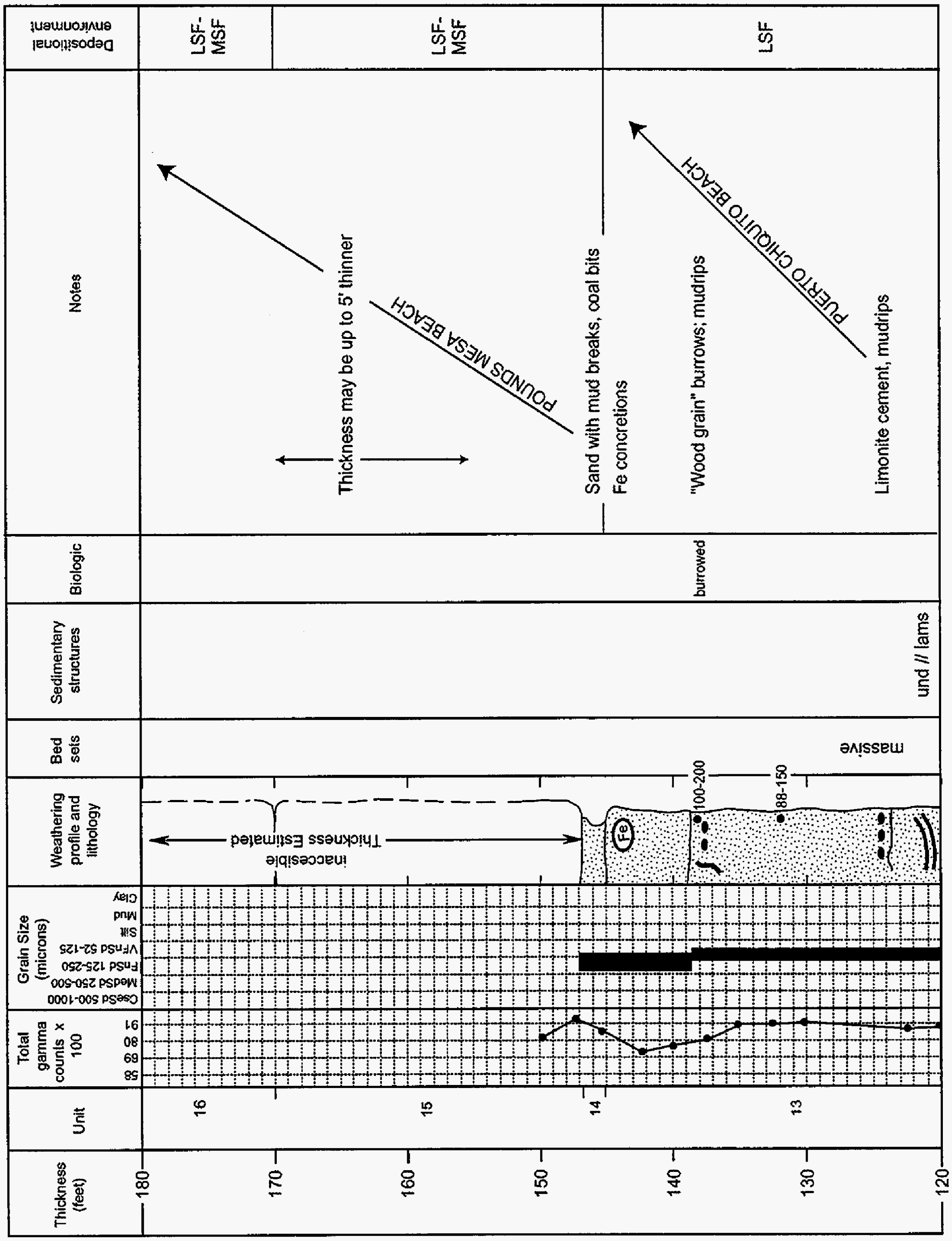
Measured Section 2: Pounds Canyon. Measured by RWD, MK-J 36 33'52" N, 106 48'16" W



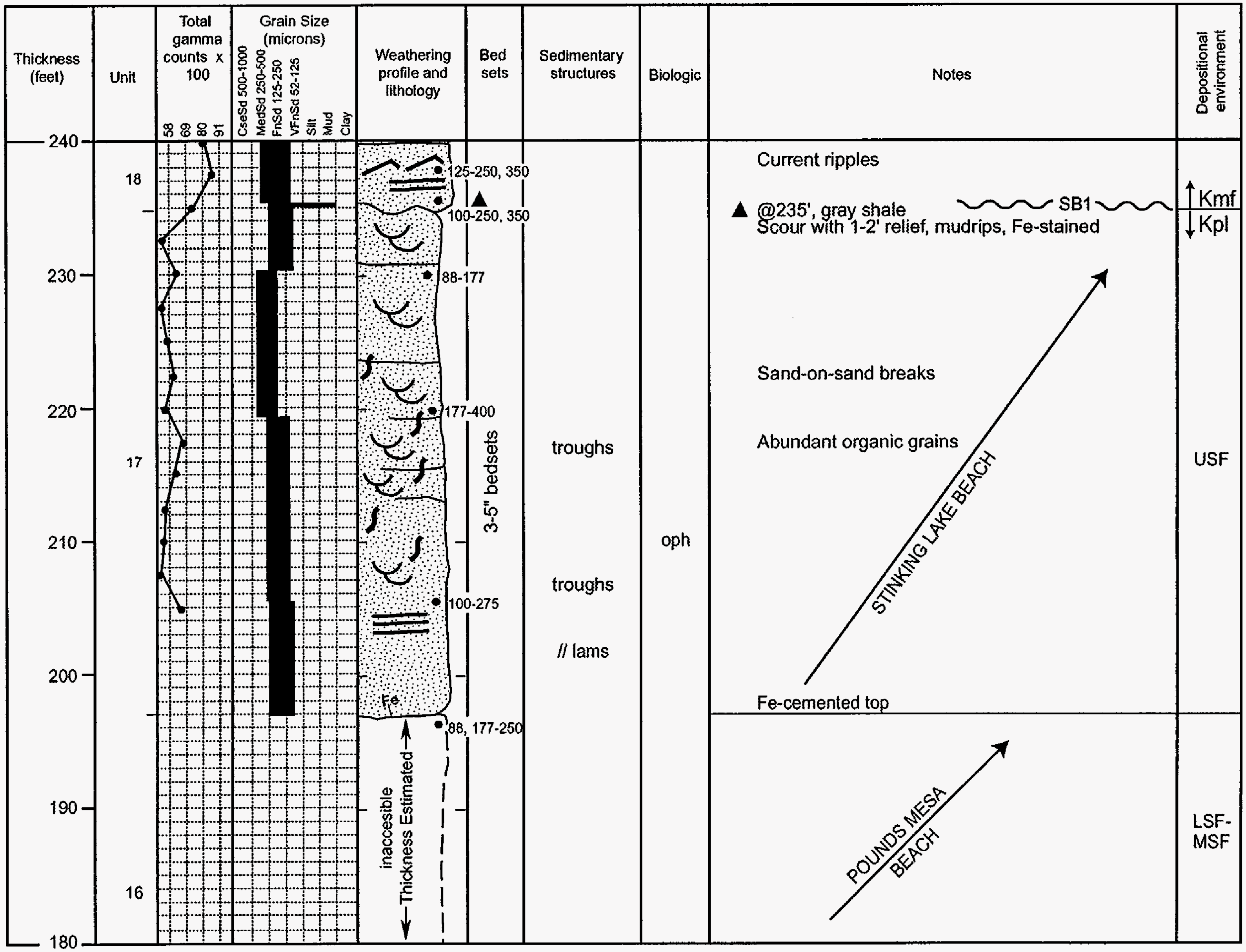
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



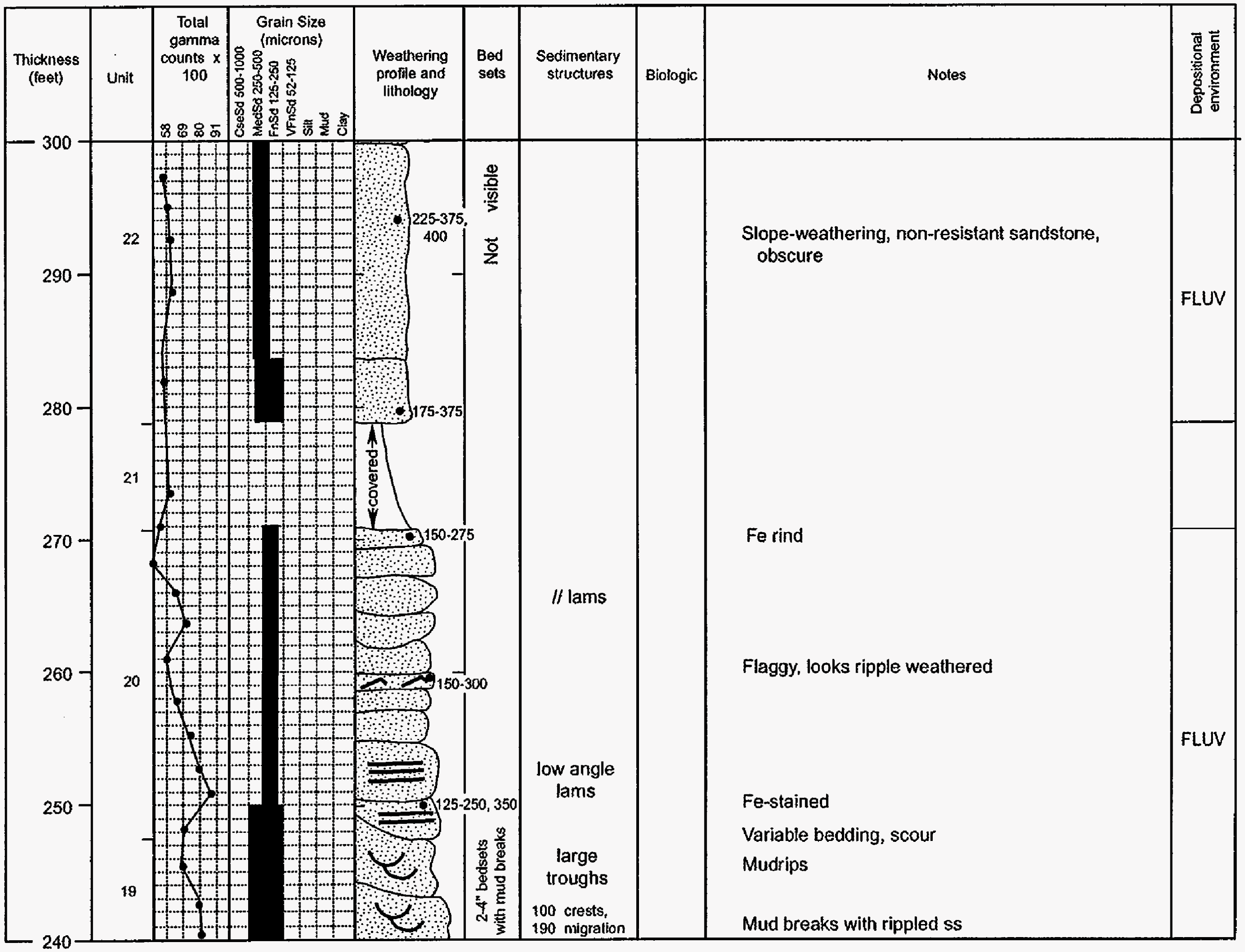
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



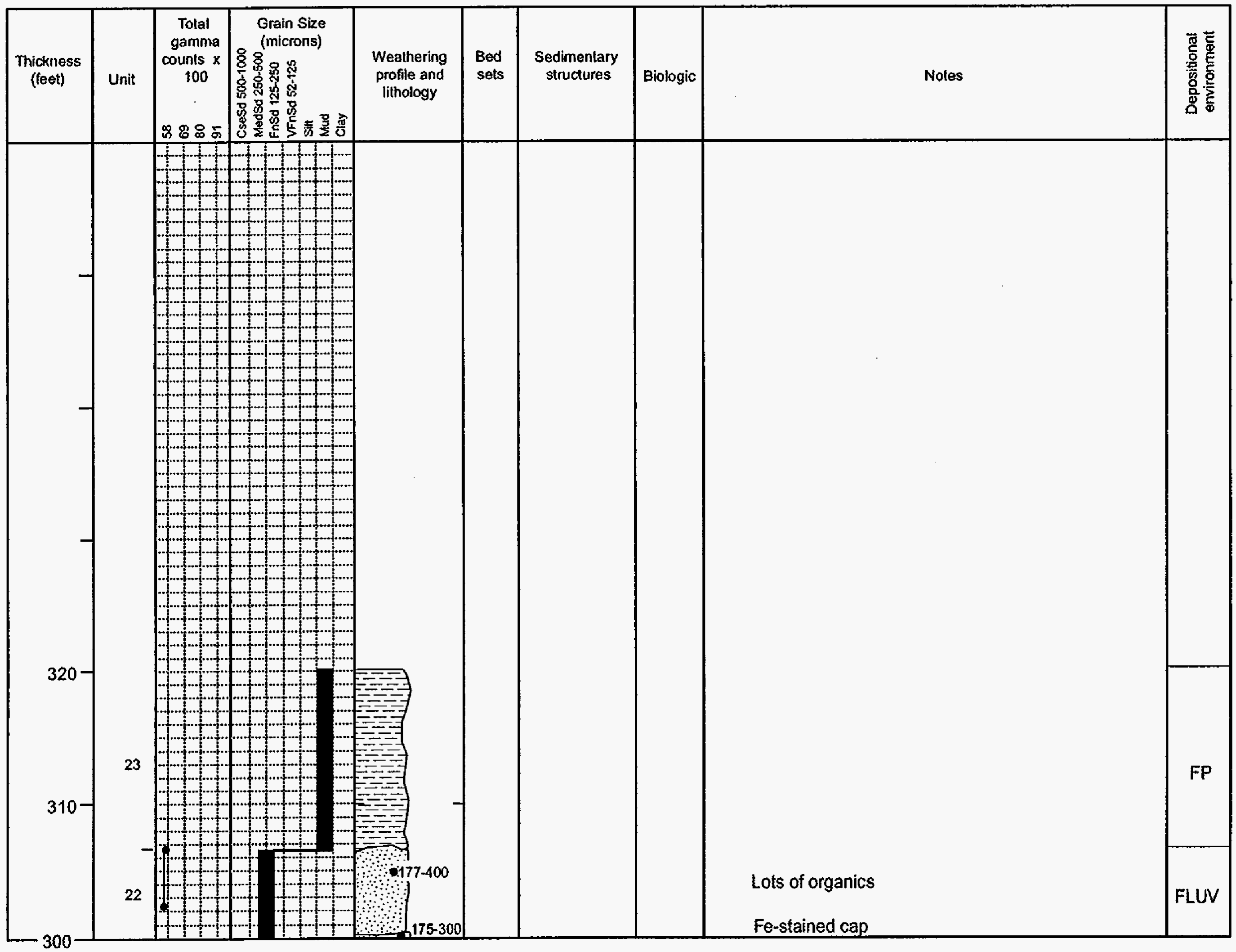
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



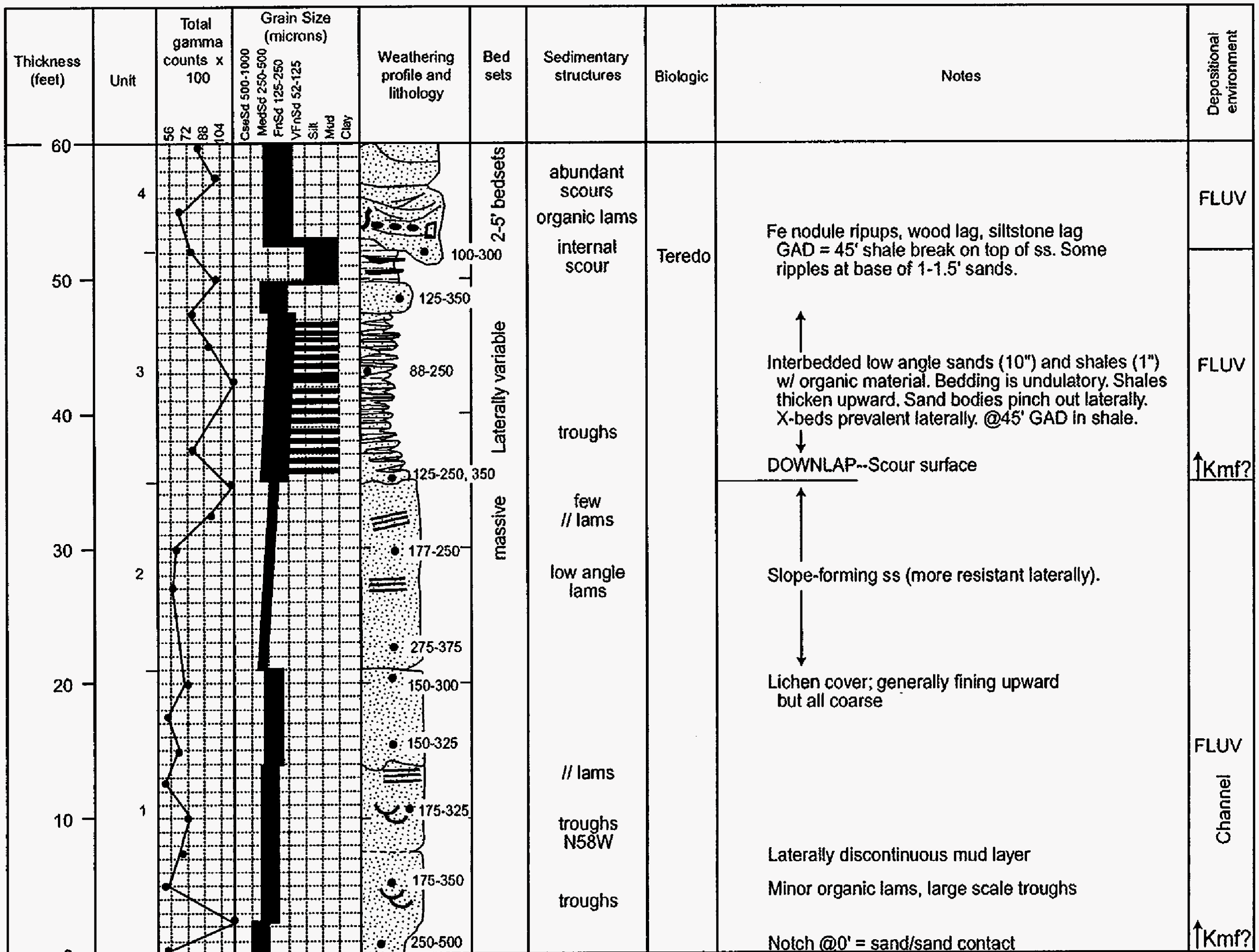
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



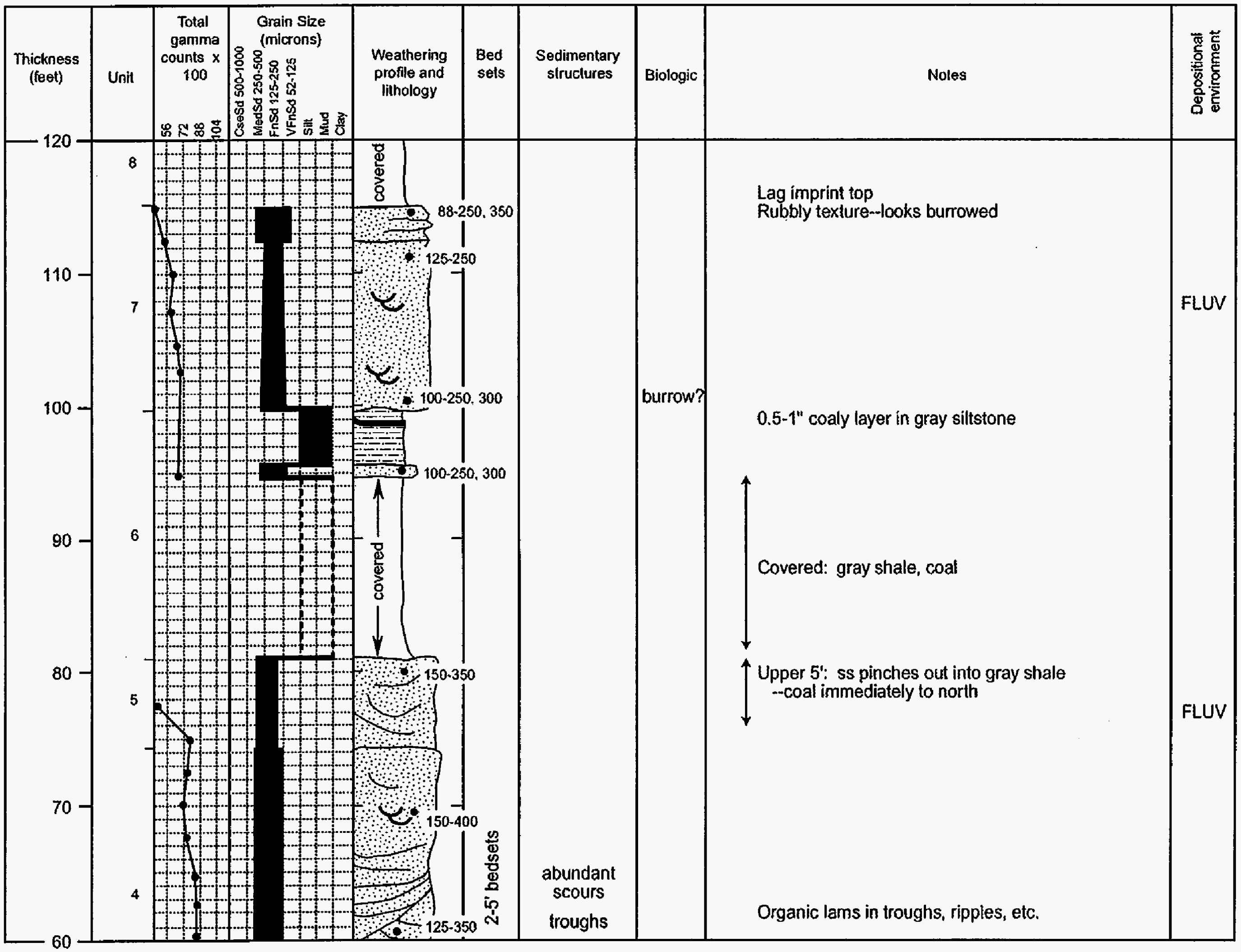
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



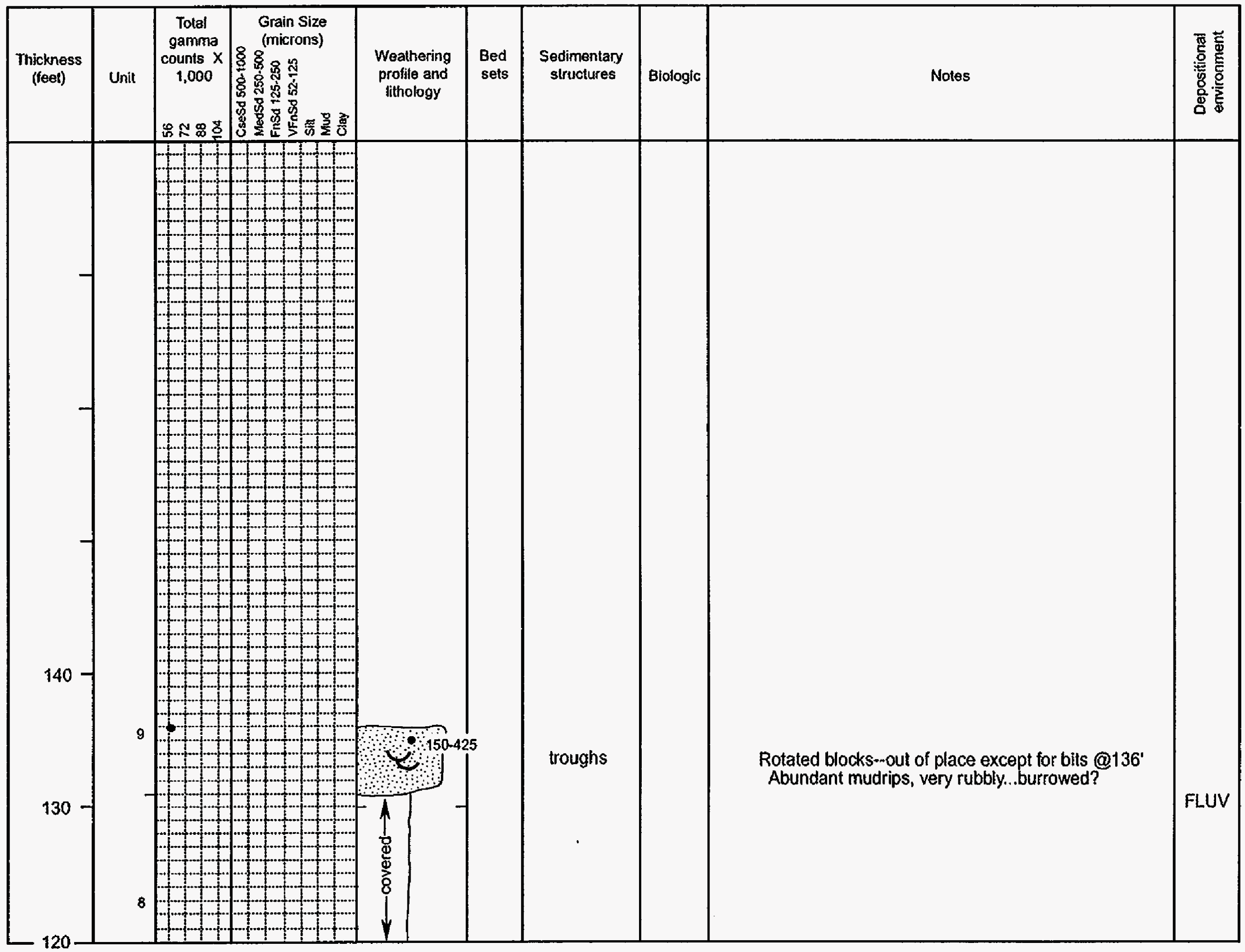
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W



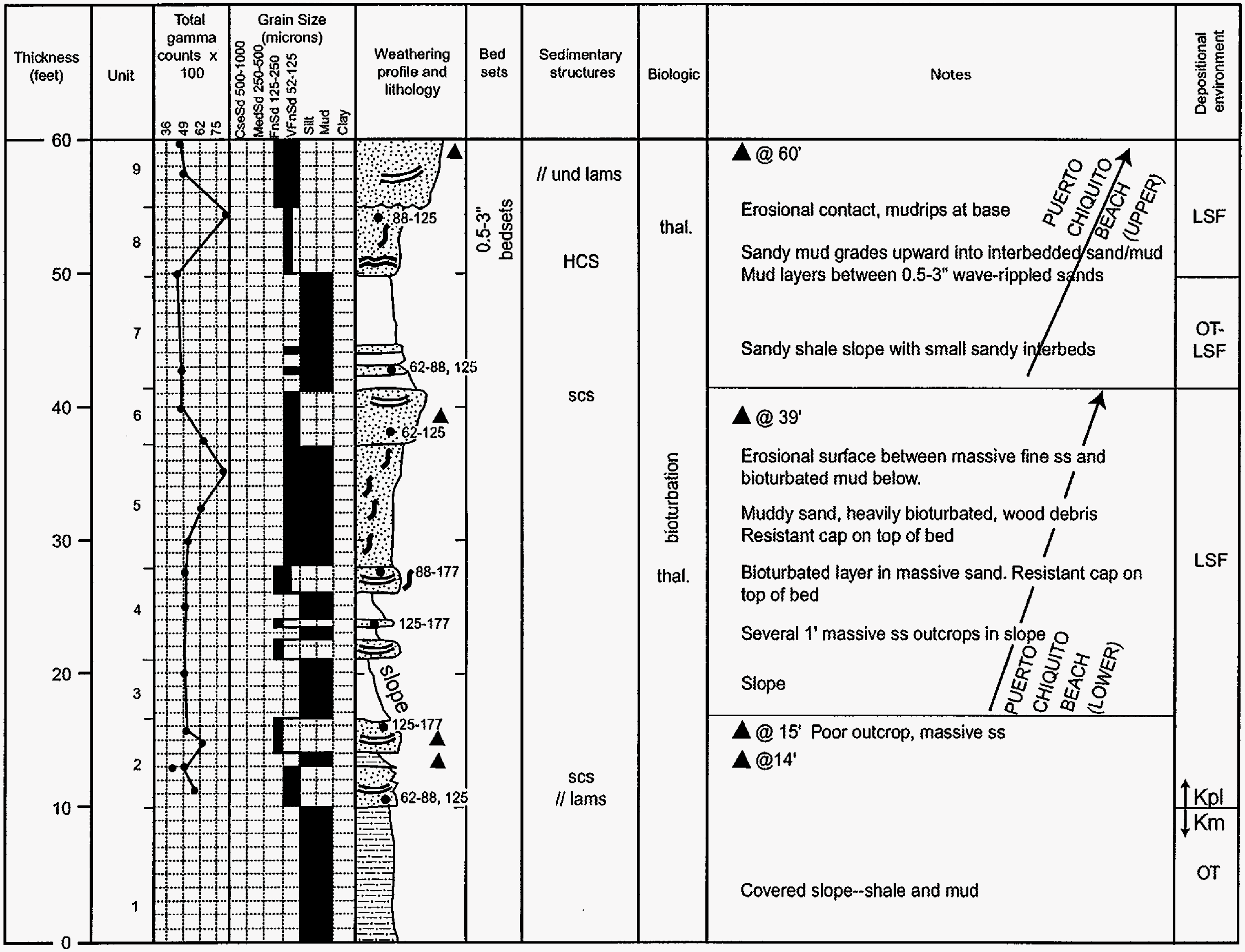
Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W



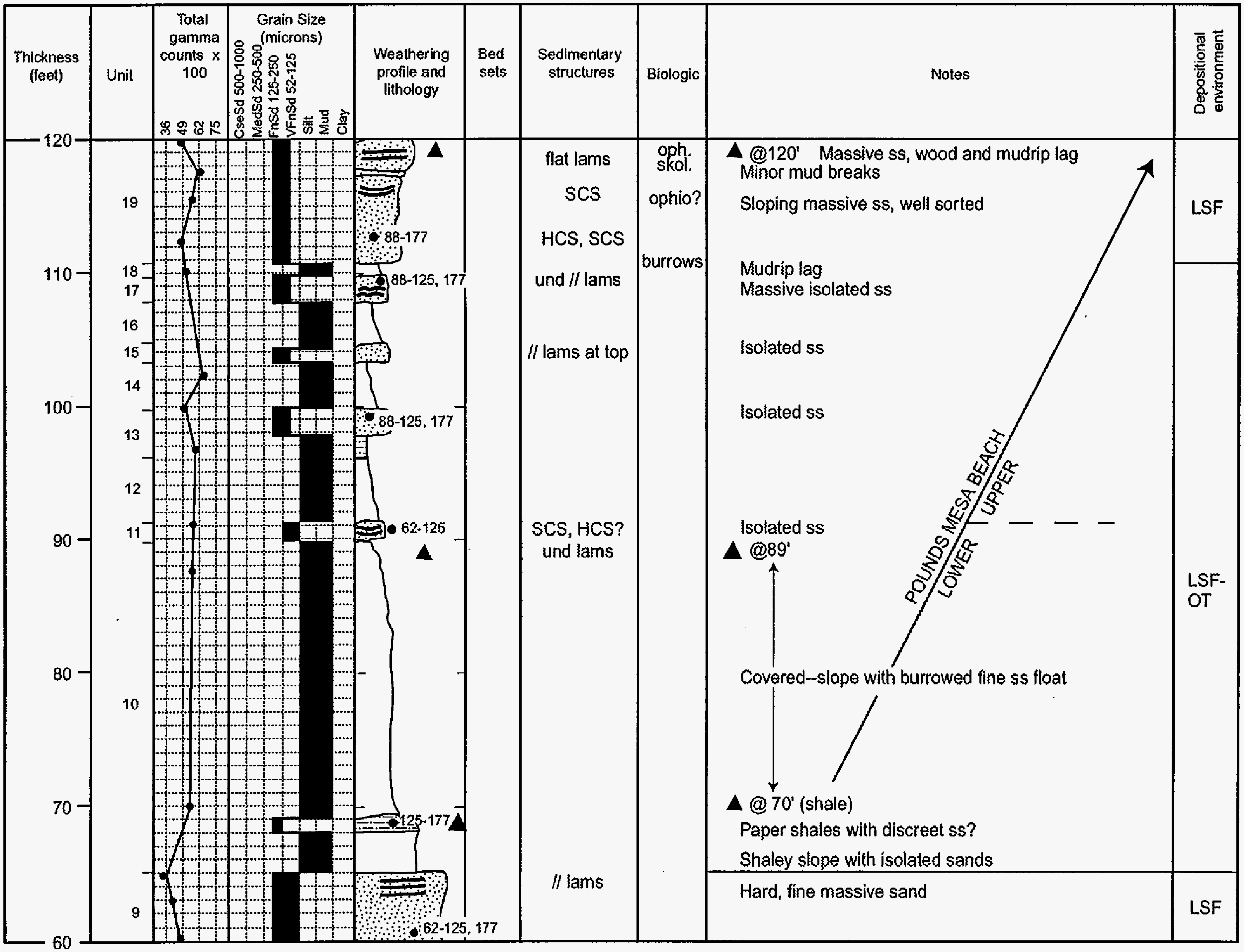
Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W



Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W



Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W



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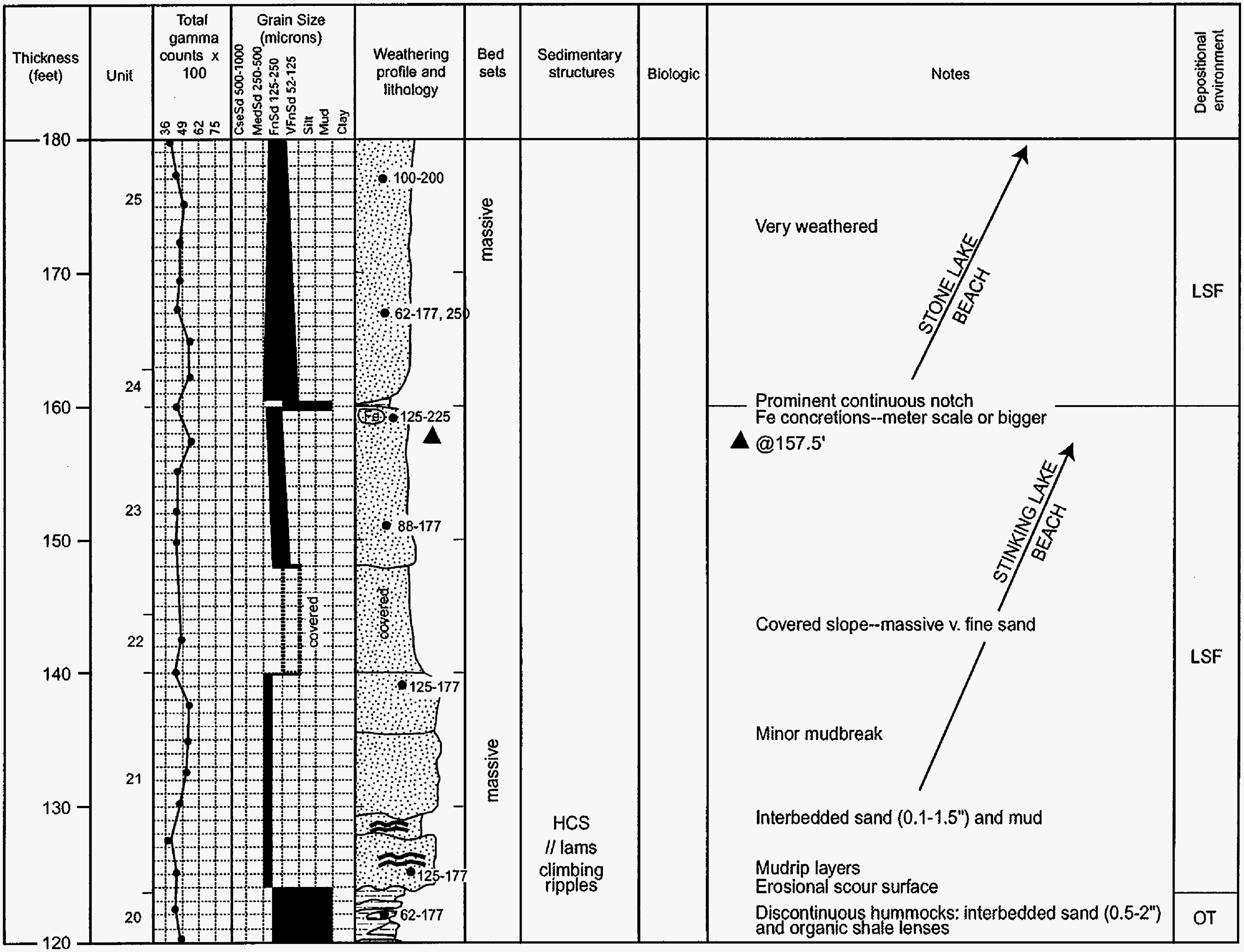

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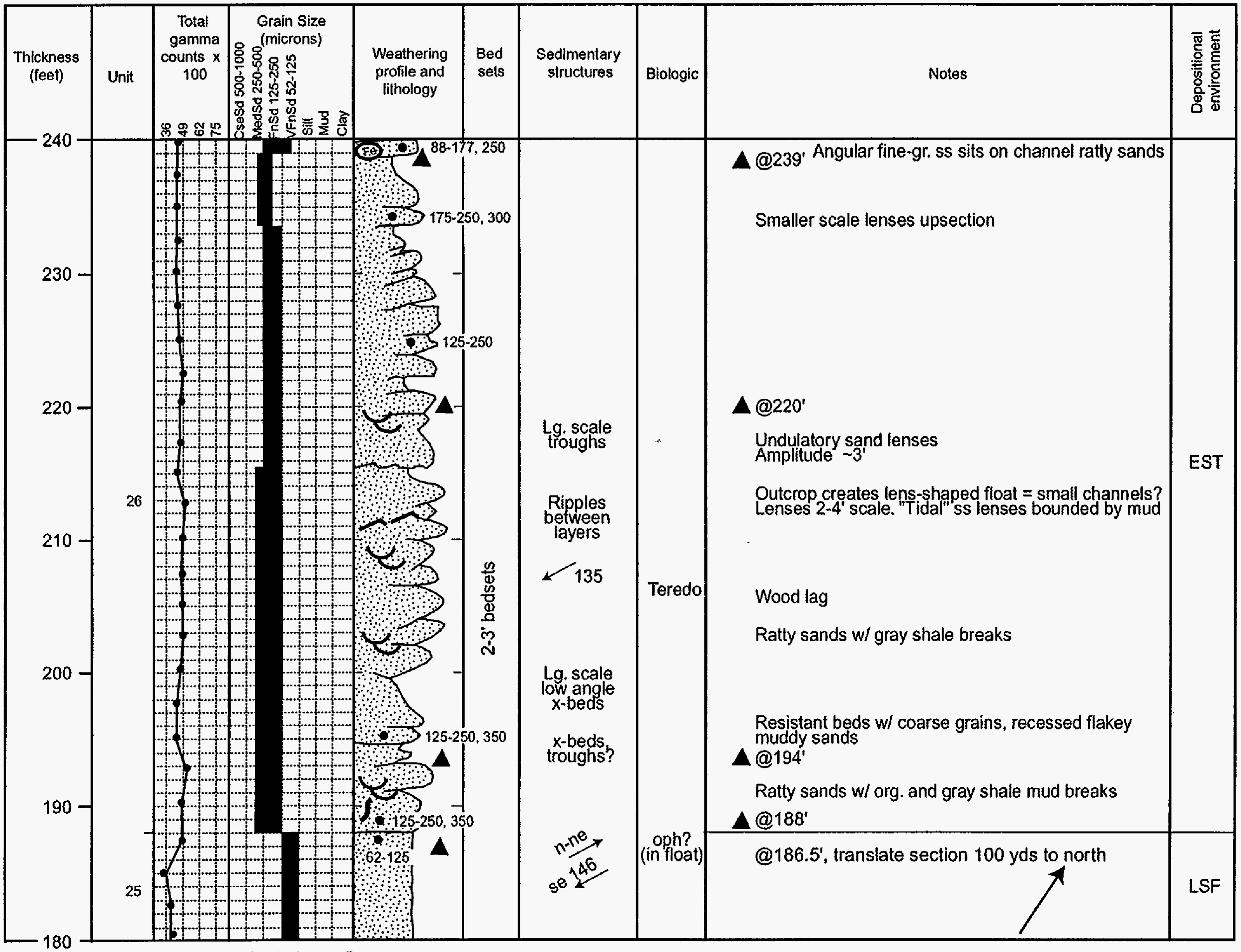

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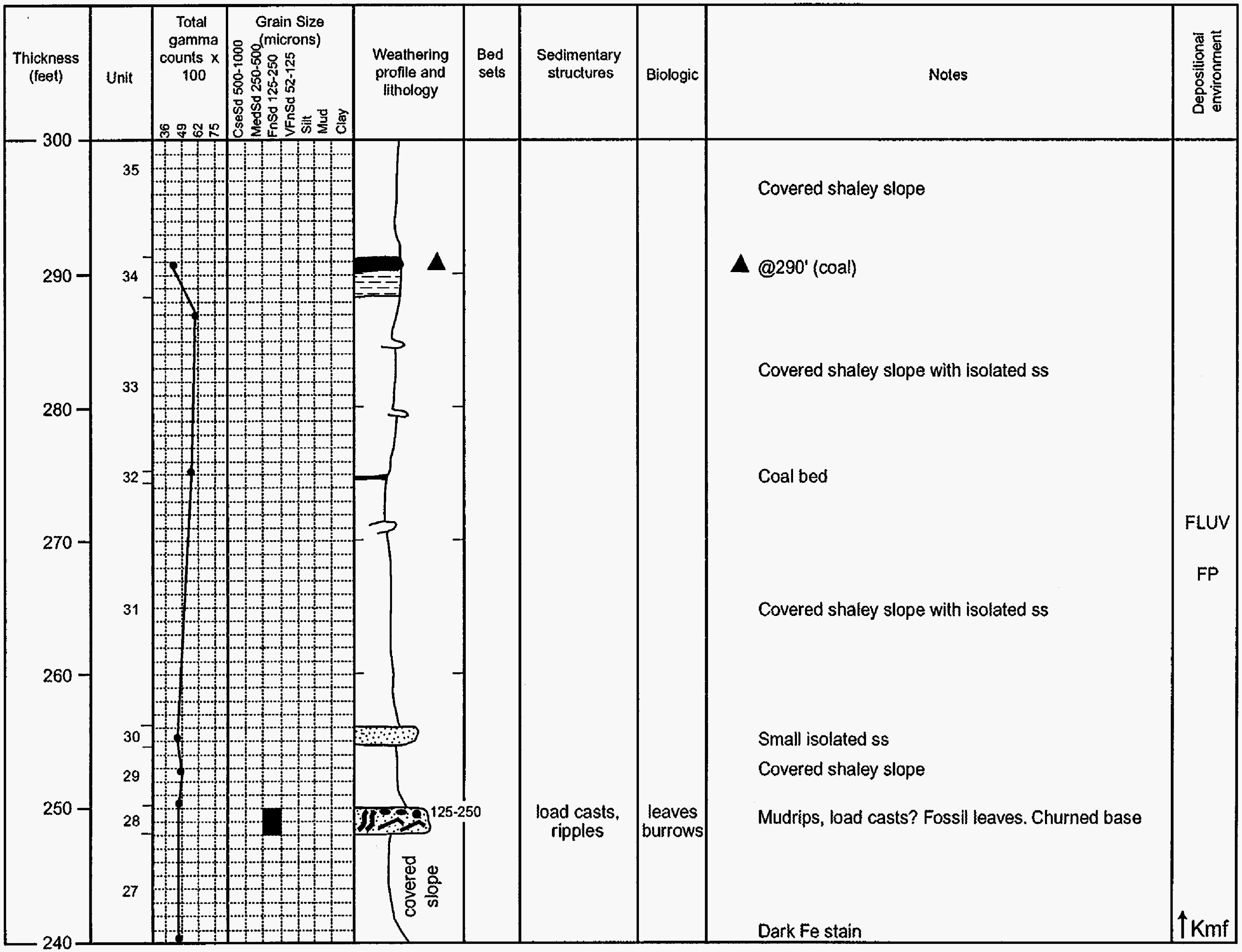

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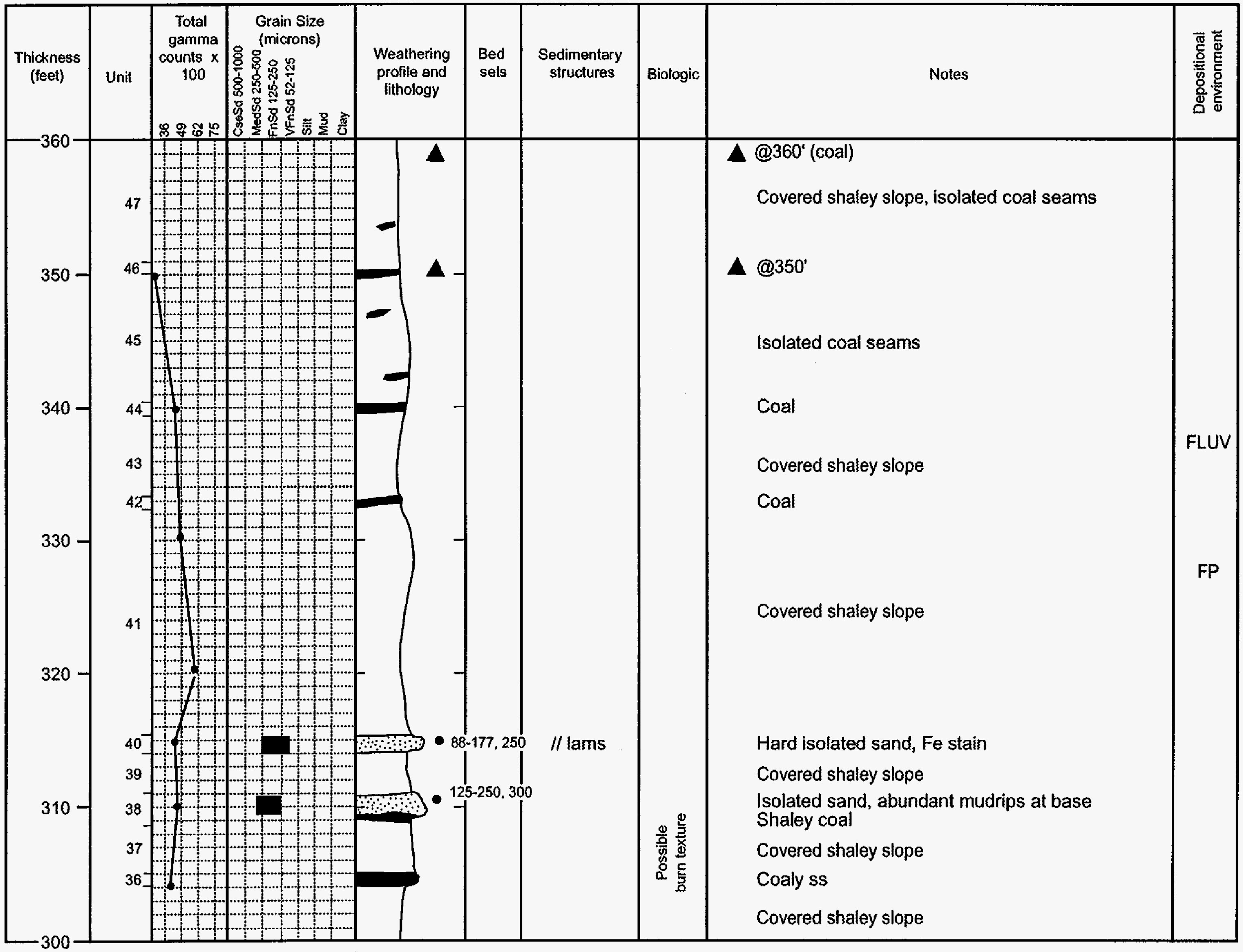

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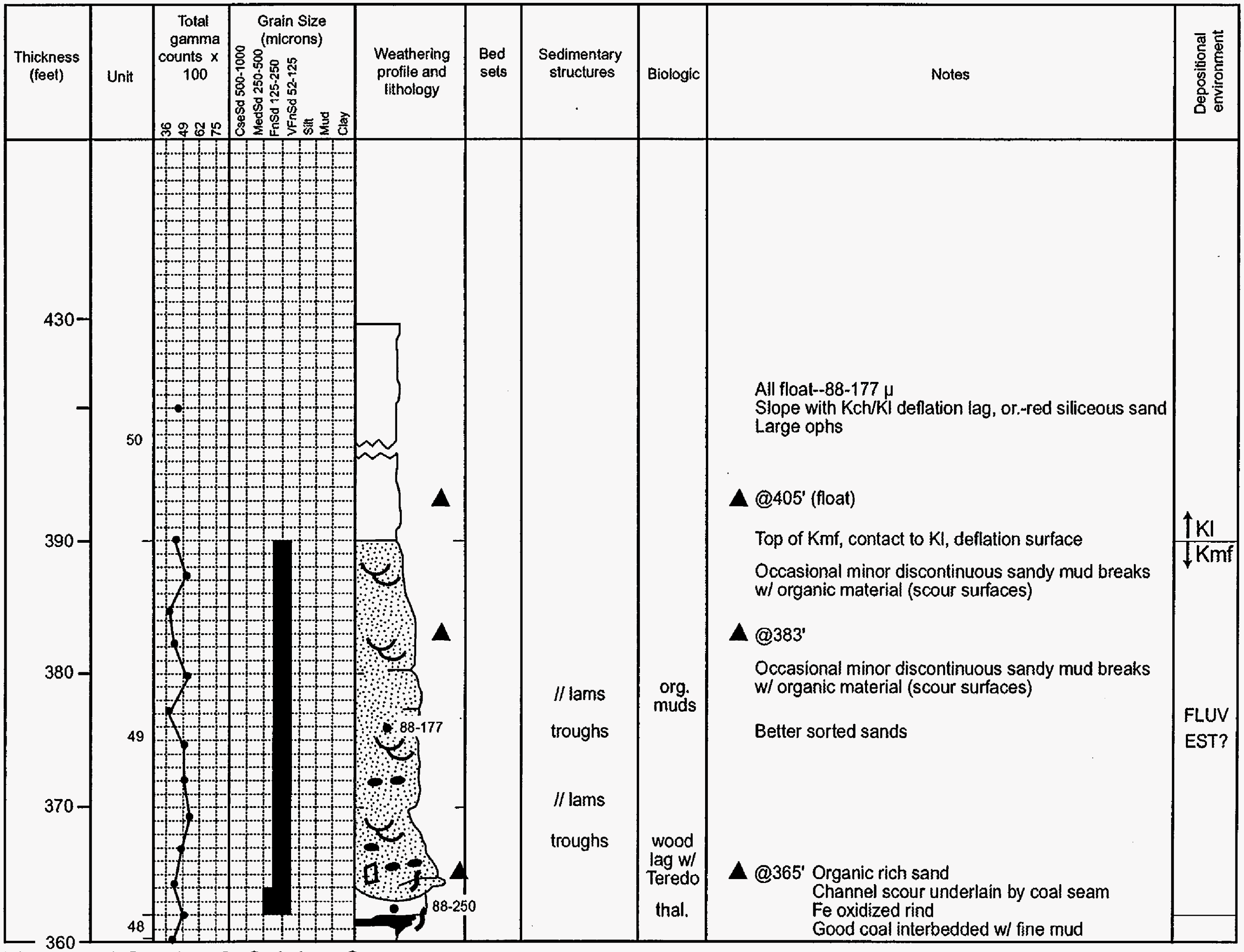

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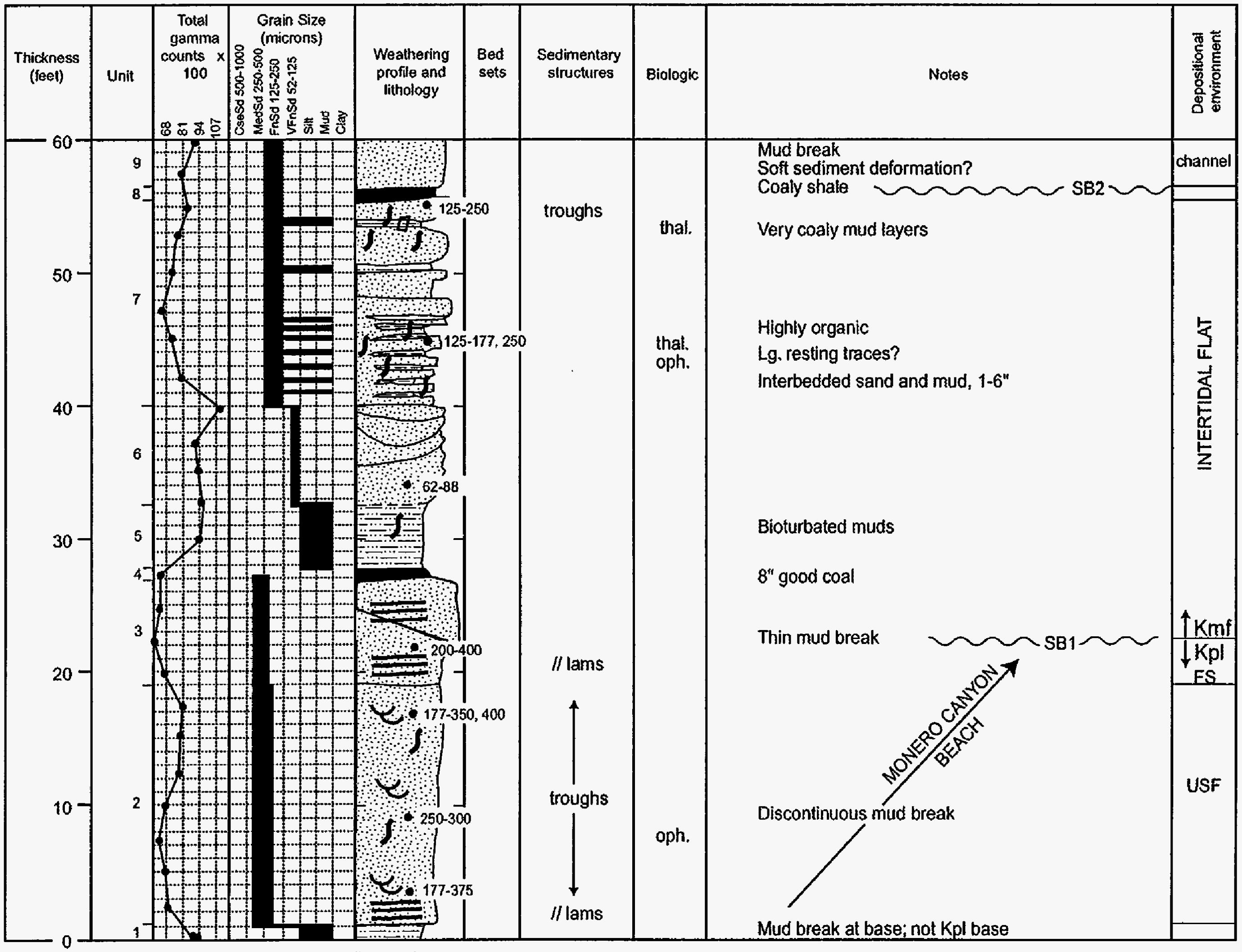
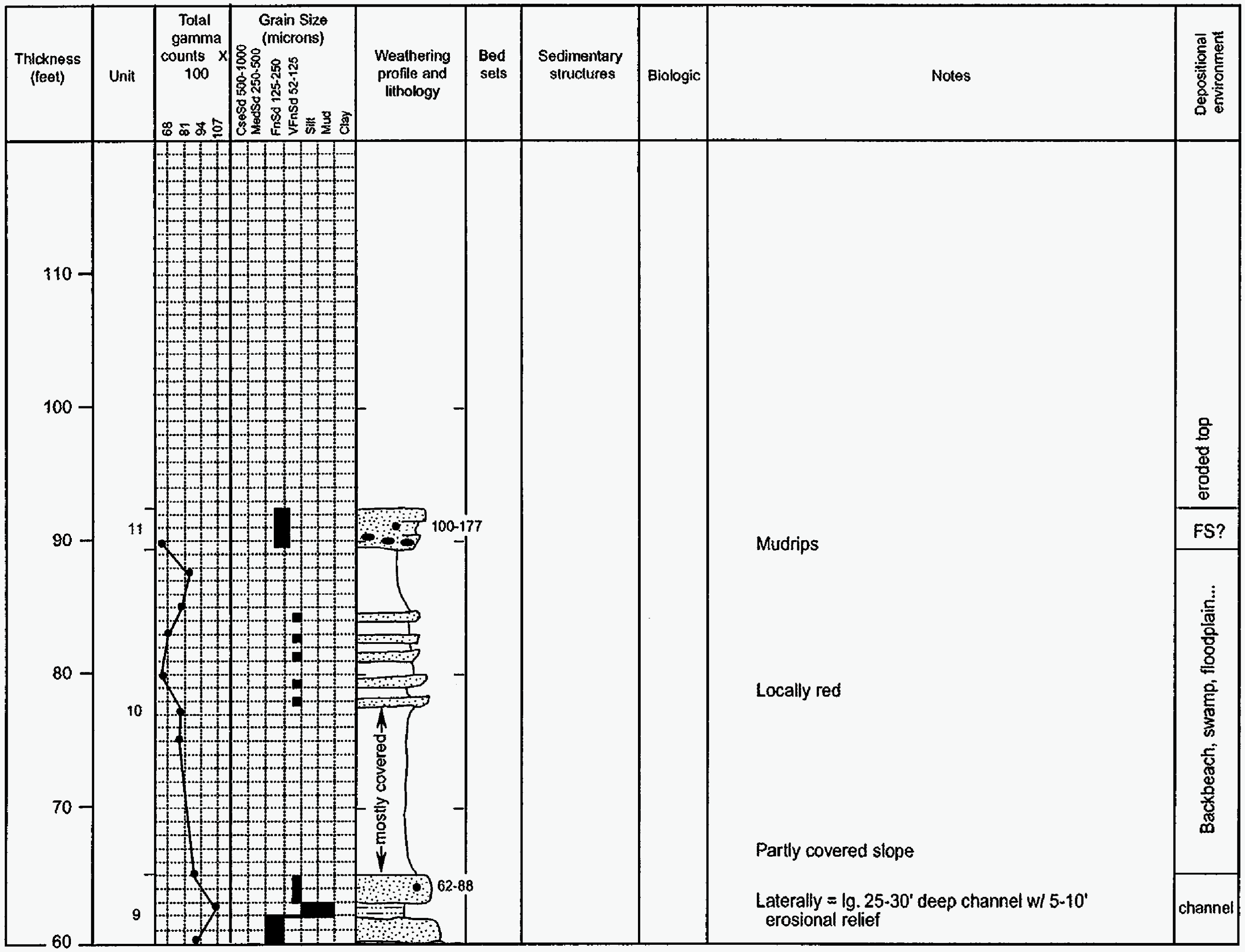


Measured Section 11: Monero Beach. Measured by RWD, MK-J, DB, AM, KO, SV 36 54'15" N, 106 51'4" W



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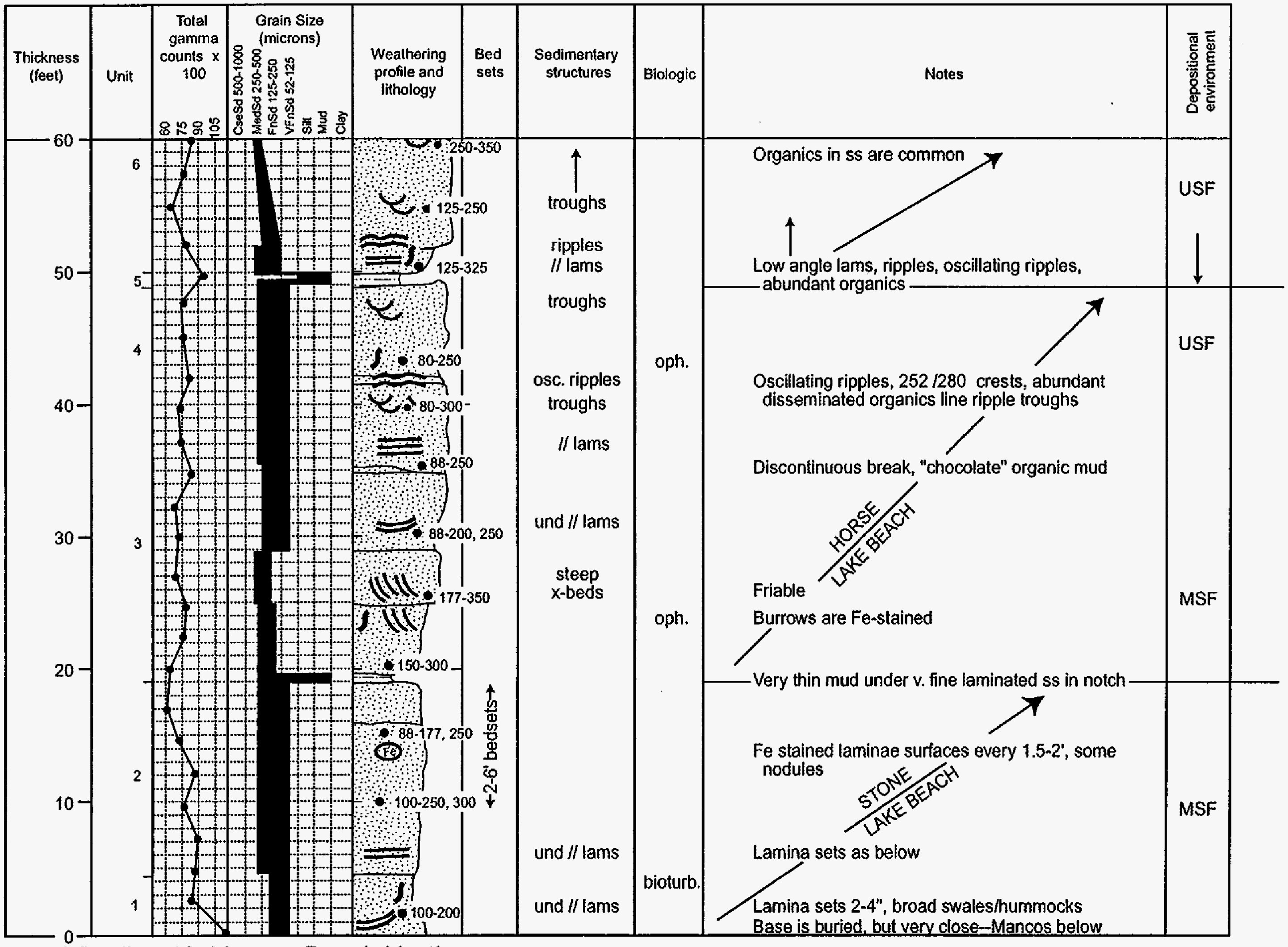
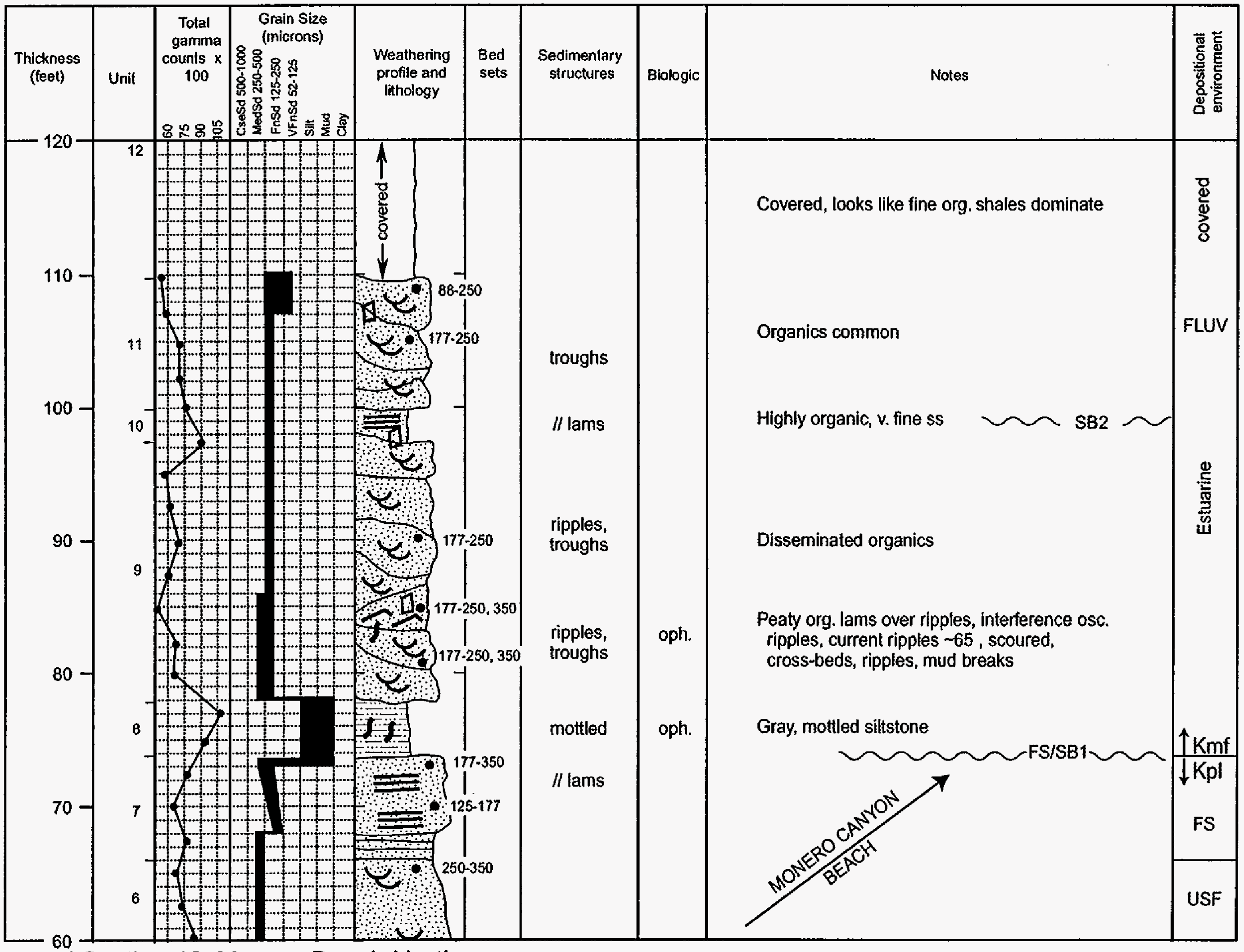


Measured Section 12: Monero Beach North. Measured by RWD, MK-J, AM, KO, DB, SV 36 54'15" N, 106 51'4" W



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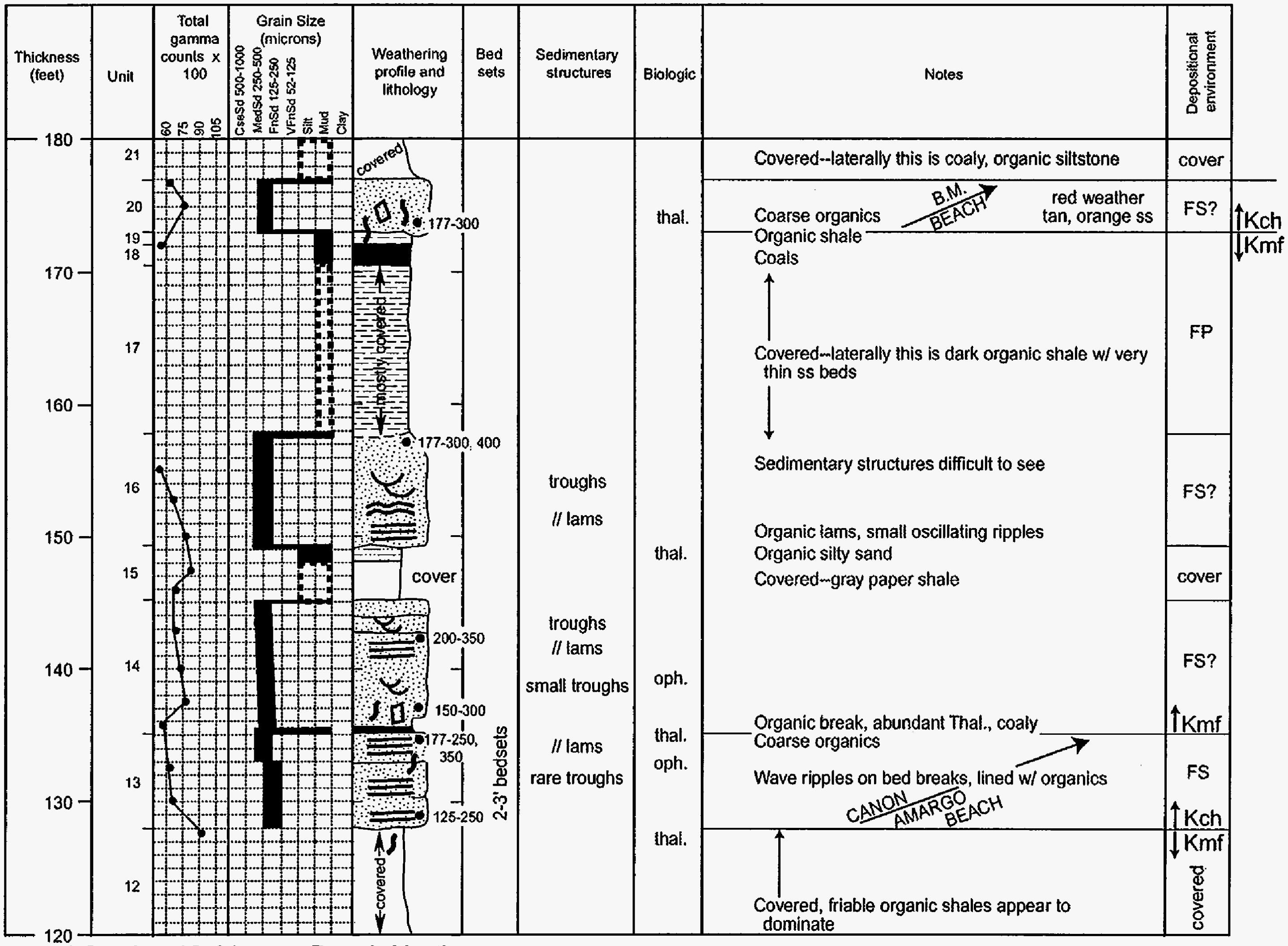

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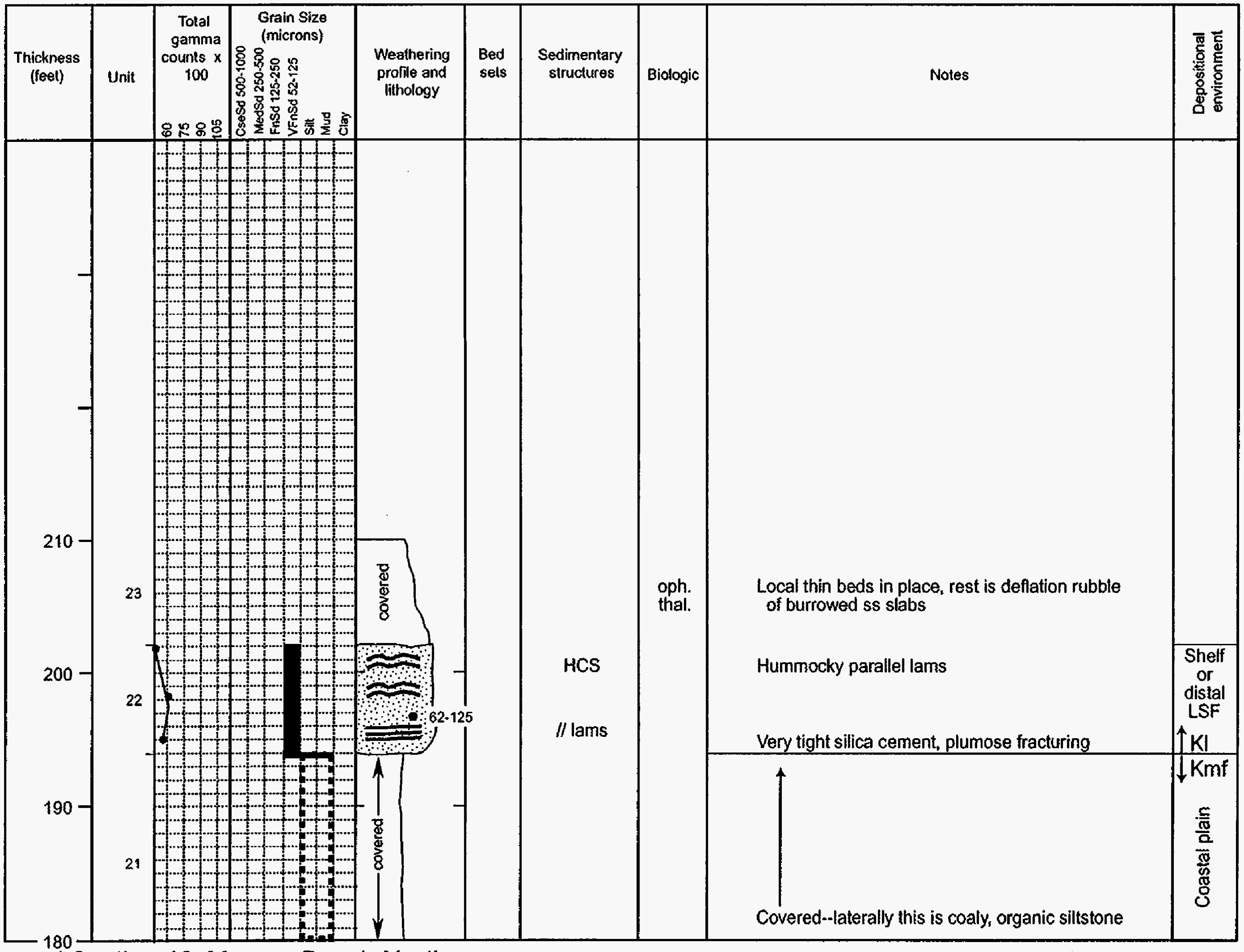

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