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OUTCROP ANALYSIS OF THE CRETACEOUS MESAVERDE GROUP: JICARILLA APACHE RESERVATION, NEW MEXICO

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January 22, 1998-June 30, 1999

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 is the Phase One contract report to the United States Department of Energy, United States Geological Survey and the Jicarilla Apache Indian Tribe on the project entitled "Outcrop Analysis of the Cretaceous Mesaverde Group: Jicarilla Apache Reservation, New Mexico." Field work for this project was conducted during July and August, 1998, at which time fourteen measured sections were described and correlated on or adjacent to Jicarilla Apache Reservation lands. A fifteenth section, described east of the main field area, is included in this report, although its distant location precluded use in the correlations and cross-sections presented herein. Ground-based photo mosaics were shot for much of the exposed Mesaverde outcrop belt and were used to assist in correlation. We conducted outcrop gamma-ray surveys at six of the fifteen measured sections using a GAD-6 scintillometer. The raw gamma-ray data are included in this report, however, analysis of those data is part of the ongoing Phase Two of this project.

Included in this report is a description and interpretation of the inner shelf, nearshore marine, estuarine, and alluvial plain sedimentary lithofacies that comprise the upper Mancos Shale, Point Lookout Sandstone, Menefee Formation, Cliff House Sandstone, and basal Lewis Shale in the northeastern San Juan Basin. Six discrete shorelines were recognized and mapped in the area between Puerto Chiquito (T.27 N., R.1 E.) and Briggs Mesa (T.31N., R.1E.).

Our work places the entire Mancos Shale to Lewis Shale interval within a sequence stratigraphic framework that includes description of two previously undocumented sequence bounding unconformities. From oldest to youngest this series includes:

- Late highstand systems tract - Mancos, Point Lookout and Menefee shallow marine and alluvial deposits prograde basinward under conditions of decreasing sediment accommodation space,
- Lowstand systems tract - base level fall and erosion produces sequence boundary SB1 and an incised valley within the middle Menefee and upper Point Lookout - minor accumulation of fluvial strata within the valley,
- Transgressive systems tract – incised valley backfills with bayhead delta and heterolithic fluvial strata in the Point Lookout and Menefee – equivalent transgressive shallow marine deposits lie north of the field area,
- Highstand systems tract – renewed shoreline progradation results in Menefee alluvial plain aggradation in field area,
- Lowstand systems tract - base level fall and erosion produces sequence boundary SB2 and a second incised valley within the middle Menefee – minor accumulation of fluvial strata within the valley,
- Transgressive systems tract – incised valley fills with Menefee fluvial strata and is overstepped by landward migrating Cliff House shallow marine sandstones – a transgressive surface separates Cliff House or Menefee strata (below) from Lewis Shale (above).

Using this stratigraphic framework, a number of hydrocarbon reservoir plays can be recognized and projected toward the subsurface. Late highstand Point Lookout shoreface and estuarine deposits underlying SB1 produce a very promising updip pinchout play that occupies the highest stratigraphic level within the marine progradational package. These rocks correlate along a ~N60W shoreline trend line to the Ignacio-Blanco field in southern Colorado. Our work suggests that this trend line separates two very different types of Mesaverde exploration strategies. Southwest of this line, complete Point Lookout shoreface sandstone packages will display the "step" and "bench" stacking patterns long familiar in the basin subsurface. These shoreline sandstones stacked vertically as they prograded seaward and thus have a thick landward-equivalent non-marine Menefee package.

Northeast of this trend line base-level fall and incised valley topography will greatly influence Point Lookout and Menefee reservoirs. Sediment eroded from the alluvial plain bypassed the San Juan Basin area (along surfaces SB1 and SB2) to accumulate north of the modern outcrop belt. Point Lookout shoreface sandstones in the northeastern San Juan Basin will be variably dissected with valleys and interfluves. Here the exploration strategies should include specific dip-aligned incised valley fill sandstones that extend from the top of the Point Lookout landward into the middle Menefee. Cliff House sandstones are present in only the extreme northeastern outcrops, suggesting their significance as reservoir units may be minimal in the northeastern part of the basin, especially on the Reservation.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

Mesaverde Group strata in the study area (Fig. 1) include a range of facies types that reflect deposition in inner shelf, nearshore marine, and coastal or alluvial plain settings. Complex intertonguing relationships make direct correlation of specific facies to individual formations difficult. In general, however, thick nearshore marine strata comprise the bulk of the Point Lookout Sandstone and its transition to the underlying Mancos Shale throughout the study area. Marine-influenced fluvial/estuarine and non-marine strata characterize the Menefee Formation, which locally contains thin wedges of Point Lookout and Cliff House coastal marine deposits. Nearshore coastal sandstones of the Cliff House Sandstone are preserved only on Brigg's Mesa in the far northeastern part of the study area (Fig. 1). South of Brigg's Mesa, poorly expressed, thin (0-7 feet) inner shelf sandstones and sandy fossiliferous lags at the base of the Lewis Shale mark passage of the Cliff House shoreline through the study area. The following lithofacies descriptions are based upon detailed measured section data presented in Appendix 1. Selected descriptive criteria are compiled in Tables 1 and 2.

Inner Shelf Strata

Very-fine Burrowed Sandstone Facies (Shelf-Modified Transgressive Lag)

Very fine sandstones contain mudrip clasts, wood imprints, shark's teeth, and shell (including oyster) fragments as basal lag components. Flaggy, lenticular bedding (<2 feet thick) dominates the sandstones, with uncommon amalgamation to a maximum of seven feet. Rarely preserved physical sedimentary structures include parallel lamination and hummocky cross-stratification (HCS). Spectacular *Ophiomorpha* trace fossils are characteristic (Fig. 2a), and bioturbation commonly obscures physical sedimentary structures. Unique to this facies is strong silica cement, with lesser Fe-oxide cement imparting an orange color in outcrop. This facies has been observed only on cliff tops at the contact between the underlying Menefee Formation and overlying offshore marine Lewis Shale. It is interpreted to represent a major marine flooding surface and associated transgressive lag coincident with passage of the Cliff House shoreline through this horizon. Modern day erosion of the cliff tops has resulted in removal of most Lewis Shale outcrop, leaving these tightly cemented, burrowed sandstones in float and locally in place.

Nearshore Marine Strata

Interbedded Mudrock/Sandstone Facies (Offshore Transition)

Thinly interbedded shales, mudstones, siltstones and sandstones comprise this facies (Fig. 2b). The number, thickness, and amalgamation of sandstone beds tends to increase upward, however, thin (< 5 feet) fining-upward trends are locally present. Mudrock beds range from less than 1 inch to approximately 10 inches thick where homogenized by burrowing. Very fine-grained sandstones range in thickness from less than 1 inch to 2 feet, and amalgamate to form beds 3-5 feet thick. Sandstones have sharp bases that locally display tool marks and gutters. Tool marks oriented NNE-SSW correspond well with the N73^{0}W shoreline trends (established by mapping updip foreshore strata). Sedimentary structures in sandstones include lenticular bedding, wave ripple stratification and HCS. Bioturbation ranges from 0 to 70%, including the trace fossils *Chondrites, Planolites, Skolithos, and Thalassinoides.*

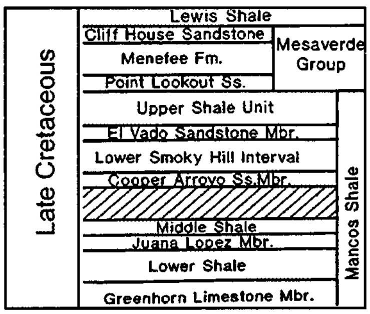
The interbedded mudrock/sandstone facies grades downward into fine-grained mudrocks and shales of the Mancos Shale and is overlain by the massive marine sandstone facies of the Point Lookout Sandstone. The interbedded facies is interpreted to reflect sedimentation under variable energy marine conditions in the offshore transition zone. Thinly bedded mudrock components and delicate trace fossil assemblages reflect a low-energy, or fair-weather, well-oxygenated marine setting (*Cruziana* ichnofacies of Pemberton et al.,1992). Storm conditions, during which waves and storm surge currents impinged on the sea floor, produced the HCS and wave rippled sands with sharp bases, tool marks and gutters (Dott and Bourgeois, 1982; Morton, 1981; Swift et al., 1983). Upward increase in storm sand thickness and amalgamation is consistent with increased storm impact on a shoaling seafloor.

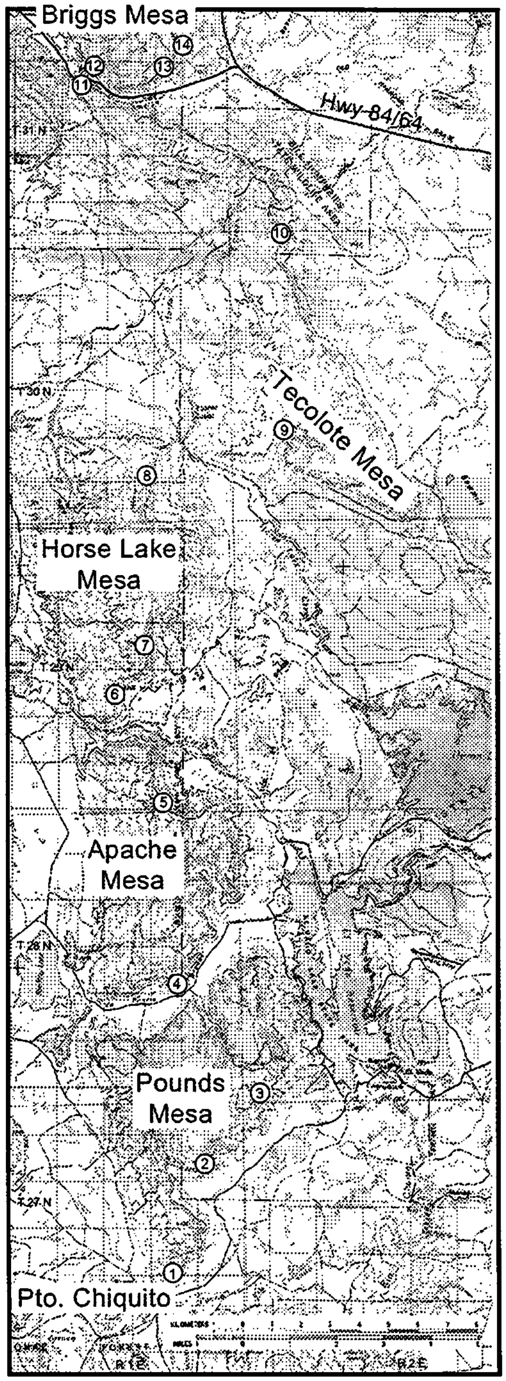
Massive Sandstone Facies (Lower to Middle Shoreface)

Overlying and locally interfingering with the interbedded mudrock and sandstone facies is amalgamated massive sandstone (Fig. 2b). This facies displays a coarsening-upward transition from very fine to fine grained sandstone and an upward transition from (less common) hummocky cross-stratification (HCS) to swaley cross-stratification (SCS) and undulatory sub-parallel lamination. Swaley cross-stratification (Leckie and Walker, 1982) displays concave-upward erosional surfaces and fill over a scale of several feet. These surfaces broaden and flatten upward to yield undulatory sub-parallel lamination. Lower

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).

(below) Stratigraphic chart for Mesaverde Group and associated Late Cretaceous rocks in the Chama Basin and northeastern San Juan Basin (from Lucas, et al., 1992). See Figure 12 for specific age ranges of Mesaverde Group strata.





bedsets (3-5 feet thick), which may be separated by thin (<3 feet) mudrock breaks, are more likely to display remnant HCS with clear convex-upward bounding surfaces. These bedsets give way over a short vertical distance, however, to sand-on-sand contacts and massive cliffs with few, if any, obvious bedding breaks. Where discernible, bedsets are on the order of 5-6 feet or more. The massive nature of the facies and its characteristic low angle sedimentary structures produced rounded-weathering outcrops that may superficially appear structureless.

Intraformational mud rip-up clasts (<1/2 inch in size) are present in isolated patches and along bedding horizons, typically within a few vertical feet of, or laterally adjacent to, a mudrock break. Such breaks can be discontinuous and local, or may correlate with laterally continuous parasequence-scale marine flooding surfaces. Bioturbation is generally less than 20% but can reach as much as 60%. Commonly recognized trace fossils are *Thalassinoides, Cylindrichnus,* and *Ophiomorpha.* The massive sandstone facies comprises a laterally continuous sheet that breaks out downdip into interbedded mudrock/sandstone facies and merges updip into trough cross-stratified sandstone.

Upward transition from HCS to SCS to undulatory parallel lamination records the effects of shoaling storm conditions (Leckie and Walker, 1982) along the prograding strandline. During storms, sediment eroded from the upper and middle shoreface is transported by down-welling storm surge currents and/or geostrophic currents (Morton, 1981; Swift et al., 1983) onto the lower shoreface and inner shelf transition zone. The amalgamation of sandstones, general lack of layered mudrock, and presence of mud rip-up clasts within these rocks suggests deposition in water depths shallower than those in which mud could be readily preserved. In this study, very fine sandstones that display HCS and/or contain local thin mudrock layers are designated as lower shoreface. Middle shoreface sandstones are very fine to fine-grained, dominated by SCS, and are typically massive.

Trough-Crossbedded Sandstone Facies (Upper Shoreface)

Vertically above and/or up depositional dip from the massive sandstone facies, fine to medium grained sandstones comprise the trough-crossbedded sandstone facies (Fig. 2c). Individual trough crossbeds have a preserved thickness of 1-2 feet (rarely greater) and occur within bedsets 3-5 feet thick. The entire facies averages 20 feet thick (and as much as 30 feet) within a single parasequence. Mud ripup clasts, which are common in underlying strata, are virtually absent in this facies. Uniformity of both grain size and sedimentary structure and the lack of mudrock interbeds yield a blocky weathering texture. Paleocurrents display a wide range of current directions, including landward, offshore, and along shore. Stratigraphic position and sedimentary structures in this facies are consistent with deposition in the upper shoreface zone influenced by asymmetrical shoaling waves and, possibly, migratory sand bars (Elliott, 1986).

Planar Laminated Sandstone Facies (Foreshore)

Capping the trough-crossbedded sandstone facies is fine to medium grained sandstone that displays tabular or wedge-shaped, seaward dipping planar lamination (Fig. 2c). Bedsets are 2-3 feet thick and comprise a total facies thickness of 5-10 feet where fully preserved. *Ophiomorpha* dominates the trace fossil assemblage, with lesser *Thalassinoides* and *Cylindrichnus.* Most burrows occur as scattered individual traces; however, the upper few feet of the facies can be fully churned and rooted. At several outcrop locations in which this facies is overlain by organic rich mudrock or coals a characteristic bleached appearance, or "whitecap," extends downward for many feet. More commonly, a 1-2 foot thick mottled and strongly iron-cemented layer tops the facies.

Where recognized, the planar laminated sandstone facies marks the top of the Point Lookout Sandstone. Marine-influenced (estuarine) or non-marine coastal plain deposits overlie, and locally erode, these sandstones. Stratigraphic association and physical characteristics of the facies suggest deposition in the foreshore, under very shallow, high-energy plane bed conditions characteristic of the swash zone (Elliott, 1986).

Estuarine and Alluvial Plain Strata

Amalgamated Marine-Influenced Sandstone Facies (Estuarine Channels, Bayhead Delta)

These rocks abruptly overlie truncated shoreface sandstones along an extensive, irregular erosional surface with 50-60 feet of relief in the northern study area (Fig. 3). Regional significance of this erosional surface (SB 1) is discussed later in this report. Found on Horse Lake, Tecolote, and Brigg's mesas (sections 8-14), this facies forms an amalgamated, sandstone-dominated sheet extending (within the

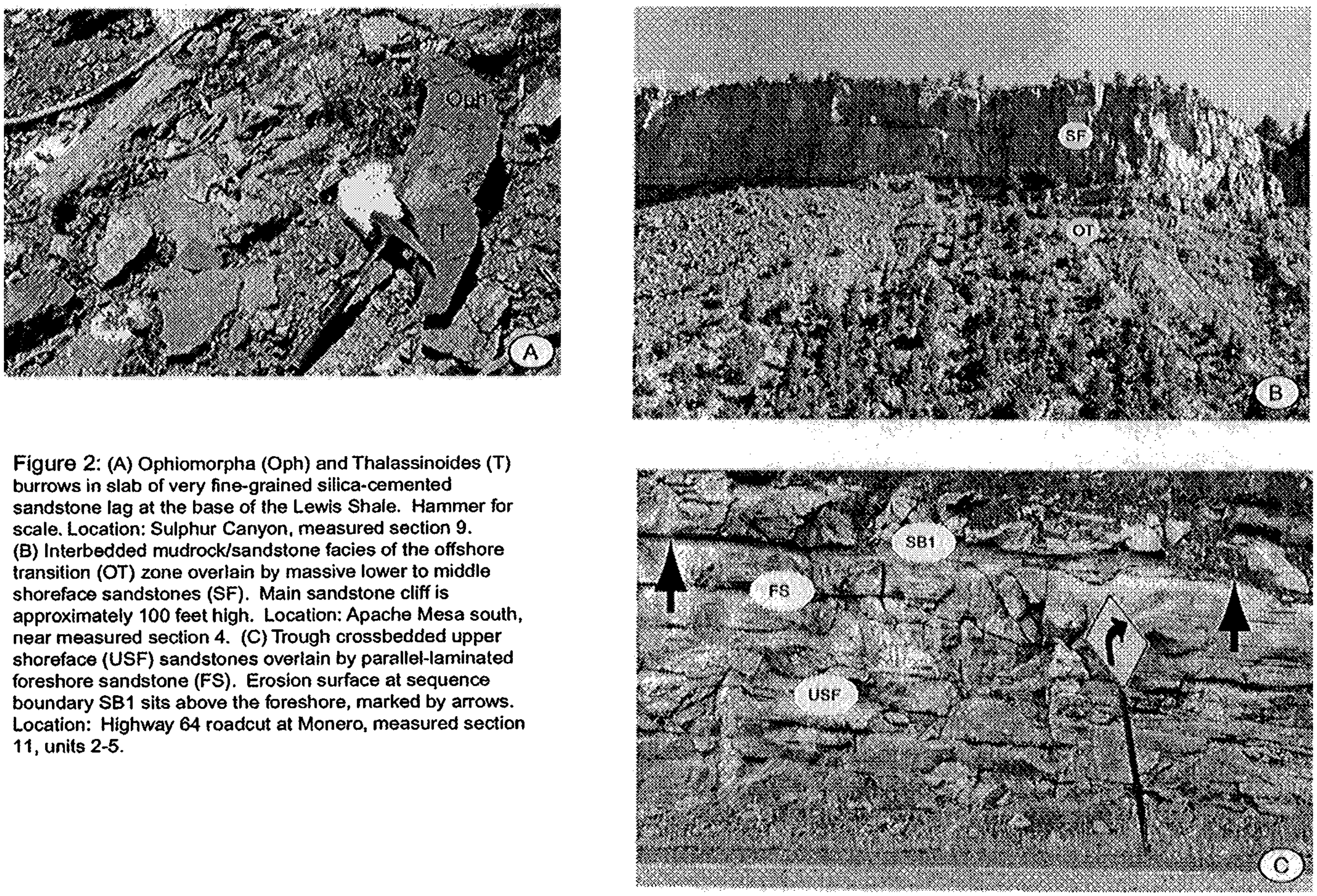
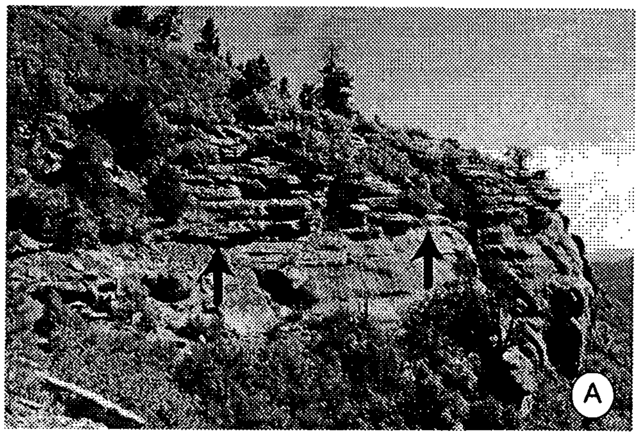
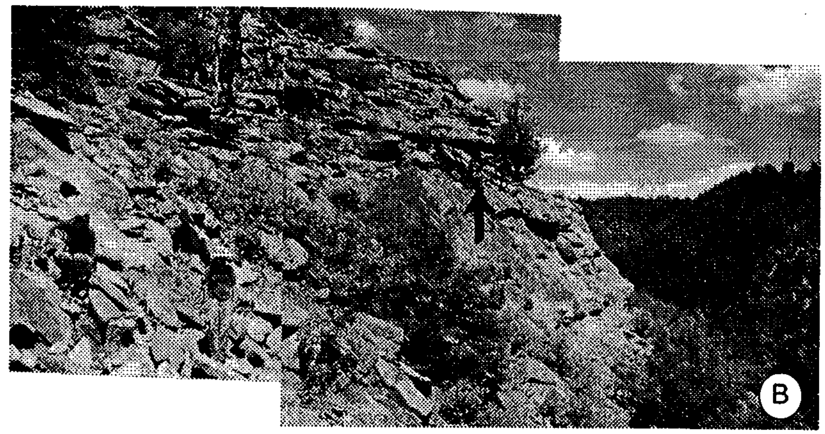


Figure 2: (A) Ophiomorpha (Oph) and Thalassinoides (T) burrows in slab of very fine-grained silica-cemented sandstone lag at the base of the Lewis Shale. Hammer for scale. Location: Sulphur Canyon, measured section 9. (B) Interbedded mudrock/sandstone facies of the offshore transition (OT) zone overlain by massive lower to middle shoreface sandstones (SF). Main sandstone cliff is approximately 100 feet high. Location: Apache Mesa south, near measured section 4. (C) Trough crossbedded upper shoreface (USF) sandstones overlain by parallel-laminated foreshore sandstone (FS). Erosion surface at sequence boundary SB1 sits above the foreshore, marked by arrows. Location: Highway 64 roadcut at Monero, measured section 11, units 2-5.

Lithofacies	Physical Description	Biogenic Components	Depositional Environment
Very fine Burrowed Sandstone Facies	Thin-bedded (2-6 inches) very fine grained sandstone with shell fragments, shark's teeth. Highly bioturbated to structureless. Fe-oxide and strong silica cement.	*Ophiomorpha* *Shark's teeth* *Shell fragments*	Inner Shelf Transgressive Lag
Interbedded Mudrock - Sandstone Facies	Thinly laminated shale, mudstone and siltstone interlayered with thickening-upward, v. fine sandstones. Mudrock bedsets up to 10 inches; sandstones to 24 inches. Sandstones display lenticular bedding, wave ripple stratification and HCS. Calcite and Fe-oxide cement.	*Skolithos* *Planolites* *Chondrites* *Thalassinoides*	Marine Offshore Transition Zone
Massive Sandstone Facies	Moderately sorted, very fine to fine-grained sandstone with rare mudrock breaks. Upward transition from HCS to SCS and undulatory parallel laminations. Isolated patches and layers of mudrip clasts. Massive rounded weathering outcrops. Calcite and Fe-oxide cement.	*Thalassinoides* *Cylindrichnus* *Ophiomorpha*	Lower to Middle Shoreface
Trough-Crossbedded Sandstone Facies	Well-sorted fine to medium grained sandstones. Trough crossbeds (1-2 feet) with lesser interference ripples. Bedsets 3-5 feet to massive. Calcite and Fe-oxide cement.	*Ophiomorpha* *Cylindrichnus*	Upper Shoreface
Planar Laminated Sandstone Facies	Gently seaward-dipping planar parallel laminations in well-sorted fine to medium grained sandstone. Locally "whitecapped" or strongly Fe-cemented at top.	*Ophiomorpha* *Thalassinoides (rare)*	Foreshore Swash Zone

Table 1: Lithofacies descriptions for rocks interpreted to be of nearshore marine and inner shelf origin.





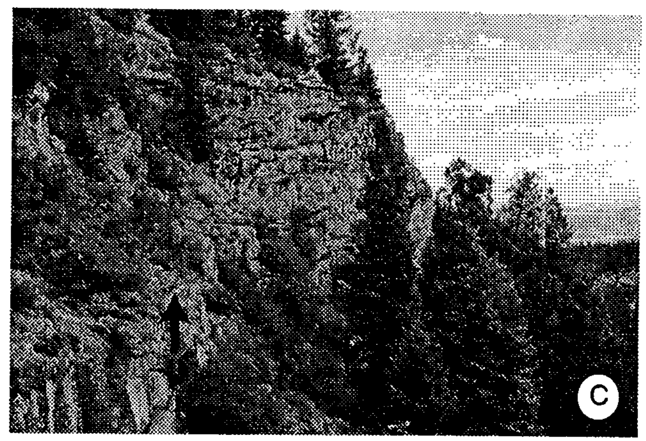


Figure 3: Amalgamated lenticular estuarine sandstones (bayhead delta deposits) overlie erosional sequence boundary (SB1, at arrows) incised into underlying Point Lookout middle shoreface sandstones at (A) Horse Lake Mesa, measured section 8, units 6-7, (B) Tecolote Mesa, measured section 9, units 25-26, and (C) Tecolote Mesa, measured section 10, units 3-5.

constraints of outcrop control) at least six miles parallel to paleoshoreline and an equivalent distance in the offshore direction (Fig. 4). Toward the south (paleo-landward) above the SB1 erosional surface, the amalgamated sandstone facies is replaced by a finer-grained, organic-rich heterolithic channel facies (described below). Toward the west the SB1 erosional surface climbs into an interfluve region (Fig. 4) and this amalgamated sandstone facies pinches out.

The amalgamated marine-influenced sandstone facies is characterized by moderately sorted, very fine to medium grained sandstone which, at the large scale, displays numerous scour surfaces and inclined bedding. Internally, the unit contains amalgamated, lenticular channel-fill sandstones. Wood and mud ripup clasts are abundant. Toward the top of the facies are lozenge-shaped (sigmoid) sandstone bodies approximately 1-2 feet thick and up to 9 feet long. These sand bodies display reactivation surfaces and mudrock or siltstone drapes. Sedimentary structures include trough crossbeds, planar tabular crossbeds, and current ripples. Paleocurrent directions are variable N-NE and SE (offshore and along shore), with subordinate S-SW (landward). Organic material, ranging from "coffee grounds" laminations and wood fragments to large *Teredo*-bored logs, is abundant. *Thalassinoides* and *Ophiomorpha* are locally found, particularly within thin, interbedded mudrocks. Northern outcrops display common marine burrows (measured sections 10, 14), decreasing to rare bioturbation toward the south (measured section 8).

Abundant scour-and-fill surfaces, moderately sorted organic sandstones, reactivation structures, and fine-grained mud drapes readily distinguish this facies from underlying, massive-weathering, well-sorted shoreface deposits (Fig. 3). Sparse *Thalassinoides* and *Ophiomorpha* and abundant Teredolites argue strongly for marine proximity. Brackish or marine conditions must have at least periodically existed during deposition of this unit. Other indicators suggestive of marine proximity are the reactivation surfaces and sigmoid -shaped sandstones with mudrock drapes (reversing tidal currents and/or fluctuating water stage), as well as inclined heterolithic strata (laterally migrating intertidal point bars). Similar physical and biogenic structures are also seen in modern inner estuary (bayhead delta) estuarine point bars and sand bars (Allen and Posamentier, 1994; Roy, 1994). This facies, interpreted to reflect fluvial/estuarine deposition, also shares many attributes of tidally, or marine-influenced, channel systems in similar aged rocks of the Kaiparowits Plateau (Shanley, et al., 1992; Hettinger et al., 1993; and Shanley and McCabe,1995). Decreasing bioturbation from north to south and coincident development of hetherolithic channel deposits (see below) marks the landward transition from bayhead delta to feeder channel systems (Fig. 4). In the study area, this transition occurs on Horse Lake Mesa (between sections 7 and 8). Evidence suggests that the bayline, or landward limit of the estuary, extended no farther south than section 7.

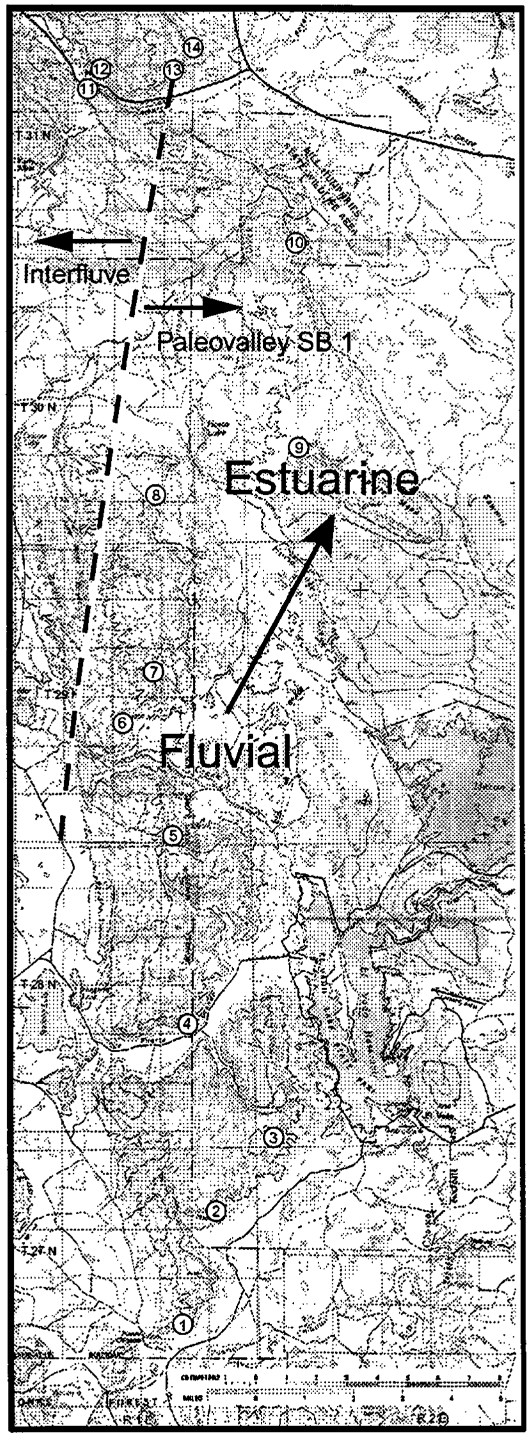
Sandstone Channel Facies (Fluvial and Tidally-influenced Fluvial)

Channel sandstones and surrounding fine-grained mudrock facies characterize much of the preserved Menefee Formation in the study area. While small channel deposits may occur throughout the Menefee, there are three specific intervals along which most large channels are concentrated. These are: (1) within the middle to lower Menefee (sections 1-12) where channel/overbank deposits directly overlie the SB1 erosional surface; (2) near the seaward depositional limit of the Menefee Formation (sections11-14) where large channel sandstones fill almost the entire 80 feet thick Menefee interval, and; (3) within the upper Menefee (sections 1,9) where channel deposits occur immediately beneath the Lewis Shale transgressive surface.

Channel/overbank deposits that directly overlie the SB1 erosion surface occupy a landward (sections 1-7) or flanking (sections 11, 12) stratigraphic position with respect to the previously described estuarine and bayhead delta deposits. Among these channelized deposits, sand-rich fill dominates toward the south (landward), being replaced by or overlain by heterolithic fill (alternating sandstone:mudrock) toward the north (seaward). Sand-rich channel fill deposits are a maximum of 30-40 feet thick and extend laterally approximately 300-500 feet. Mudrock breaks are present, but are greatly subordinate to sand-on-sand bedding contacts. Internally, bedsets (2-4 feet thick) display large-scale trough cross-stratification, lesser current ripple stratification, and sub-horizontal parallel laminations. These medium- to coarse-grained sandstones are moderately sorted, fine-upward, and commonly contain mica. Compound scour surfaces with basal mud clast lags suggest some degree of amalgamation of smaller channels. No biogenic structures have been observed within these sandstones.

Toward the north along the SB1 erosional surface, heterolithic channel fill and adjacent fine-grained organic deposits replace or overlie the sand-rich channel fill described above (section 7, units 3-6; section 11, units 4-8). Heterolithic rocks commonly display scour and undulatory, inclined bedding (Fig. 5a, b) and are characterized by alternating medium-grained sandstone (1-2 feet thick) and organic mudrock

Figure 4: Transition from fluvial channels to estuarine channels and bayhead delta deposits occurs from south to north between measured sections 7 and 8. A broad amalgamated estuarine sheet caps the Point Lookout Sandstone on northern Horse Lake Mesa, Tecolote Mesa, and portions of Briggs Mesa (sections 8-10, 14). The bayline, defined by the landward limit of this facies, falls between sections 7 and 8, with maximum marine influence at sections 10 and 14. The dashed line marks the approximate edge of a paleo-valley and adjacent interfluve region produced by erosion during development of the SB1 sequence boundary.



laminations. Abundant organic debris forms both paired and single laminations along trough and ripple foresets. Biogenic structures include *Teredolites* in woody material, and locally abundant *Thalassinoides* and *Ophiomorpha* in interbedded or laterally adjacent organic mudrocks.

Both the sand-rich and heterolithic channel deposits described above are interpreted as river channels with variably preserved, fine-grained overbank deposits. Several lines of evidence suggest that heterolithic strata were deposited in a more seaward position on the coastal plain (closer to time-equivalent shoreline) than sand-rich counterparts. Sand-rich channels tend to be coarser, contain fewer mud breaks, display more scour surfaces with coarse lag material, and have less preservation of overbank or floodplain mudrocks than heterolithic counterparts. Sand-rich channels show no evidence of direct marine influence, while heterolithic channels and overbank material locally contain marine trace fossils and *Teredo*-bored wood. Inclined heterolithic strata were produced by lateral accretion of migratory point bars. These display the abrupt lithologic alternation, persistent mud drapes, and paired organic laminations that are indicative of fluctuating fluvial discharge combined with tidal current variation in both modern and ancient intertidal/lower coastal plain rivers (Thomas, et al., 1987; Shanley, et al.,1992). The high organic content (including coals) of laterally adjacent overbank deposits further supports interpretation of a low gradient, poorly-drained coastal plain setting for these heterolithic units.

The second area of significant channel development occurs east of Monero along Brigg's Mesa (sections 11-14). In this area, the Menefee Formation thins to less than 100 feet as it approaches its (preserved) seaward pinchout. Outcrop observations (this study) and Menefee drill-hole data (Hoffman, 1991) indicate that fine-grained, coal-rich deposits west of Monero yield to increasingly sandstone-rich facies toward the east. Erosional surface SB2 (Fig. 5b), at the base of this sandstone facies, truncates underlying coal-bearing (heterolithic) fluvial (sections 11-13) or estuarine rocks (section 14) with a minimum of 25 feet of erosional relief. Channel-fill is moderately- to well-sorted, fine- to medium-grained sandstone with local gray shale breaks. Bedsets, <1 ft to 4 feet thick, are dominated by large scale trough- and planar-tabular crossbeds with lesser parallel laminations and soft-sediment deformation features. Numerous scour surfaces contain large coal clasts, mudrips, wood, and sandstone concretions as basal lag material (especially apparent at section 14). No marine trace or body fossils have been observed in either the channel sandstones or interbedded shales.

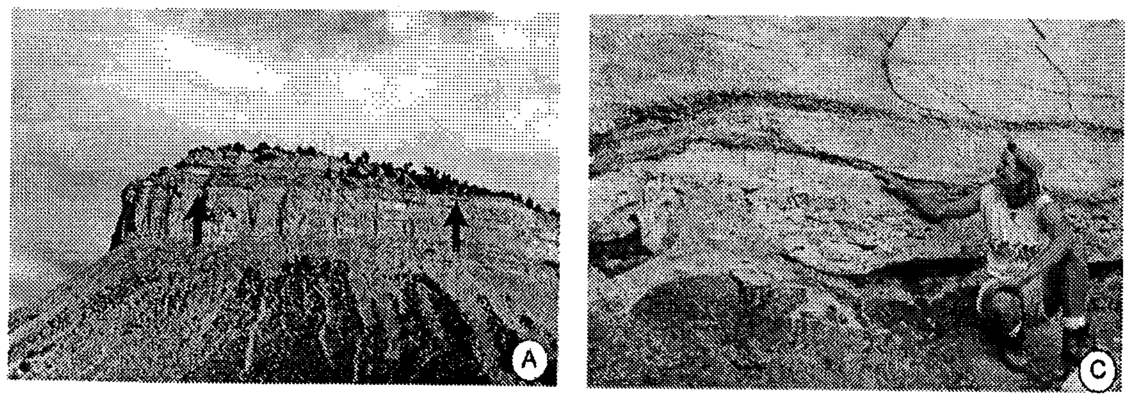
Channel geometry, abundant erosional scour surfaces, sedimentary structures, and lack of marine indicators support interpretation of these deposits as fully non-marine channel fill and adjacent overbank deposits. Erosional surface SB2 appears to have removed at least 25 feet of underlying material, much of which had undergone some degree of early cementation or compaction (as supported by the presence of cemented concretions among the lag material). There is no evidence to date that surface SB2 eroded through the underlying SB1 surface, but the two nearly merge at section 13 on Brigg's Mesa.

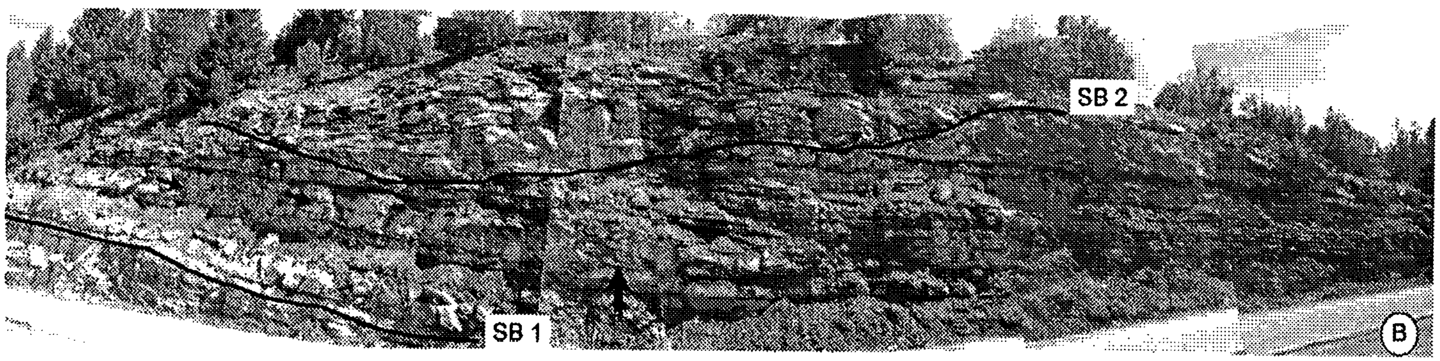
The final horizon along which thick channel deposits developed is in the uppermost Menefee, beneath the marine flooding surface at the base of the overlying Lewis Shale (sections 1, 9). These channel fill deposits contain fining-upward, fine to medium grained sandstone with discontinuous organic mud breaks. Sedimentary structures include large-scale trough- and planar-tabular cross beds. As with previously described channel sandstones, these contain numerous internal scour surfaces. Intraformational mud clasts dominate the lag material. Logs with *Teredolites* borings are common, and locally dramatic (Fig. 5c). Marine bioturbation (*Thalassinoides, Ophiomorpha*) occurs both within the sandstones, and at the basal contact to underlying mudrocks and coals. As is the case for marine-influenced sandstones described previously, *Thalassinoides, Ophiomorpha* and abundant *Teredolites* argue strongly for marine proximity. These deposits accumulated under estuarine or nearshore fluvial conditions associated with the landward incursion of the Lewis sea (itself marked by the overlying transgressive surface and inner shelf shark tooth lag).

Organic Mudrock Facies (Alluvial floodplain)

Much of the Menefee Formation consists of very fine-grained mudrock with discontinuous thin sandstones and varying amounts of organic material. In outcrop, these deposits are poorly preserved on dip slopes and are prone to cover; thus only very general facies descriptions were made during this study. Exposures permitting, however, efforts were made to specifically locate included coals and coaly shales in measured sections. The facies includes mottled organic shales, gray fissile shales, siltstones, discontinuous rippled organic sandstones, and coals. Plant fossils (Fig. 6) and disseminated organic flakes are common. Color ranges from gray to light brown/black with increasing organic content. Most coals are discontinous

Figure 5: (A) Heterolithic beds, inclined from upper right to lower left, overlie surface SB1 (arrows) which eroded shoreface sandstones of the underlying Stinking Lake Beach. These heterolithic beds are interpreted as fluvial point bar deposits. Location: Apache Mesa, approximately halfway between sections 4 and 5. (B) Heterolithic strata between erosional surfaces SB1 and SB2 display characteristic mudrock sandstone interbedding, inclined strata (small arrows), and internal scour (large arrow). Ophiomorpha and Thalassinoides burrows are common. Location: Monero roadcut, section 11. (C) Large Teredolites-bored log in channel near basal contact to underlying coal. Lewis transgressive surface (not in photo) overlies this sandstone. Location: Puerto Chiquito, section 1





or shale layers (<0.5 feet thick). Wood fragments, iron nodules and mud ripups are common lag materials. Sedimentary structures include trough-crossbedding, current ripple stratification, and sub-horizontal and less than 2 feet thick, although several northwest trending zones in the Monero area contain coals 3½-5 feet thick (Hoffman, 1991). Mudrocks and associated thin sandstones range from <1" to 3 feet, with less common isolated sandstone channels (up to 5 feet). Marine bioturbation is rare, and is restricted to thin horizons associated with locally intertonguing marine sandstones. The organic mudrock facies is interpreted to represent sediment accumulation on the floodplain. Zones of higher organic content and coal preservation are considered to have accumulated in more poorly drained, swampy portions of the coastal plain, while less organic (more gray) mudrocks and siltstones reflect better drained floodplain conditions (Collinson, 1986).

STRATAL STACKING PATTERNS AND SEQUENCE STRATIGRAPHIC INTERPRETATION

This chapter provides an overview of the stacking patterns of Mesaverde Group rocks in outcrops of the Jicarilla Apache Reservation and offers a sequence stratigraphic interpretation of these patterns. Two cross sections (Fig. 7), one oriented approximately along depositional dip (Plate 1) and the other along depositional strike (Plate 2) display these relationships.

Strandplain Aggradation/Progradation (Highstand Systems Tract)

Throughout the field area, the upper Mancos Shale and Point Lookout Sandstone display a classic regressive, or coarsening-upward profile, in which successively younger shoreline deposits overlie older, deeper marine rocks (Fig. 8). This regressive pattern was not, however, the product of a steady or continuous shallowing of the seaway. Hollenshead and Pritchard (1961) noted that this regression produced a series of (aggradational) vertical steps and (progradational) seaward benches on a basinwide scale. Subsequent work has shown that, within this larger framework, much smaller scale marine coastal elements can be resolved and correlated (Wright, 1986; Devine, 1991) to enrich our understanding of the dynamics of Mesaverde shoreline movement.

These coastal elements correspond to genetically related shoreface packages (parasequences of van Wagoner, et al., 1988). Individual parasequences are separated from one another by high-frequency marine flooding surfaces that recorded periodic small landward and vertical shifts in the shoreline. These landward shifts produced erosional ravinement surfaces, where underlying strata were modified by the landward marching surf zone, or simple flooding surfaces, where underlying shoreface deposits were buried beneath deeper water facies. Because these modifications produce lithologic heterogeneity within shoreface deposits, parasequences can be readily traced in both outcrop and the subsurface (van Wagoner, et al., 1988; 1990). In this study, flooding surfaces were walked between sections and/or correlated using photomosaics to define seven distinct parasequences that are fairly completely represented in the field area. Parasequences were given local geographic names based upon the preserved landward limit of beach (foreshore) deposits. From south to north (Plate 1; Fig. 9) these are: North Llaves Beach, Puerto Chiquito Beach (upper and lower), Pounds Mesa Beach (upper and lower), Stinking Lake Beach, Stone Lake Beach, Horse Lake Beach, and Monero Canyon Beach. At least six parasequences older than North Llaves Beach are partially preserved in the southern part of the field area (Plate 1, sections 1-5), but these very distal elements were not individually named.

The top of the Point Lookout Sandstone displays a dramatic stratigraphic rise of approximately 130 feet over a distance of 4-6 miles in the southern part of the field area. Puerto Chiquito, Pounds Mesa, and Stinking Lake shoreline deposits stacked vertically (Plate 1, between sections 1 and 4) to form a progradational (almost aggradational) parasequence set (Fig. 10; van Wagoner, et al., 1990) that resulted in the thickest expression (>240 feet) of marine shoreface sandstones in the study area (measured section 3). Each of these marine parasequences is bounded by a well-defined flooding surface and each has a preserved coastal plain equivalent in landward, fine-grained Menefee Formation organic shales and coals.

Compared to the Puerto Chiquito, Pounds Mesa, and Stinking Lake shorelines, the younger Stone Lake, Horse Lake and Monero Canyon parasequences display stronger progradation and much less stratigraphic rise (Plates 1, 2). While it is difficult to place the precise landward limit of these parasequences due to later erosion, flooding surface correlation and comparison to the Lewis Shale datum suggest there is less than 20 feet of stratigraphic rise between Stinking Lake and Stone Lake shorelines. There is little or no vertical rise between Stone Lake and Monero Canyon foreshore deposits (measured

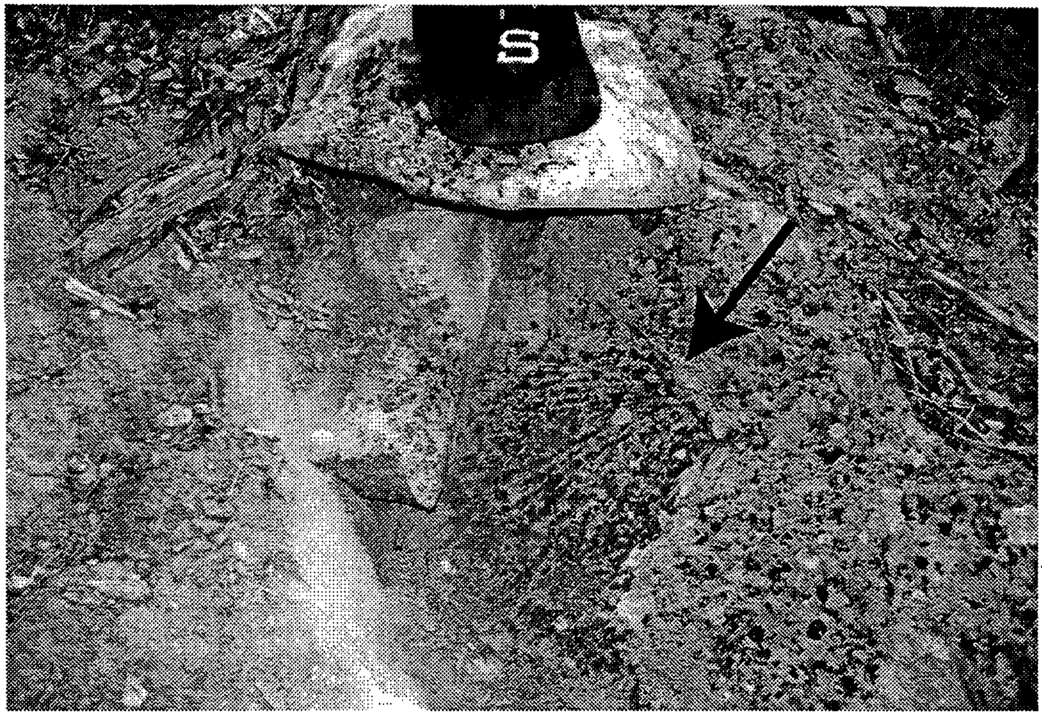
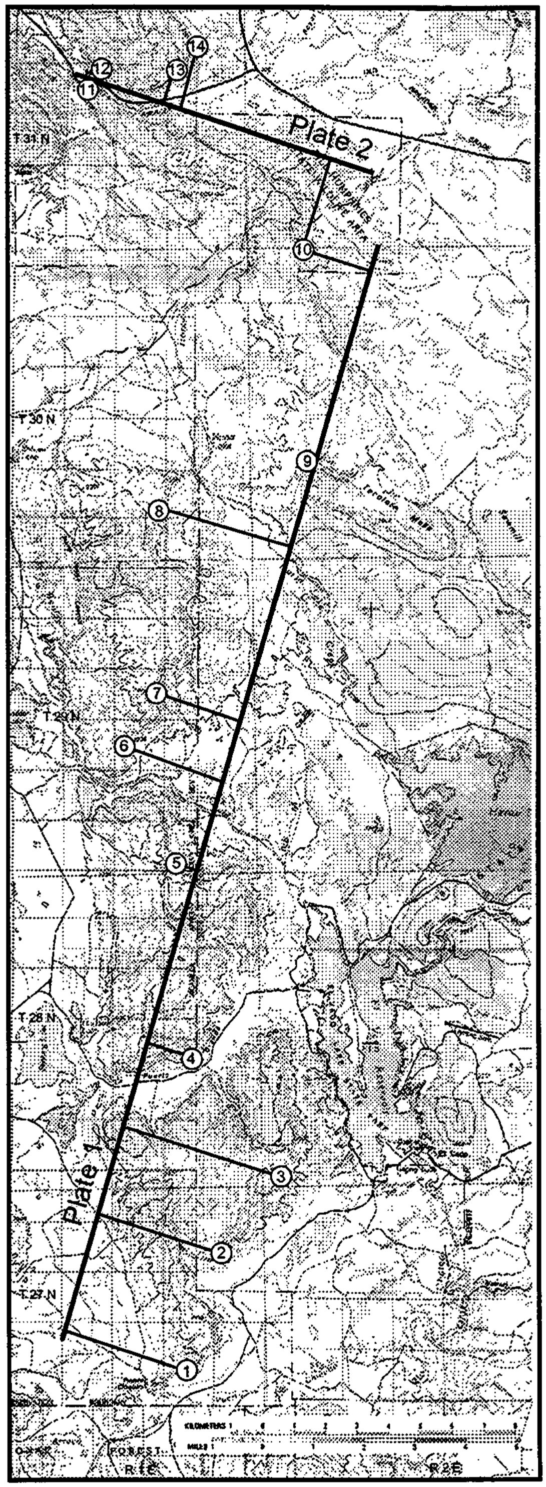


Figure 6: Palm frond imprint (arrow) in Menefee sandstone float block. Location: Pounds Mesa, section 3.

Figure 7: Location of dip cross section (Plate 1) and strike cross section (Plate 2) and measured section control points.



Lithofacies	Physical Description	Biogenic Components	Depositional Environment
Amalgamated Marine-Influenced Sandstone	Moderately sorted, very fine to medium grained sandstone. Amalgamated scours and channel fill. Sigmoid bedding, reactivation surfaces, mud drapes, trough/planar-tabular crossbeds, current ripple stratification. Abundant organic matter, wood, intraformational mud clasts.	*Ophiomorpha* *Thalassinoides* *Teredolites*	Estuarine and Bayhead Delta
Sandstone Channel Facies (sand-rich)	Moderately sorted, medium to coarse grained (micaceous) sandstone. Individual channels with numerous internal scour surfaces. Large-scale trough crossbeds, current ripple stratification and horizontal laminations. Intraformational mud clasts, wood, coal clasts, and concretions as lag. Discontinuous mudrock breaks.	*None*	Non-marine Fluvial
Sandstone Channel Facies (sand-rich, marine-influenced)	Moderately to well-sorted, fine to medium grained sandstone. Large-scale trough and planar-tabular crossbeds. Intraformational mud clasts and wood as lag materials. Discontinuous (organic) mudrock breaks.	*Ophiomorpha* *Thalassinoides* *Teredolites*	Marine-influenced Fluvial or Estuarine
Sandstone Channel Facies (heterolithic)	Alternating medium-grained organic sandstone (1-2 feet thick) and organic mudrock or shale (<0.5 feet thick). Wood fragments, Fe nodules, and mud clasts as lag on scours. Inclined, lateral accretion bedding. Trough crossbeds, current ripple stratification, horiz. lams. Paired organic drapes.	*Ophiomorpha* *Thalassinoides* *Teredolites*	Marine-influenced Fluvial
Organic Mudrock Facies	Mottled organic shales, gray fissile shales, siltstones, discontinuous rippled organic sandstones, and thin coals. Color ranges from gray to light brown/black.	None (except where associated with intertonguing marine ss)	Alluvial Floodplain

Table 2: Lithofacies descriptions for rocks interpreted to be of alluvial plain and estuarine origin.

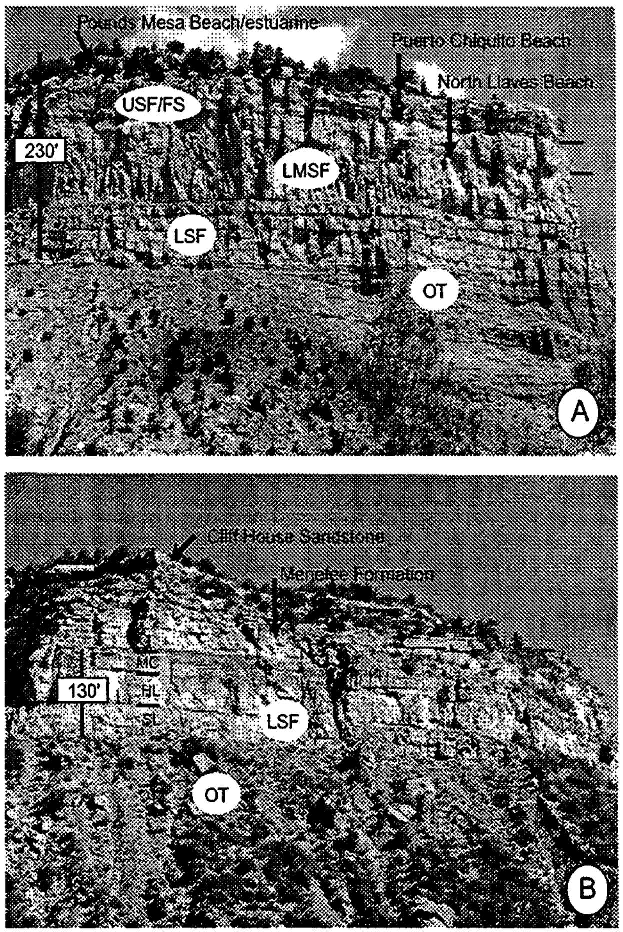


Figure 8: (A) Classic coarsening-upward profile produced by progradational-to-aggradational strandplain rocks. Interbedded very thin sandstones and mudrocks of the Mancos Shale offshore transition zone (OT) are overlain by thicker sandstones and mudrocks of the lower shoreface (LSF) and massive sandstones of the lower to middle shoreface (LMSF) in a series of unnamed stacked parasequences (see Plate 1, section 2). North Llaves Beach and lower Puerto Chiquito beach comprise the upper half of the massive cliff. Both contain upper shoreface and foreshore strata. Location: Pounds Mesa, immediately north of section 2. (B) Abrupt coarsening-upward profile produced by strongly progradational strandplain rocks. Mancos transition (OT) contains relatively little sandstone and there is little mudrock within the overlying Point Lookout lower shoreface (LSF). The Stone Lake (SL), Horse Lake (HL), and Monero Canyon (MC) parasequences comprise the Point Lookout marine section. Location: Briggs Mesa, immediately east of section 13.

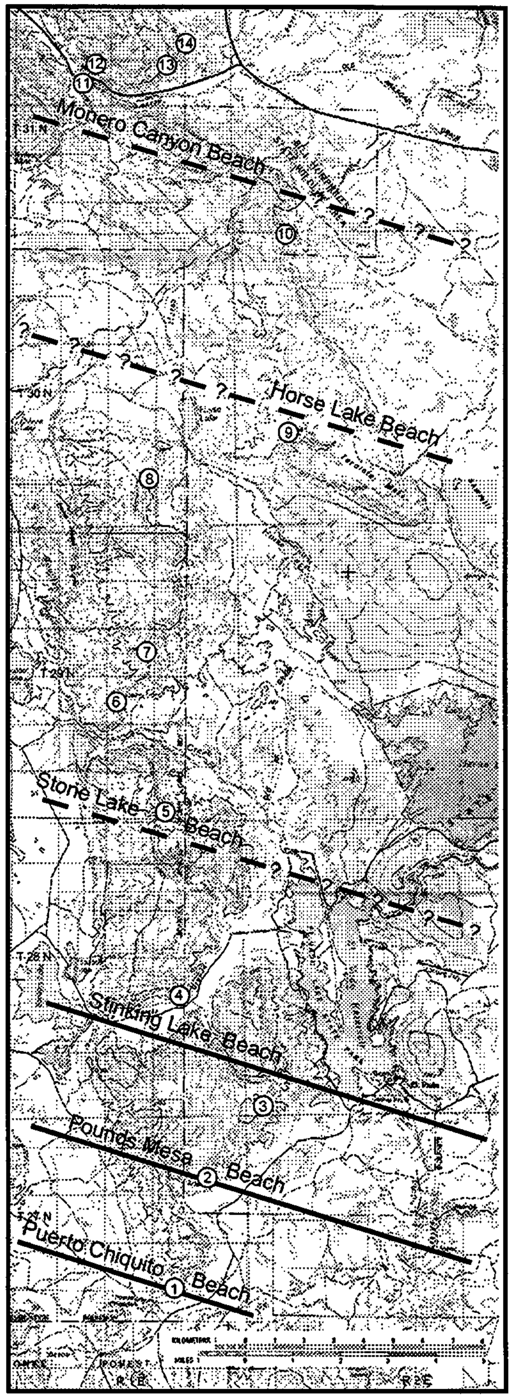


Figure 9: Location of individual beach parasequences in the study area. Foreshore deposits constrain the location of the Puerto Chiquito, Pounds Mesa, and Stinking Lake shorelines. (Foreshore positon of North Llaves beach is located somewhere to the south of the study area, and is therefore not shown.) 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.

sections 6 and 12), a downdip distance of approximately 12.5 miles. These strongly progradational younger parasequences are bounded by more subtle, yet recognizable, flooding surfaces and they have little or no preserved coastal plain equivalents in the updip Menefee Formation. A look at marine facies shows that the total thickness of stacked shoreface deposits thins northward (from ~240 feet at section 3 to ~130 feet at section 13). Also, the transition from distal Point Lookout sands to Mancos mudrocks becomes much more abrupt (compare figures 8a and 8b).

Thus, late stage deposition of the Point Lookout Sandstone and time-equivalent strata in the Menefee Formation and Mancos Shale display two distinct stacking patterns in the study area: progradation/aggradation (Puerto Chiquito through Stinking Lake parasequences) followed by strong progradation (Stone Lake through Monero Canyon parasequences). This arrangement can be attributed to variation in the balance between the rate of sediment deposition and the rate of sediment accommodation (Fig. 10, Van Wagoner et al., 1990). During the progradation/aggradation phase, the rate of deposition slightly exceeded the rate of overall sediment accommodation and dramatic stratigraphic rise accompanied a slight shoreline progradation. As accommodation space declined and/or deposition increased, progradation was enhanced and the younger shorelines built successively farther basinward with minimal or no stratigraphic rise. These characteristics suggest that the progradation/ aggradation phase and subsequent strong progradation phase occupy a sequence stratigraphic position in the late highstand (Van Wagoner,1995). The possibility was also considered that the late stage strong progradation could have accompanied a "forced regression" (Posamentier, et al., 1992) in which accommodation space declined due to relative sea level fall. While the sharp base of the Stone Lake shoreface on Briggs Mesa (fig. 8b) could be consistent with this model (Plint, 1988), marine flooding surfaces still punctuate a thick overlying shoreface succession including the Stone Lake, Horse Lake, and Monero Canyon parasequences. These relationships are more compatible with a position in the late Highstand Systems Tract (HST), rather than Lowstand Systems Tract (LST), sequence stratigraphic position (Van Wagoner,1995). Significantly, the top of the Point Lookout *does* drop in the seaward direction between sections 12 and 13 (Plate 2), however, this drop is attributed to syn-depositional faulting (post- Point Lookout, pre-Lewis) rather than forced regression.

Incised Valley Formation (Sequence Boundary SB1)

Throughout the study area an erosion surface truncates the top of Point Lookout strandplain deposits with up to 60 feet of relief (surface SB1, Plates 1 & 2). Parasequences most affected by erosion are Stinking Lake, Stone Lake, Horse Lake and Monero Canyon. Above this surface in the southern study area are fluvial channel and floodplain deposits. In the northern study area, bay head delta sandstones, estuarine channel deposits, or marine influenced mudflat strata overlie the erosion surface. Juxtaposition of these estuarine and alluvial plain deposits above lower and middle shoreface sandstones argues for a seaward shift in facies. The SB1 surface that separates these disparate facies is interpreted as an erosional sediment bypass surface, or sequence boundary (van Wagoner, et al., 1988). Facies relationships suggest that this erosional surface produced a roughly north-northeast trending fluvial valley in the study area, with an interfluve boundary to the west (Monero area) and an undetermined eastern boundary (Fig. 4). Sediment removed during valley excavation would have been transported toward the north-northeast (presumably beyond the limits of the study area) to accumulate in a lowstand, potentially isolated, shoreface deposit.

The transition from aggradation/progradation to strong progradation followed by incision (SB1) builds a strong case for declining accommodation space and base level fall at the end of Point Lookout deposition. This unconformity has been documented elsewhere in the northwestern San Juan Basin (Wright Dunbar et al., 1992; Crandall, 1992), where a series of fluvial channel belts dissects the upper Point Lookout (Fig. 11). Recognition of similar relationships in rocks on the Jicarilla reservation confirms the widespread nature of this surface. Chronostratigraphic control on the seaward limit of the Mesaverde Group constrains the age of the unconformity to the *Baculites sp.* (weak flank ribs) ammonite zone, between 80.7-80.9 mya (Fig. 12a,b).

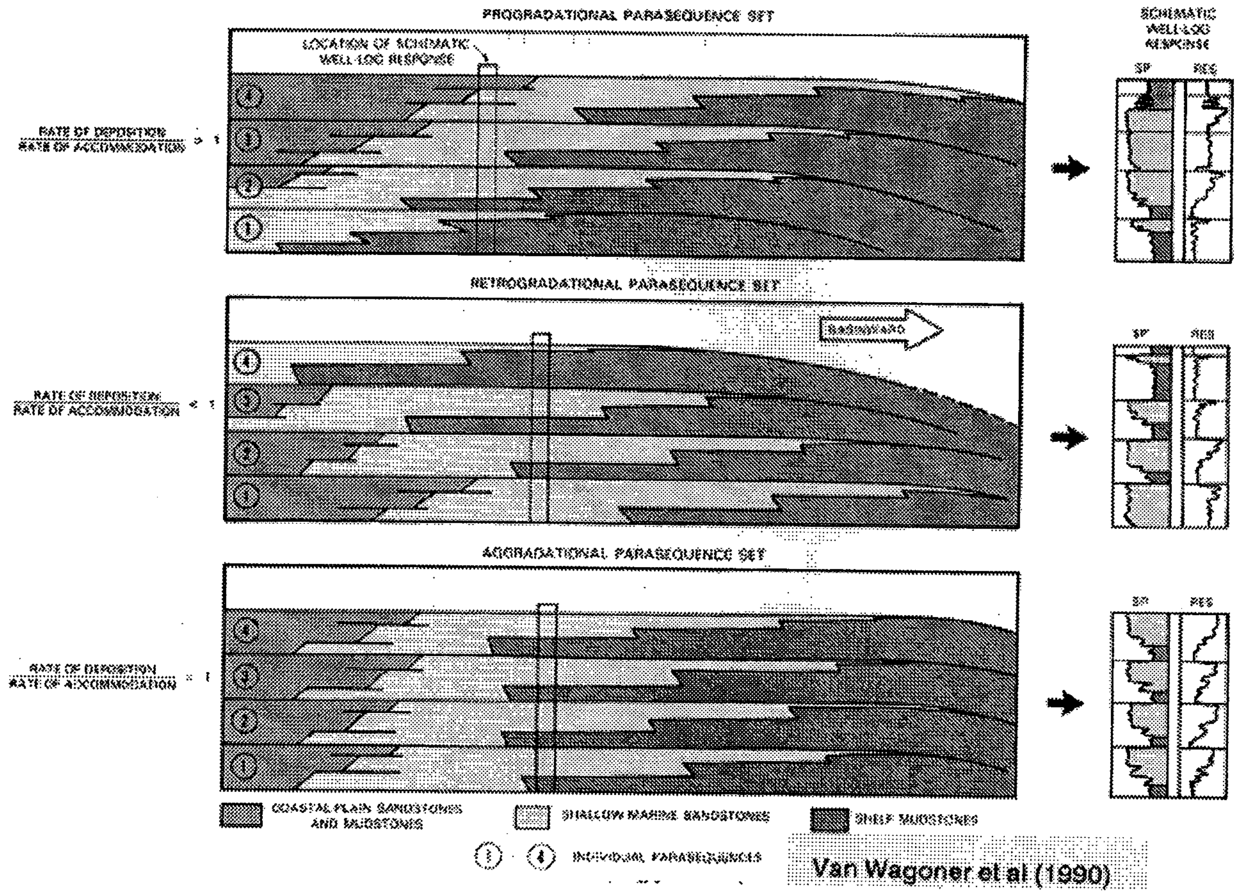


Figure 10. Parasequence stacking patterns in parasequence sets from Van Wagoner and others (1990).

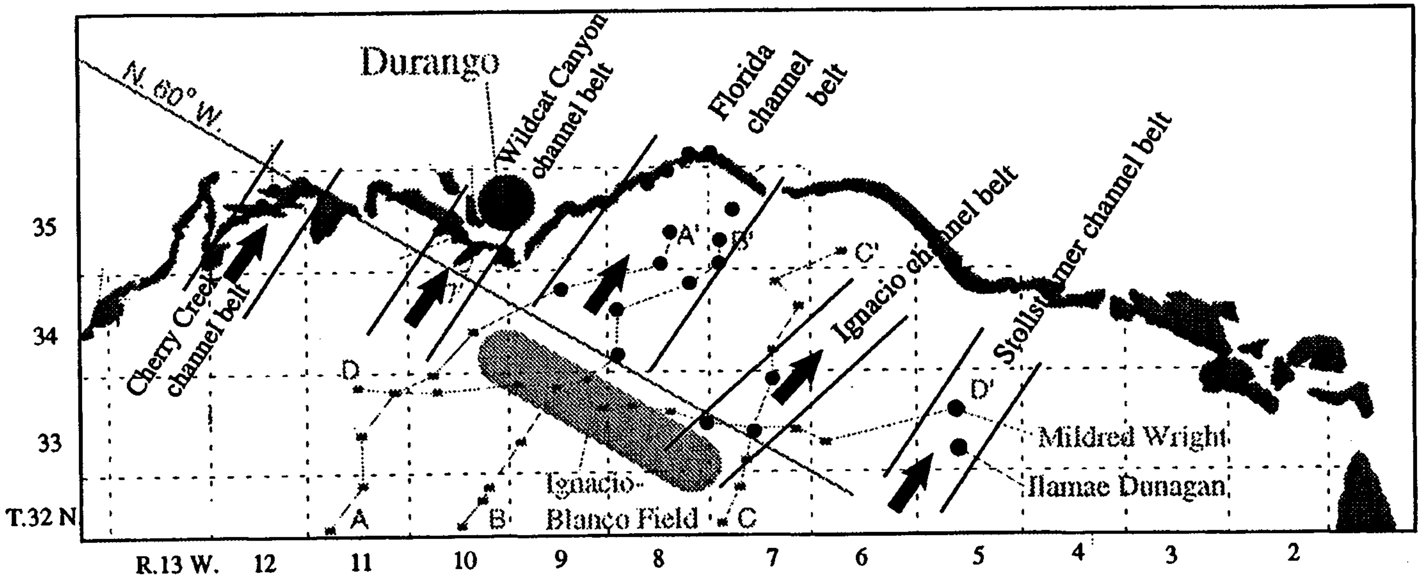


Figure 11: Map of Point Lookout Sandstone outcrops in southern Colorado showing major fluvial channel belts observed in outrcop or interpreted from core (Mildred Wright, Ilamae Dunagan) and well logs (well data from Molenaar and Baird, 1993). Within each of these channel belts the uppermost Point Lookout is interpreted to contain an erosional unconformity correlative with SB1 in this study and an overying fluvial sandstone fill. (from Zech and Wright Dunbar, unpublished data).

Fluvial/Estuarine Aggradation (Lowstand and Transgressive Systems Tracts)

From south to north (seaward), the deposits overlying the SB1 erosion surface undergo transition from 1) sand-rich fluvial to 2) sand-rich fluvial and heterolithic to 3) sand-rich estuarine (Plate 1). Where these facies are juxtaposed vertically (e.g. measured section 7) there is an upward transition from coarser grained, sand-dominated fluvial channel deposits to heterolithic fluvial deposits with *Teredolites* borings. Thus, there is evidence for a vertical, as well as a seaward, increase in marine influence within the valley-filling strata. Zaitlin et al. (1994) highlight the evolution of a valley-filling sequence similar to that described in this study (Fig. 13). In their model initial valley incision (SB1 of this study) produces valley and interfluve topography. Sediment is bypassed offshore as part of a Lowstand (Fan) Systems Tract (beyond the limits of this study area). Accumulation of fluvial fill in the valley begins with the Lowstand (Wedge) Systems Tract (LST) during which time rivers maintain a declining, yet sufficient, gradient to base-level. The coarse sand-rich channel fill preserved in landward sections (e.g. measured section 4) and at the base of deeper valleys (measured section 7) in this study may have begun accumulating during this phase of valley-filling, however it is not possible to determine whether these deposits accumulated under LST or subsequent transgressive conditions.

In the Zailtlin et al. model, increasing rate of base-level rise produces the Transgressive System Tract (TST) in which the fluvial system loses gradient, becomes flooded, and is overstepped by marine and estuarine deposits. During this phase, older fluvial sediments are at risk of being removed and/or reworked into the overlying estuarine sediment package. The record of this base level rise in the study area is in the vertical transition from sand-rich non-marine channels to marine-influenced/heterolithic fluvial deposits and in the superposition of bay head delta deposits and estuarine channel sands directly above the SB1 unconformity surface. In this latter case, any pre-existing non-marine fluvial sediments must have been reworked during transgression.

Overall facies relationships in the study area indicate a relatively landward position within the incised valley system. Applying Zaitlin et al.'s (1994) longitudinal profile terminology (Fig. 14), Jicarilla outcrops display facies relationships of the inner incised valley (sections 1-6; fully fluvial throughout valley filling history) and middle incised valley (sections 7-14; estuarine/bay head delta overlain by fluvial) segments. At maximum marine transgression, a drowned valley estuary filled the northern study area. Nowhere in the study area have the more seaward facies of the outer incised valley segment (muddy central estuary or sand-rich backstepping barrier/inlet complexes) been observed at this stratigraphic level. Thus, somewhere to the northeast of Briggs' Mesa these missing facies tracts may yet be found.

Alluvial Floodplain Aggradation (Highstand Systems Tract)

Overlying the sand-rich fluvial, heterolithic fluvial, and estuarine deposits throughout most of the study area are Menefee Formation fine-grained alluvial deposits, thin sandstones, and discontinuous coals. These are interpreted to represent the Highstand Systems Tract (HST) stage in Zaitlin et al.'s (1994) incised valley model in which the pre-existing topography becomes completely buried during renewed progradation of the shoreline and coastal plain (Fig. 14). Because outcrop exposures (dominated by vegetated dipslopes) did not permit broad correlation of facies and stratigraphic boundaries at this level, limited detailed work was done on these deposits. This may become critical for future work, however, in resolving the significance of a thick fluvial channel complex on far eastern Briggs Mesa (sections 13, 14) interpreted below.

Incised Valley Formation? (SB2 Sequence Boundary)

At the same stratigraphic level as the fine-grained HST Menefee mudrocks discussed above, a multi-story channel complex erosively overlies (and locally removes) estuarine sandstones and marine-influenced mudrocks in the Monero and Briggs Mesa areas (sections 12-14). The SB2 erosional surface (figure 5b & Plate 2) at the base of the channel complex is a likely candidate for a second sequence boundary responsible for removing any aggradational Menefee HST deposits that may have been present as well as portions of the underlying TST estuarine strata. The fact that cemented sandstone concretions are included within the basal channel lag strongly suggests that some degree of early cementation had occurred within eroded underlying strata. This, combined with the fact that the channel fill is fully non-marine, makes it is less reasonable to interpret this as an equilibrium channel eroding its contemporary marine-

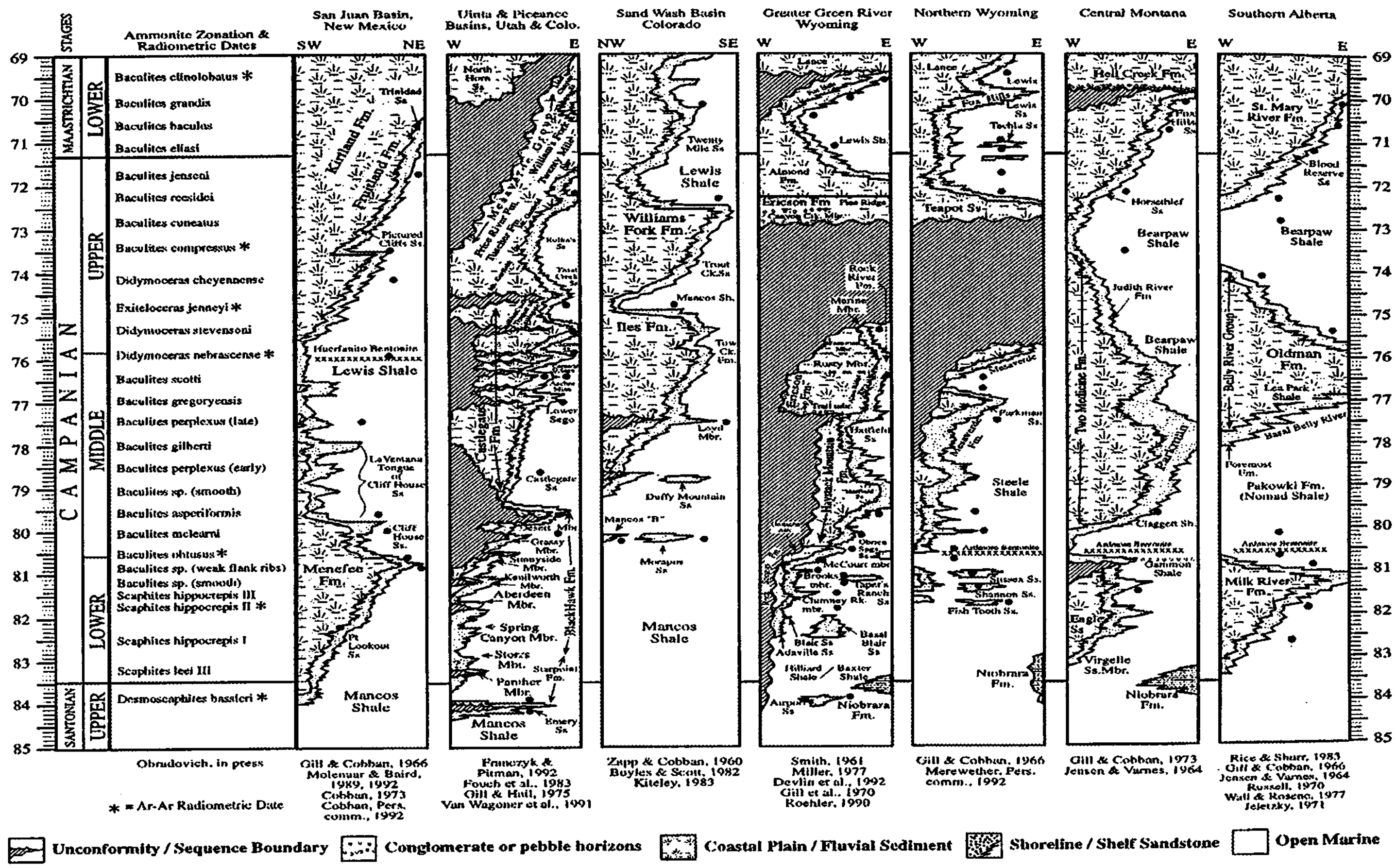


Figure 12a: Campanian to early Maastrichtian chronostratigraphic correlation chart, New Mexico to Alberta. Modified from Krystinik and DeJarnett, 1995. Compare San Juan Basin Mesaverde Group (Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone) to sequence stratigraphic interpretation in figure 12b.

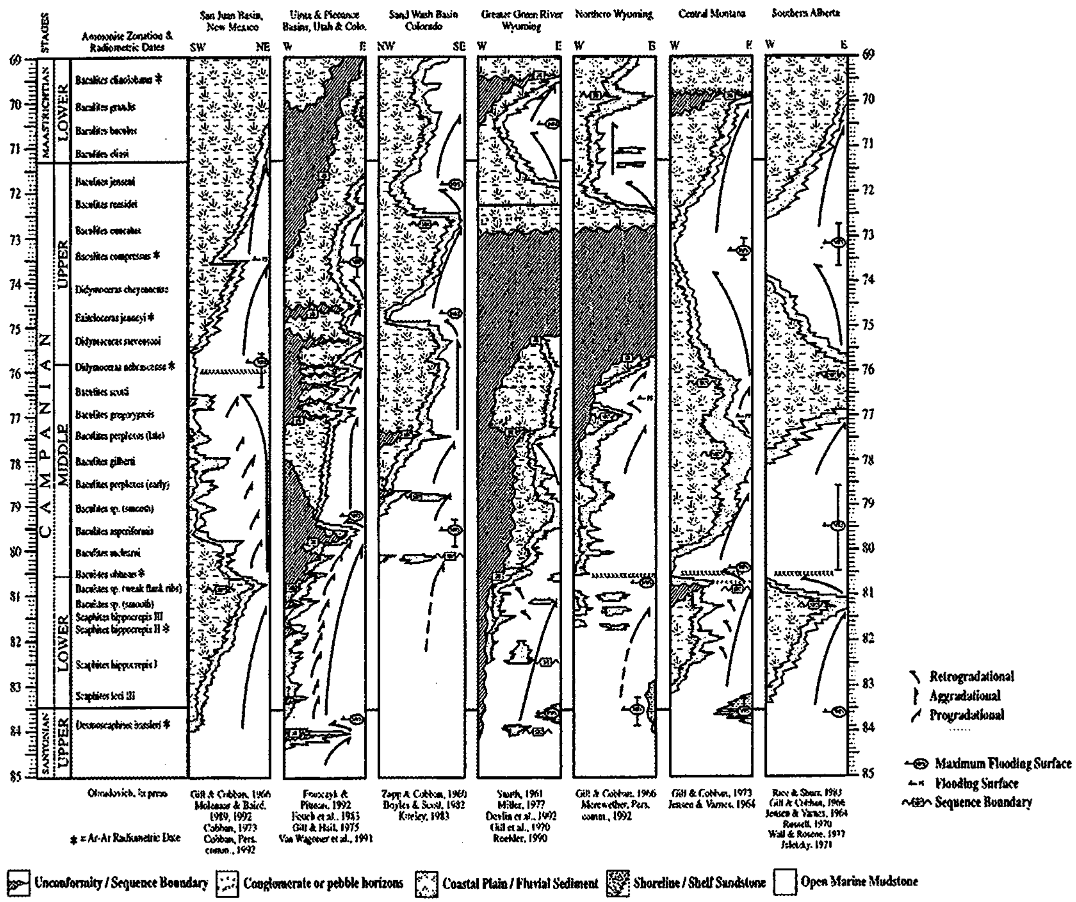


Figure 12b: Campanian to early Maastrichtian chronostratigraphic correlation chart, New Mexico to Alberta, with formation names removed and sequence stratigraphic interpretations applied. Modified from Krystinik and DeJarnett, 1995. Sequence boundaries SB1 and SB2 from the current study would both fall within the Baculites sp. (weak flank ribs) ammonite zone.

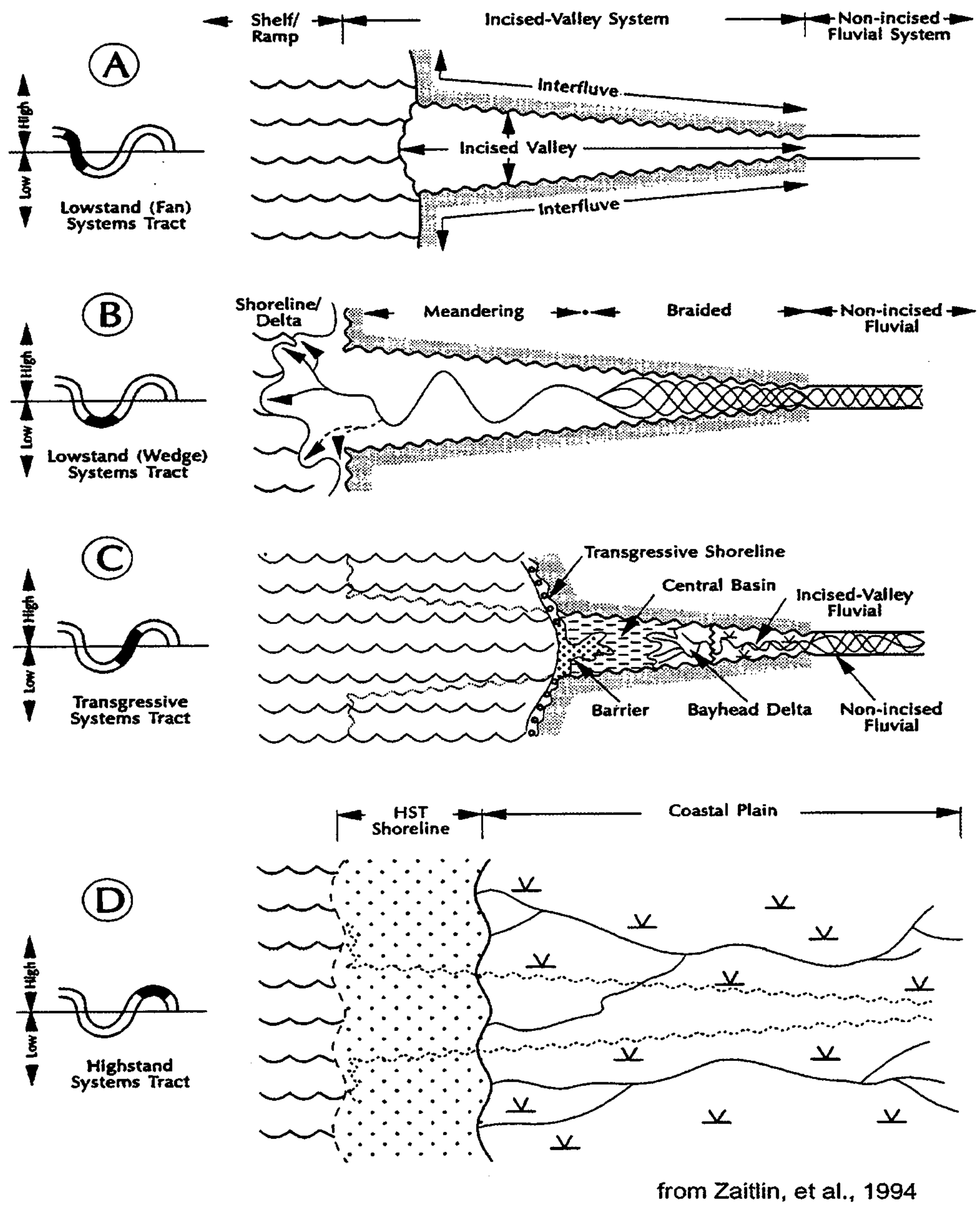


Figure 13. Idealized plan view of a simple, piedmont incised-valley system showing its evolution over one complete sea-level cycle (sea level fall to subsequent highstand). (A) Lowstand (fan) time showing the incised-valley system passing headward into a non-incised fluvial channel system. (B) Lowstand (wedge) time showing a lowstand delta at the mouth of the incised valley, and the beginning of fluvial deposition throughout the incised-valley system. (C) Transgressive systems tract time showing the development of a tripartite,wave-dominated estuarine system within the incised valley. (D) Highstand time with a progradational shoreface and alluvial plain that extends beyond the margins of the buried incised valley. From Zaitlin ad others, 1994.

influenced coastal plain. If further work confirms this SB2 surface as a sequence boundary, sediment bypassed northward during incision would have accumulated offshore in yet another, potentially isolated, lowstand shoreface.

The SB2 surface was not systematically traced to the south and its correlative position within the poorly exposed upper Menefee outcrops at sections 1-10 is speculative. This would be an important sequence stratigraphic surface to locate, however, as it would separate HST Menefee strata (below) from TST Menefee strata (above) and mark the location within the landward alluvial plain that coincides with backstepping Cliff House beach sandstones to the north.

Strandplain Aggradation/Retrogradation (Transgressive Systems Tract)

Only in the far northern field area, on Briggs Mesa, is good evidence preserved of landward-encroaching Cliff House shorelines. Between measured sections 11 and 14 (and above the SB2 channel-fill package) the upper 80 feet of the Menefee Formation contains the extreme landward limits of two intertonguing nearshore marine sandstones, the Canon Amargo and Briggs Mesa beaches (Plate 2). Any significant Cliff House sandstone buildup associated with the seaward merger of the Point Lookout and Cliff House shoreline systems must therefore exist to the north of Briggs Mesa, where these sandstones thicken to form well-developed shoreface deposits. South of Briggs Mesa (landward of these shorelines) the upper Menefee Formation contains isolated channel sandstones and organic-rich fine grained mudrocks interpreted to have aggraded on the coastal plain during the base level rise associated with this shoreline transgression. The uppermost of these fluvial sandstones (measured section 1, units 23-25; measured section 9, unit 49) displays strong estuarine evidence, signaling the southward encroachment of the Cliff House shoreline.

This retrogradational Cliff House parasequence set (Fig. 10) marks the point in the basin filling history in which the overall rate of sediment accommodation exceeded the rate of deposition. The flooding surface associated with this transgression is marked throughout the area by the presence of a very thin, silica-cemented transgressive lag (inner shelf very fine burrowed sandstone facies) that contains sharks' teeth, shells, wood fragments and mudrip lag materials (Fig. 2a). Most commonly this lag separates Menefee Formation strata (below) from Lewis Shale outcrops (above) with little evidence of the intervening Cliff House shoreface.

RESERVOIR ANALYSIS

The sedimentary facies descriptions, sequence stratigraphic relationships and structural interpretations made during the course of this outcrop study provide a framework for subsurface correlation and assist in the prediction and prioritization of Mesaverde Group reservoir targets. The following discussion presents an exploration view of potential reservoir units, and specifies correlation strategies that may help resolve these in the subsurface.

Stratigraphic Reservoir Plays

Van Wagoner et al.'s (1990) and Van Wagoner's (1995) sequence stratigraphic framework for exploration plays on a ramp (foreland basin) margin provides a means by which Mesaverde Group reservoirs in the northeastern San Juan Basin can be evaluated and prioritized. The following discussion summarizes for each Mesaverde play type the common reservoir facies, bounding surfaces and potential seals, stratal stacking patterns, general reservoir quality, and reservoir geometry. Major characteristics of these reservoirs are summarized in Table 3. Figure 15 is a schematic diagram of Mesaverde Group stratal relationships and hydrocarbon play types for the northeastern San Juan Basin.

Highstand Reservoir Plays

The most promising reservoir plays within the highstand systems tract occur at the updip pinchout of the Point Lookout Sandstone where marine shoreface deposits and locally associated estuarine sandstones undergo landward transition into the Menefee Formation (Fig. 15). The seals in this situation are the surrounding non-marine mudrocks, enhanced at the uppermost level by the basinward step in coastal plain fluvial strata associated with the capping sequence boundary unconformity.

An example of this play type in the study area occurs at the landward depositional limits of the Puerto Chiquito, Pounds Mesa, and Stinking Lake shorelines. These strata are arranged as slightly progradational parasequences that intertongue with Menefee Formation mudrock seals and are bounded

Systems Tract	Depositional Environment and Rock Types		Bounding Surfaces	Stratal Stacking Pattern	Reservoir Quality	Reservoir Geometry
	Marine	Non-marine				
Highstand Systems Tract	**Point Lookout Ss:** Estuarine, foreshore, upper shoreface, and lower shoreface medium to very fine sandstones **Mancos Shale:** Offshore transition zone mudrocks and very fine sandstones	**Menefee Fm:** Coastal plain overbank and channel systems; organic mudrocks, siltstones, thin coals and fine to very fine sandstones	Internal bounding surfaces include parasequence marine flooding surfaces and landward equivalents. Systems tract is overlain by sequence boundary SB1.	**Point Lookout/Mancos:** Fairly complete aggradational to progradational parasequence sets in marine rocks. Each marine parasequence has an equivalent non-marine coastal plain stratal package.	**Marine:** Moderate to good in estuarine and shoreface sandstones, quality decreasing to poor basinward. **Non-marine:** Moderate. Fine-grained.	**Marine:** laterally continuous sheet sandstones up to 40 feet thick separated by thin continuous mudrock or cemented layers. Updip pinchout into coastal plain. **Non-marine:** isolated, discontinuous sandstones
Lowstand Systems Tract	**Point Lookout Ss:** Foreshore, upper shoreface and lower shoreface medium to very fine sandstones *(not observed in study area)* **Mancos Shale:** Offshore transition zone mudrocks and very fine sandstones *(not observed in study area)*	**Menefee Fm:** Fluvial channel deposits dominated by fining-upward upper medium- to fine-grained sandstones *(locally present in study area).*	Underlain by sequence boundary (SB1 or SB2). Overlain by bay line flooding surface and its landward equivalent (SB1) or marine flooding surface and its landward equivalent (SB2).	**Point Lookout/ Mancos:** *Predicted* progradational parasequence set in marine strata. **Menefee:** amalgamated and multi-story channel deposits in non-marine.	**Marine:** *Predicted* as moderate to good in shoreface sandstones. **Non-marine:** Good quality in coarser sandstones	**Marine:** *Predicted* as a restricted, thin sandstone wedge bounded above and below by offshore marine mudrocks. **Non-marine:** Discontinuous preservation (0-35 feet thick) within incised-valley.

Transgressive Systems Tract	**Point Lookout/Menefee:** Estuarine channel fill and bay-head delta sandstones. **Cliff House Ss:** Foreshore, upper shoreface, lower shoreface sandstones medium to very fine sandstones. **Lewis Sh:** offshore marine mudrock with thin silica-cemented fossil lag at base.	**Menefee Fm:** Coastal plain overbank and channel systems; organic mudrocks, siltstones, coals and fine to very fine sandstones	Underlain by bay line flooding surface, commonly merged with sequence boundary SB1 (Point Lookout/Menefee), or underlain by marine flooding surface above SB2 (Cliff House/Lewis Sh). Overlain by downlap surface marking change to progradational marine parasequences (and landward equivalents) above.	**Point Lookout/Menefee:** aggradational to deepening-upward transition from fluvial/erosional (below) to estuarine sheet sandstone. **Cliff House/Lewis Sh:** aggradational to strongly retrogradational parasequence set. **Menefee Fm:** aggradational coastal plain	**Transitional Marine:** Moderate to good sandstone-dominated estuarine fill. **Marine:** Moderate to good in shoreface sandstones, quality decreasing to poor basinward. **Non-marine:** Moderate to good in channel deposits.	**Transitional Marine:** Estuarine sandstones form broad sheet up to 50 feet thick filling incised paleovalley. **Marine:** laterally continuous sheet sandstones up to 35 feet thick separated by thin continuous mudrock or cemented layers. Updip pinchout into coastal plain **Non-marine:** Discontinuous, isolated channel sandstones

Table 3: Summary of general reservoir characteristics for the Mesaverde Group (modeled after Van Wagoner, 1995)

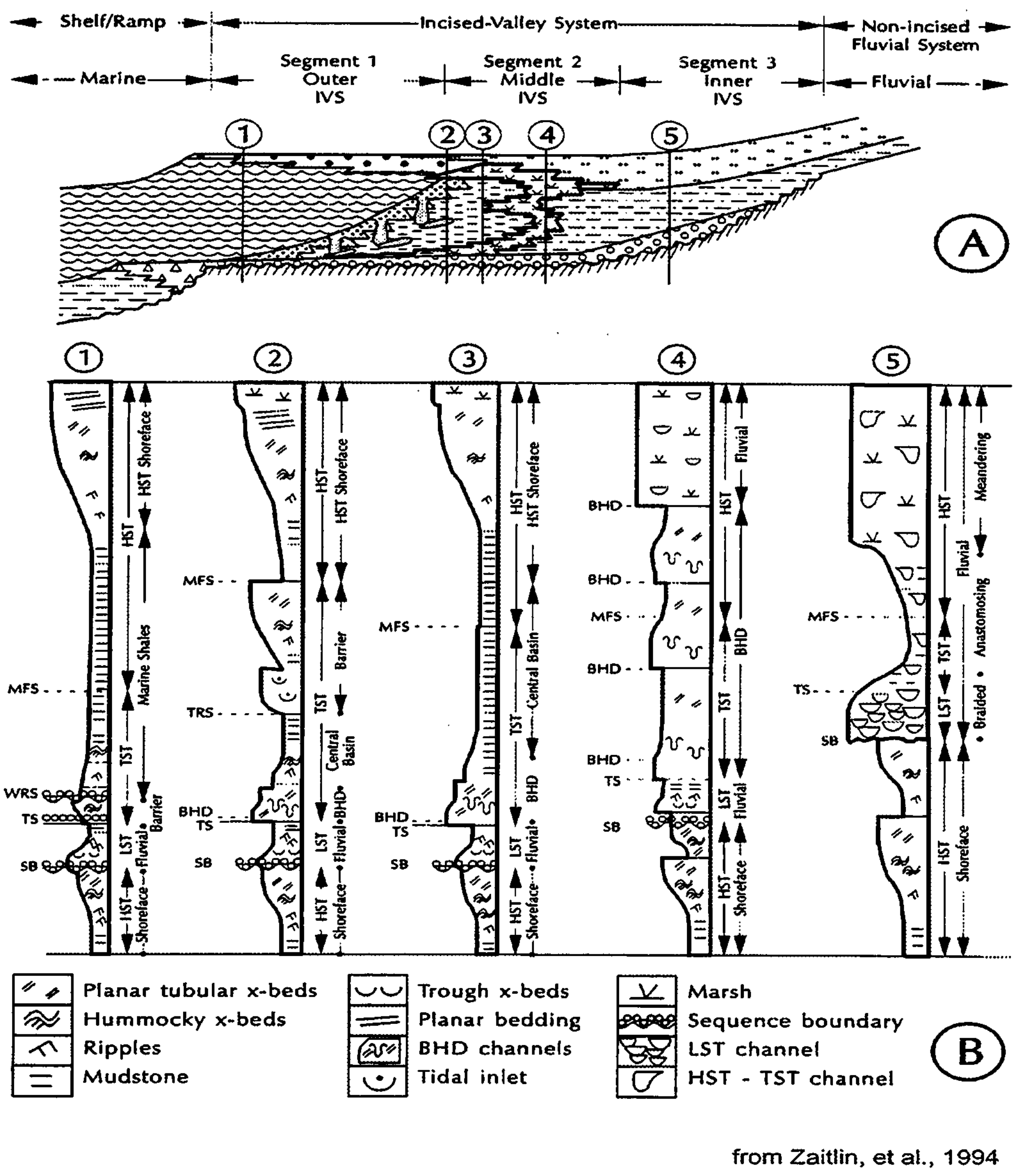


Figure 14. (A) Idealized longitudinal section of a simple, incised-valley system showing the location of schematic vertical profiles illustrated in (B). LST = lowstand systems tract; TST = transgressive systems tract; SB = sequence boundary; TS = transgressive surface; WRS = wave ravinement surface; MFS = maximum flooding surface; FCD = fluvial channel diastem; TRS = tidal ravinement surface; BHD = bayhead delta. No particular horizontal or vertical scale intended. From Zaitlin and others, 1994. Valley-fill deposits in this study are interpreted to fall within the middle and inner incised valley fill (similar to schematic profiles 4 and 5).

above by the SB1 sequence boundary. The highest original porosity and permeability would characterize the sand-rich estuarine facies and foreshore/upper shoreface sandstones, with reservoir quality declining basinward into the fine-grained middle and lower shoreface deposits. These shoreline deposits produced strike-aligned, broad sheet sandstones each on the order of 30-50 feet thick. Regional orientation of these sandstones is approximately N60W, but may locally shift to as much as N70W in the field area. This trend suggests a direct correlation between this highstand shoreface, updip pinchout play and the Ignacio-Blanco field in southern Colorado.

While these individual sheet sandstones stack vertically to form a massive, 130-foot-thick "step" (sensu Hollenshead and Pritchard, 1961) they are separated from one another by thin mudrocks or cemented sandstone horizons that coincide with the internal parasequence marine flooding surfaces. The likelihood that these marine flooding surfaces produced significant permeability barriers within the Point Lookout is minimal in the massive upper shoreface, but can be expected to increase offshore as the surfaces become more mud-rich.

Menefee Formation non-marine strata can be expected to yield very poor highstand systems tract reservoir targets. Mud-rich coastal plain deposits and thin discontinuous coals dominate these units; interbedded sandstones tend to be isolated and fine-grained.

Lowstand Reservoir Plays

Processes associated with early lowstand conditions were dominated by erosion and presumed sediment bypass across erosional surfaces SB1 and SB2. Incised valley topography (Fig. 13a) was produced in the study area by this process and sediment transported toward the northeast may have produced lowstand marine shoreface deposits in the Point Lookout (Fig. 15). These lowstand shoreface deposits comprise an excellent reservoir play because they are typically sealed above and below by finer-grained marine shales (Van Wagoner, et al., 1990). Field relationships suggest that this play is not of significance to Jicarilla exploration, however, because such a lowstand shoreface would lie northeast of the modern outcrop belt.

During late lowstand conditions (Fig. 13b) fluvial sediment may begin to backfill the incised valley. These deposits can be highly attractive reservoir targets because they are among the coarsest grained sandstones and (constrained by the incised valley geometry) have the highest potential for amalgamation and continuity within the non-marine depositional package. In the study area, sandstones interpreted as early valley filling deposits overlie unconformities SB1 and SB2 (Fig. 15). The sandstones above SB1 can be traced seaward from a stratigraphic position within the middle Menefee to a position in which they incise the Point Lookout shoreface. Throughout this interval the fluvial sandstones are overlain and sealed by aggradational non-marine and marine influenced coastal plain mudrocks. The north-northeast trending valley (Fig. 4) associated with the SB1 erosion surface is the only such feature within the study area for which a sense of scale and orientation is available (and even this is unconstrained to the east). Correlation efforts in the subsurface should use, as a starting point, a model of north-northeast trending valleys with a minimum width of six miles. Thickness of the basal fluvial fill ranges from zero (near channel edges and/or where reworked into younger estuarine fill) to 35 feet. Clearly, individual channels and tributaries will be of smaller scale than this and a detailed treatment of the paleo-topography and local fluvial distribution networks might yield complex results.

Recognition of these fluvial sandstones and their bounding unconformities is critical to mapping the axes of Menefee and Point Lookout incised valley reservoir targets in the subsurface. Where the unconformity cuts into the top of the Point Lookout Sandstone, fluvial channel sandstones will be directly superimposed upon marine shoreface sandstones. Every attempt should be made in the subsurface to distinguish subtle fining-upward sandstone trends at the top of the marine sandstone package that may indicate fluvial incision. Likewise, careful mapping of fluvial sandstone trends (channel belts) in the middle Menefee Formation (such as in Figure 11) will highlight the incised valleys and adjacent interfluves. Exploration plays that target the dip-aligned incised valleys will have the highest potential to intersect these basal fluvial deposits, as well as certain transgressive reservoir plays discussed in the subsequent section.

Valley fill sandstones above SB2 are interpreted only in the northern field area (on Briggs Mesa), and landward correlation of these units was not accomplished due both to limited time and poor exposure. Thus, an exploration model for these rocks applied to the southern subsurface should be considered speculative. Where documented, the sandstones are capped by transgressive shoreface deposits or by coastal plain mudrock of the transgressive systems tract. The latter is expected to dominate toward the

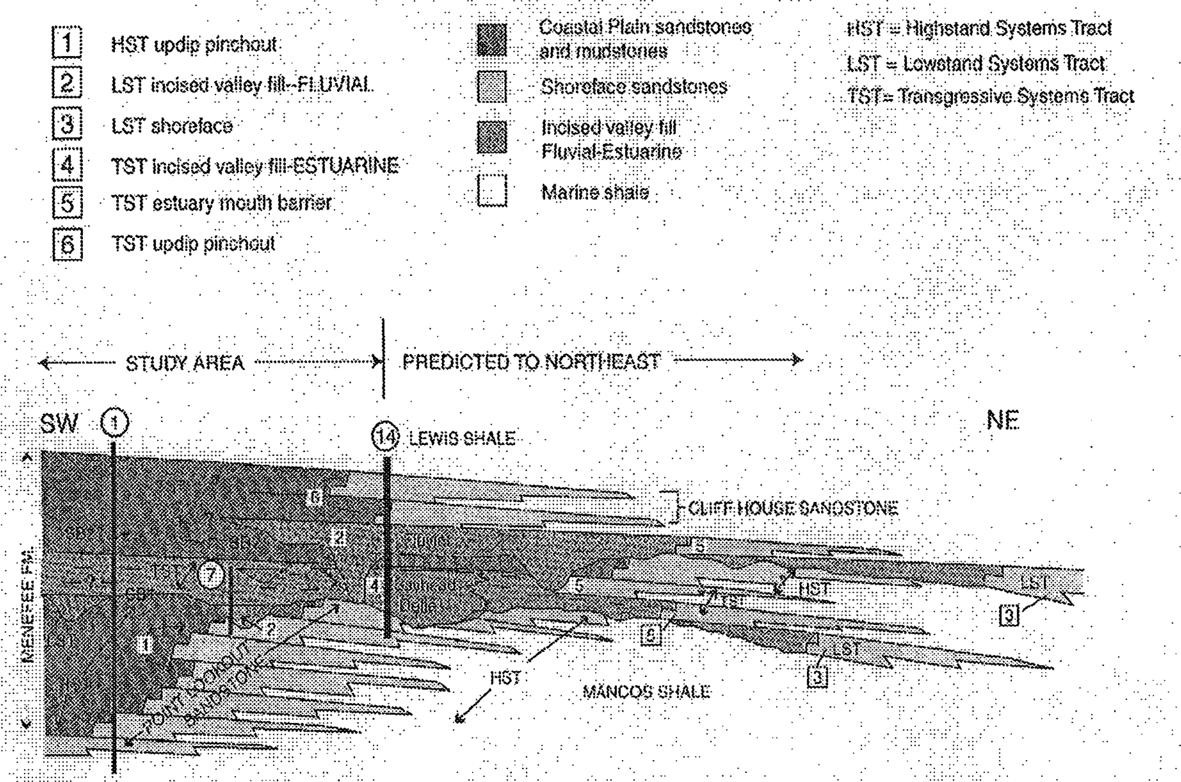


Figure 15. Schematic diagram depicting observed/predicted stratal relationships and hydrocarbon play types for the Mesaverde Group, northeastern San Juan Basin. Modeled after Van Wagoner et al., 1990. Approximate relationship to measured sections is indicated by schematic sections 1, 7, and 14.

south and the fluvial reservoir targets would be well sealed within the upper fine-grained Menefee. It is impossible to determine from the present data the extent to which these sandstones comprise a correlatable or significant sand-rich Menefee horizon (as can be demonstrated for the older SB1 fluvial system). Another intriguing, yet speculative, consideration is that the position of these thick fluvial deposits on northeastern Briggs Mesa may have been controlled by syn-depositional faults (*see Structural Reservoir Plays*). In such a case, fault block orientation, rather than regional paleoslope, may guide correlation to the south.

Transgressive Reservoir Plays

While a basal component of the incised valley fill may have accumulated under lowstand conditions, the bulk of the valley fill is interpreted as transgressive, having accumulated under conditions of rising base level and back-flooding of the fluvial system to form estuaries, bays, and aggrading fluvial channels (Fig. 13c). This process can generate two significant reservoir targets (Fig. 15). At the estuary mouth a transgressive barrier may develop, stepping landward over time and terminating in an updip pinchout into fine-grained central basin estuarine fill. At the head of the estuary, sand-rich estuarine channel and bayhead delta deposits may aggrade in step with rising base level and the landward-migrating barrier.

Transgressive estuary mouth deposits were not observed during the course of this study, and if developed, these and any central basin fine-grained deposits must have been present north of the modern outcrop belt. The bayhead delta system, on the other hand, could be a significant facies component of incised valley targets in extreme northeastern basin plays. These sand-rich estuarine deposits overlie a bayline flooding surface that is typically merged with the underlying SB1 sequence boundary. Merger of these surfaces suggests that any lowstand fluvial sand present in this part of the valley during estuarine inundation was reworked into the overlying estuarine sediment package.

Bayhead delta reservoir targets are incised into Point Lookout marine shoreface sandstones. They are sealed above by coastal plain mudrocks and are transitional updip within the valley into heterolithic (muddy) fluvial strata. Reservoir quality is considered moderate to good (at best) in these deposits, which are less well-sorted and more heterogeneous than upper shoreface sandstones. Although incompletely preserved in outcrop, these deposits form an amalgamated sandstone sheet at least 36 miles square and up to 50 feet thick.

A different transgressive reservoir play in the area is expressed on Briggs Mesa where landward-stepping Cliff House marine sandstones display updip pinchout into the upper Menefee Formation (Fig. 15). These aggradational to retrogradational shoreface sandstones share many of the same strong reservoir characteristics as the previously described highstand Point Lookout shoreface deposits, however this buildup of the Cliff House is specifically situated at the seaward preserved limit of fine-grained Menefee strata. The better "reservoir" sandstones here are located in *outcrop* toward the north, and do not have specific analogs in the southern subsurface. Younger Cliff House transgressive reservoirs do exist in the subsurface toward the southwest (Molenaar and Baird, 1991) and may prove of interest to Jicarilla exploration.

A final type of transgressive reservoir play observed during this study is in the uppermost Menefee. Here medium grained, sand-rich estuarine deposits, preserved beneath the ravinement level of the Cliff House/Lewis marine transgressive surface, sit encased within fine-grained continental and marine mudrocks. Although there is no evidence to suggest these sandstones have the same degree of amalgamation or lateral continuity as estuarine facies within the incised valley fill, attention might be paid to them as secondary, opportunistic reservoir targets.

Structural Reservoir Plays

Syn-depositional fault movement may have influenced sediment accumulation at least in the northeastern part of the field area. The detailed structural fieldwork confirming this observation has not been accomplished, and these comments should, consequently, be taken as a working hypothesis to guide subsurface correlation. With the Lewis Shale marine flooding surface as a horizontal datum, the top of the Point Lookout foreshore drops approximately 40 feet down-to-the-east along an inferred fault between measured sections 12 and 13 (Plate 2) on Briggs Mesa. A southern extension of the fault is suggested to lie between sections 8 and 9 (Plate 1) near Horse Lake, where approximately 50 feet of down-to-the-east motion best explains the observed stratigraphic relationships. Additional work is required to confirm these offsets as fault controlled and to achieve the level of correlation control necessary to confidently define the specific time of movement. The timing appears to be post-Point Lookout, based upon offsets in shallow marine sandstones and bayhead delta deposits, and syn-depositional with the Menefee, based upon thickness changes documented on Briggs Mesa.

It is interesting to note that: (1) SB1 incised valley estuarine deposits thin and undergo landward facies change west-southwest across the fault, (2) the overlying SB2 incised valley fluvial deposits thin west-southwest across the fault, and (3) the retrogradational Cliff House marine sandstones thin west-southwest across the fault. Although there could be unrelated facies explanations for these patterns, the vertical coincidence of these changes strongly suggests that Cretaceous topography (higher in the Monero area, lower toward the east) may have been fault controlled. If substantiated, these results suggest that incised valley reservoir targets in the subsurface may preferentially follow an inherited structural grain.

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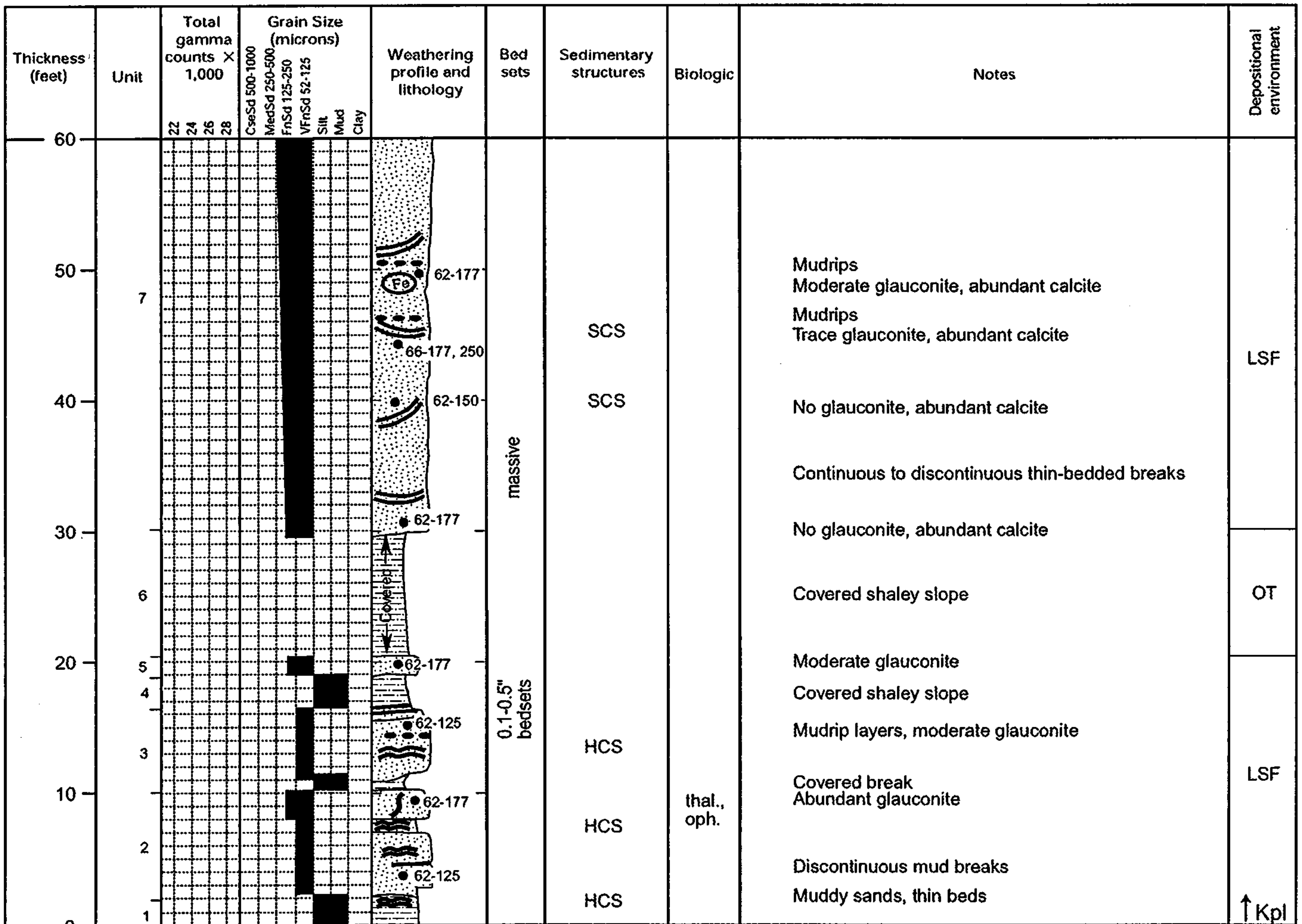
APPENDIX 1



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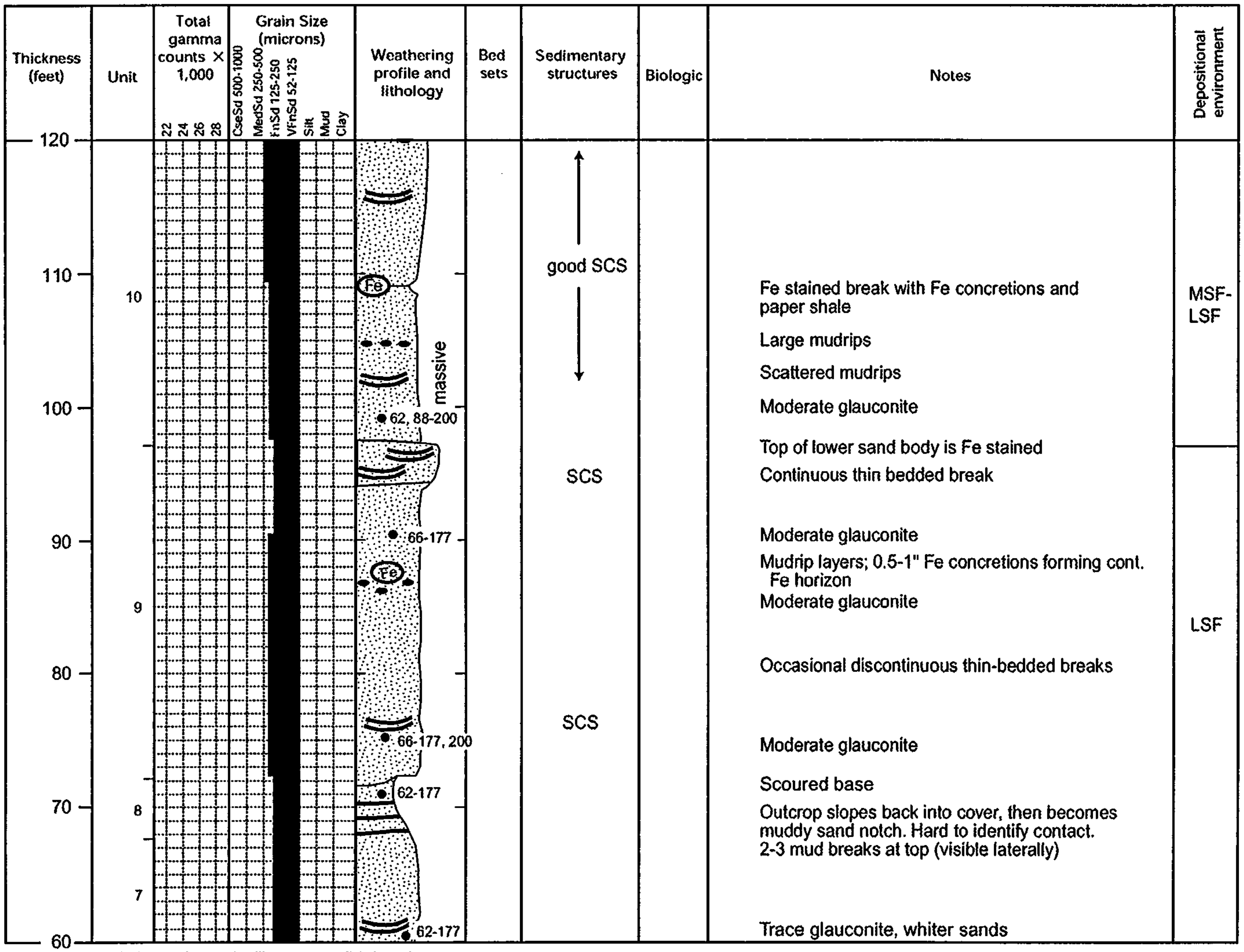

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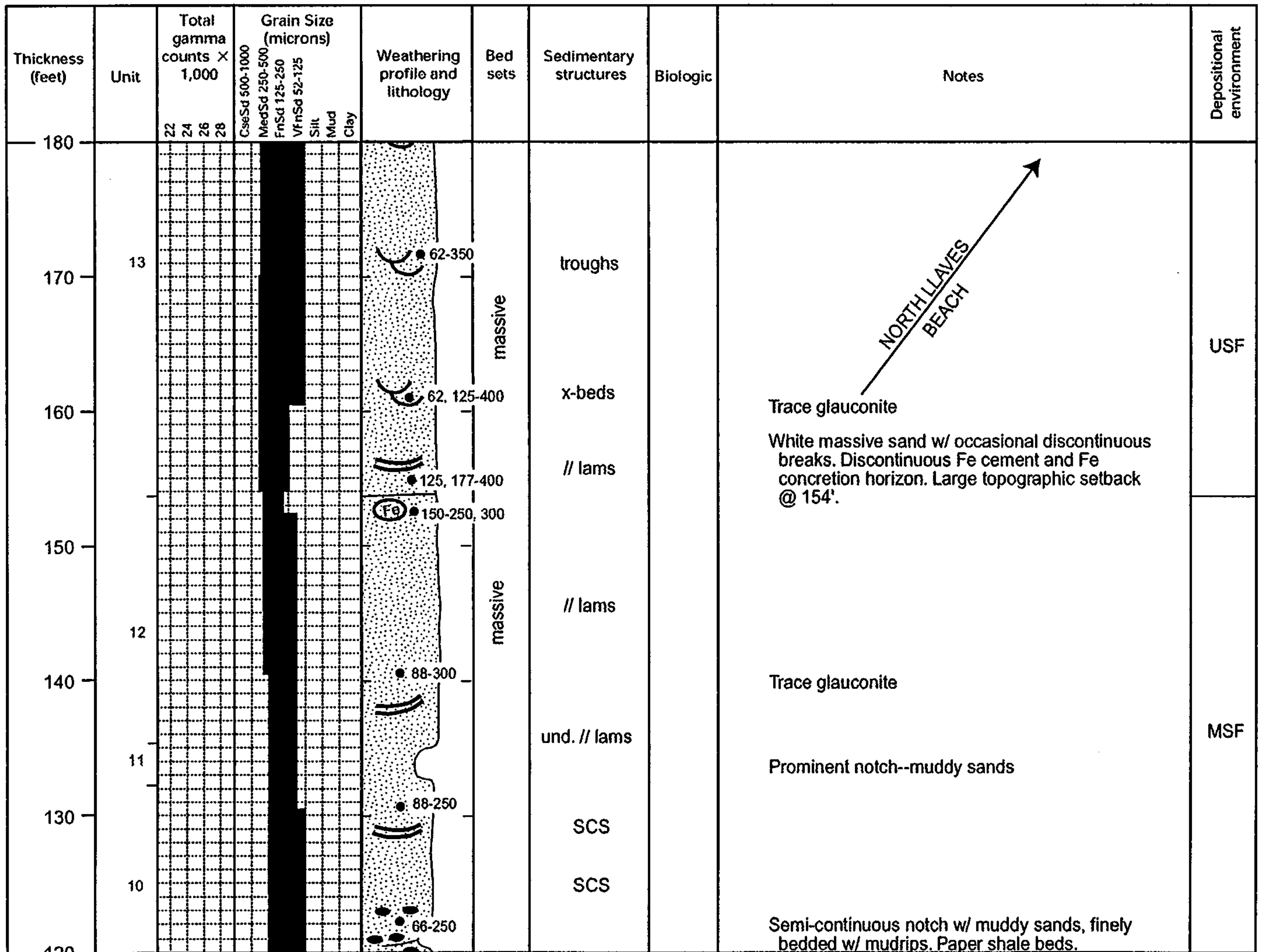

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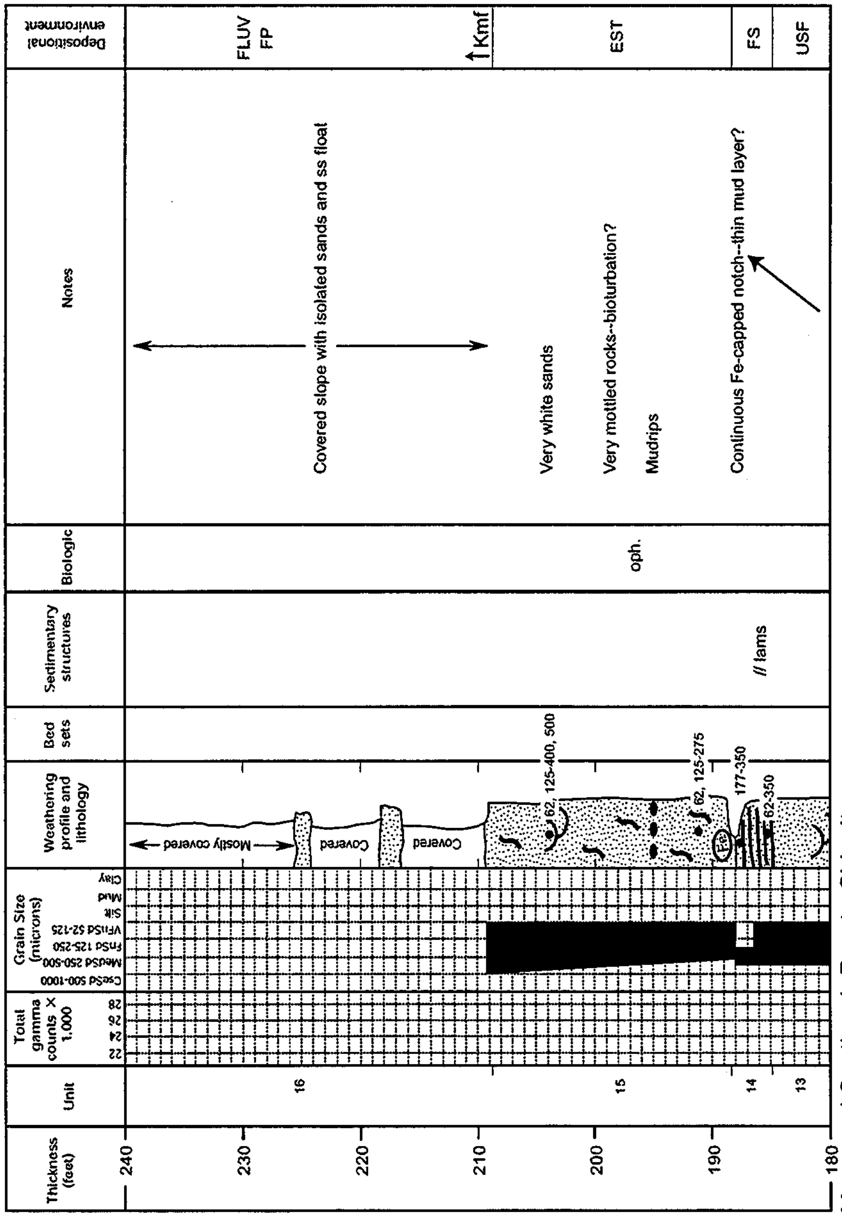

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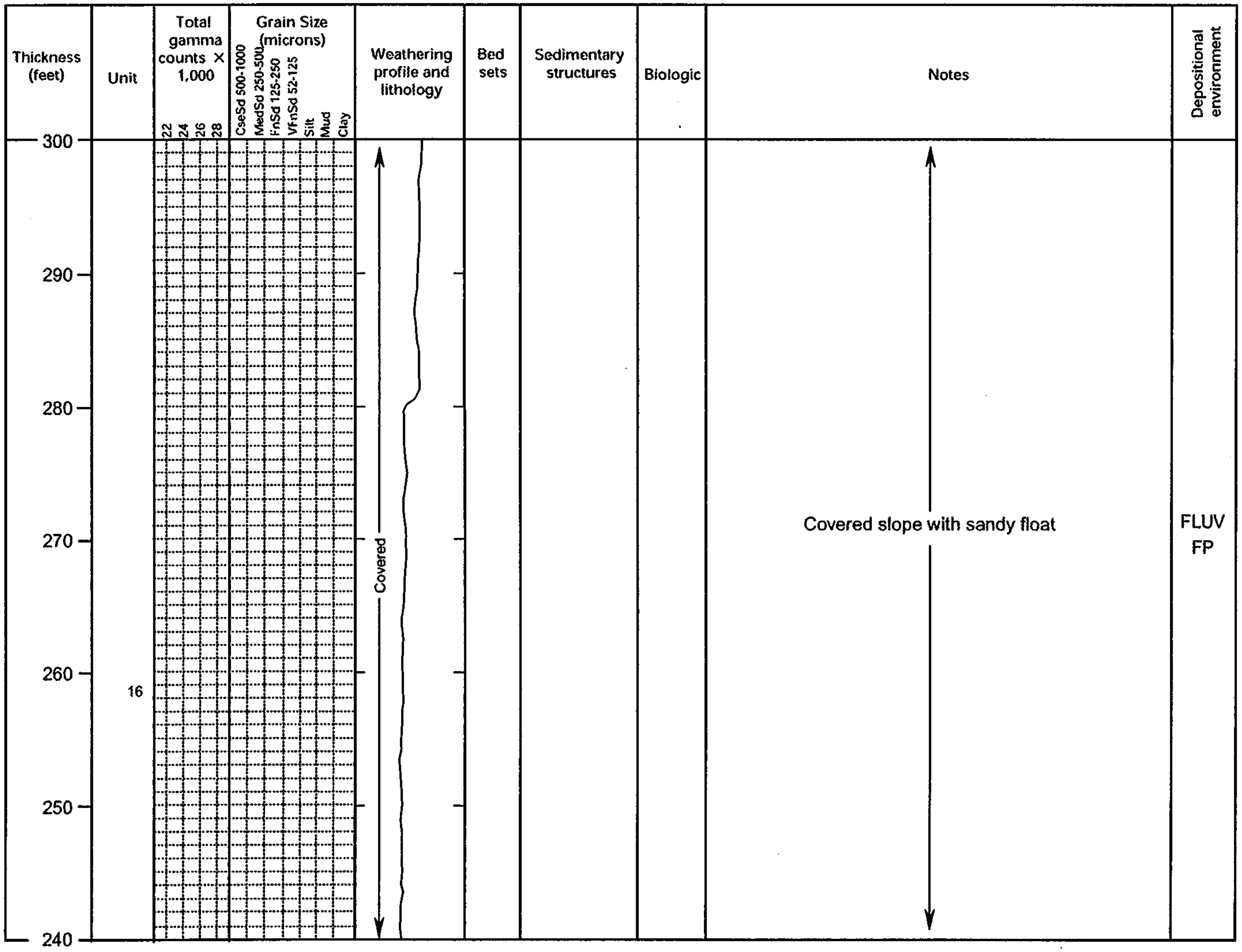

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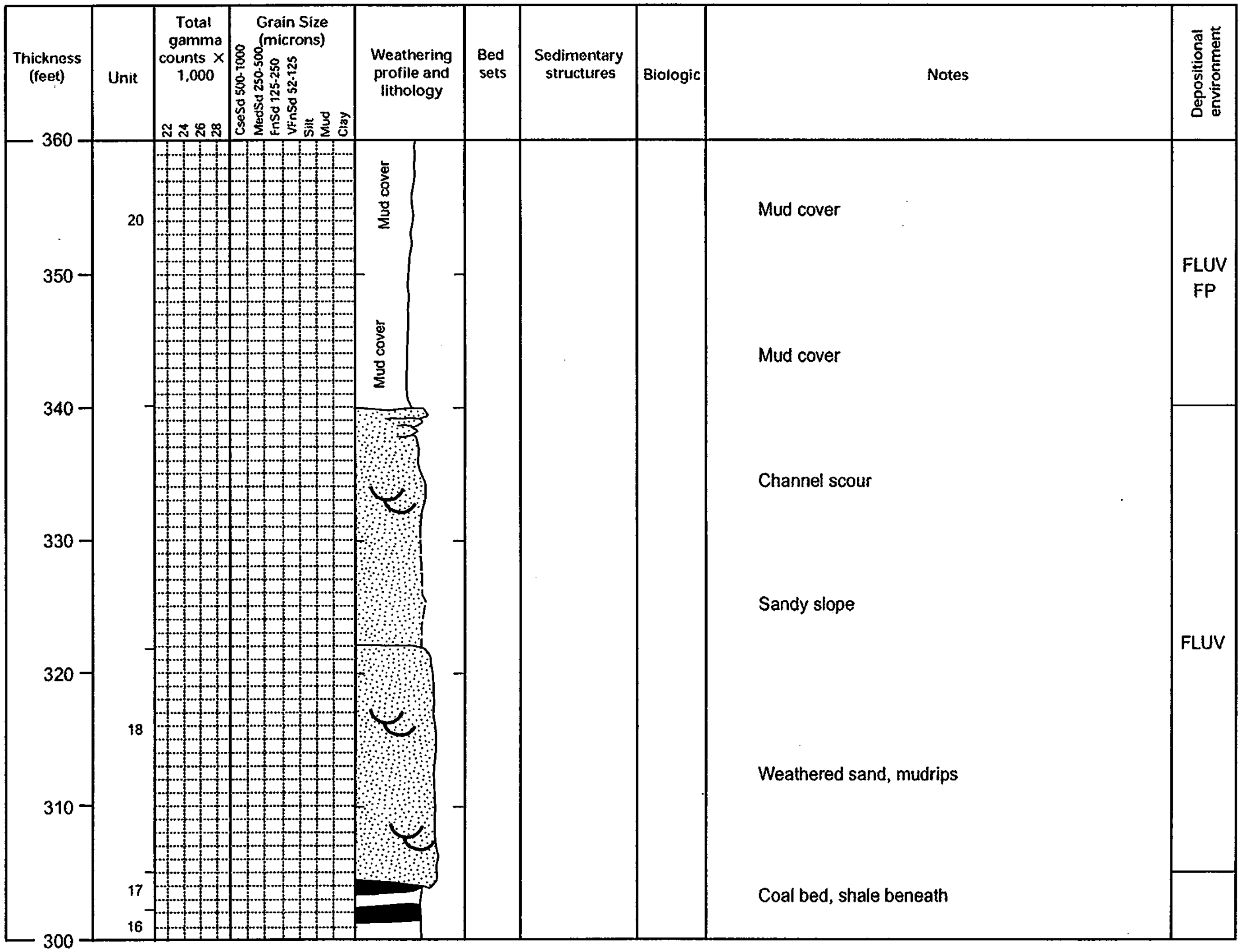

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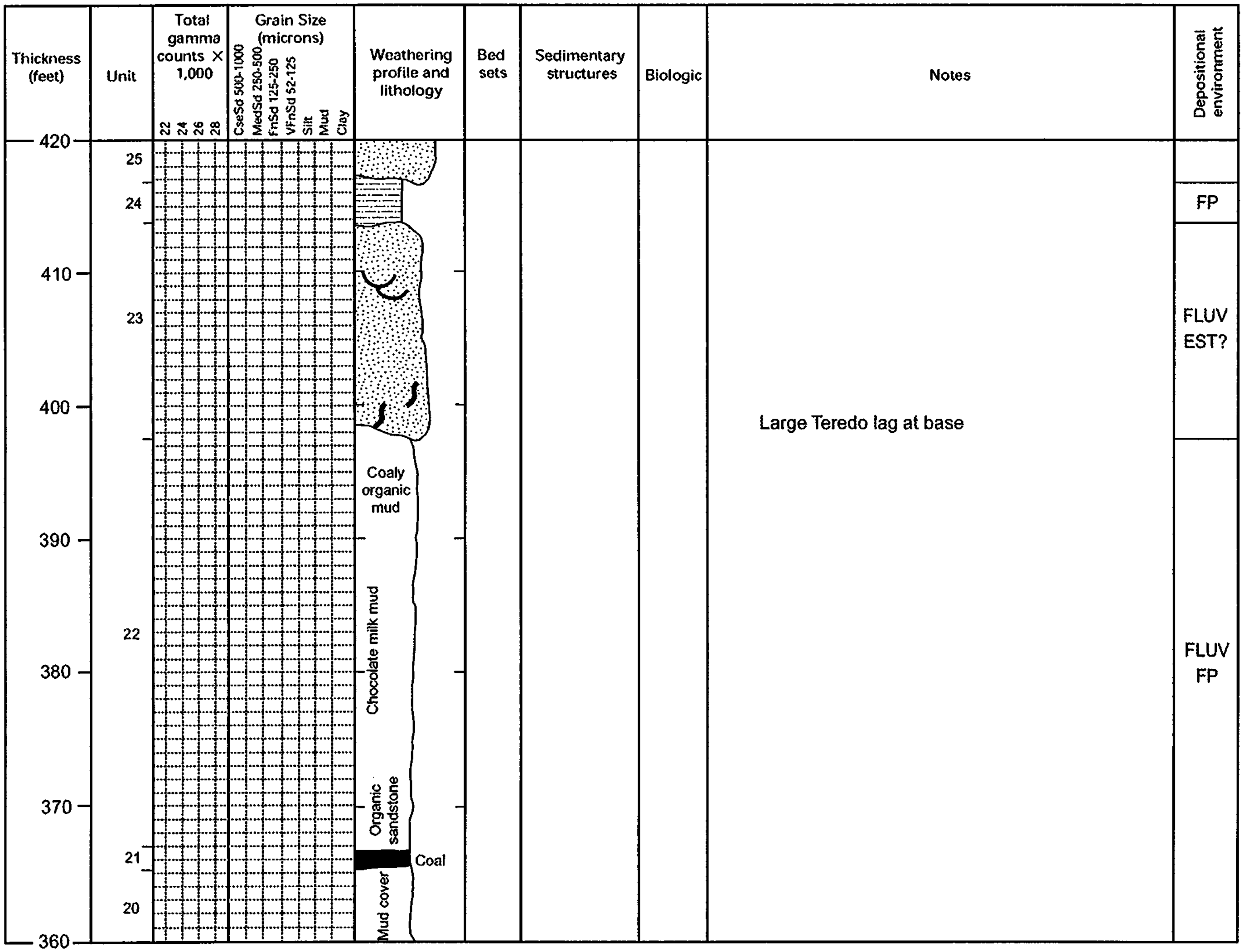

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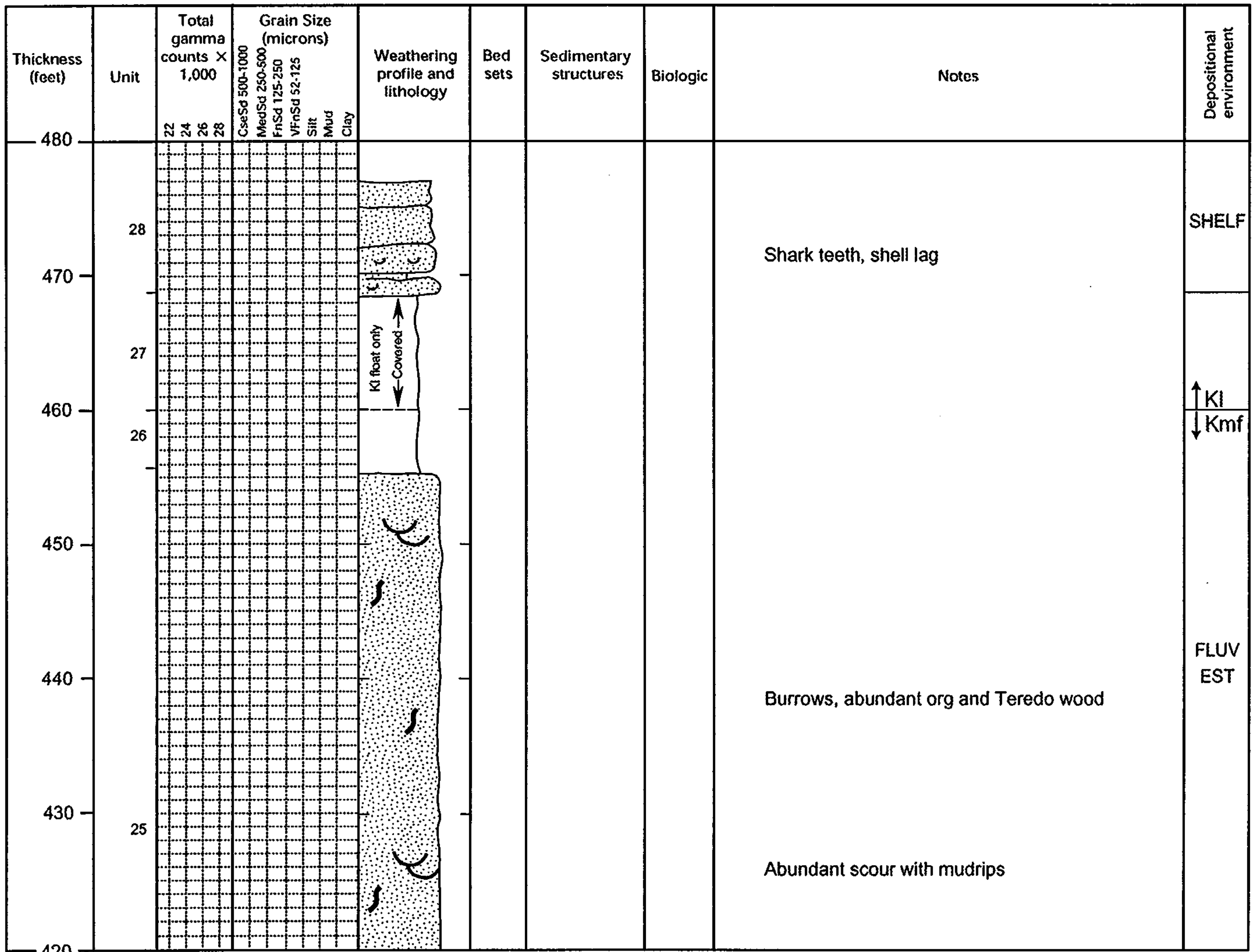

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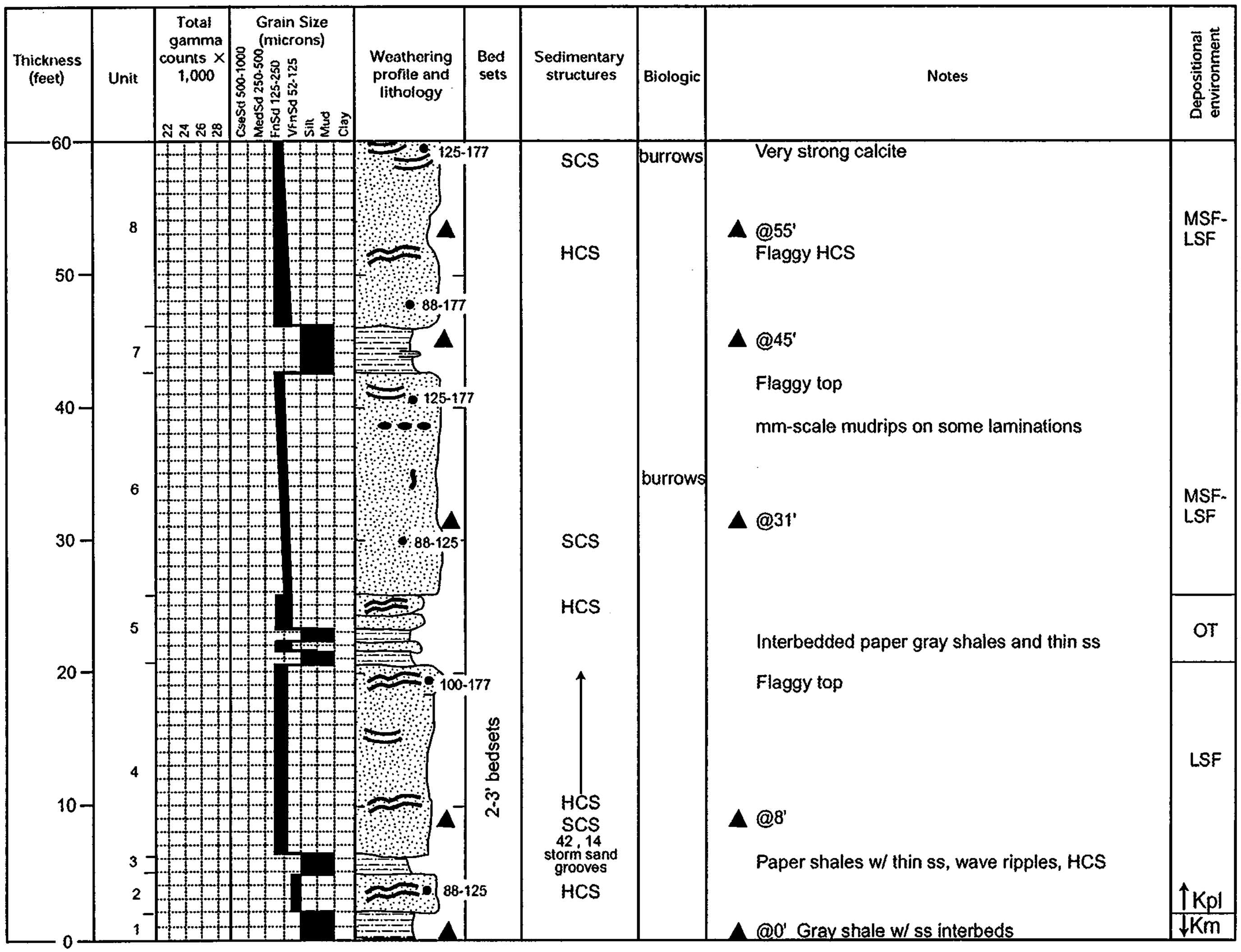

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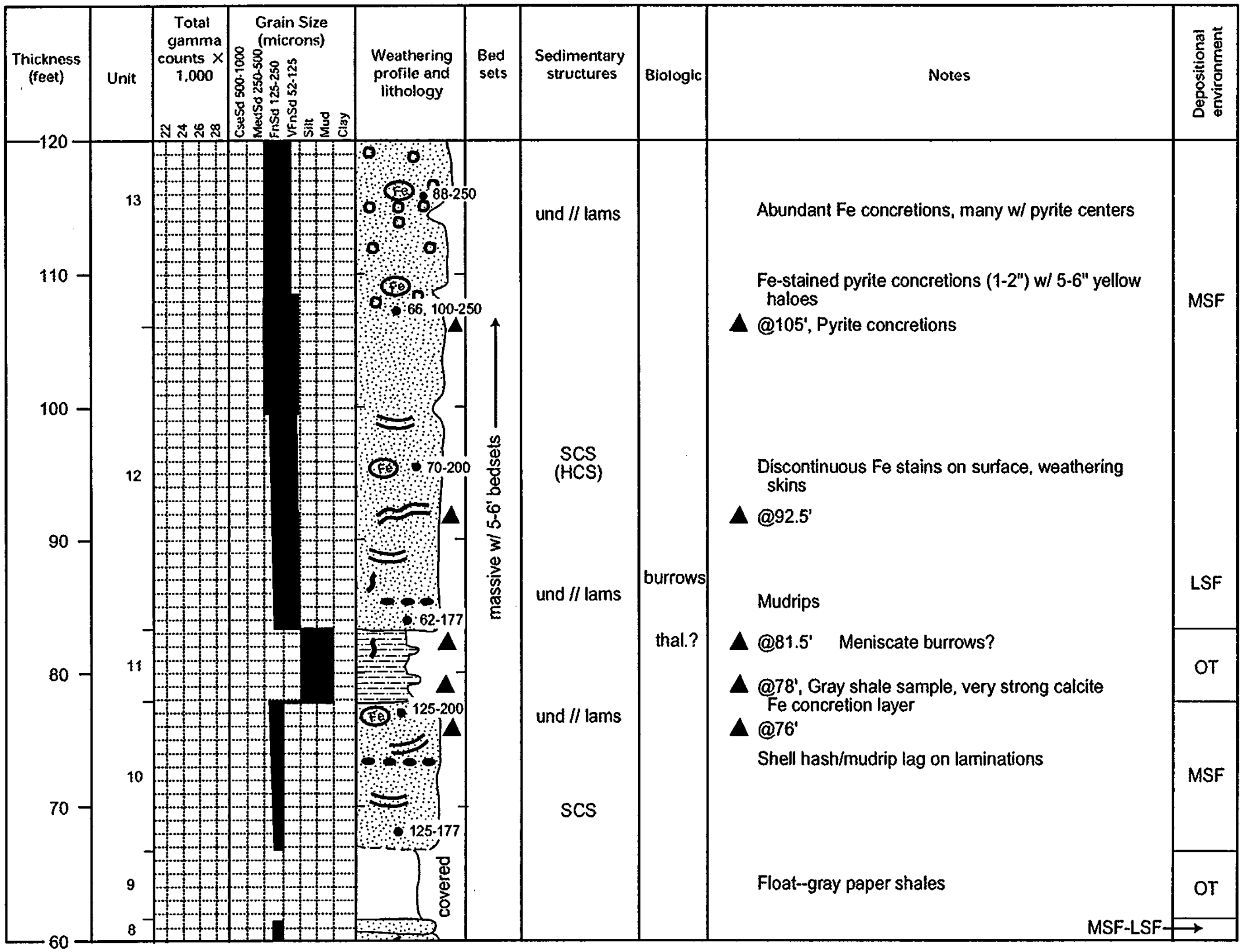

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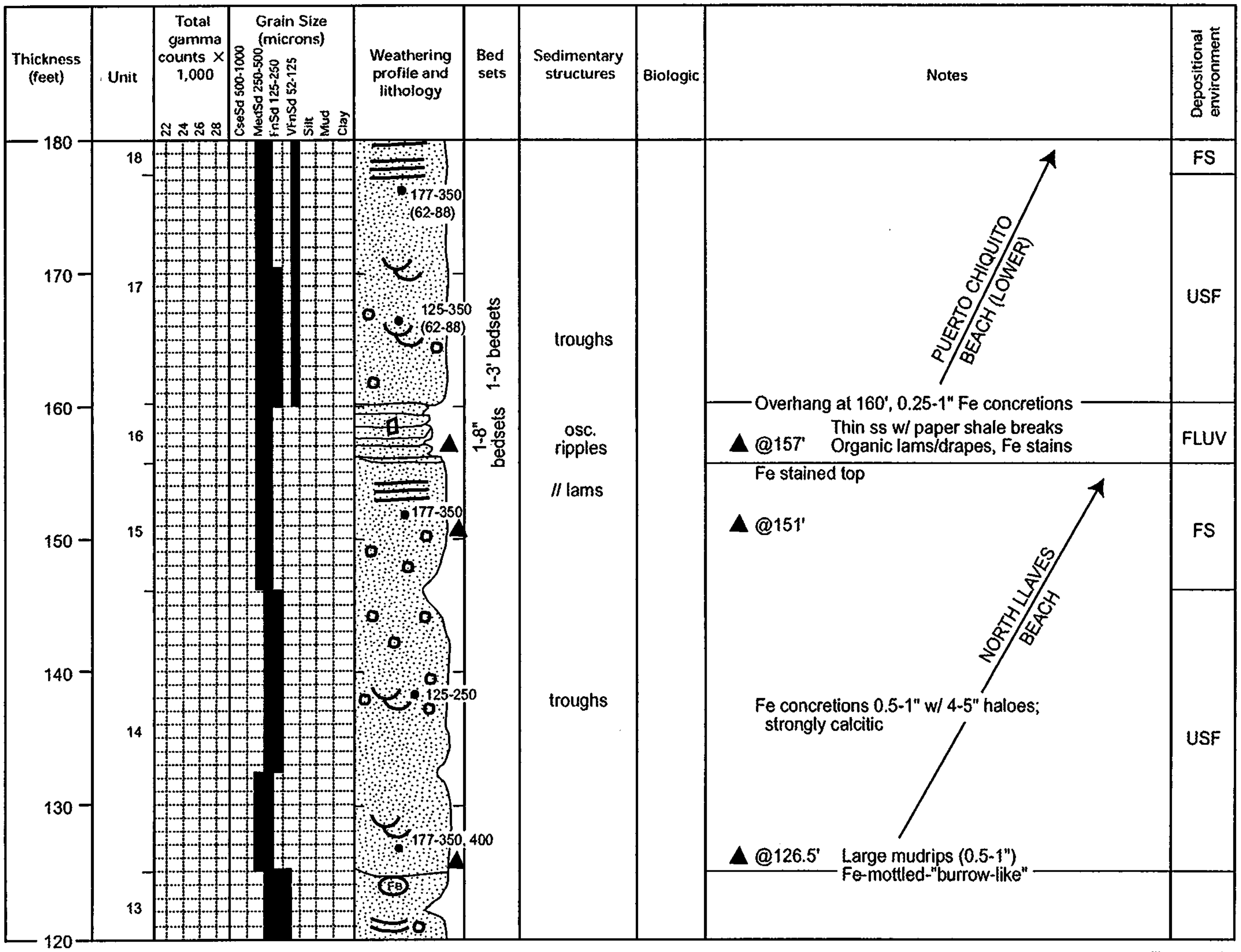

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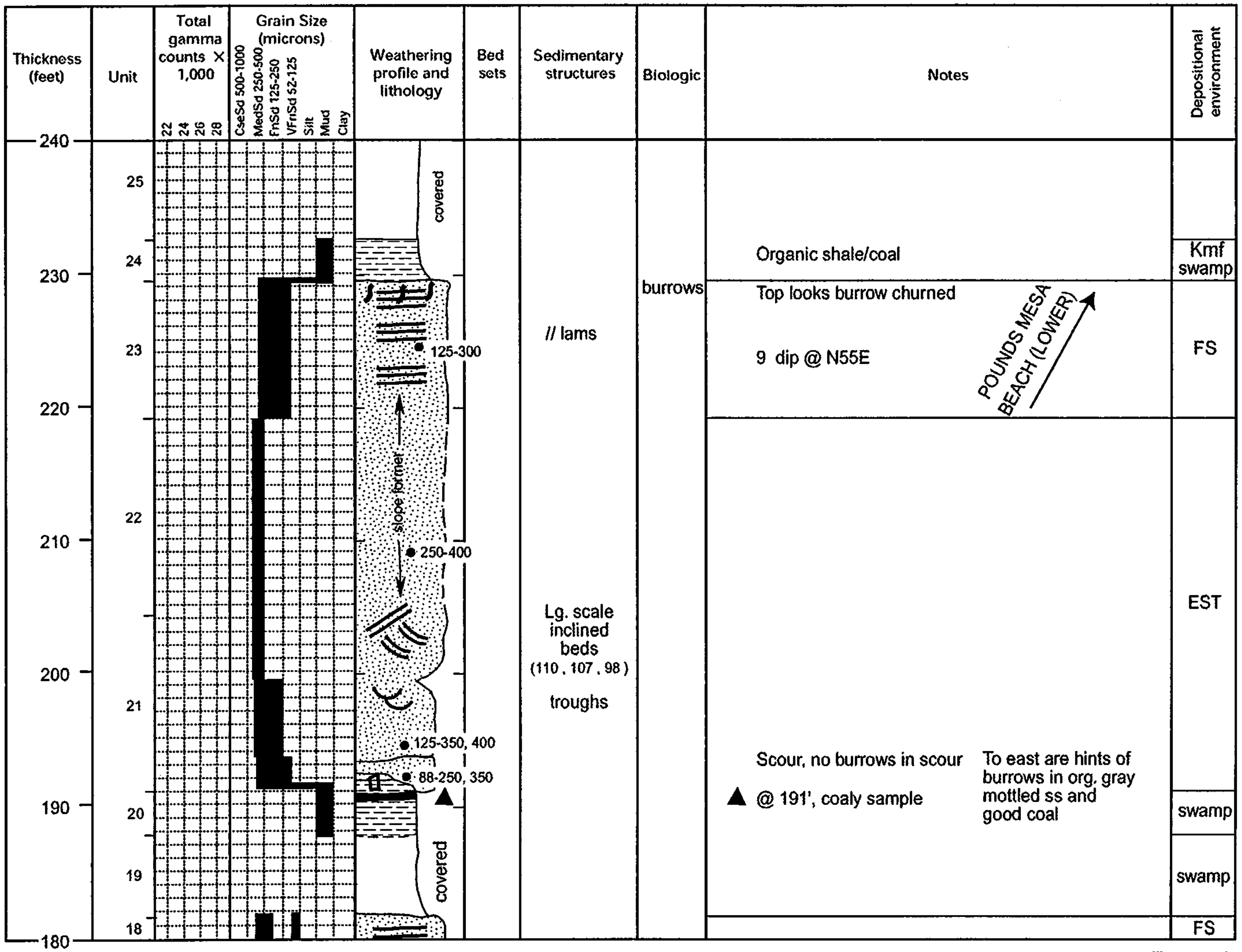

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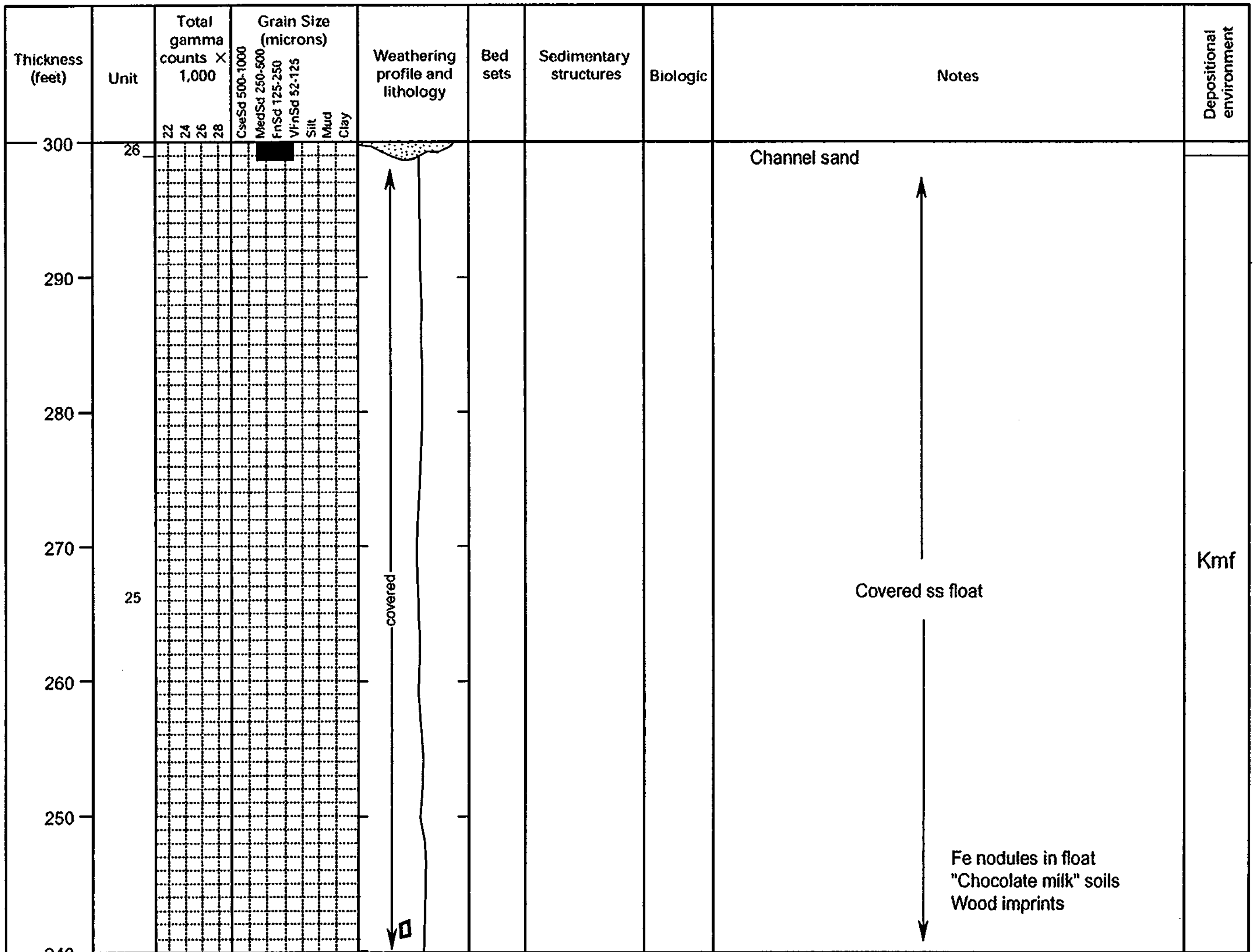

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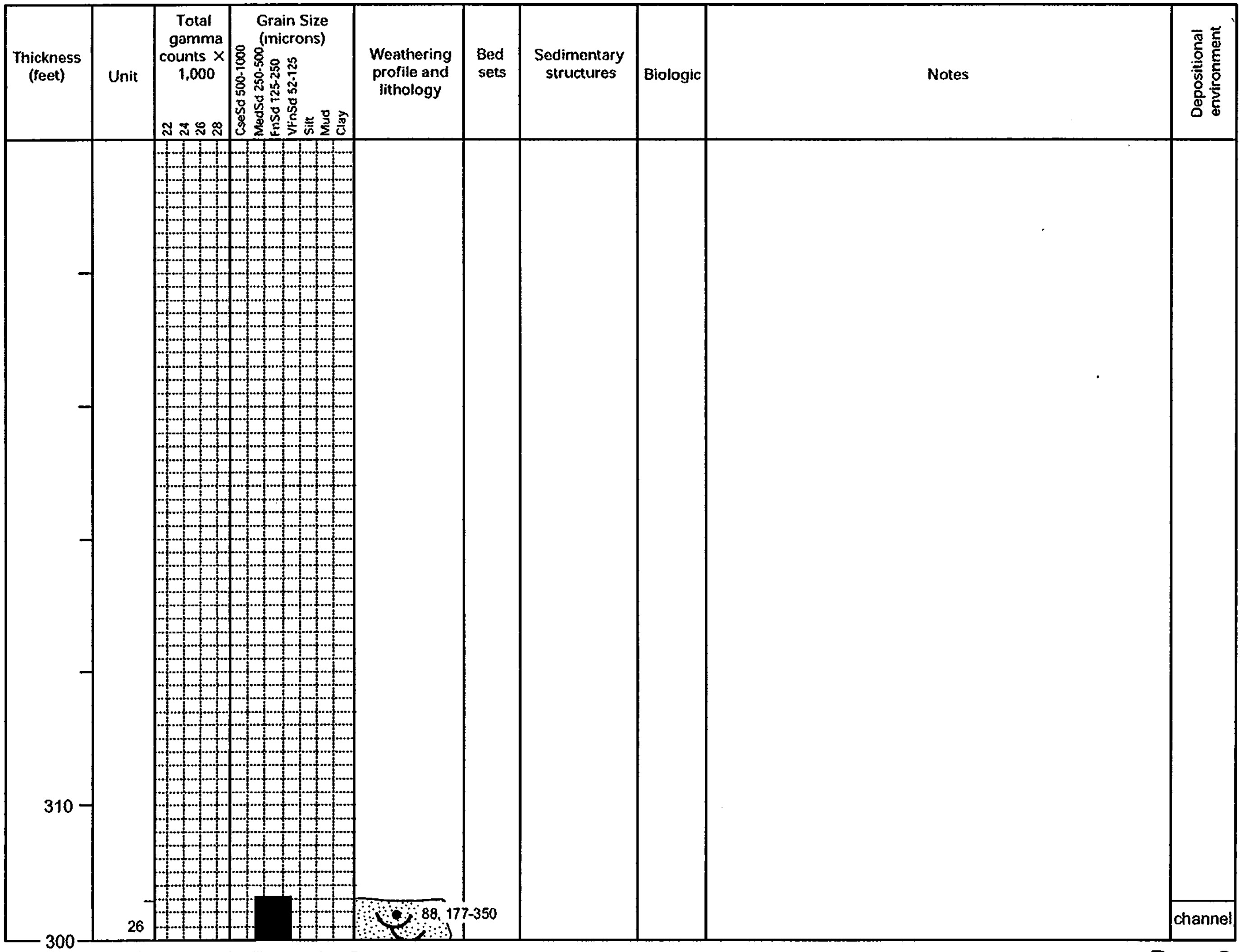

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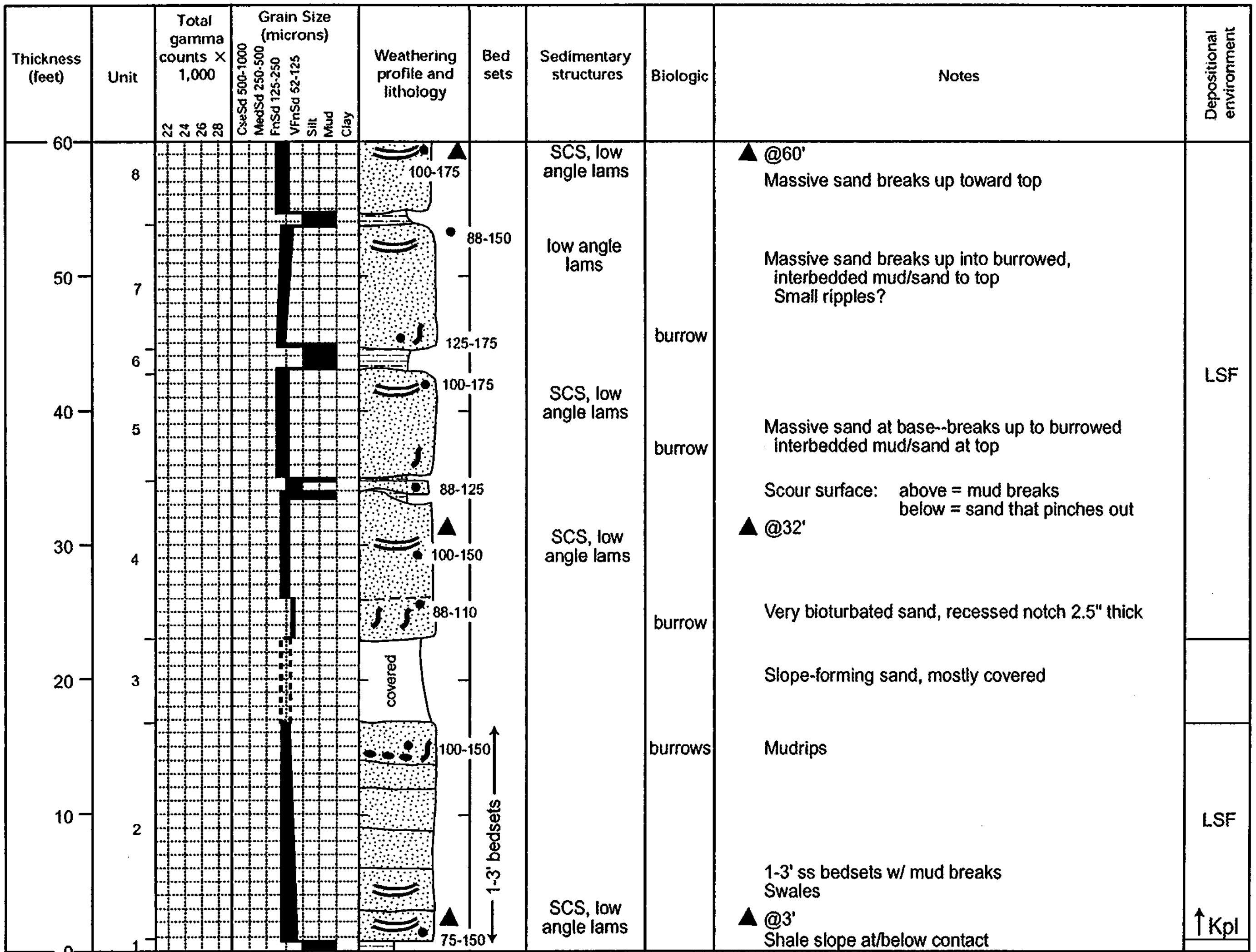

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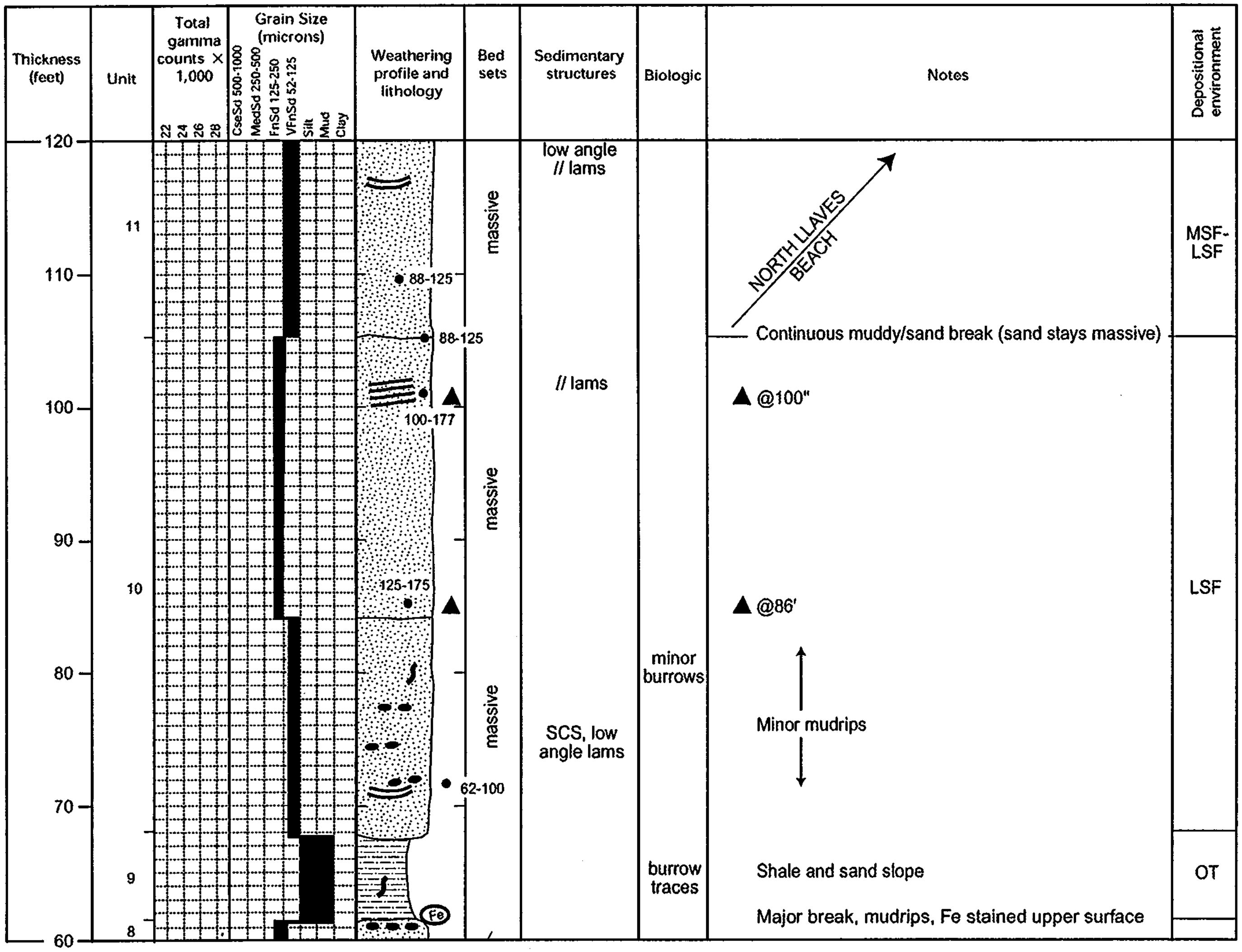

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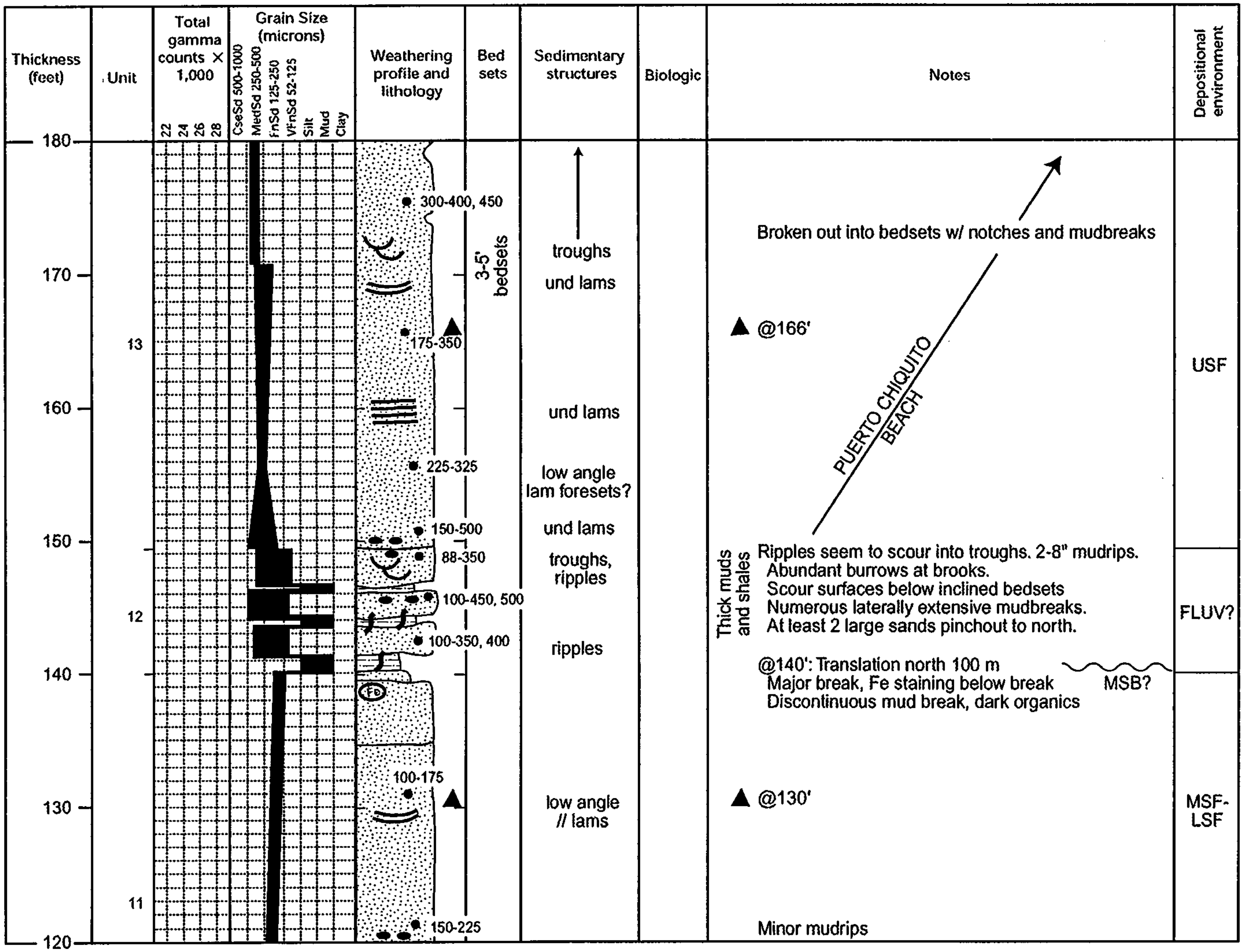

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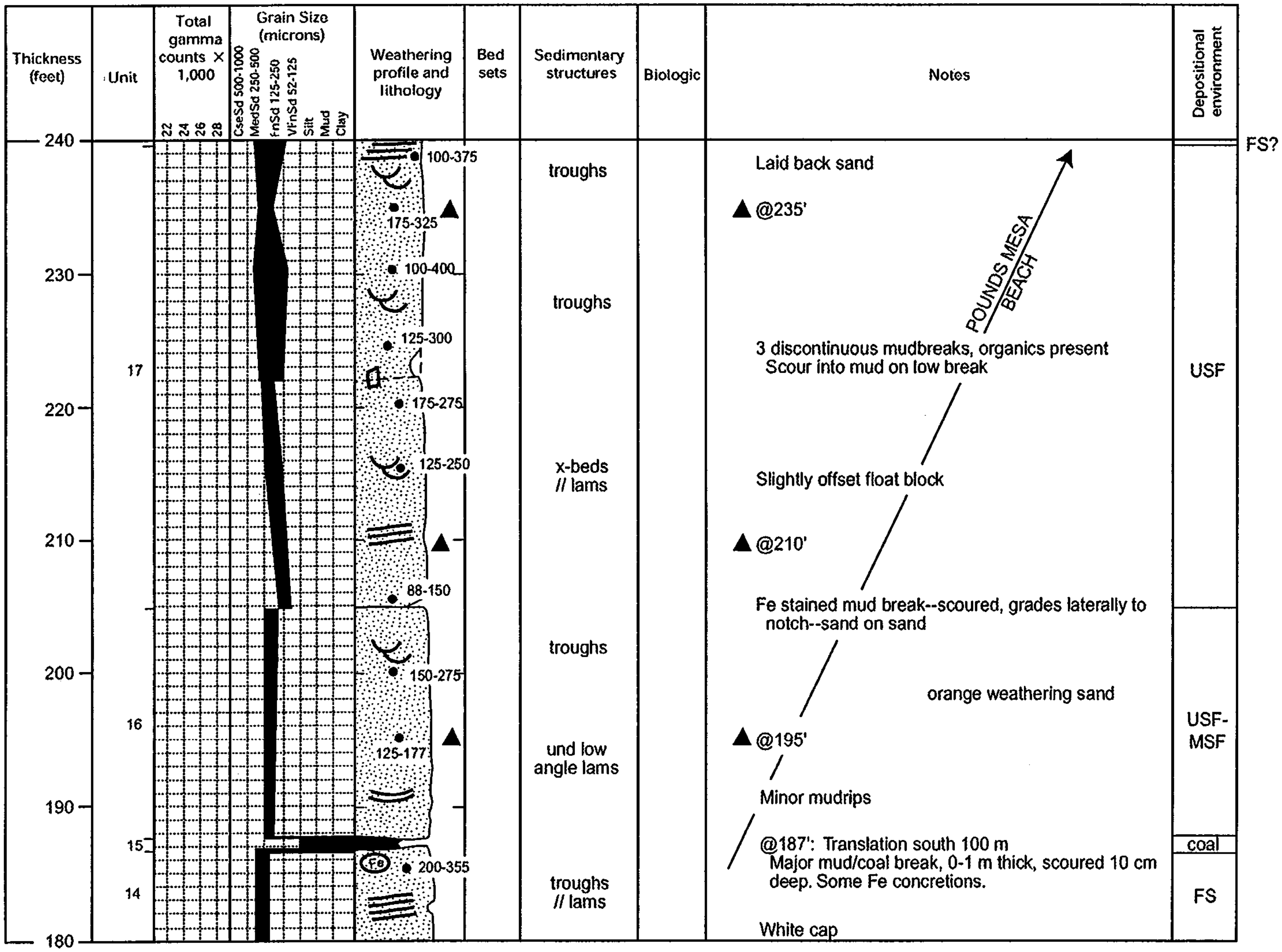

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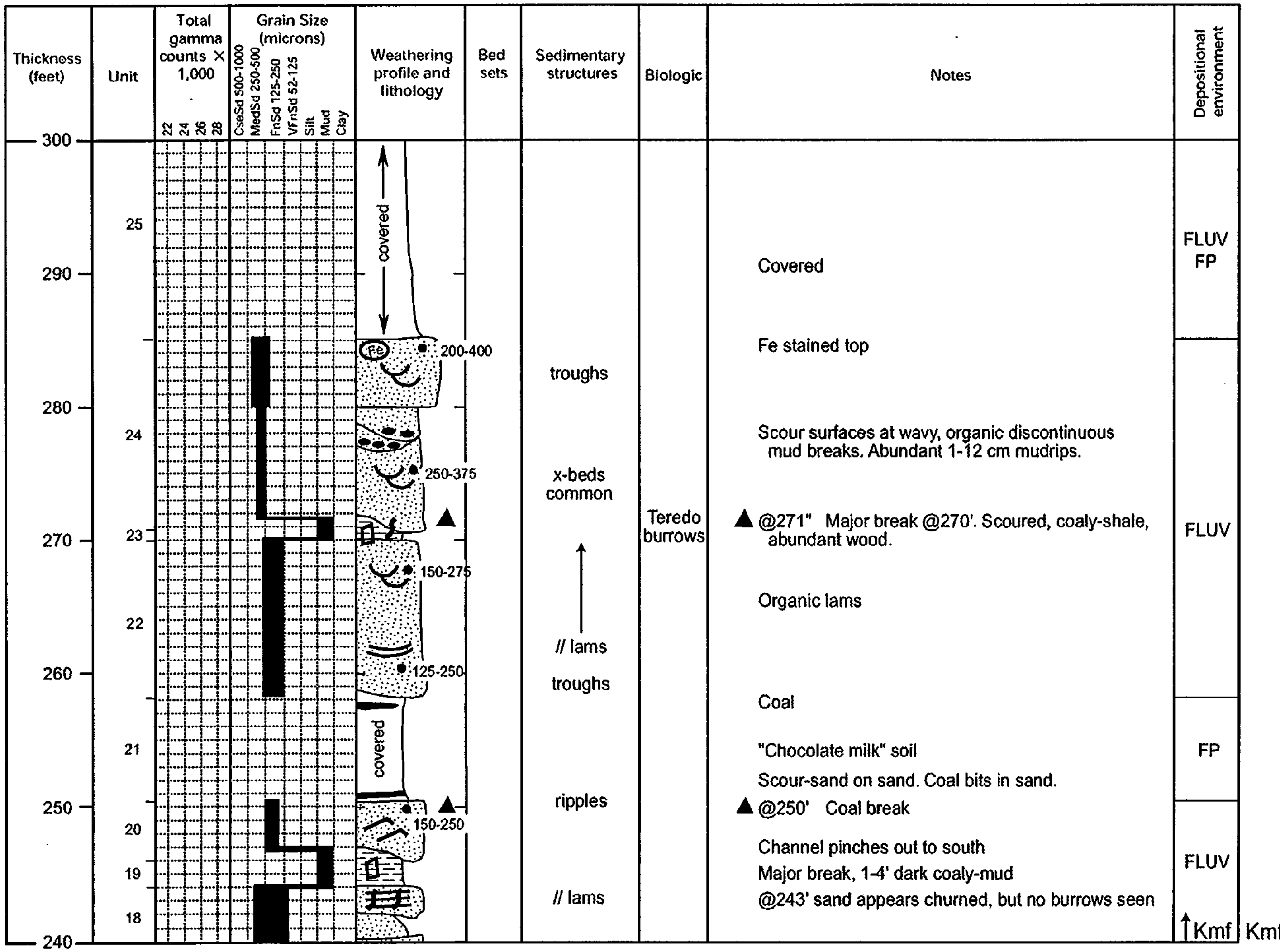

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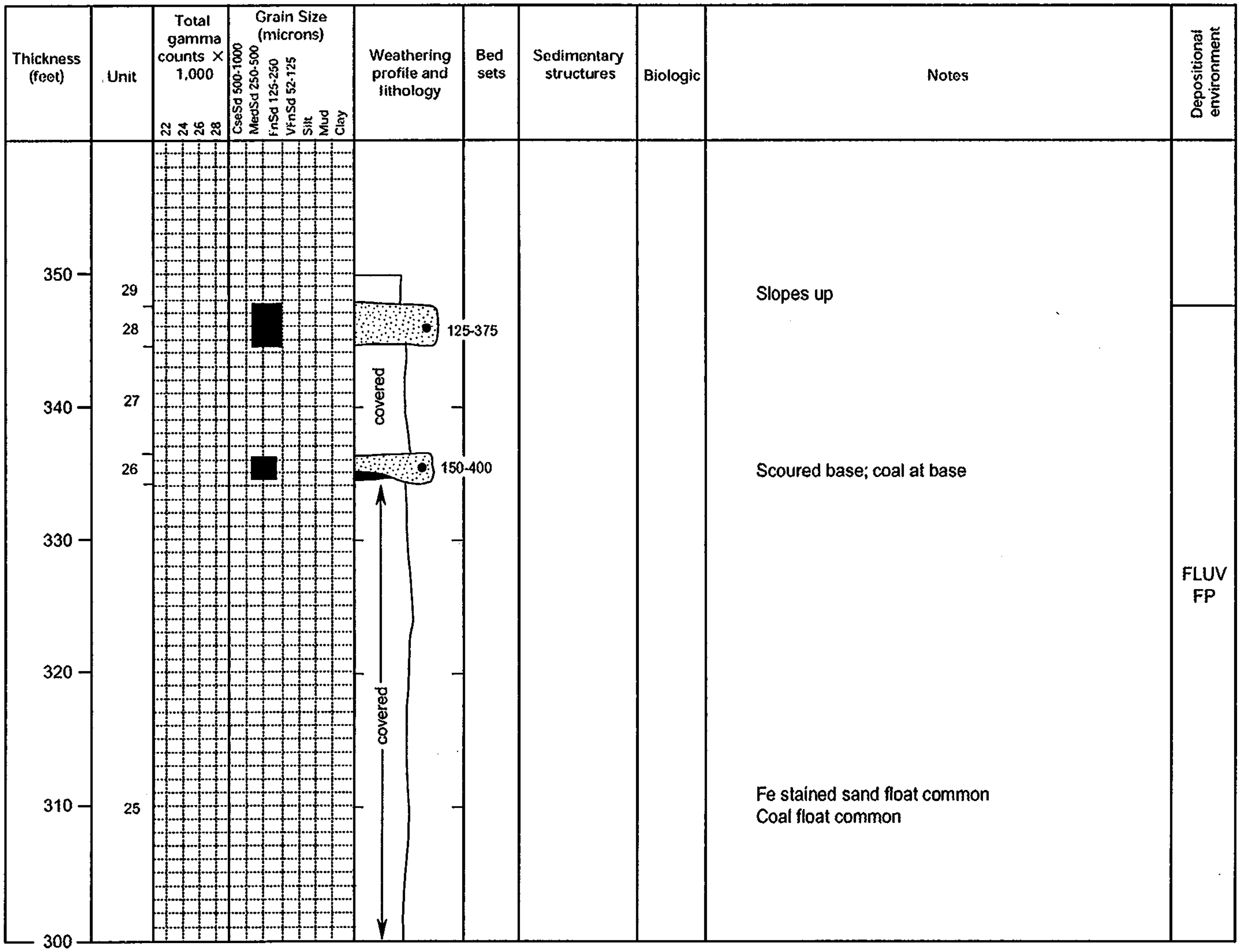

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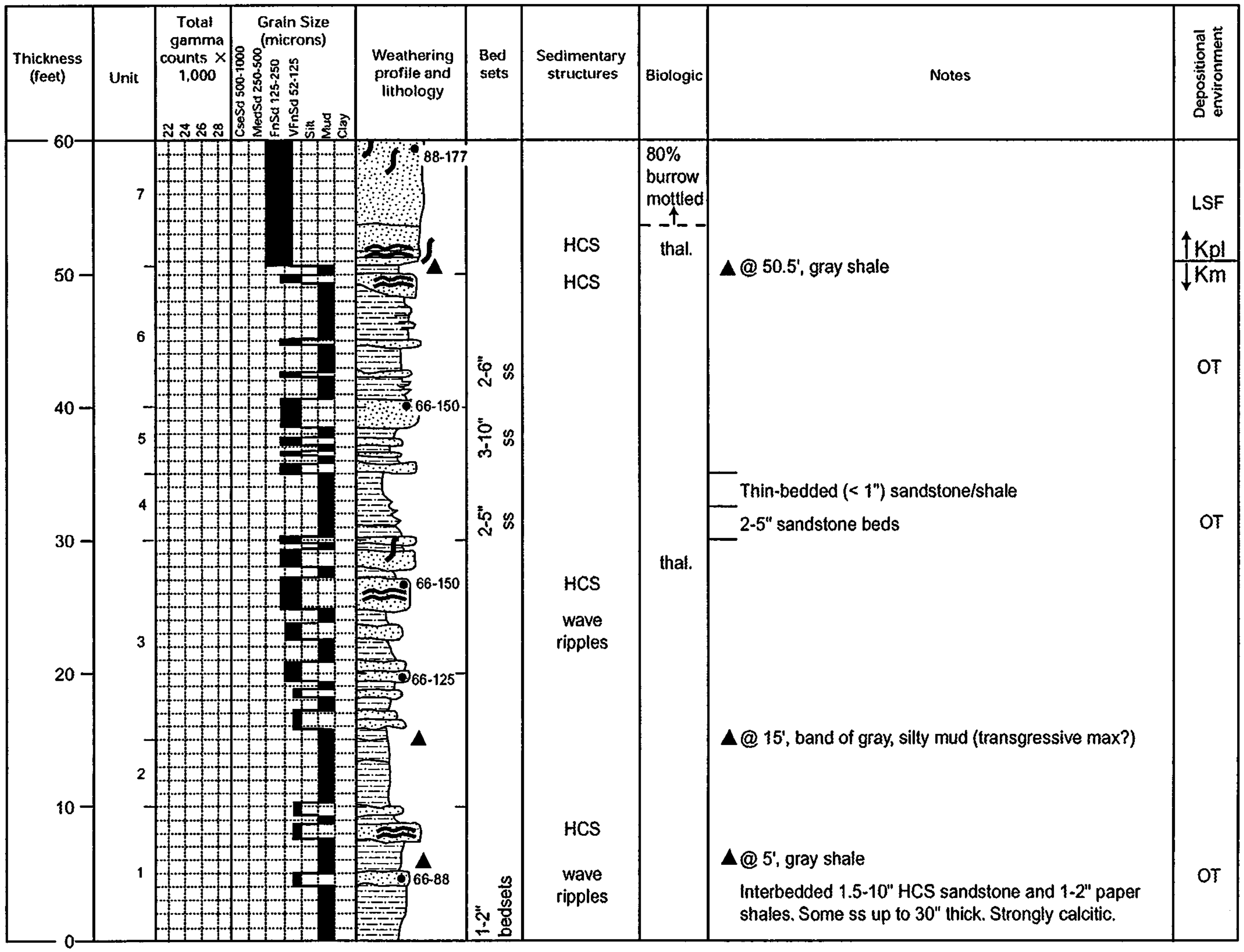

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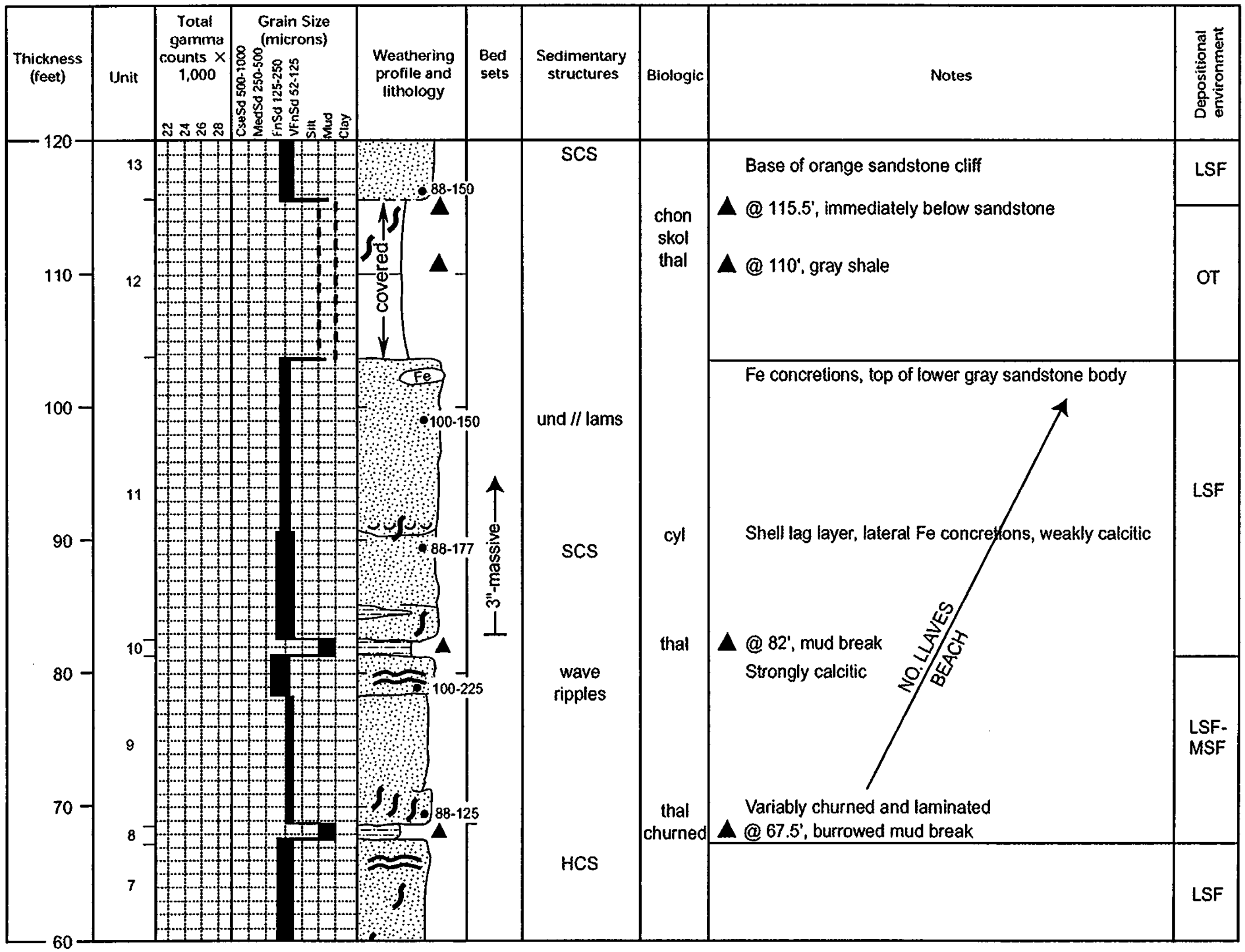

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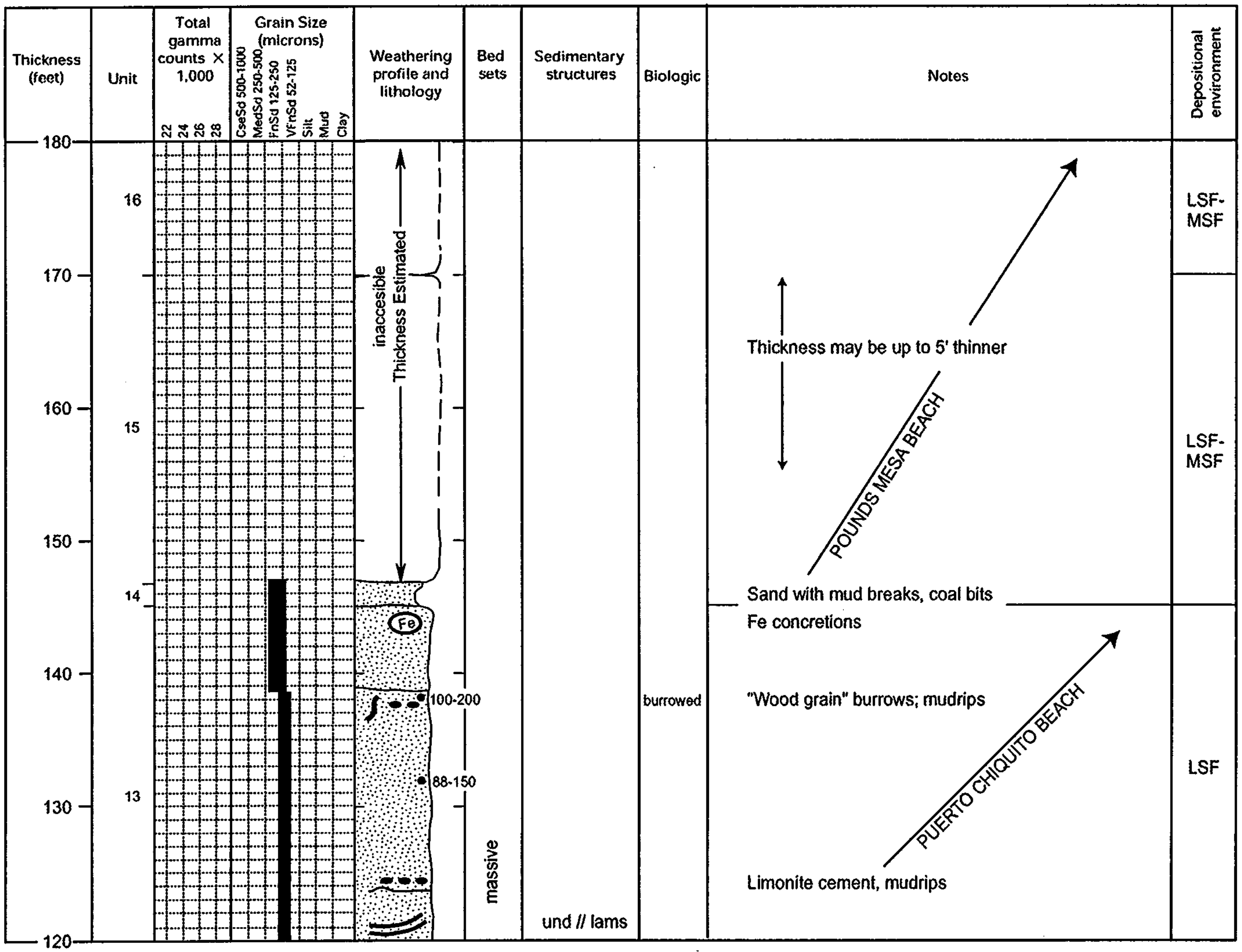
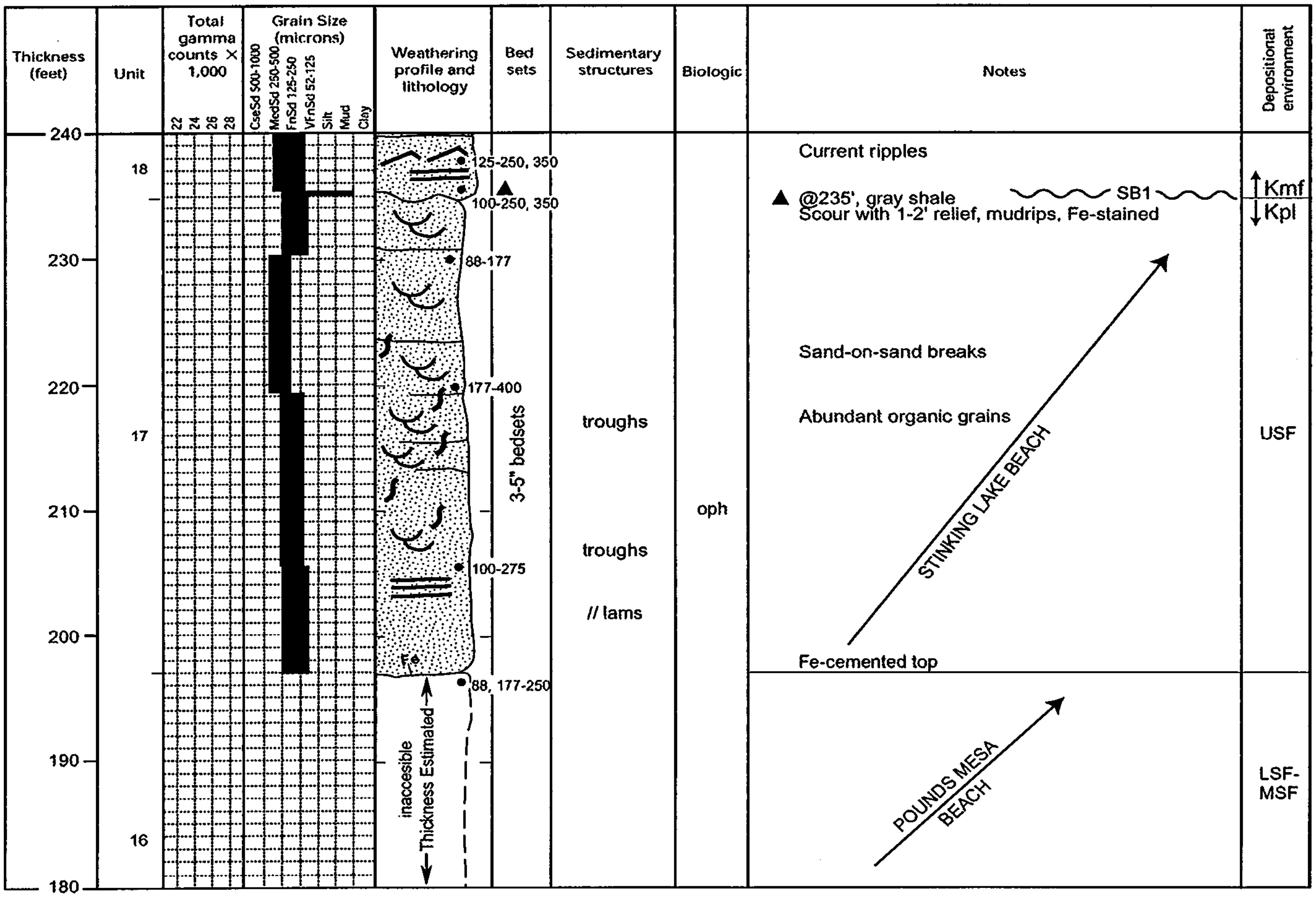
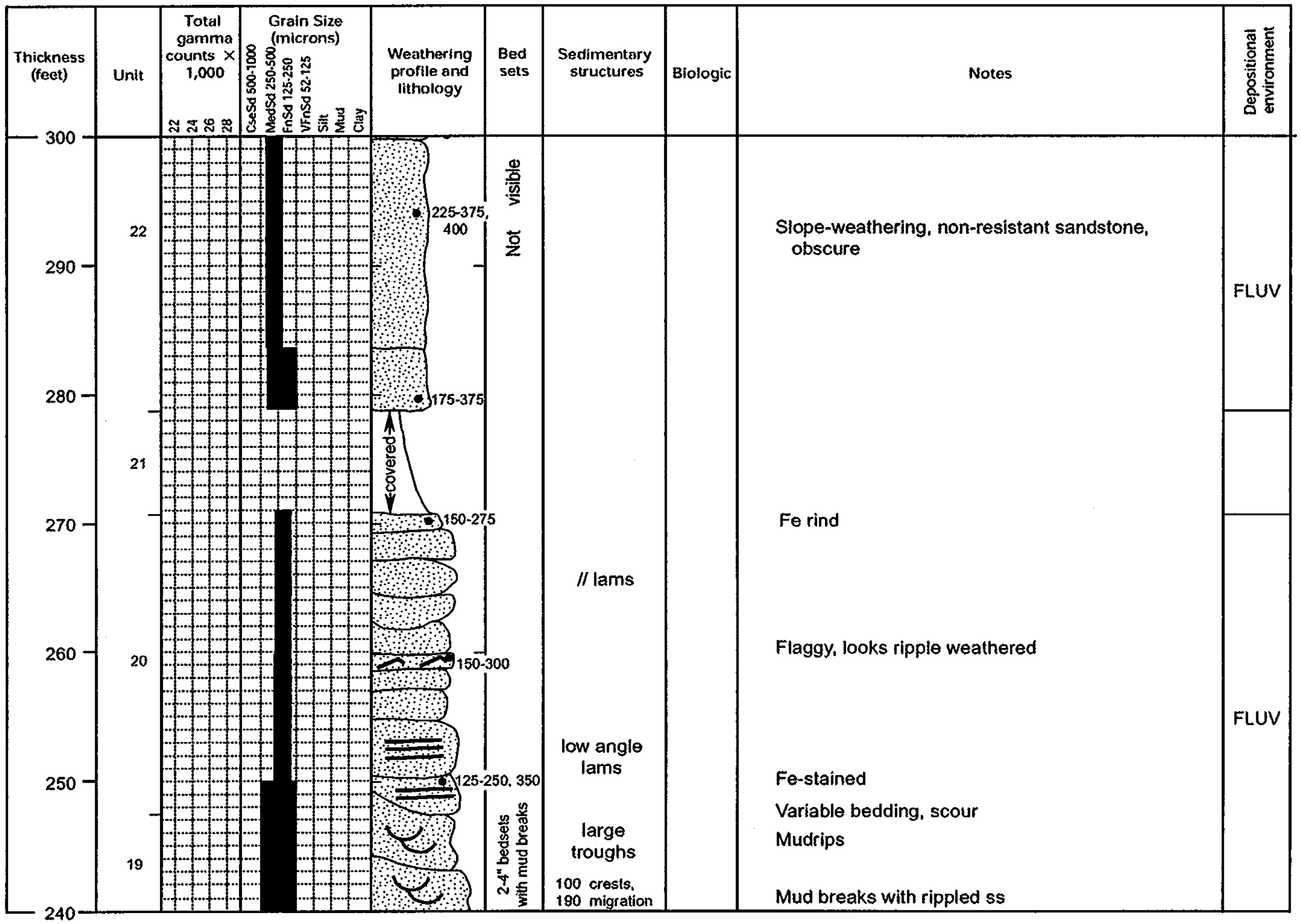


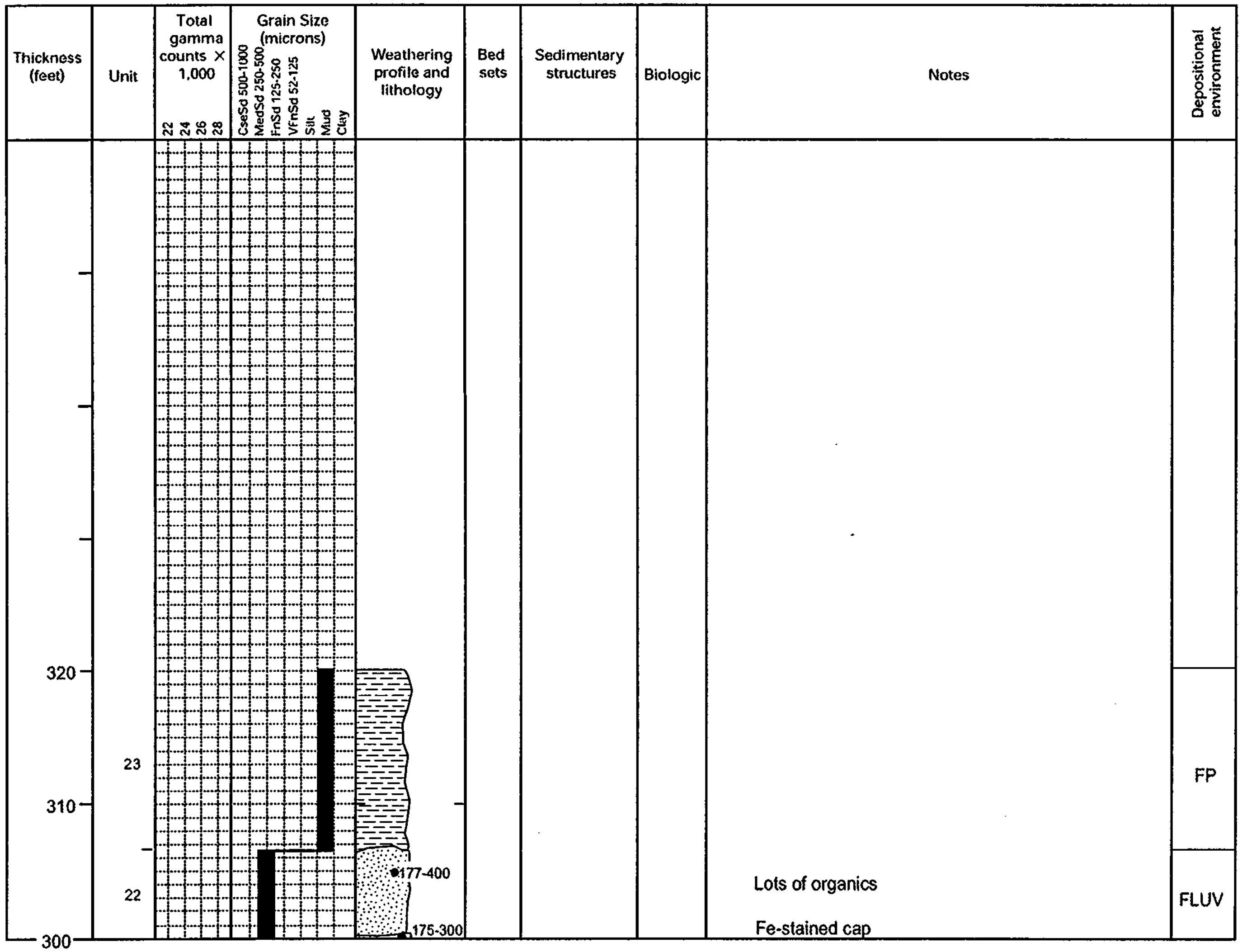
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W Page 3



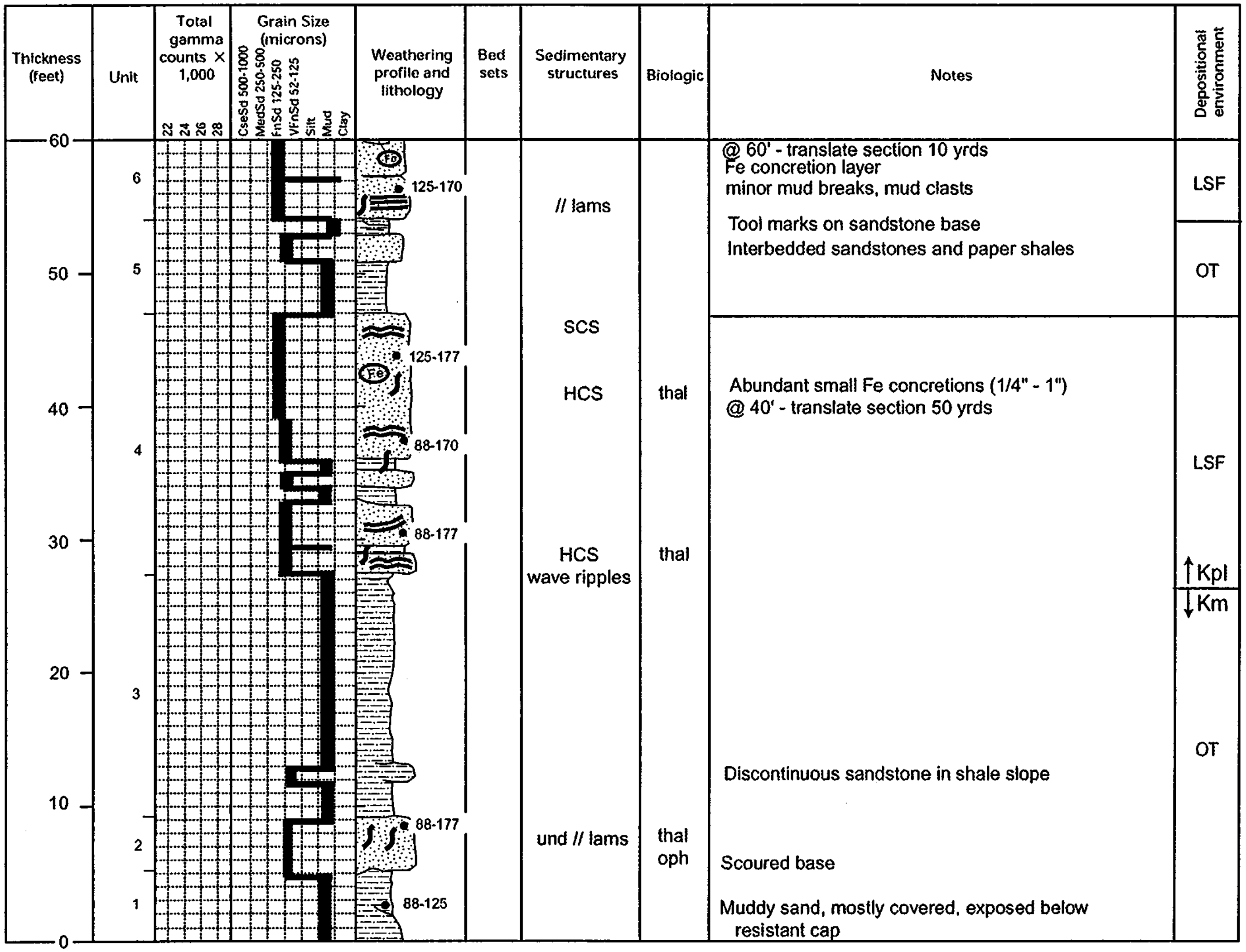
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W Page 4



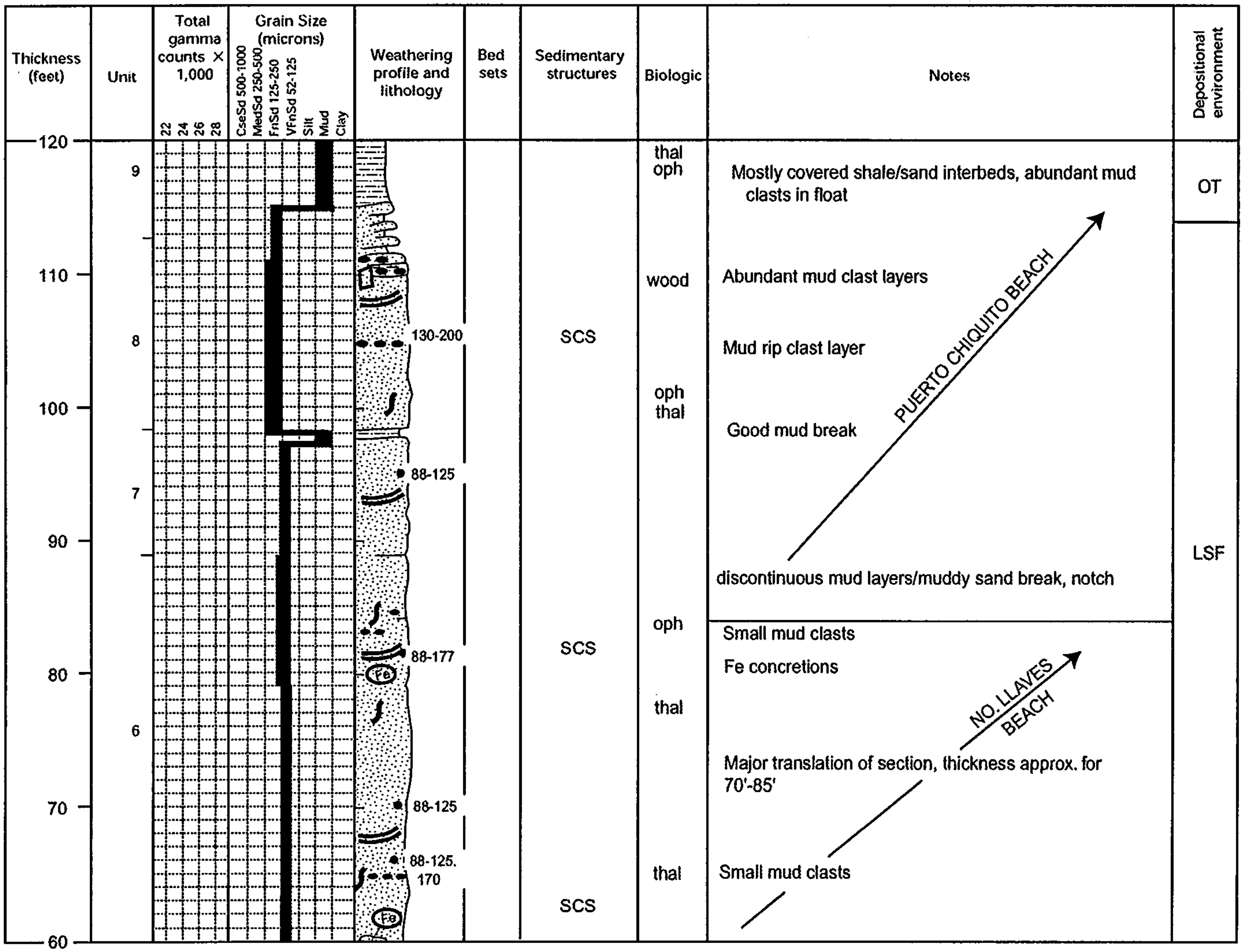
Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W Page 5



Measured Section 4: Apache Mesa South. Measured by RWD, KO, AM 36 37'9" N, 106 48'46" W Page 6



Measured Section 5: Apache Mesa North. Measured by MK-J, SV 36 39'29" N, 106 49'13" W Page 1



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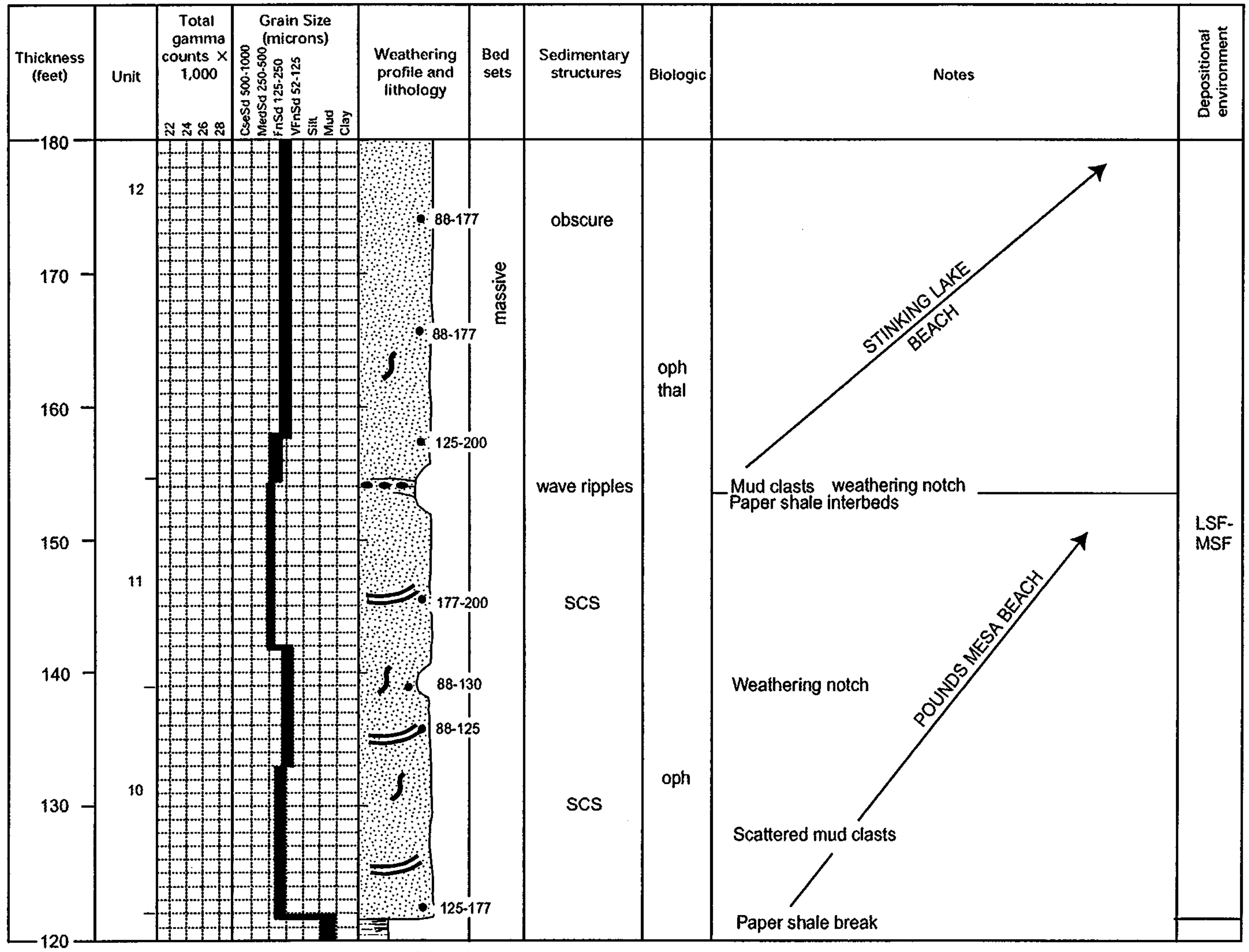

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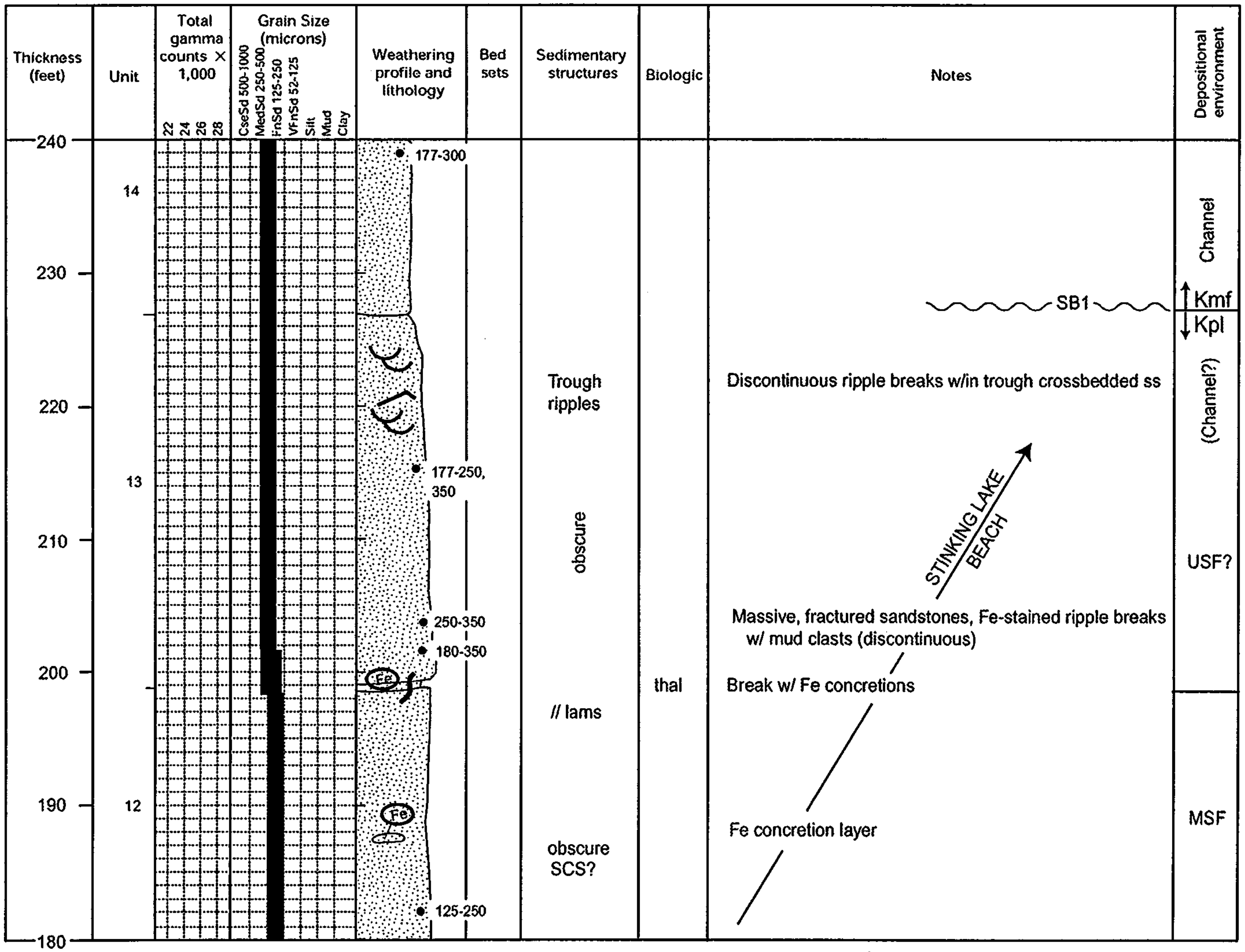

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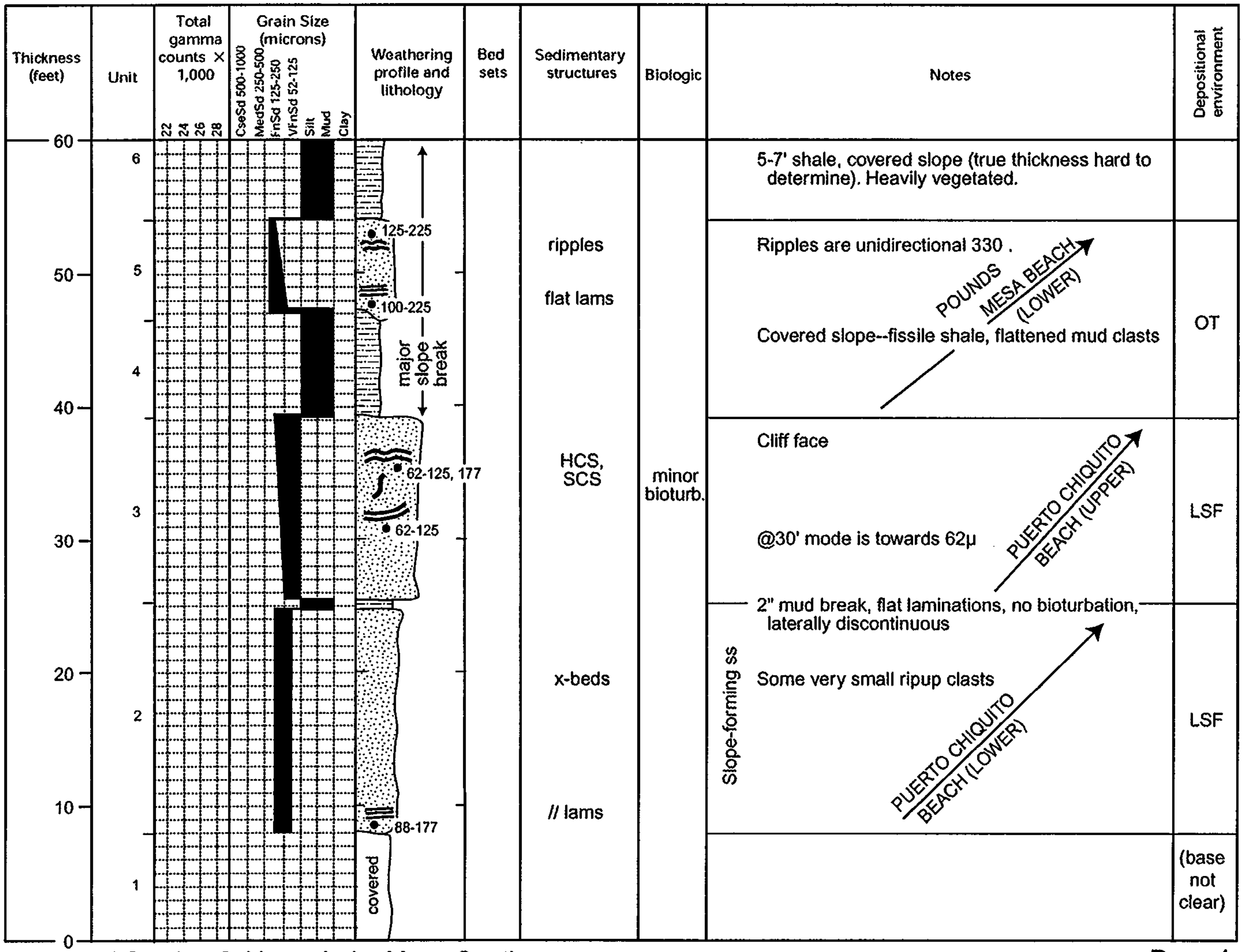
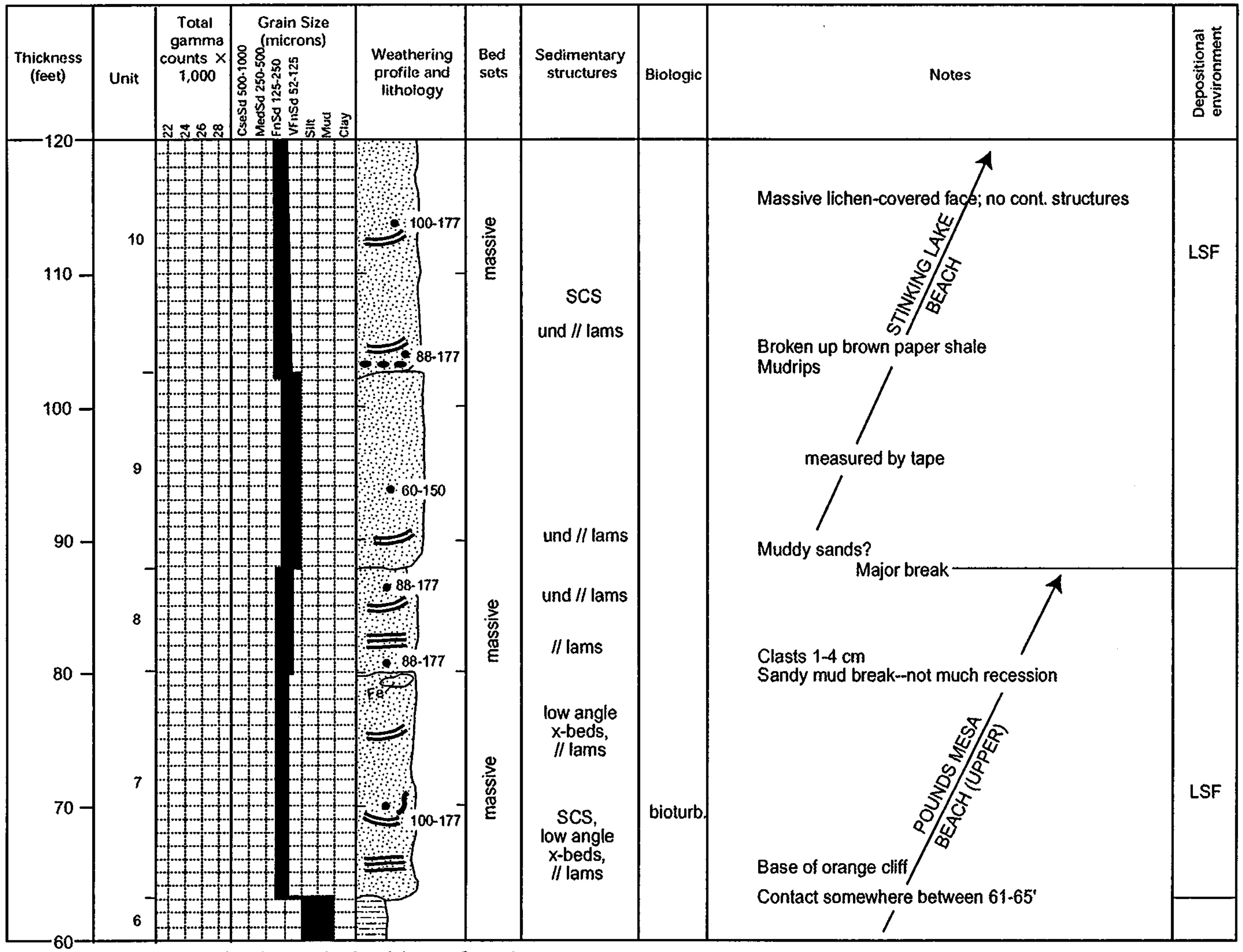
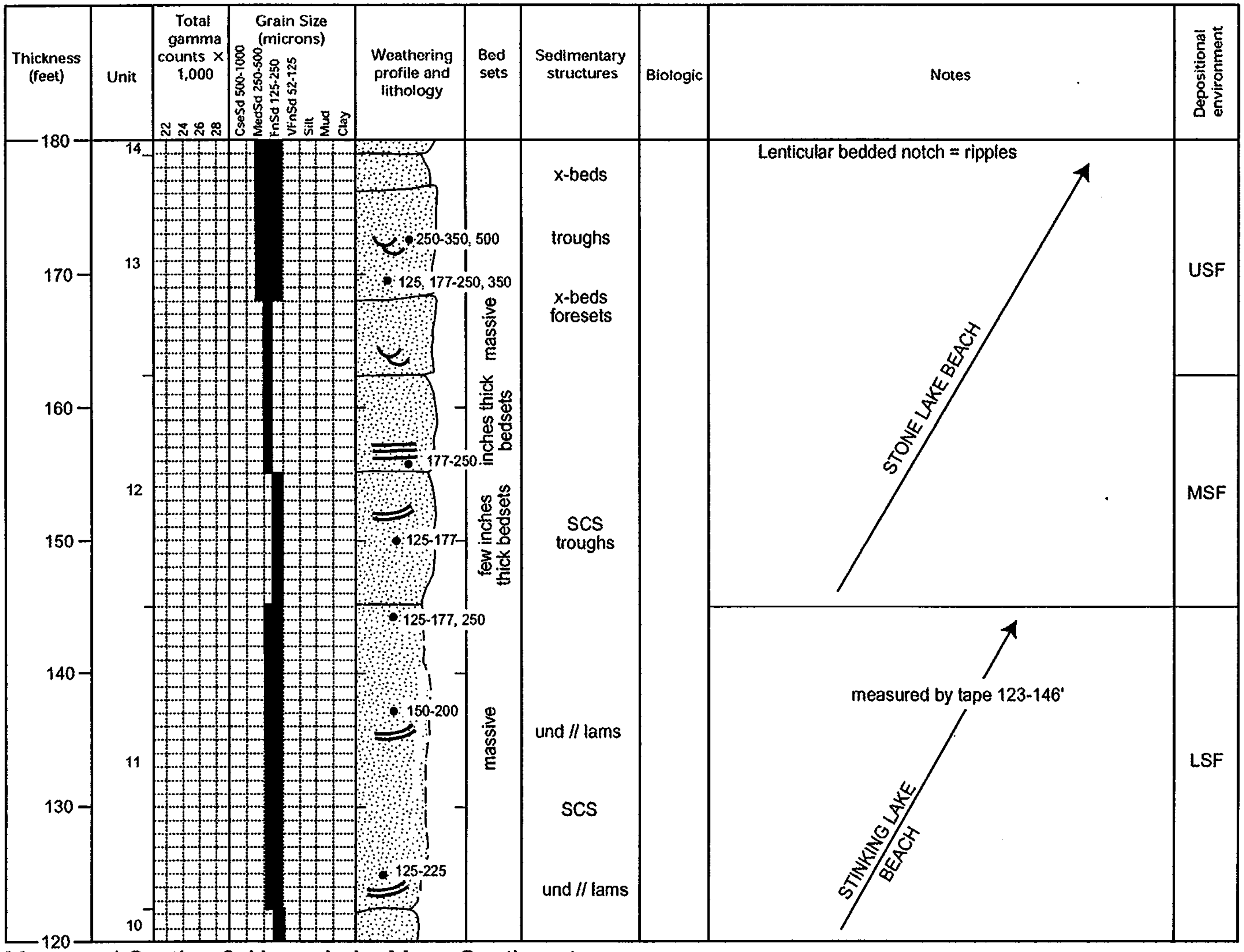


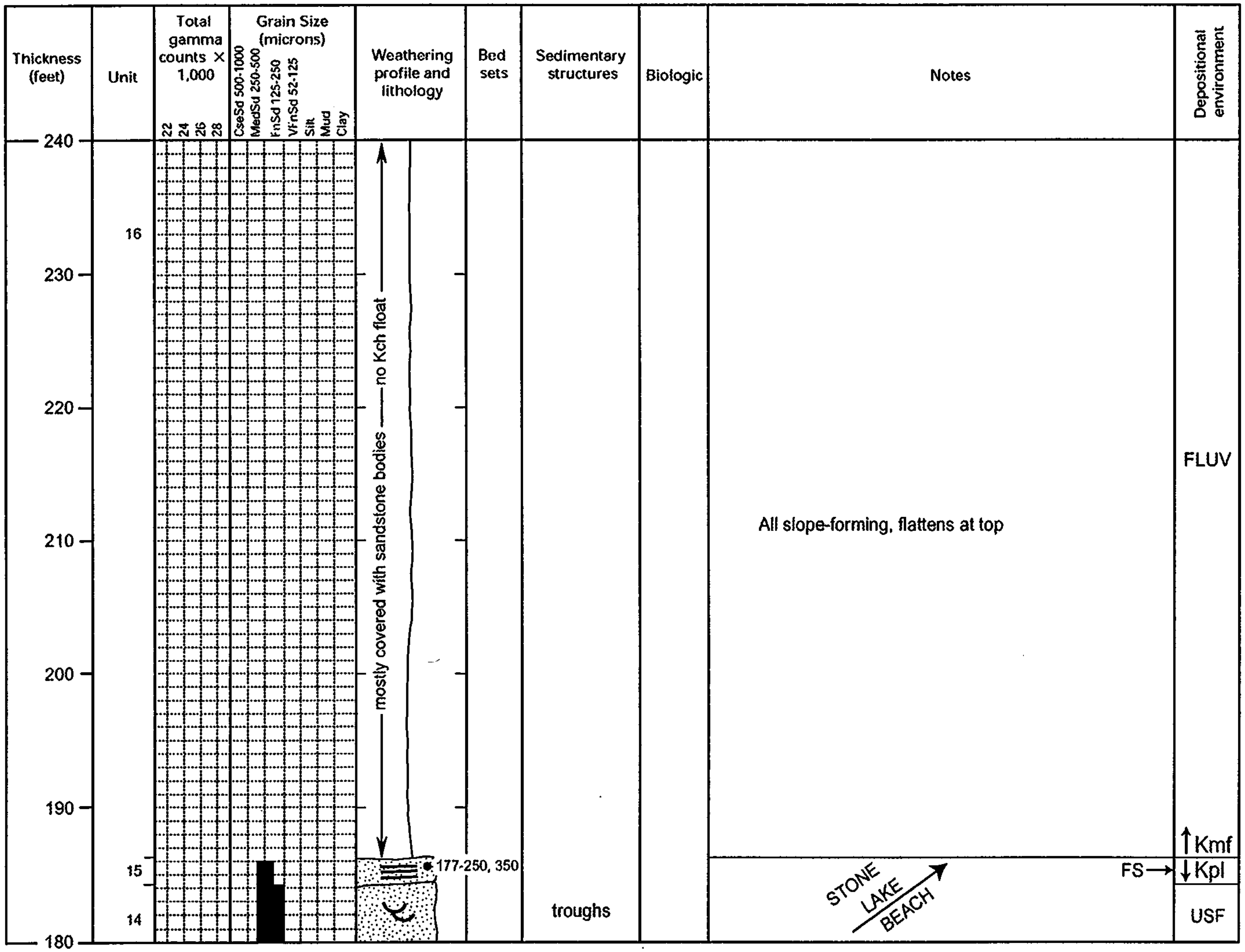
Measured Section 6: Horse Lake Mesa Southeast. Measured by DB, AM 36 42'43" N, 106 50'18" W Page 1



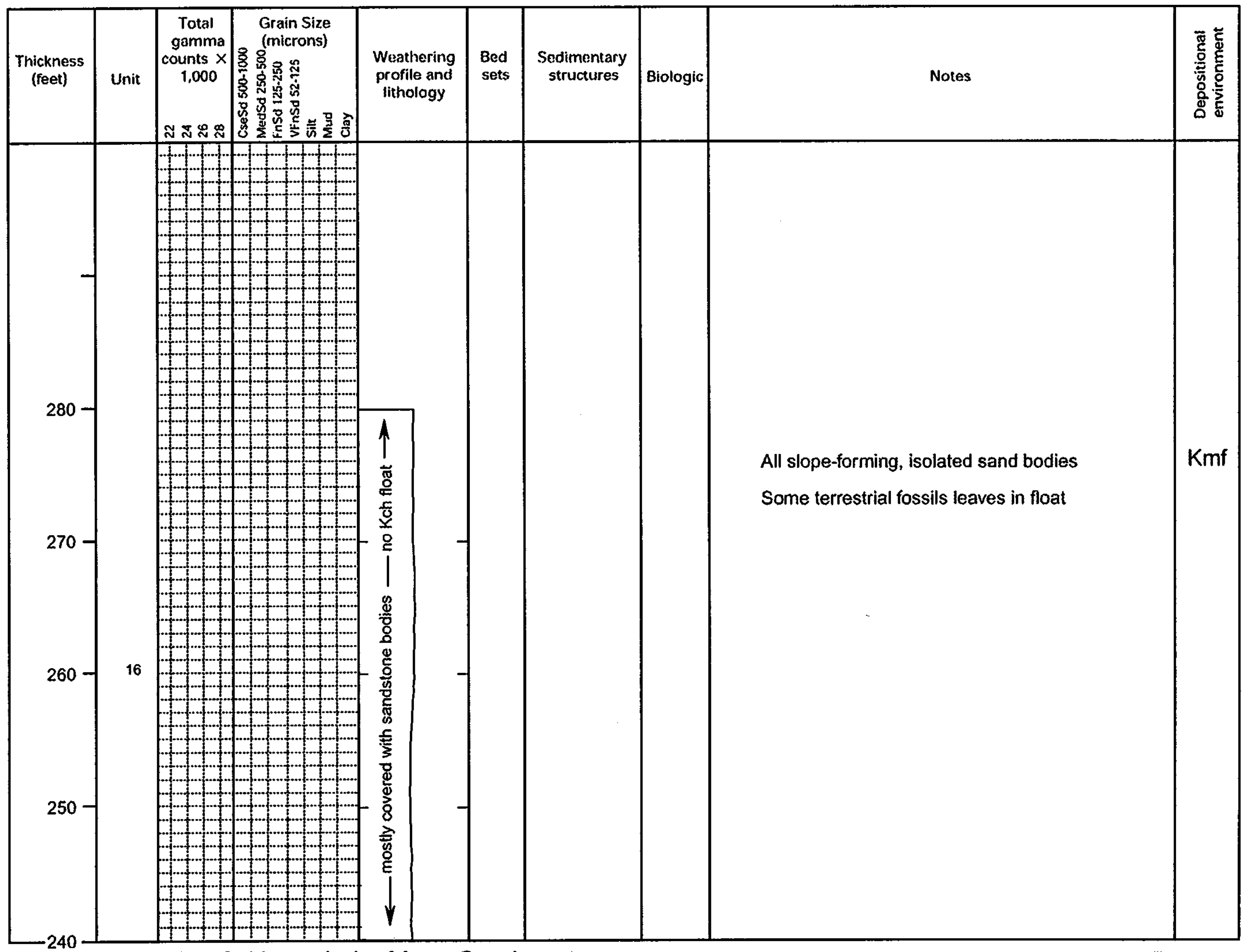
Measured Section 6: Horse Lake Mesa Southeast. Measured by DB, AM 36 42'43" N, 106 50'18" W Page 2



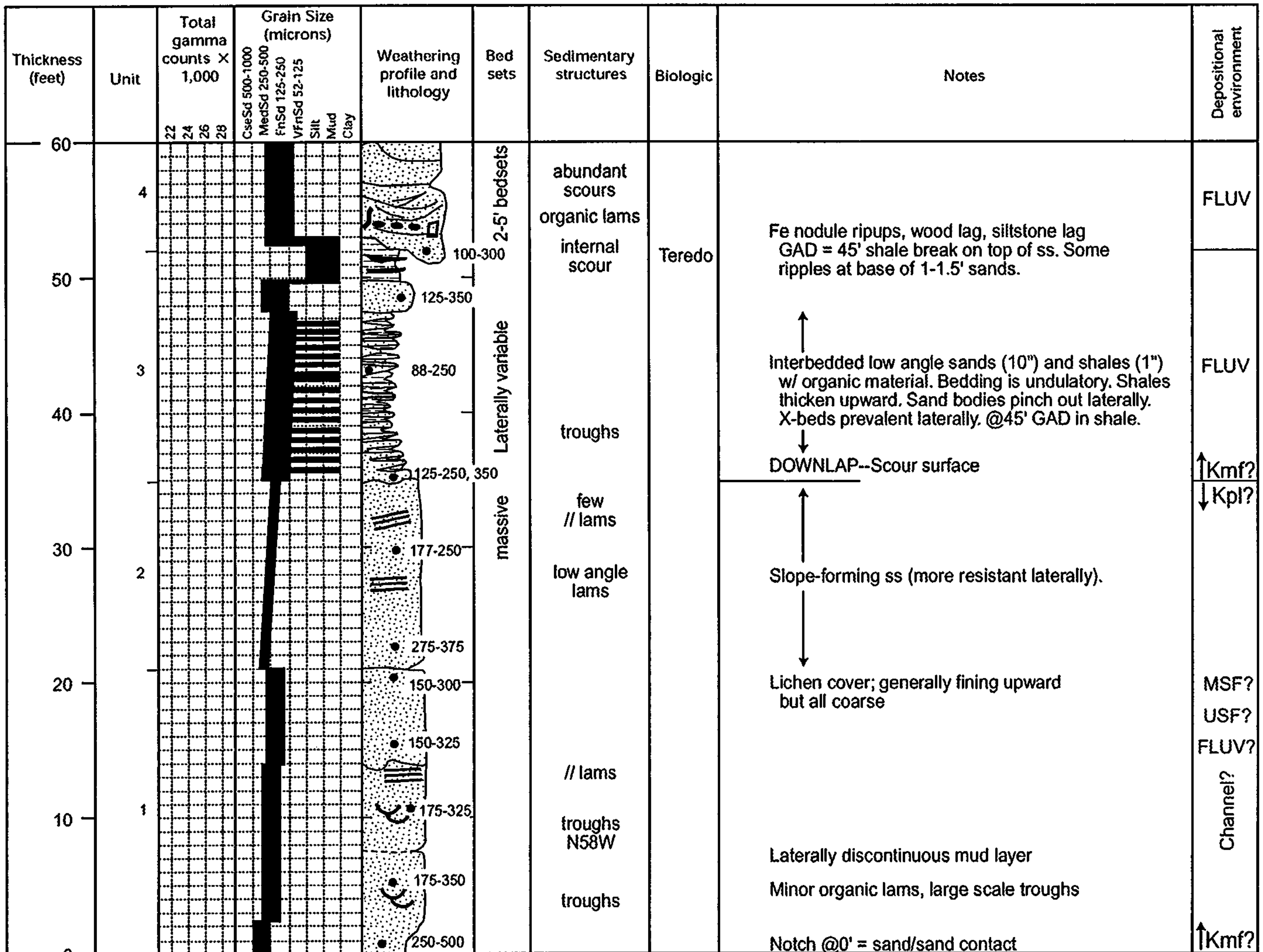
Measured Section 6: Horse Lake Mesa Southeast. Measured by DB, AM 36 42'43" N, 106 50'18" W Page 3



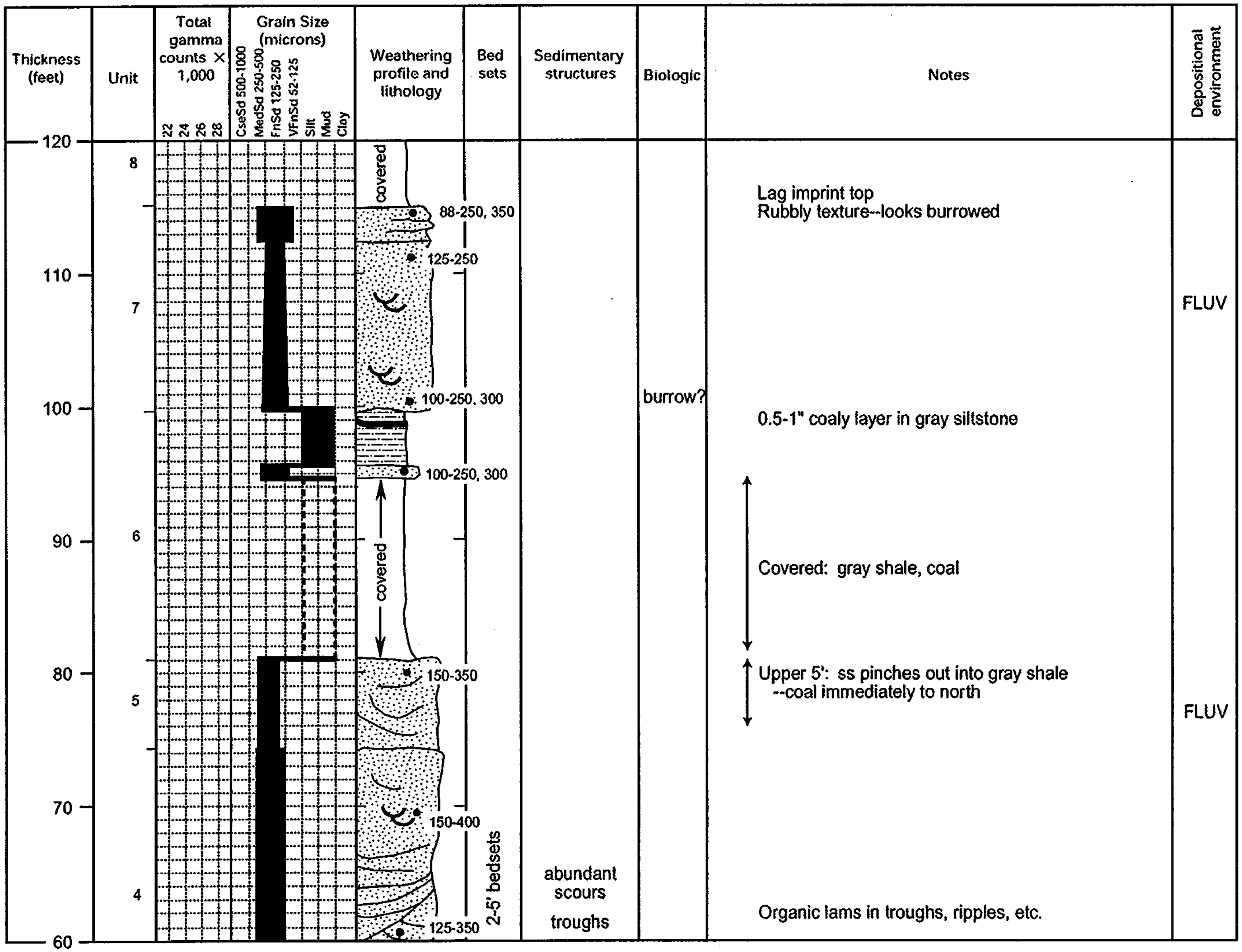
Measured Section 6: Horse Lake Mesa Southeast. Measured by DB, AM 36 42'43" N, 106 50'18" W Page 4



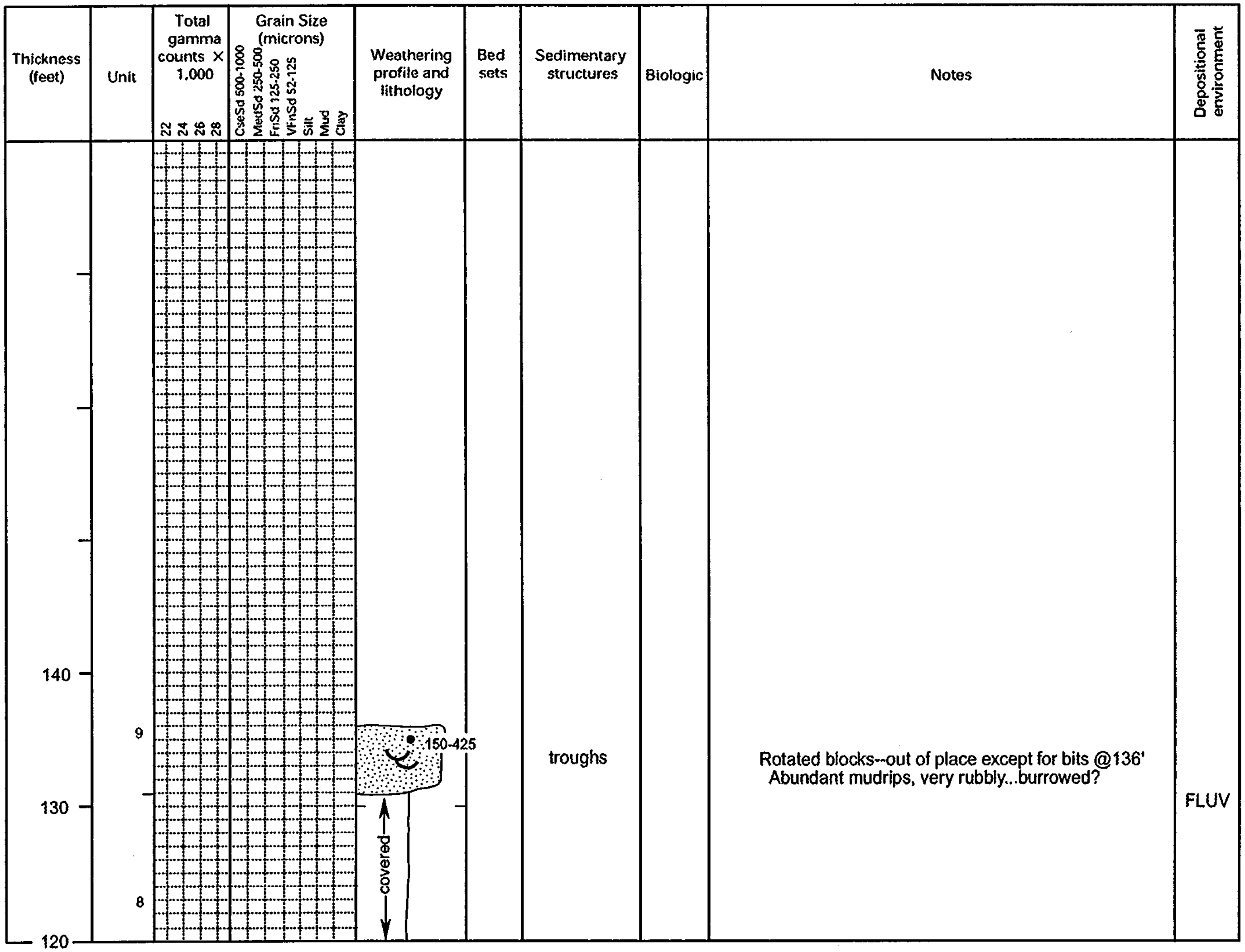
Measured Section 6: Horse Lake Mesa Southeast. Measured by DB, AM 36 42'43" N, 106 50'18" W Page 5



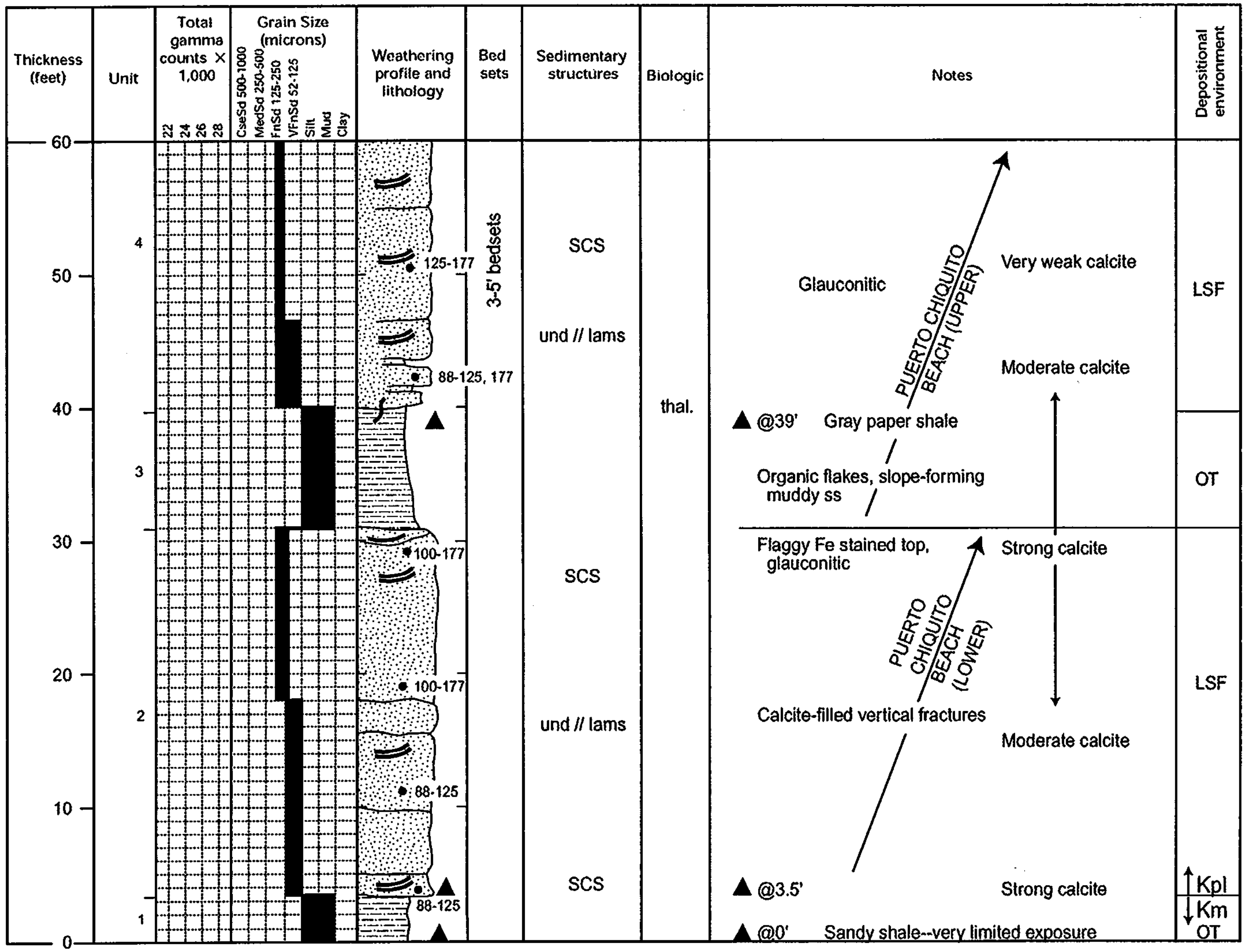
Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W Page 1



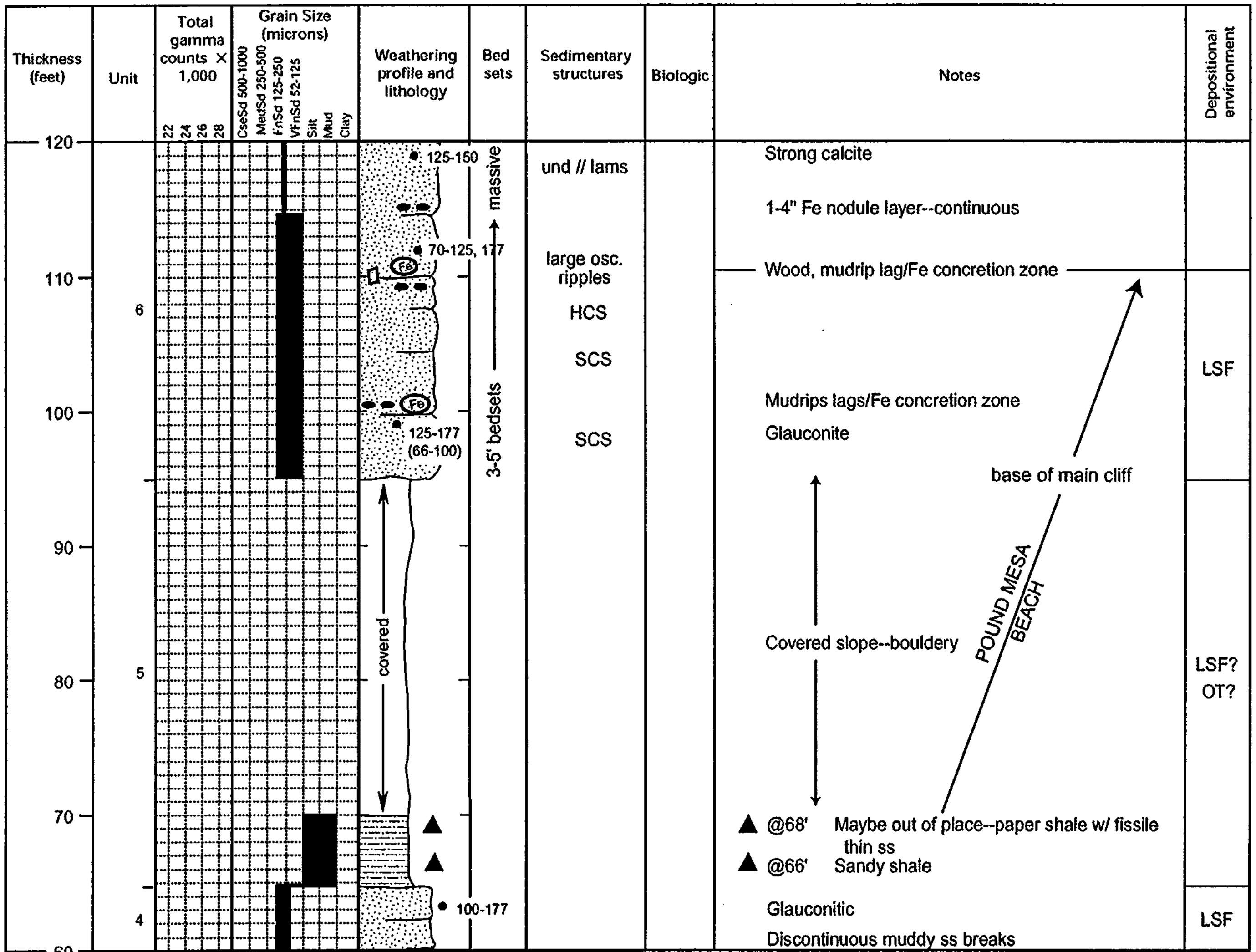
Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W Page 2



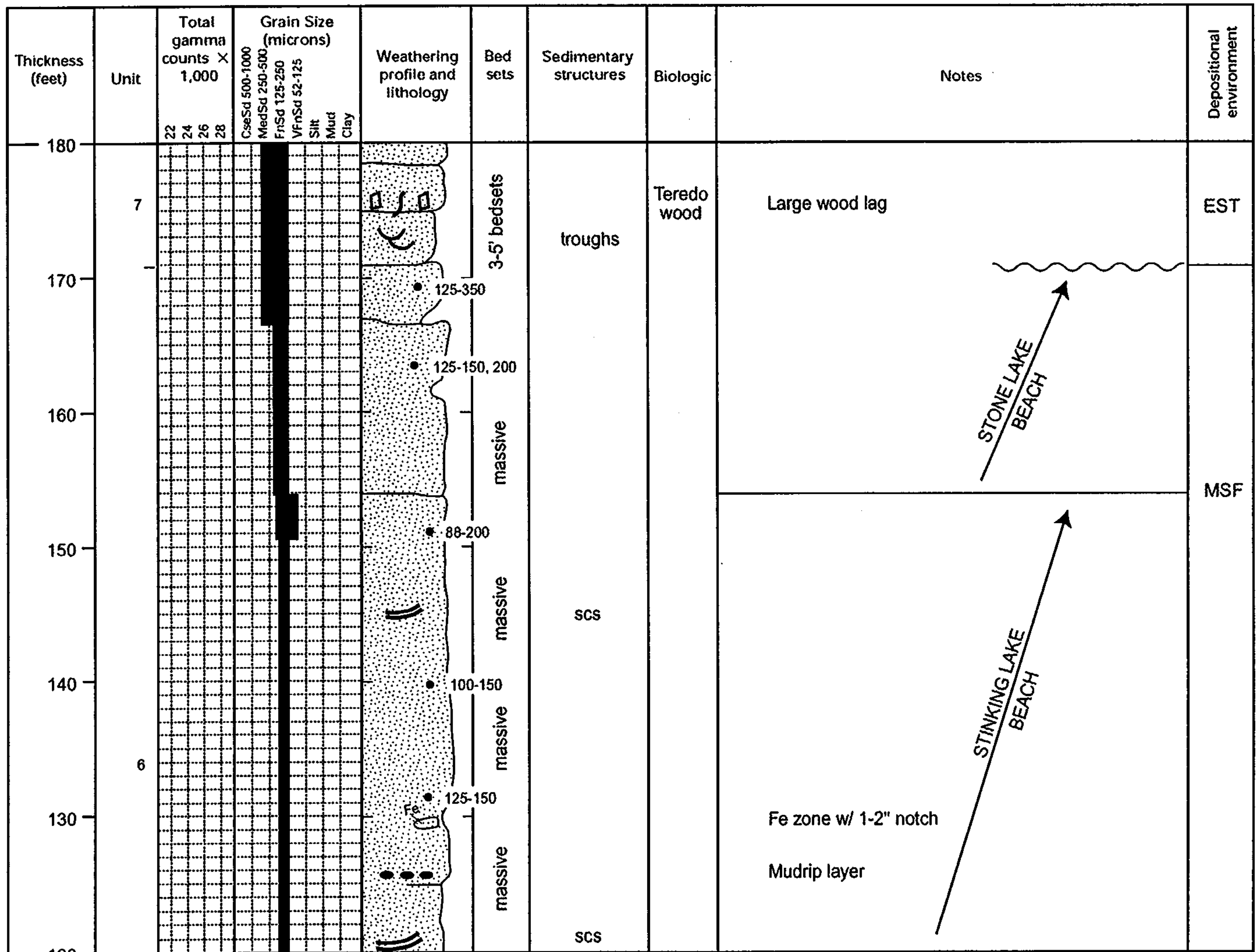
Measured Section 7: Horse Lake Mesa NE. Measured by RWD, KO, DB, AM 36 43'29" N, 106 49'39" W Page 3



Measured Section 8: Horse Lake Mesa North. Measured by RWD, MK-J, KO 36 46'39" N, 106 49'43" W Page 1



Measured Section 8: Horse Lake Mesa North. Measured by RWD, MK-J, KO 36 46'39" N, 106 49'43" W Page 2



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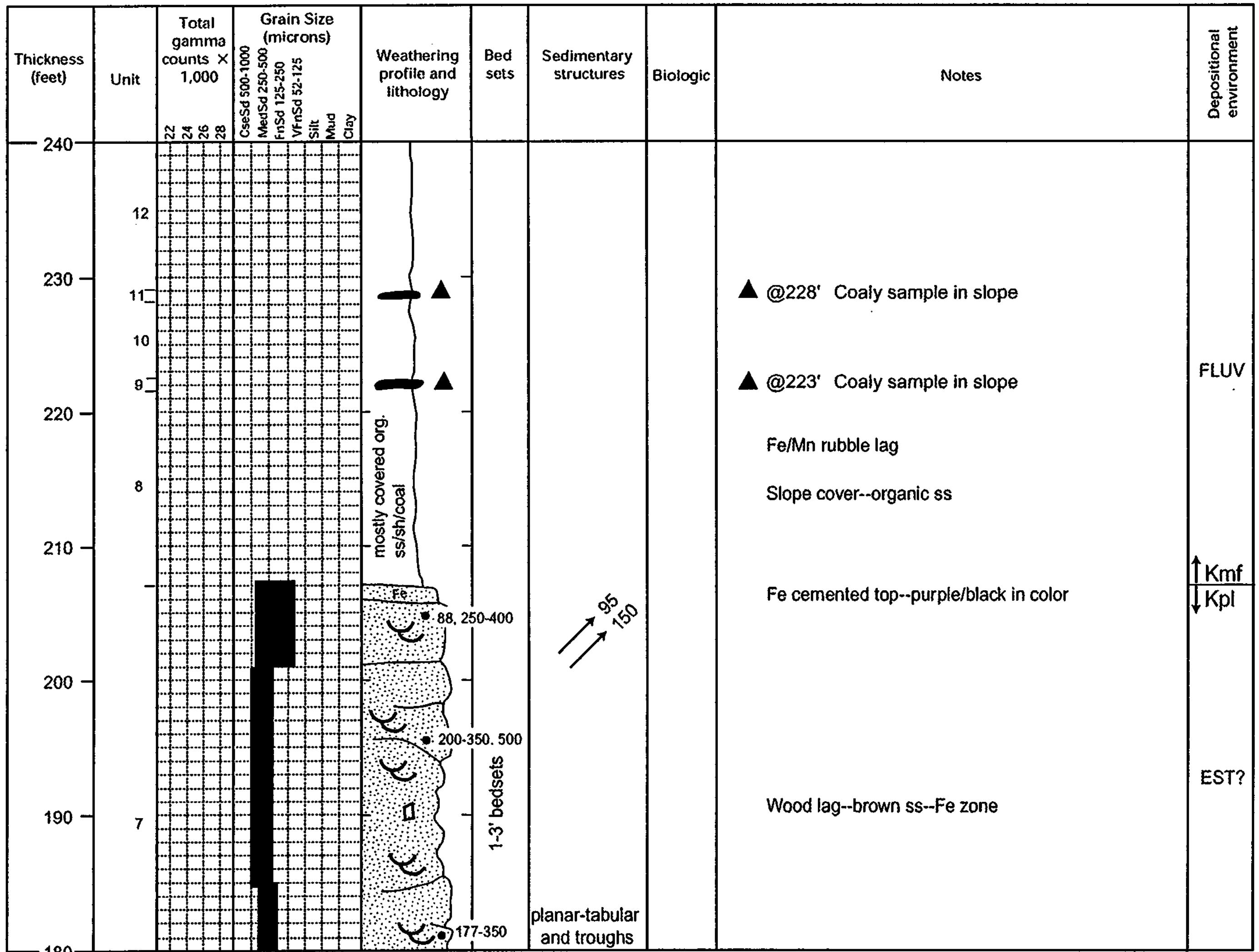
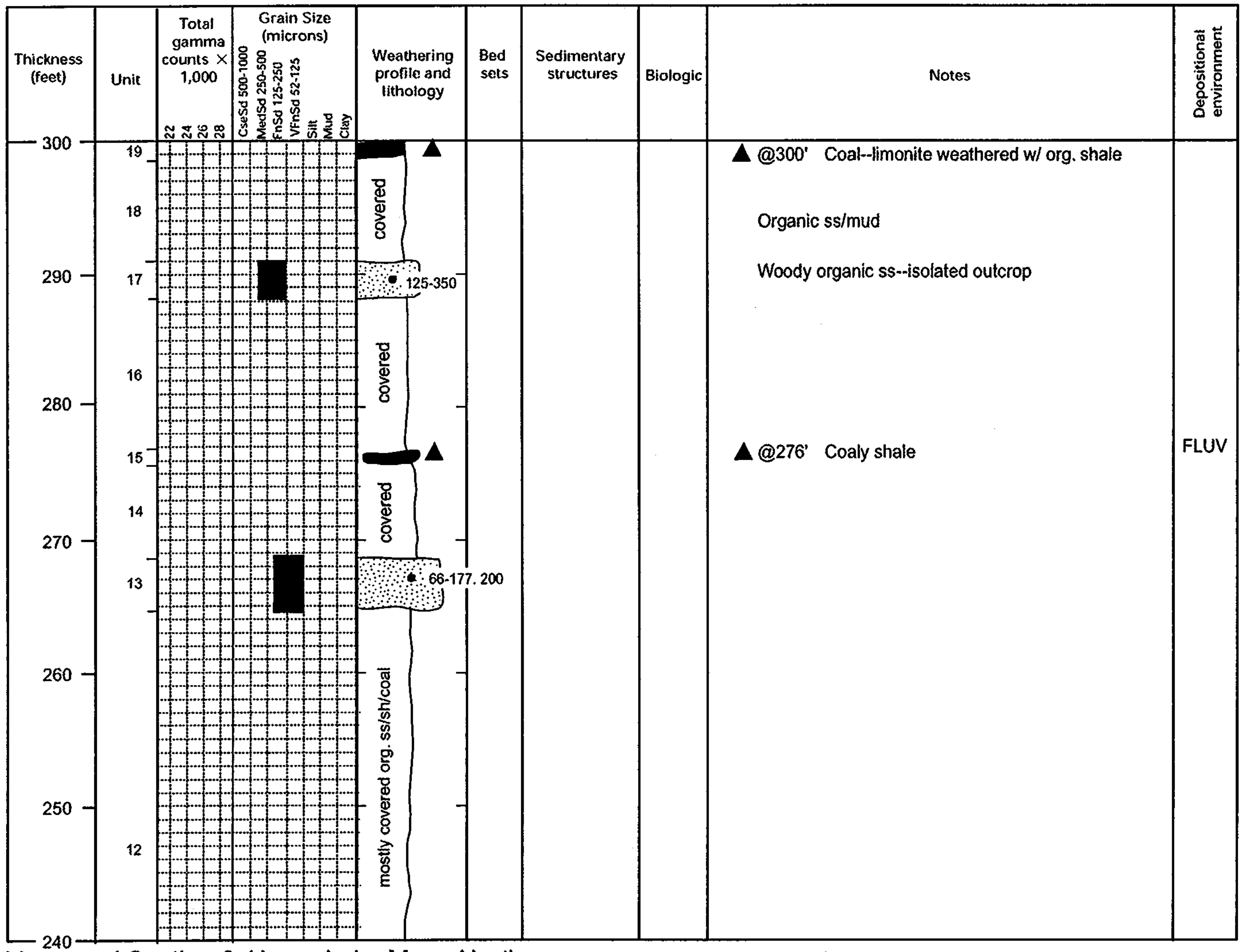


Measured Section 8: Horse Lake Mesa North. Measured by RWD, MK-J, KO 36 46'39" N, 106 49'43" W Page 4



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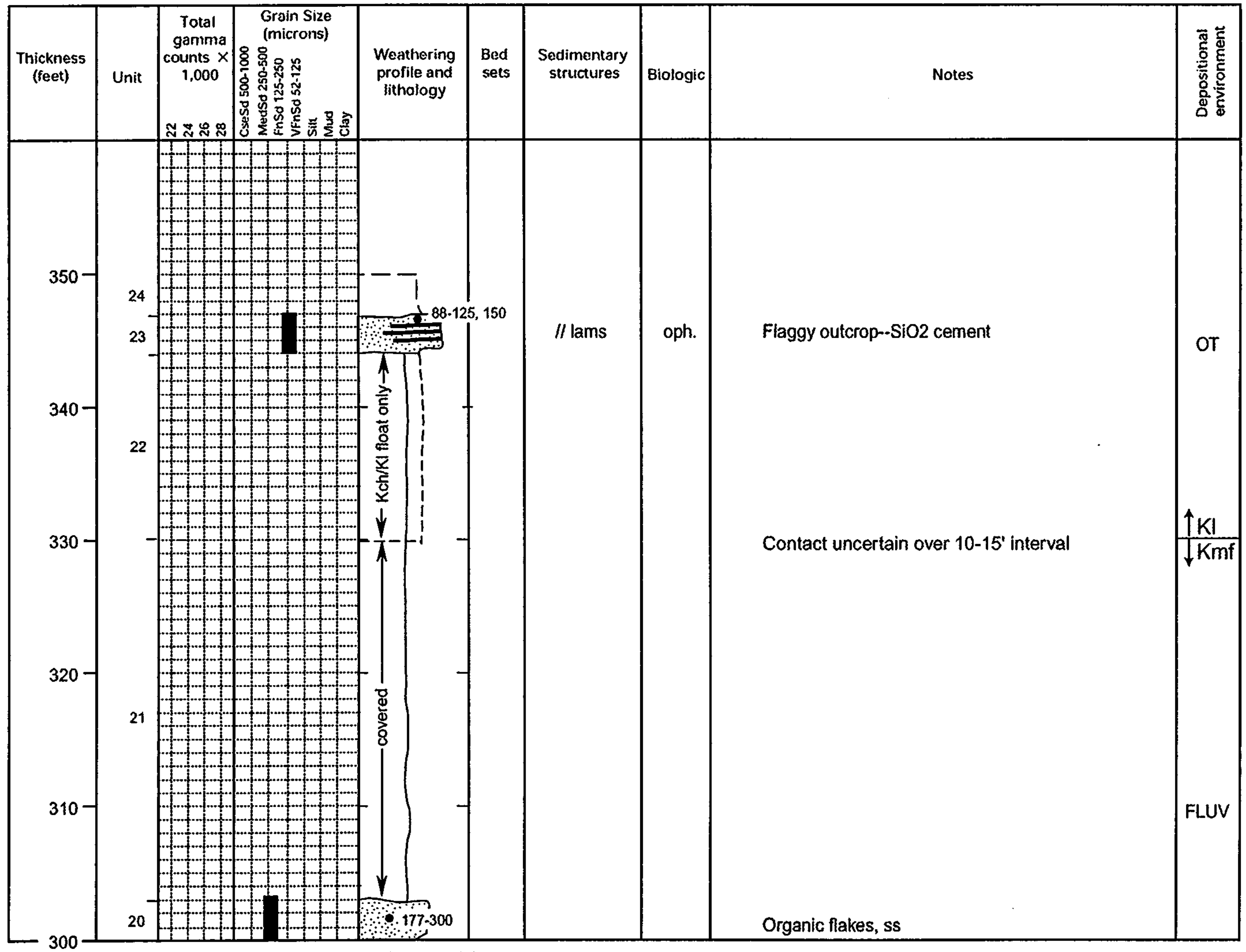
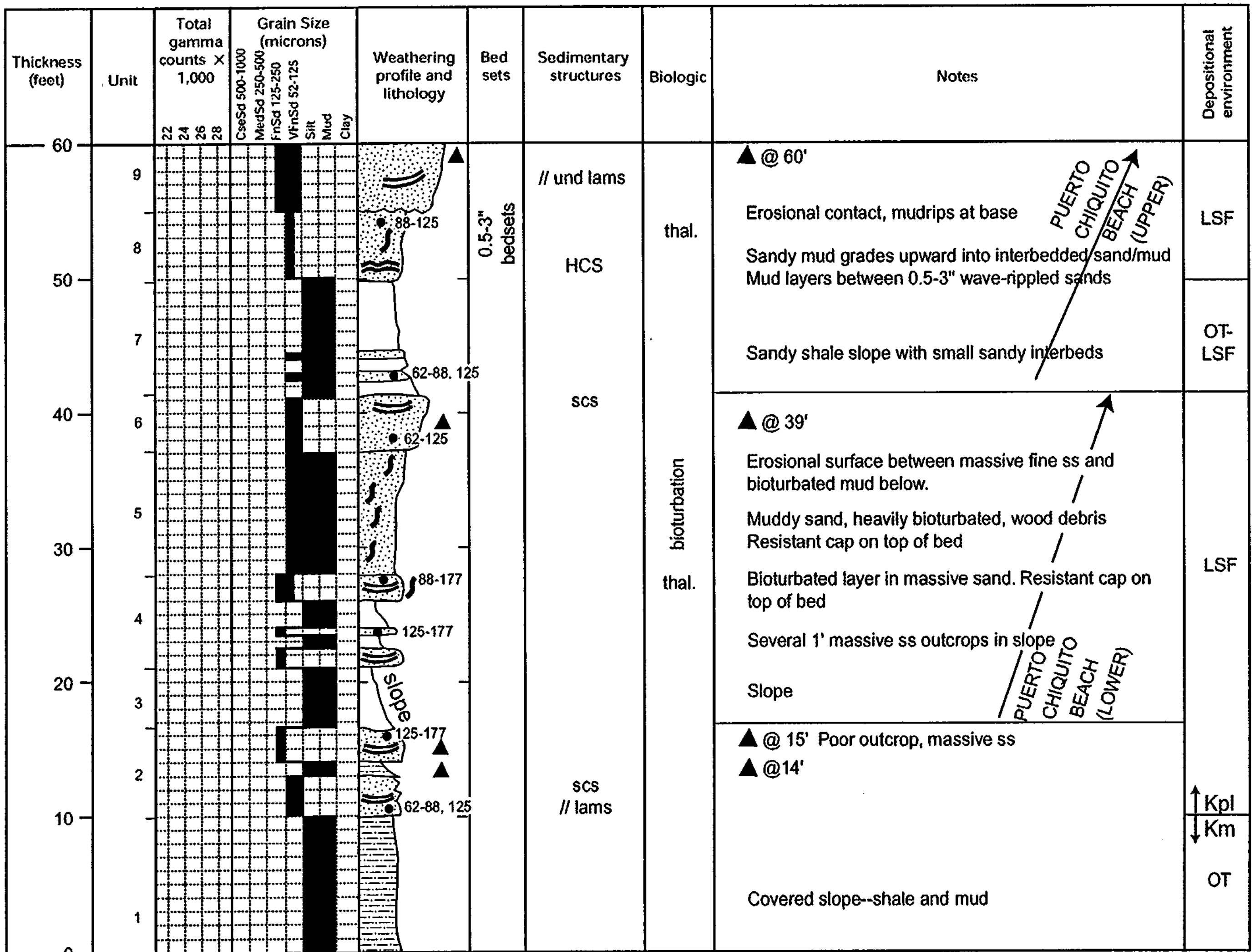
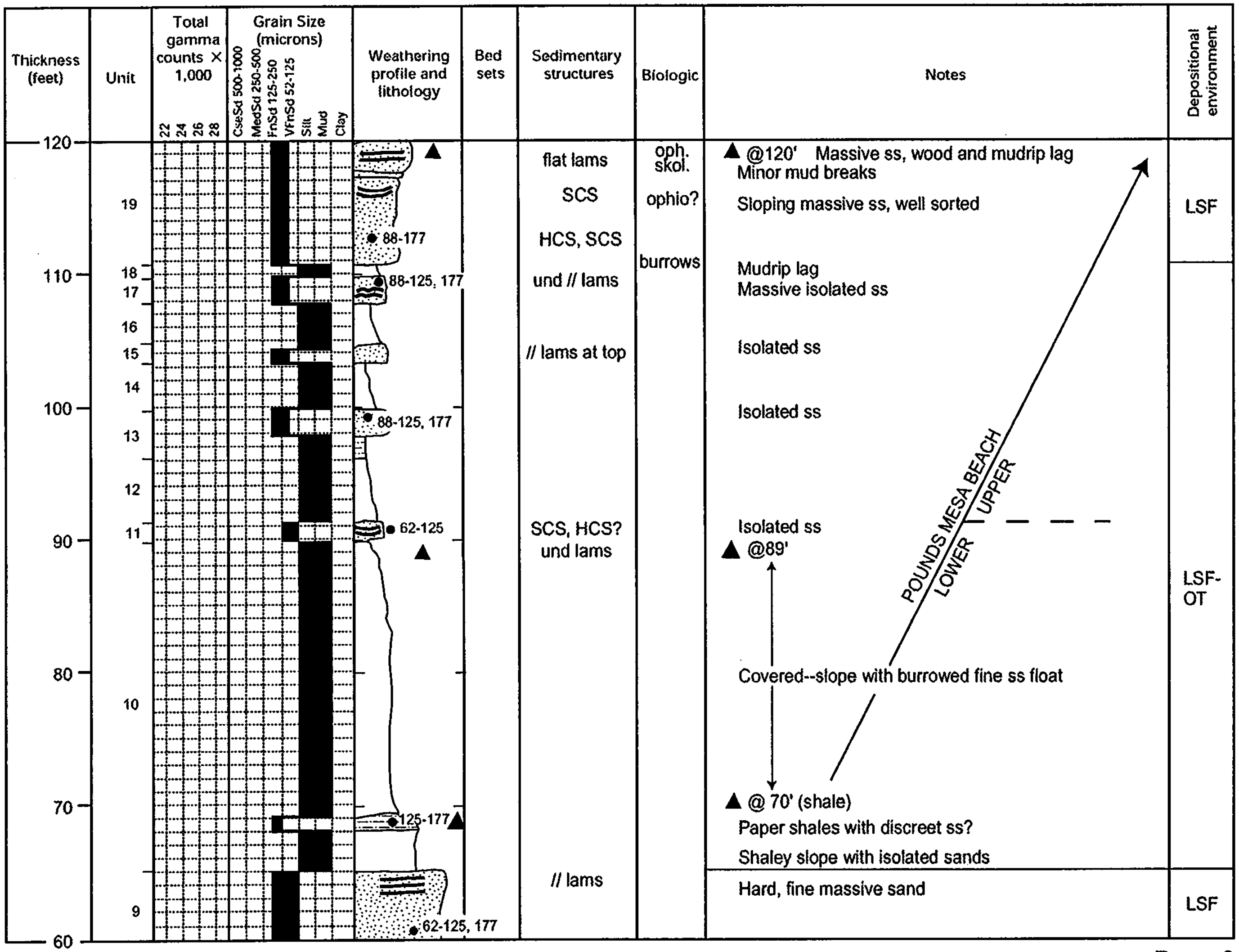


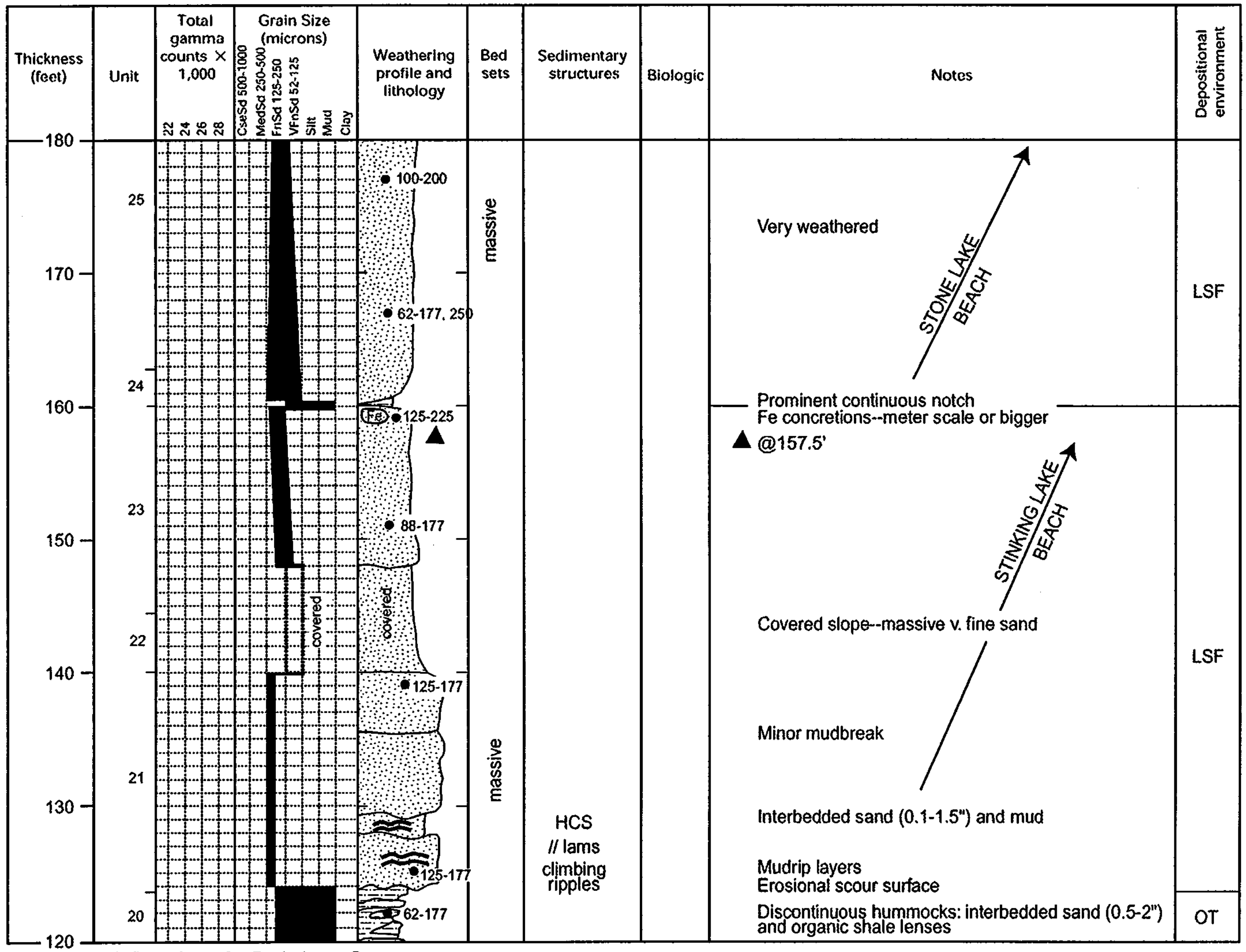
Measured Section 8: Horse Lake Mesa North. Measured by RWD, MJ-K, KO 36 46'39" N, 106 49'43" W Page 6



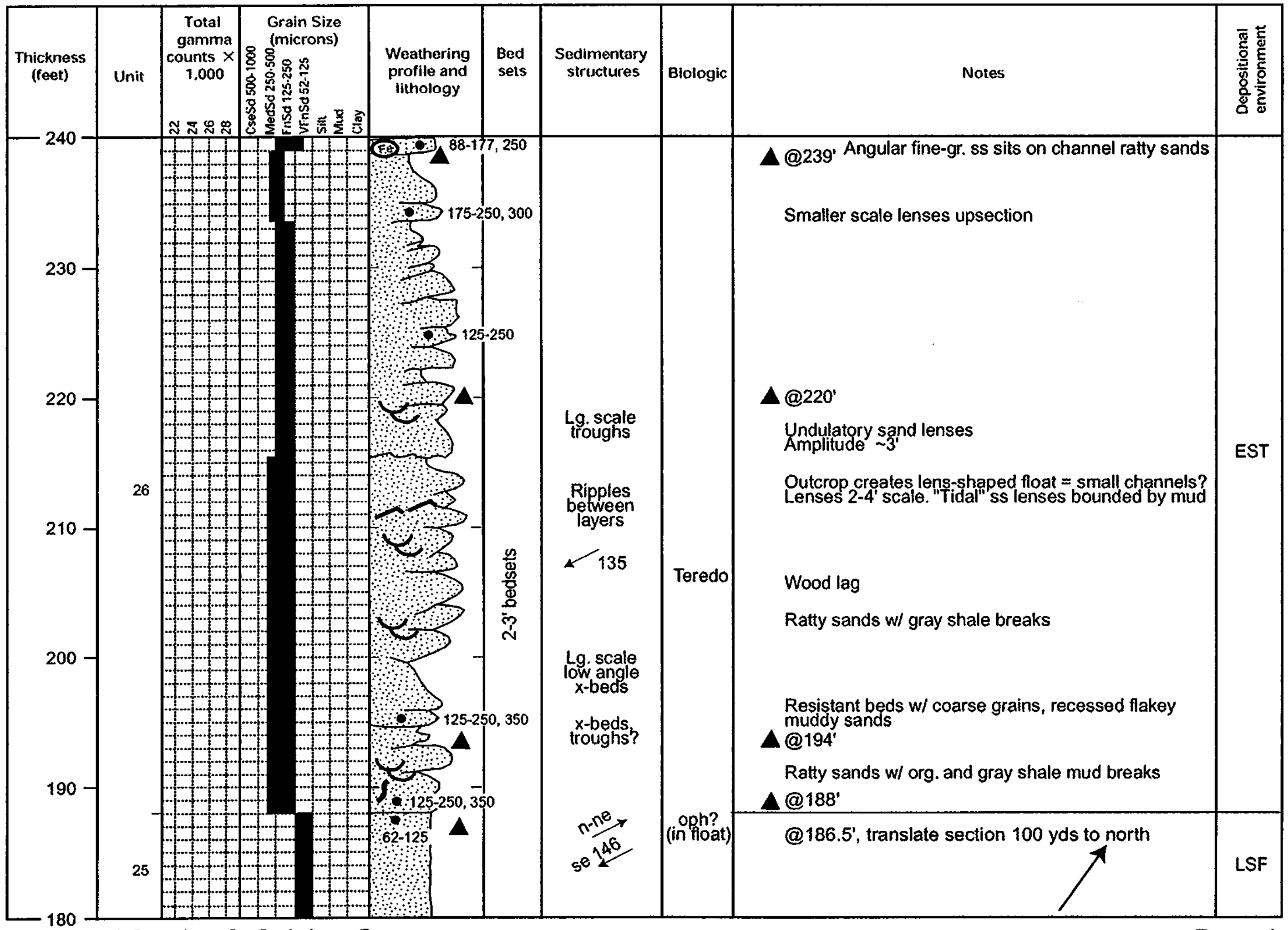
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 1



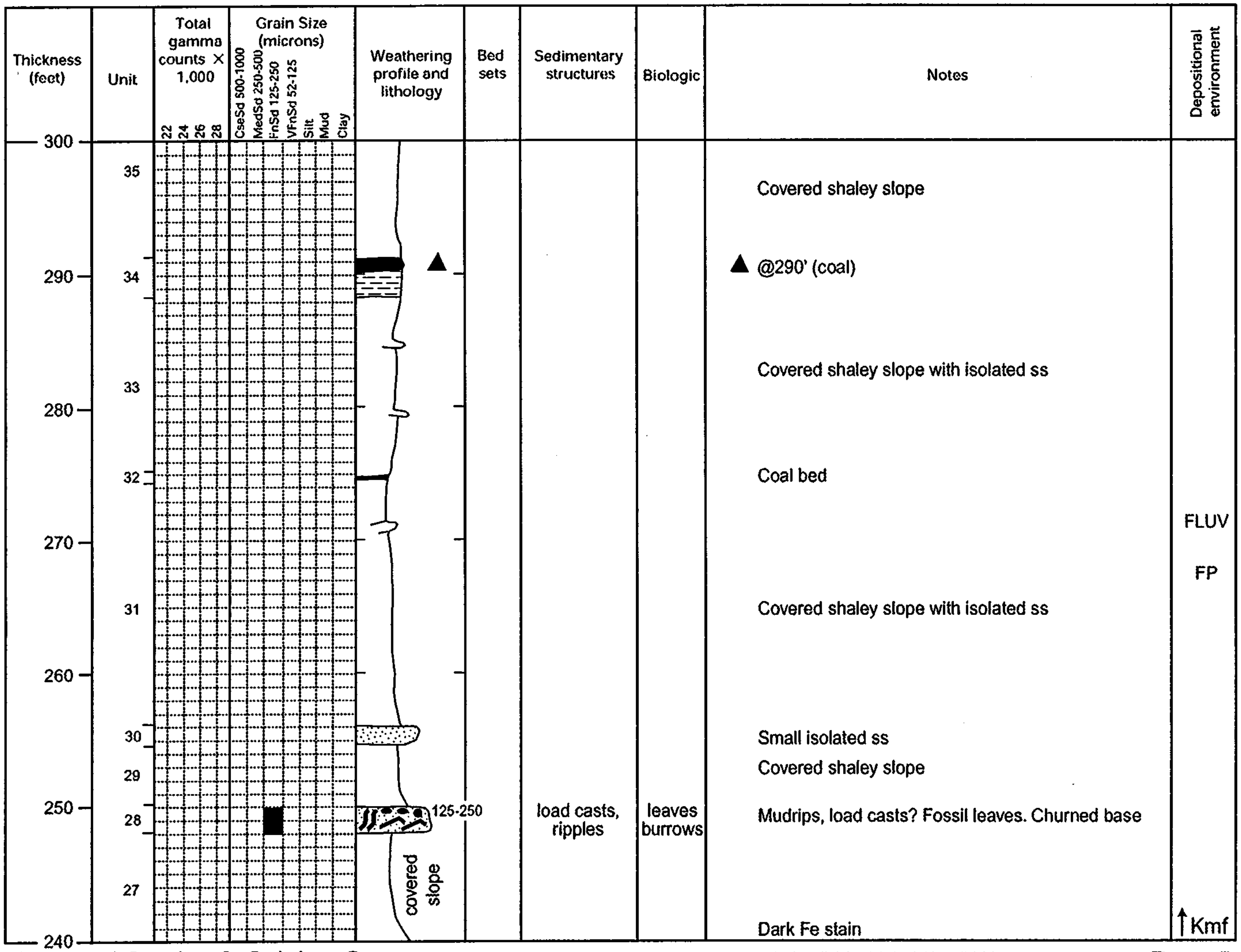
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 2



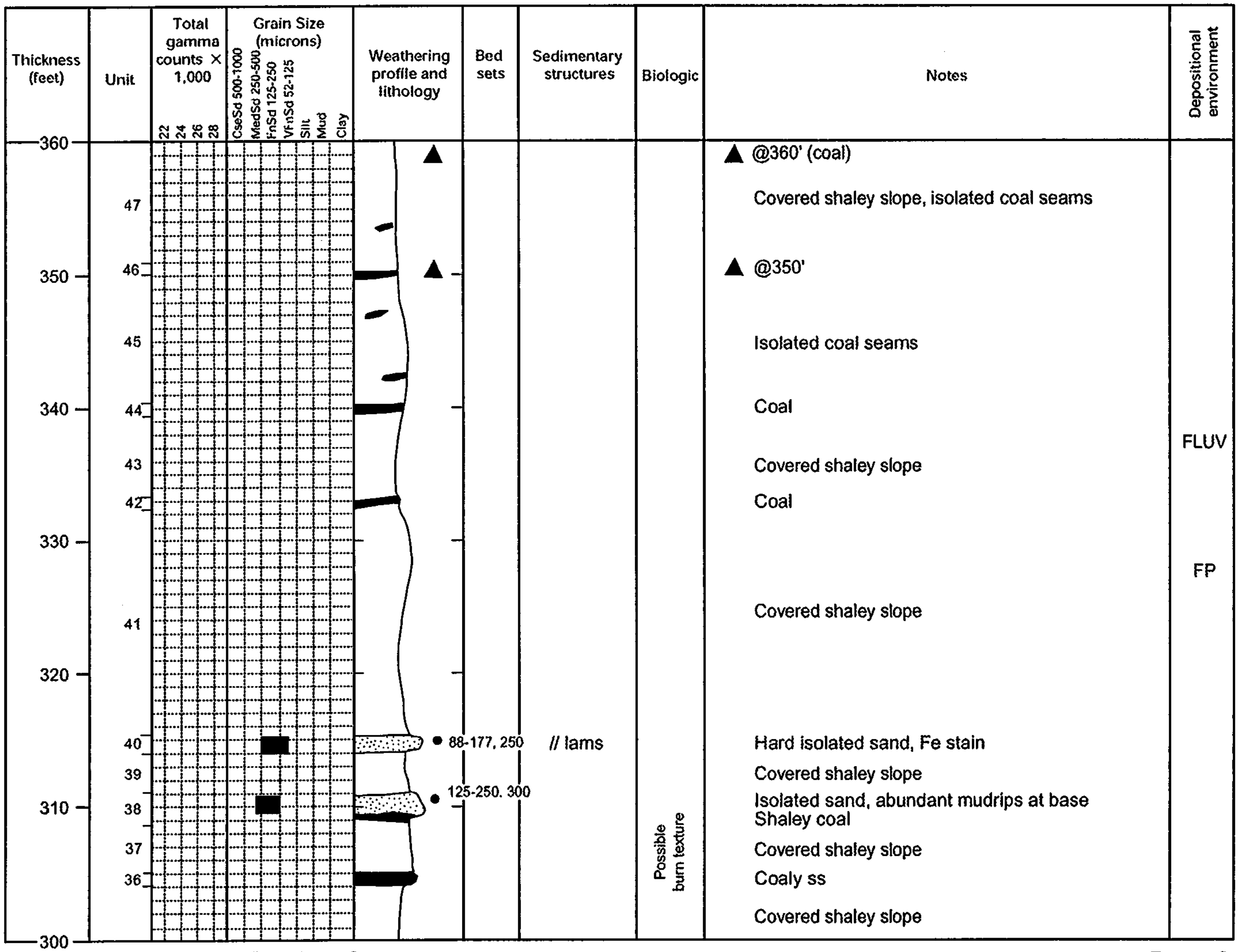
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 3



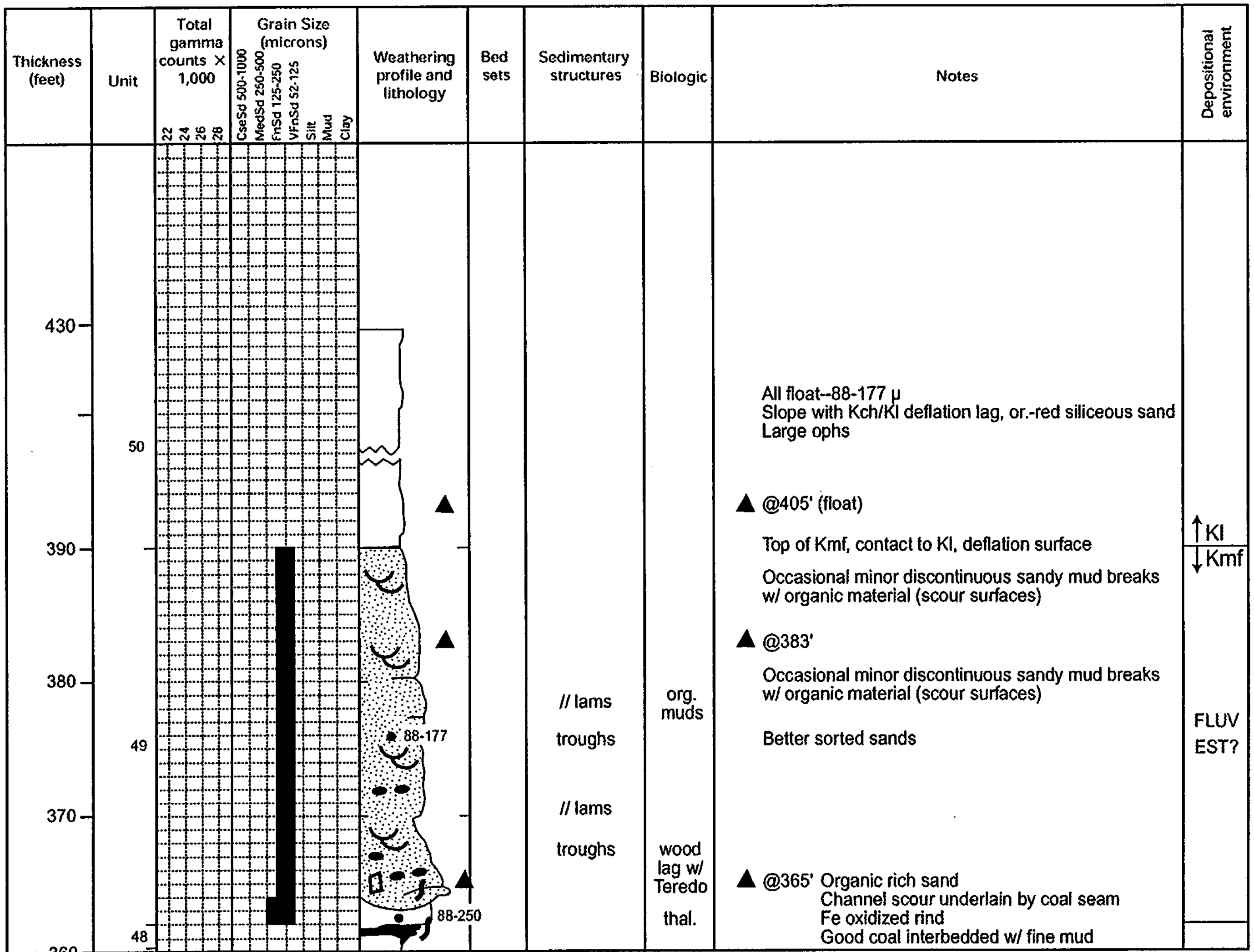
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 4



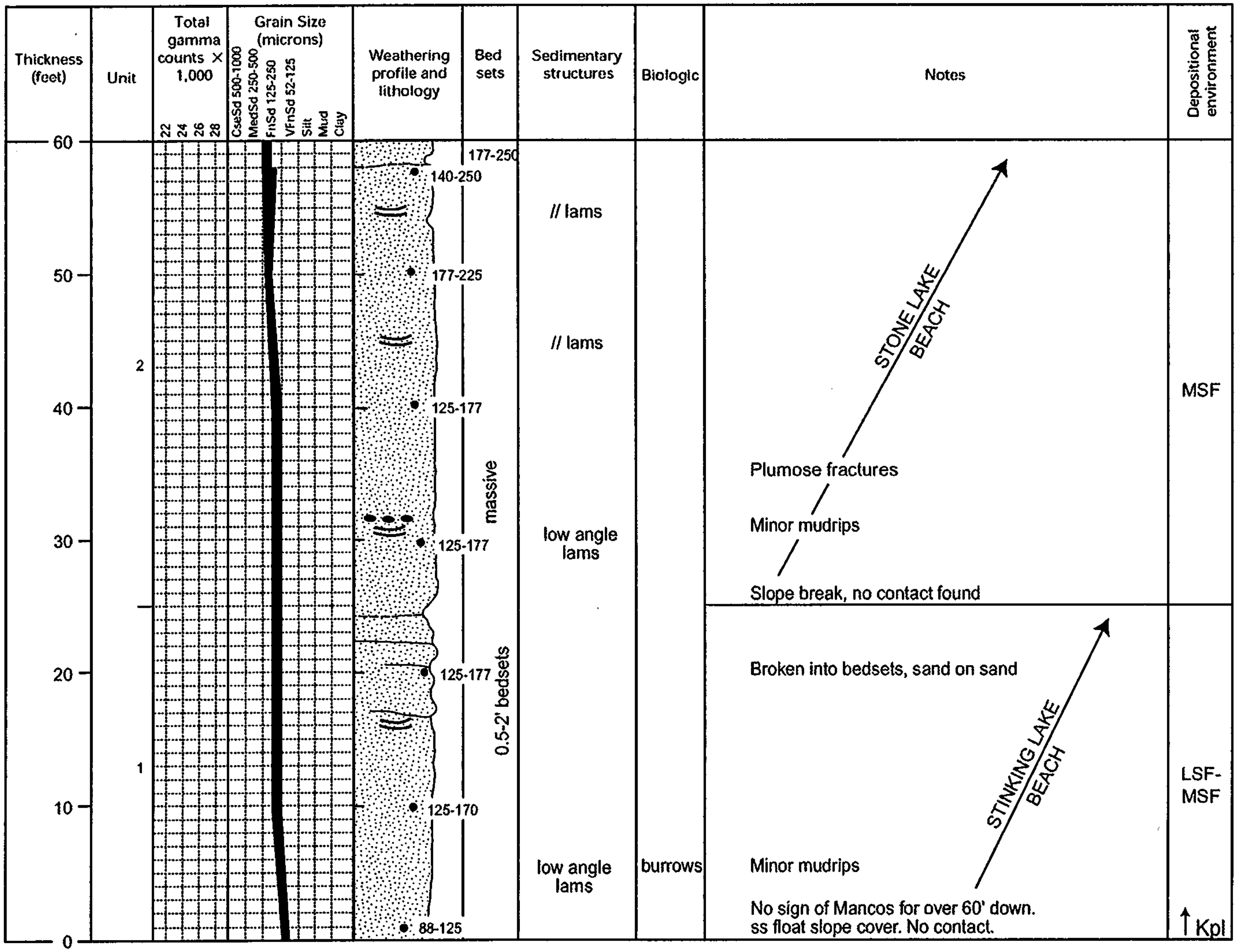
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 5



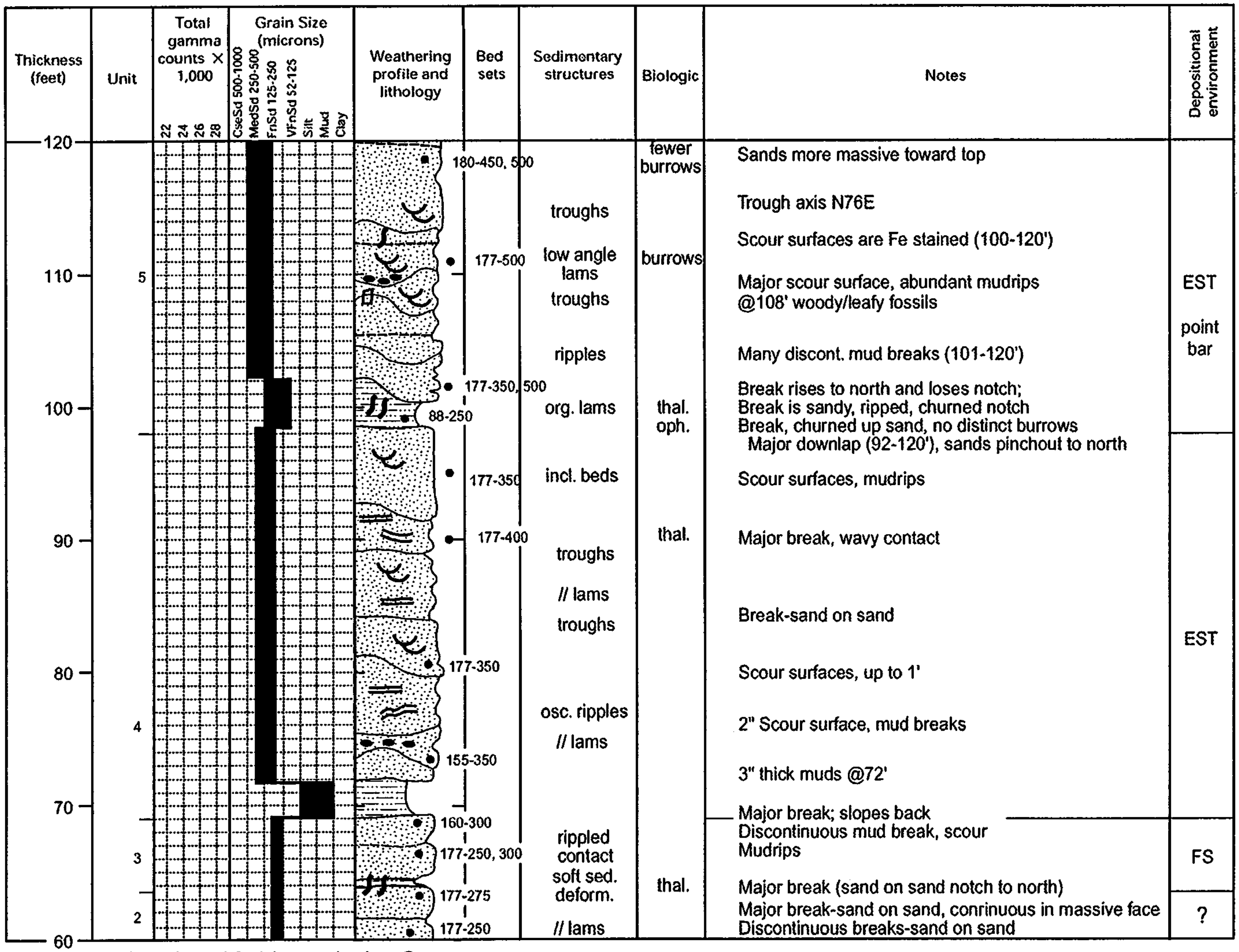
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 6



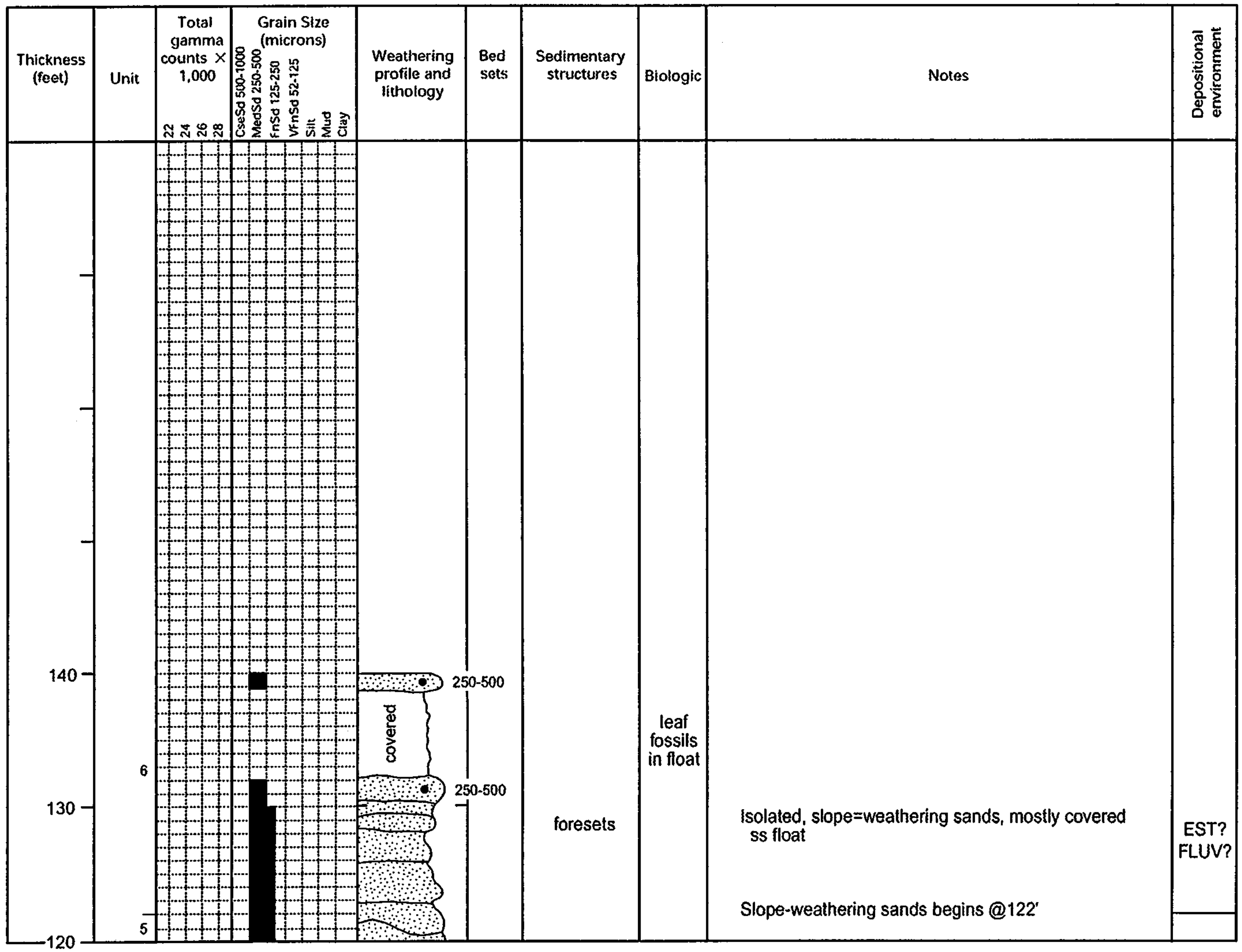
Measured Section 9: Sulphur Canyon. Measured by RWD, MKJ 36 47'32" N, 106 46'26" W Page 7



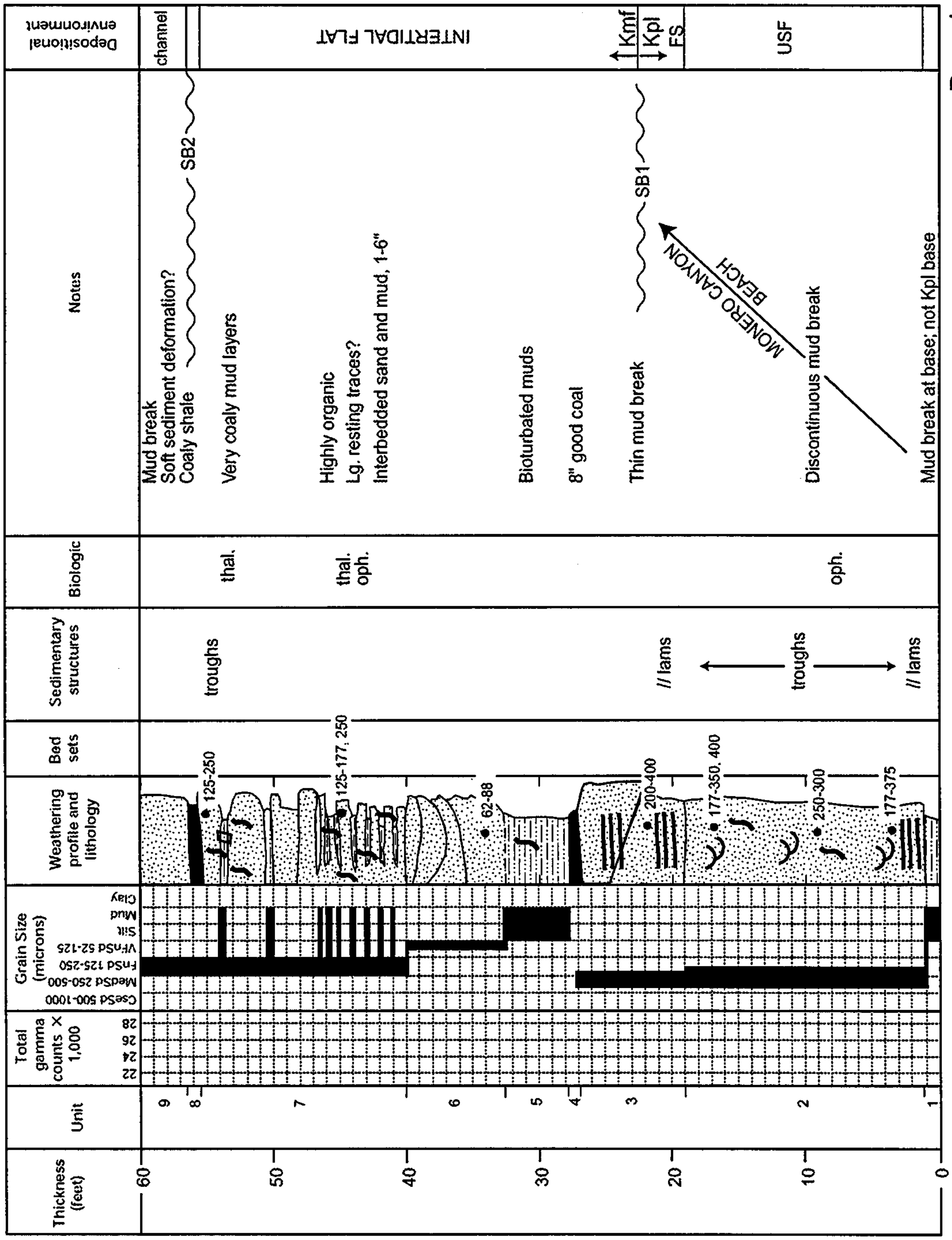
Measured Section 10: Horse Lake Gap. Measured by KO, SV 36 51'13" N, 106 46'29" W Page 1



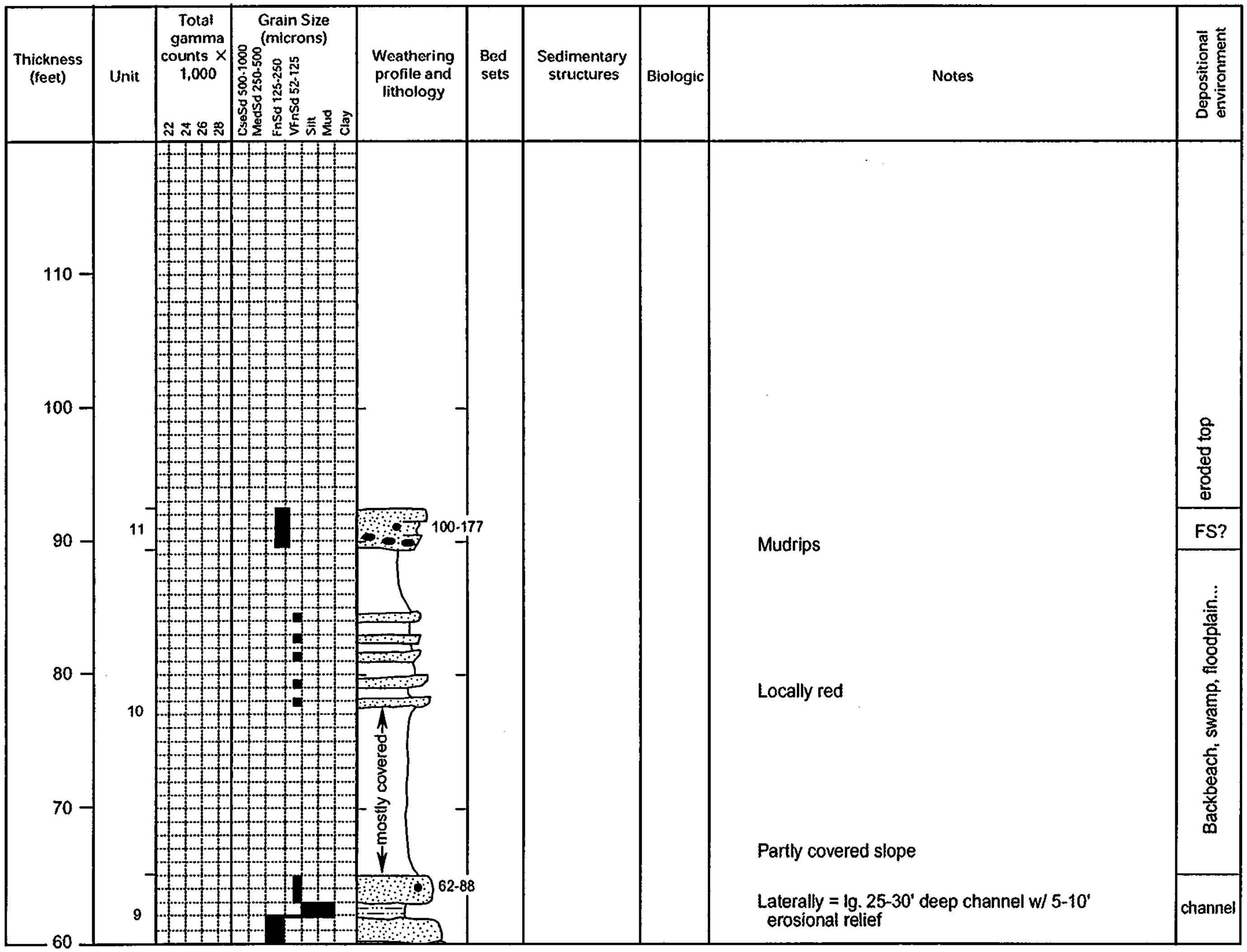
Measured Section 10: Horse Lake Gap. Measured by KO, SV 36 51'13" N, 106 46'29" W Page 2



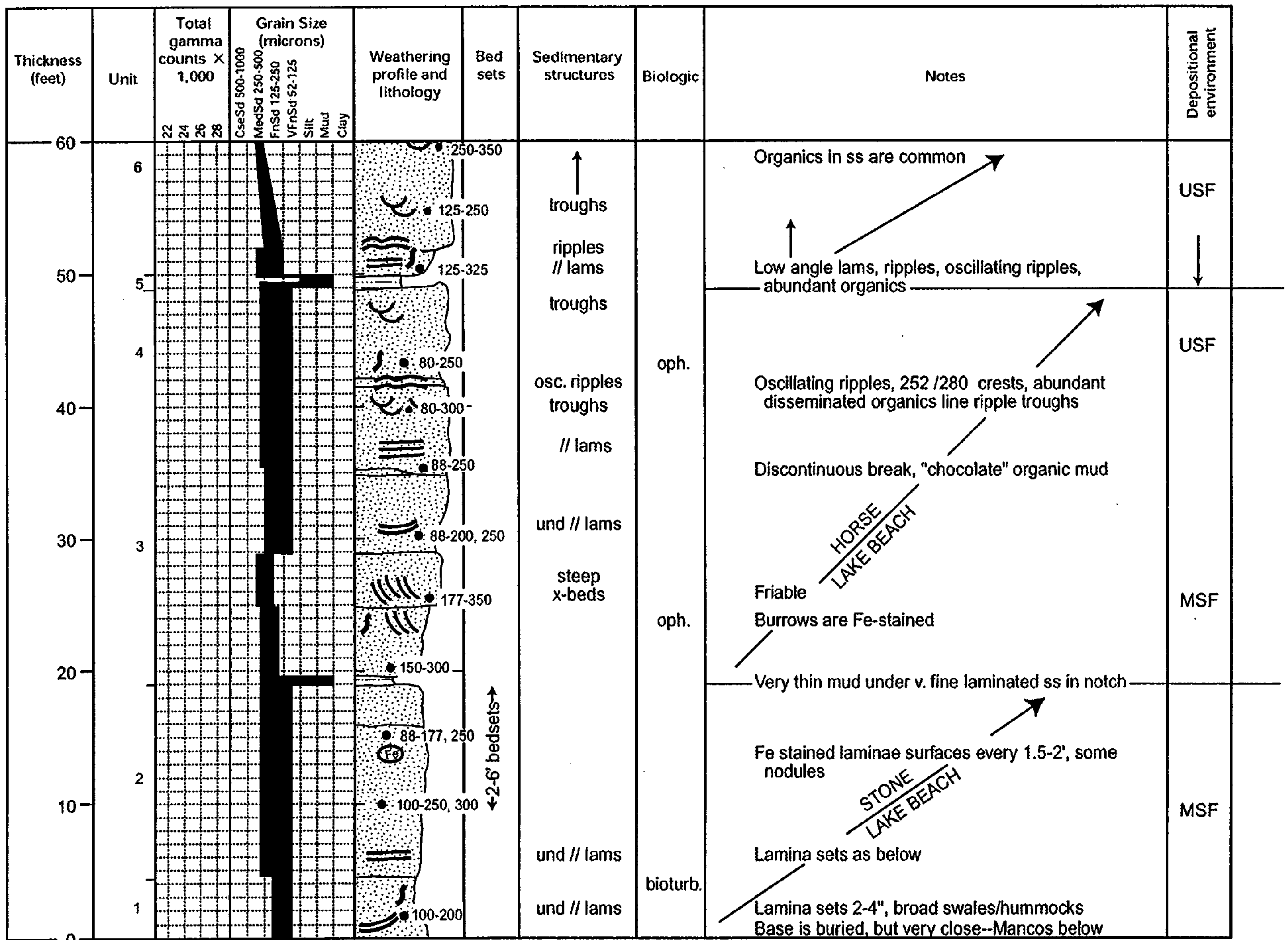
Measured Section 10: Horse Lake Gap. Measured by KO, SV 36 51'13" N, 106 46'29" W Page 3



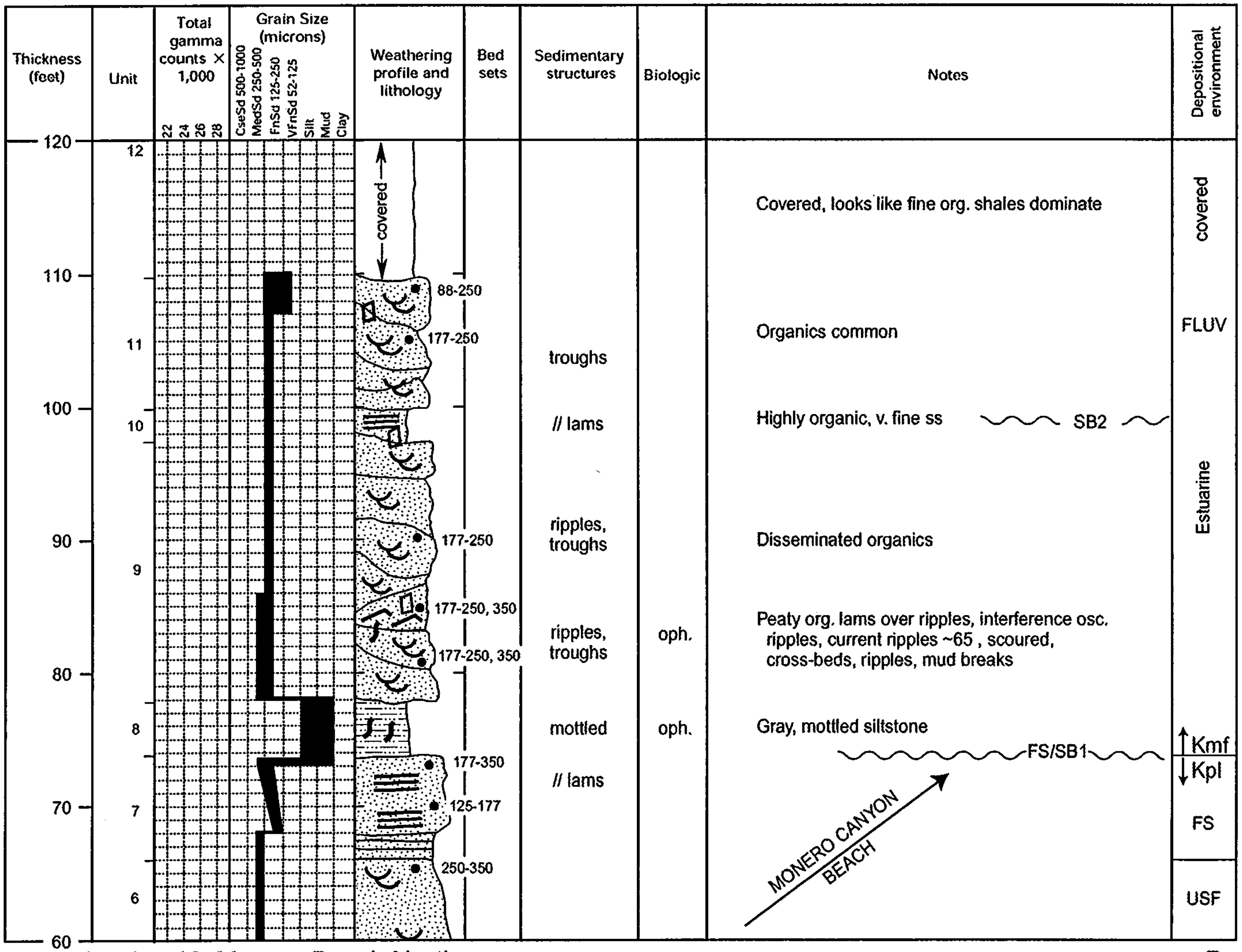
Measured Section 11: Monero Beach. Measured by RWD, MK-J, DB, AM, KO, SV 36 54'15" N, 106 51'4" W Page 1



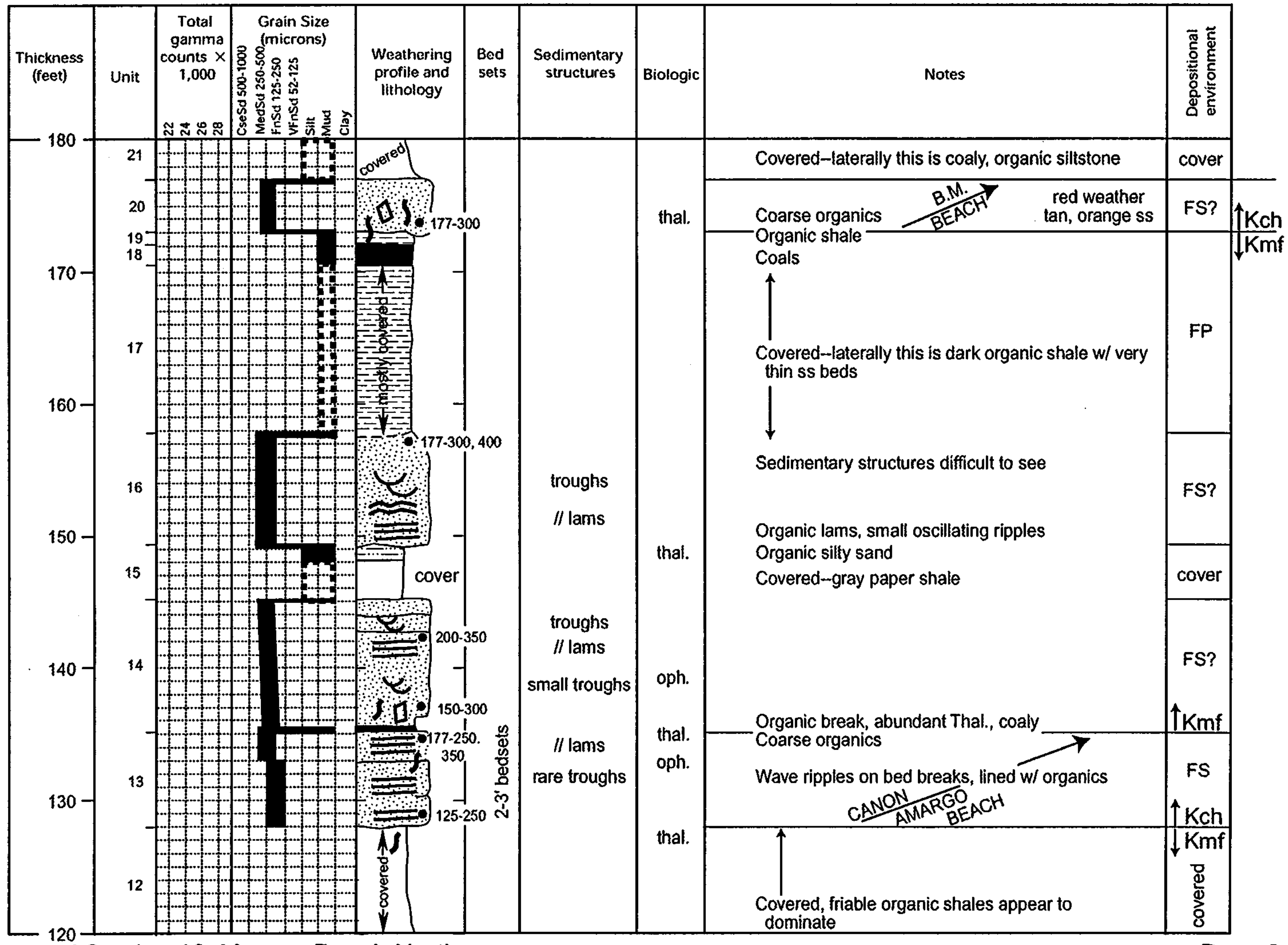
Measured Section 11: Monero Beach. Measured by RWD, MK-J, DB, AM, KO, SV 36 54'15" N, 106 51'4" W Page 2



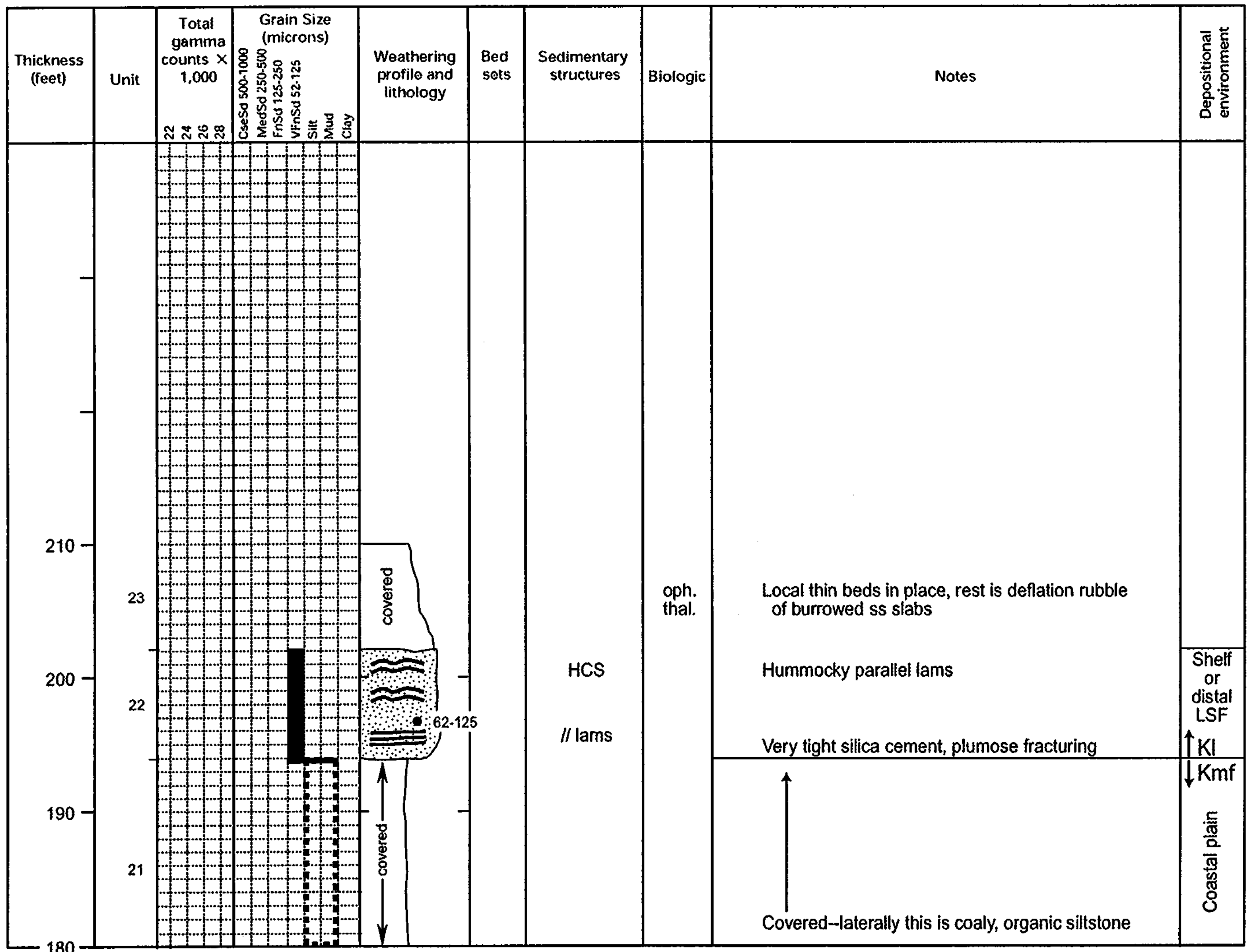
Measured Section 12: Monero Beach North. Measured by RWD, MK-J, AM, KO, DB, SV 36 54'15" N, 106 51'4" W Page 1



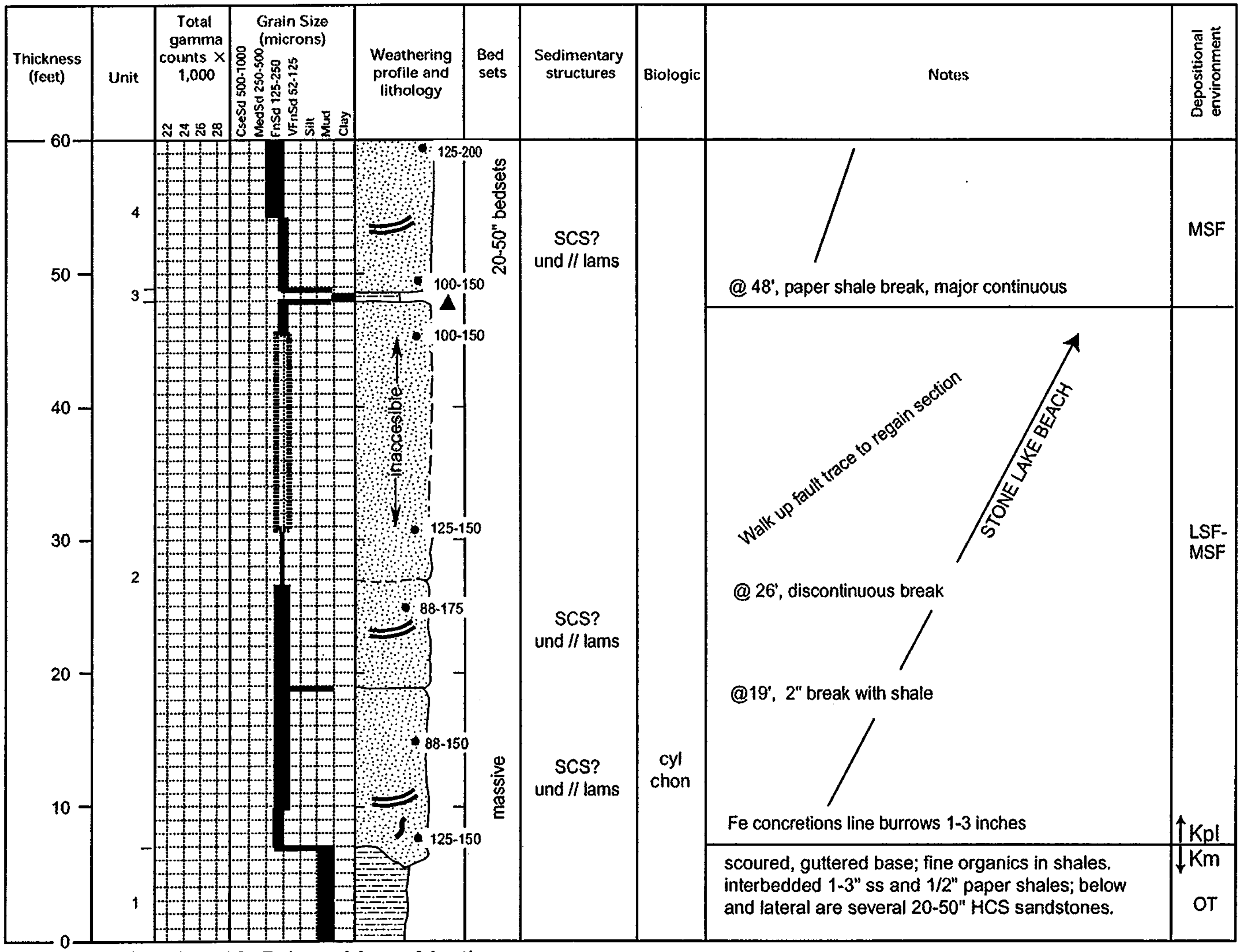
Measured Section 12: Monero Beach North. Measured by RWD, MK-J, AM, KO, DB, SV 36 54'15" N, 106 51'4" W Page 2



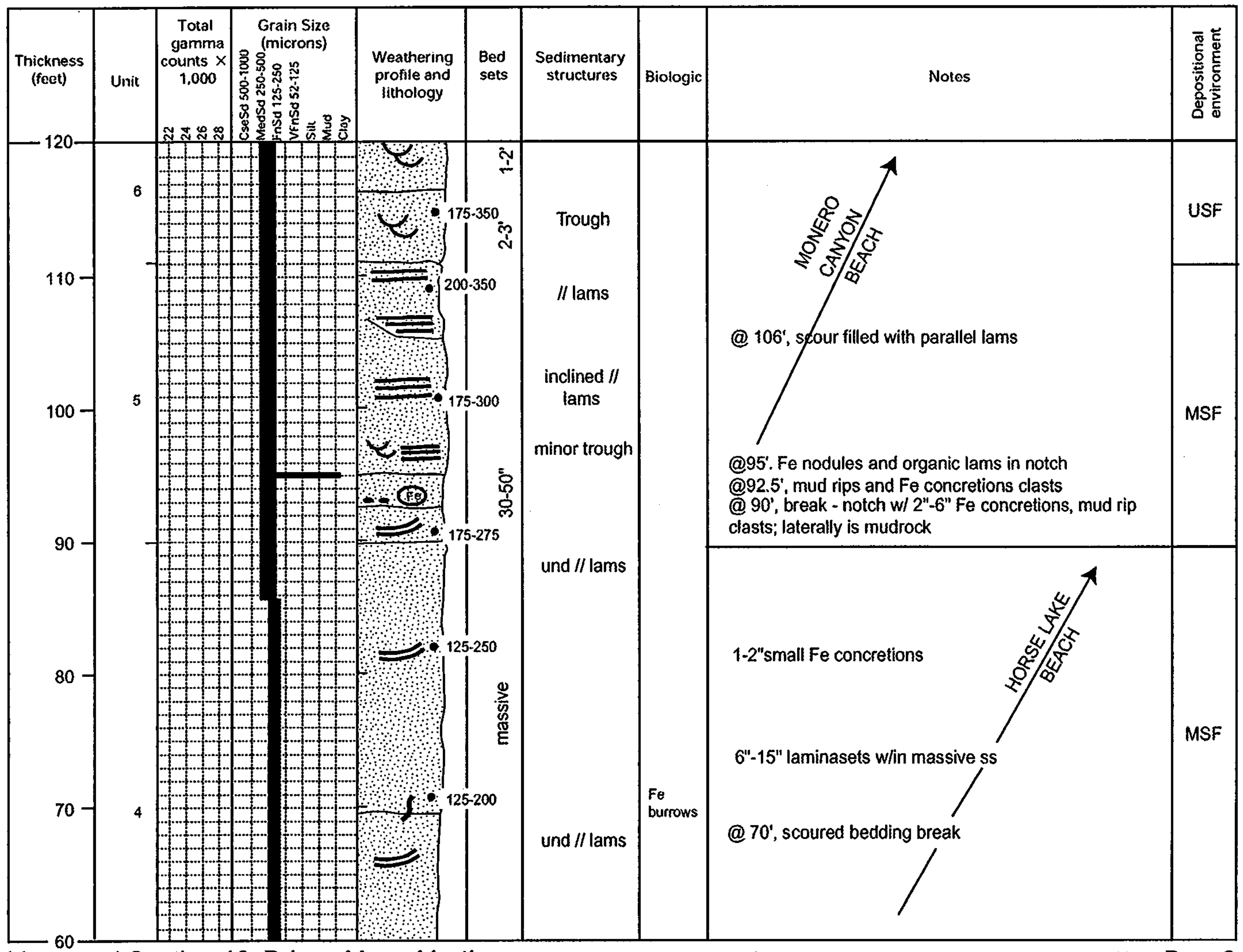
Measured Section 12: Monero Beach North. Measured by RWD, MK-J, AM, KO, DB, SV 36 54'15" N, 106 51'4" W Page 3



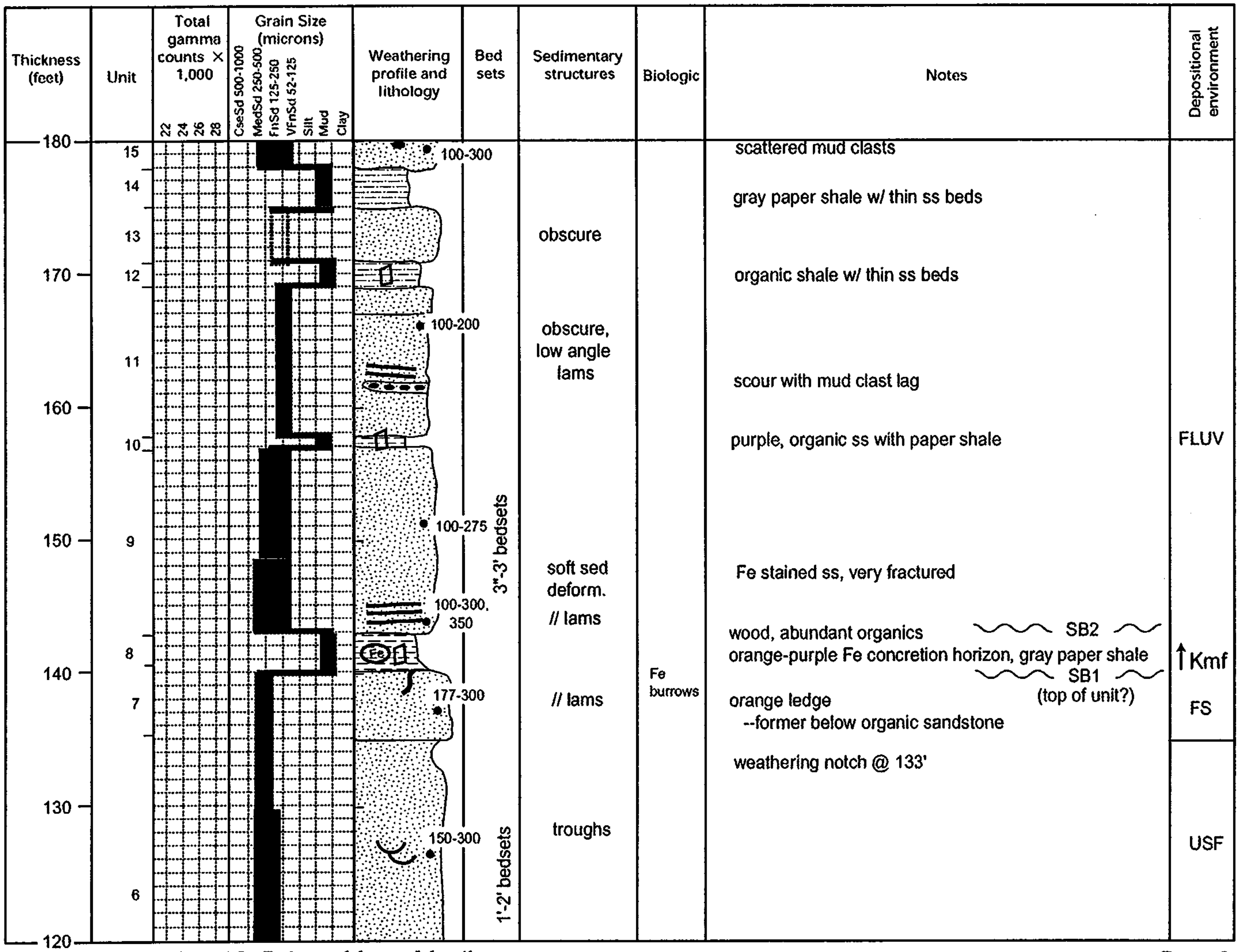
Measured Section 12: Monero Beach North. Measured by RWD, MK-J, AM, KO, DB, SV 36 54'15" N, 106 51'4" W Page 4



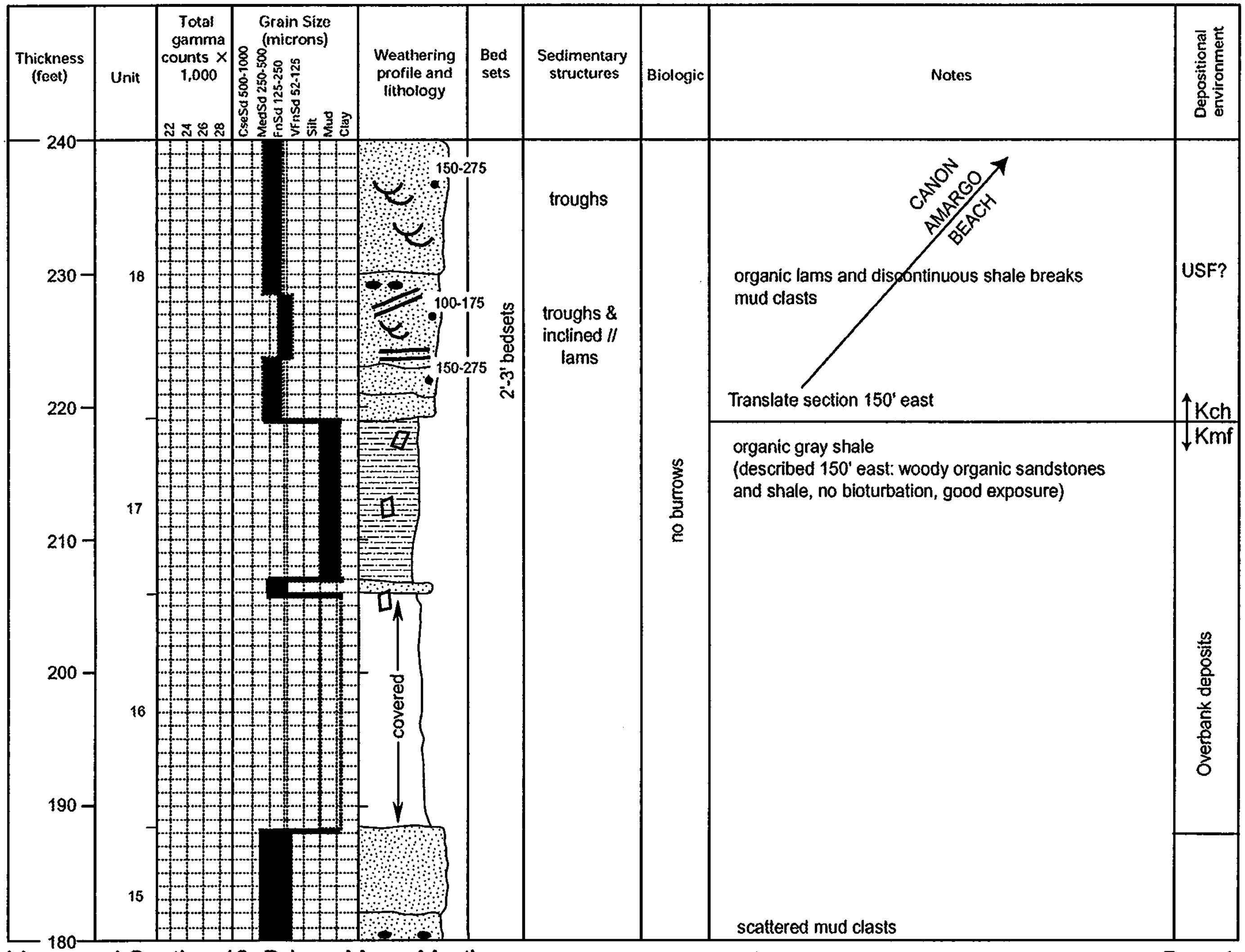
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 1



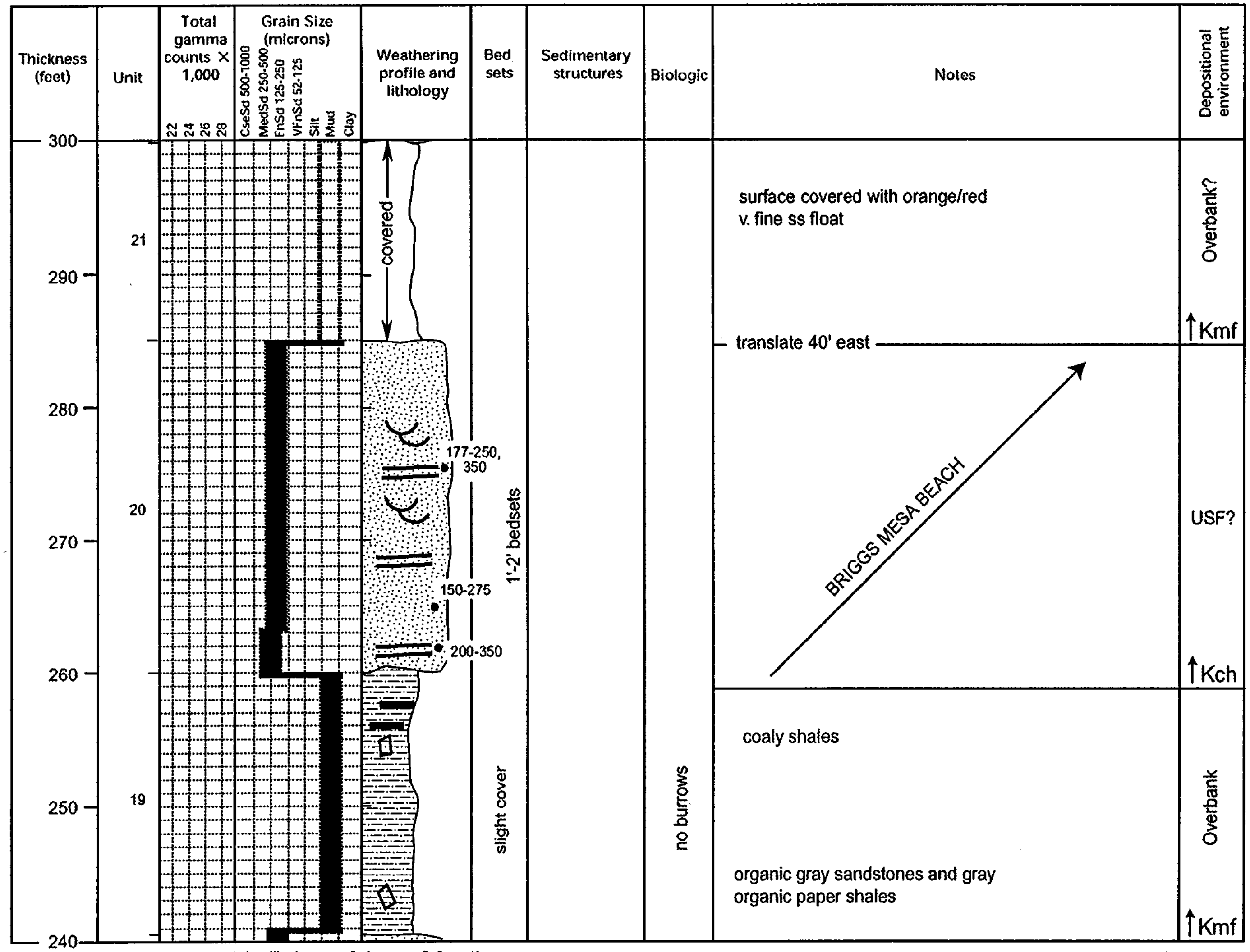
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 2



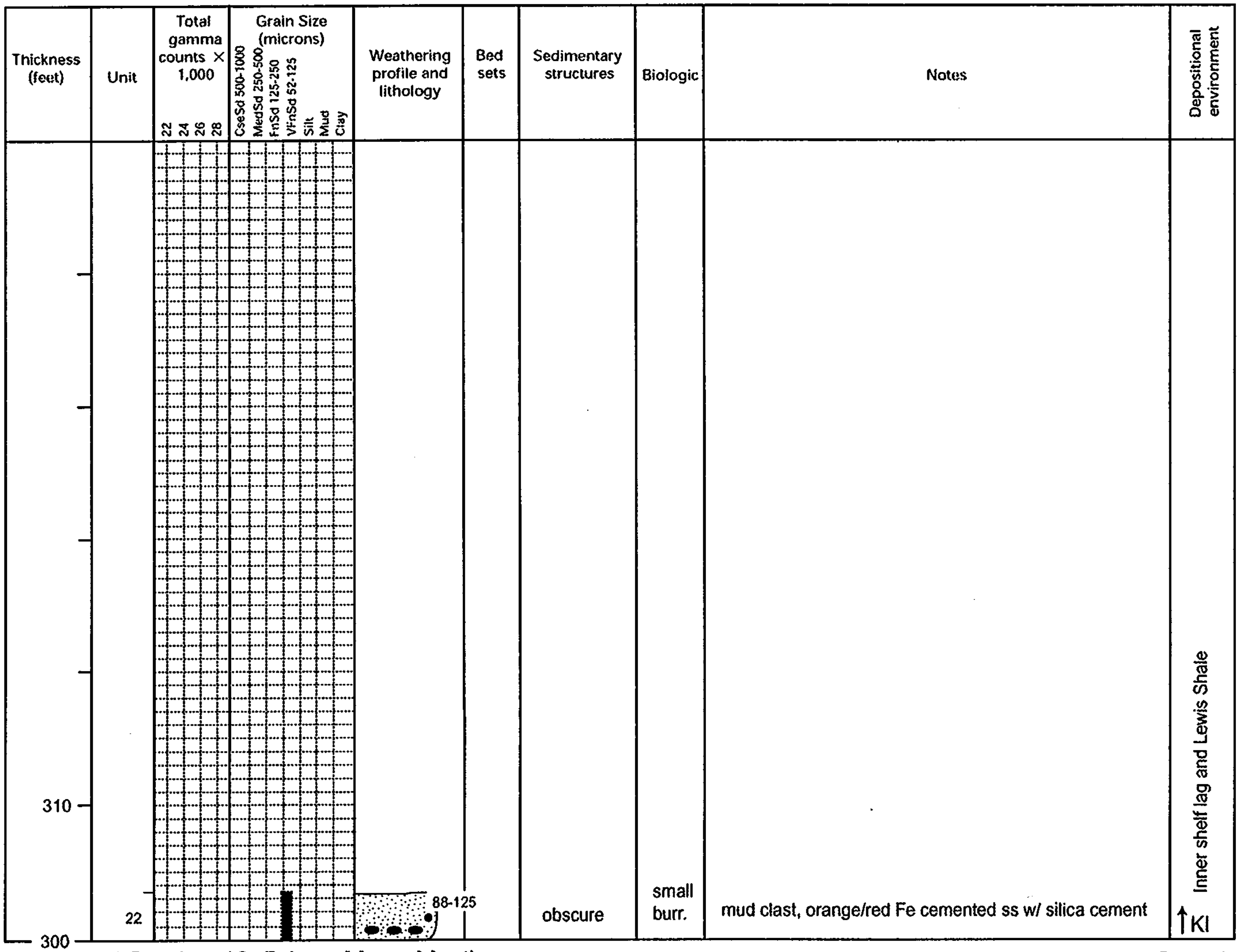
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 3



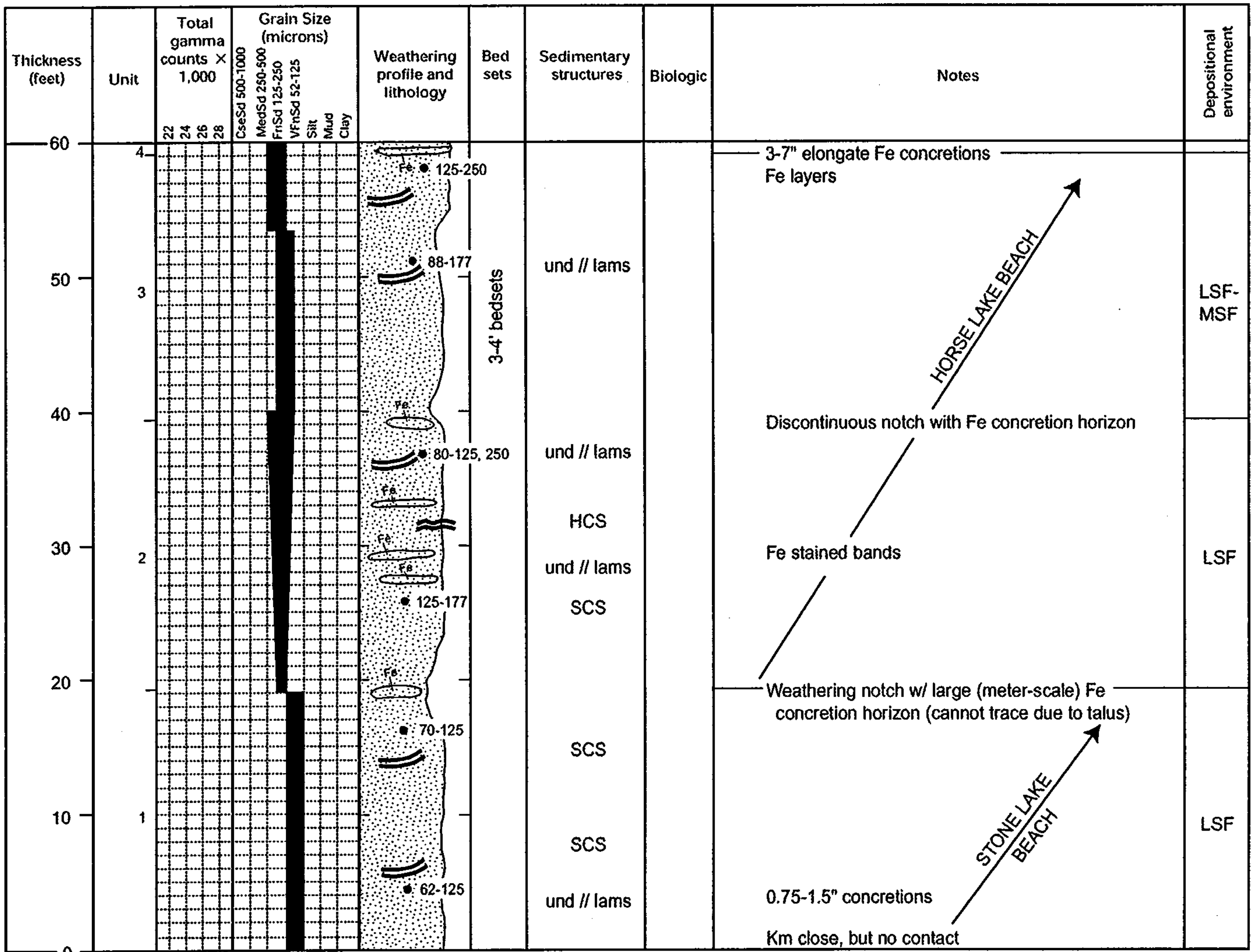
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 4



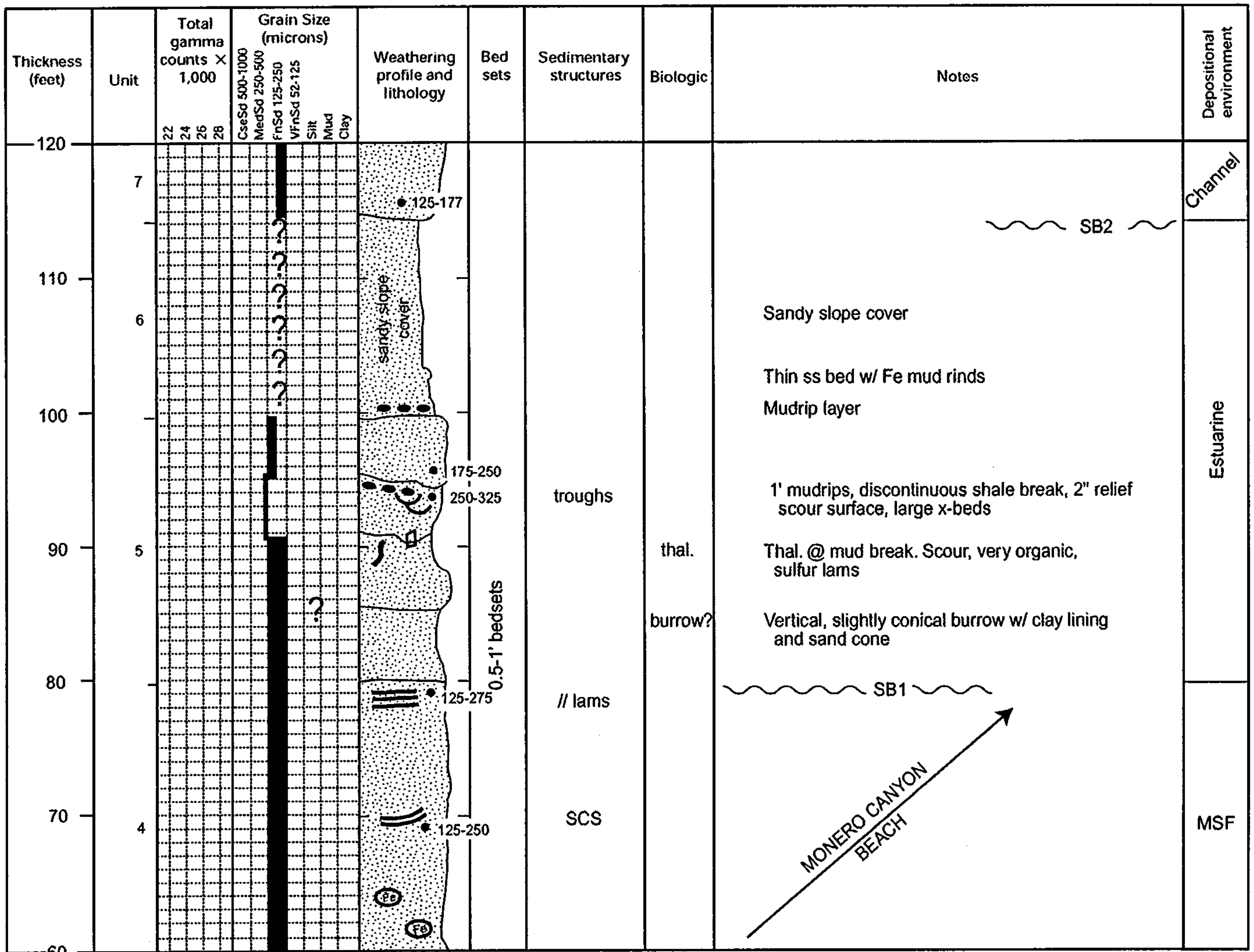
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 5



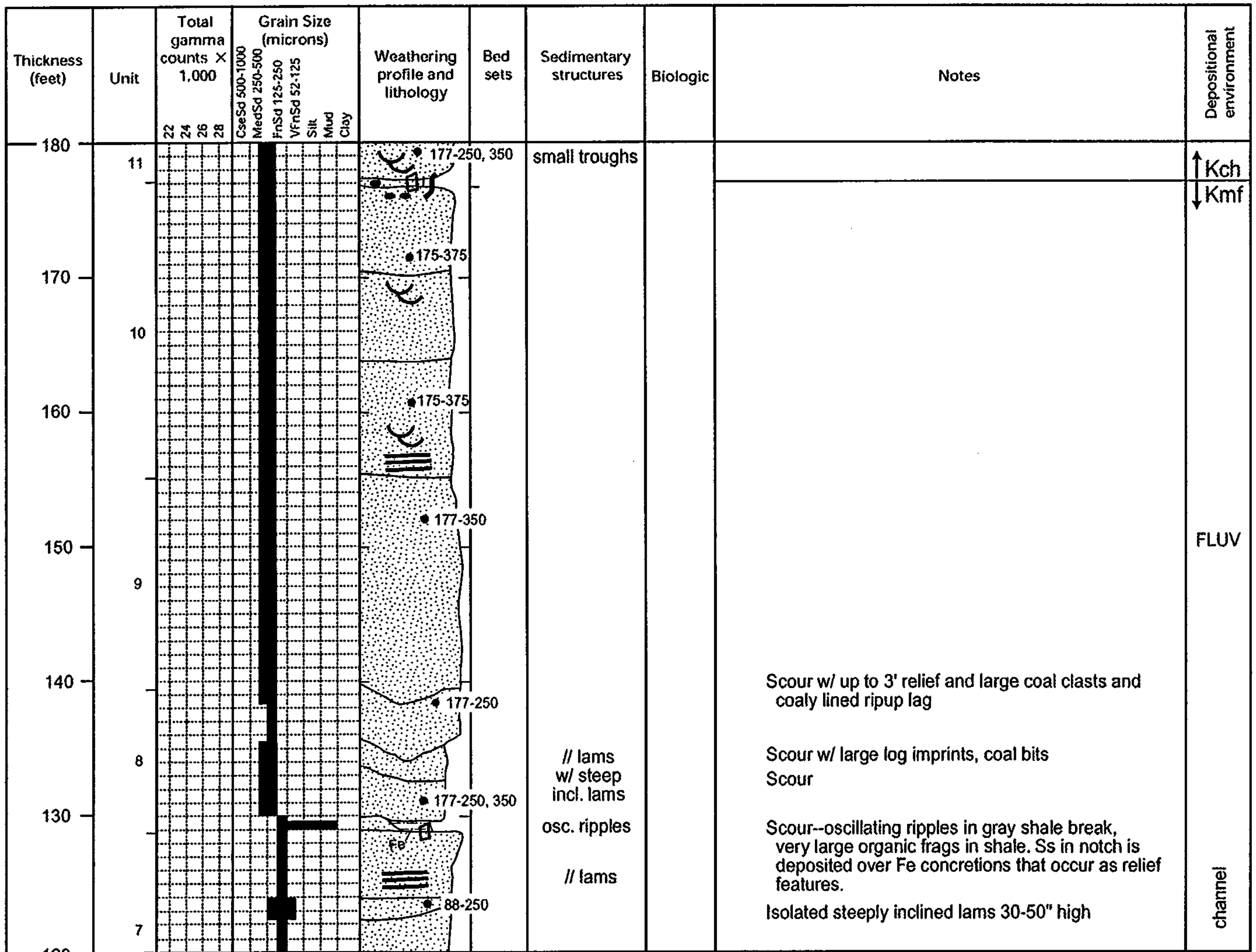
Measured Section 13: Briggs Mesa-Martinez. Measured by RWD, KO, AM 36 54'12" N, 106 49'17" W Page 6



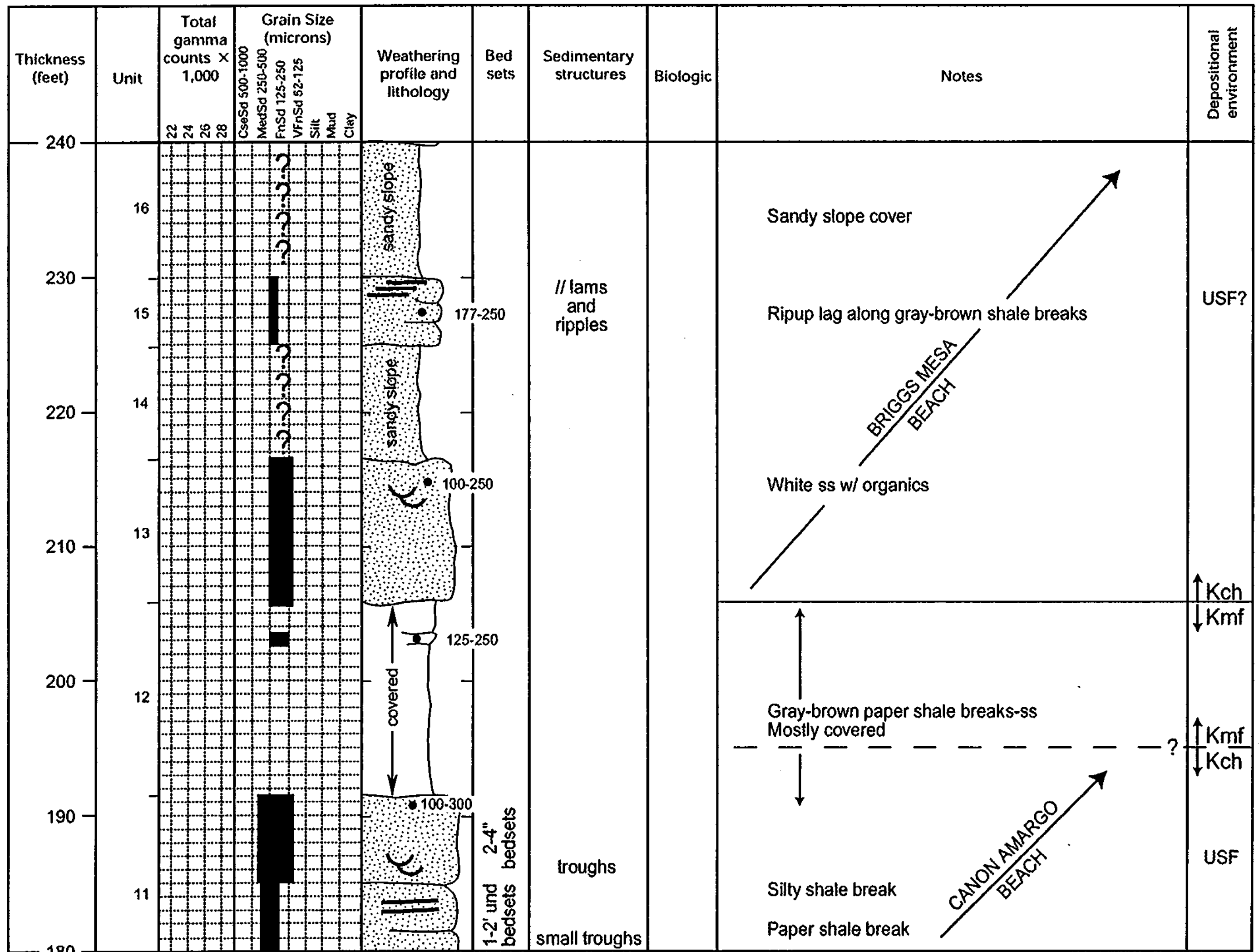
Measured Section 14: Briggs Mesa-East Rim. Measured by RWD, KO, AM, SV 36 54'38" N, 106 48'55" W Page 1



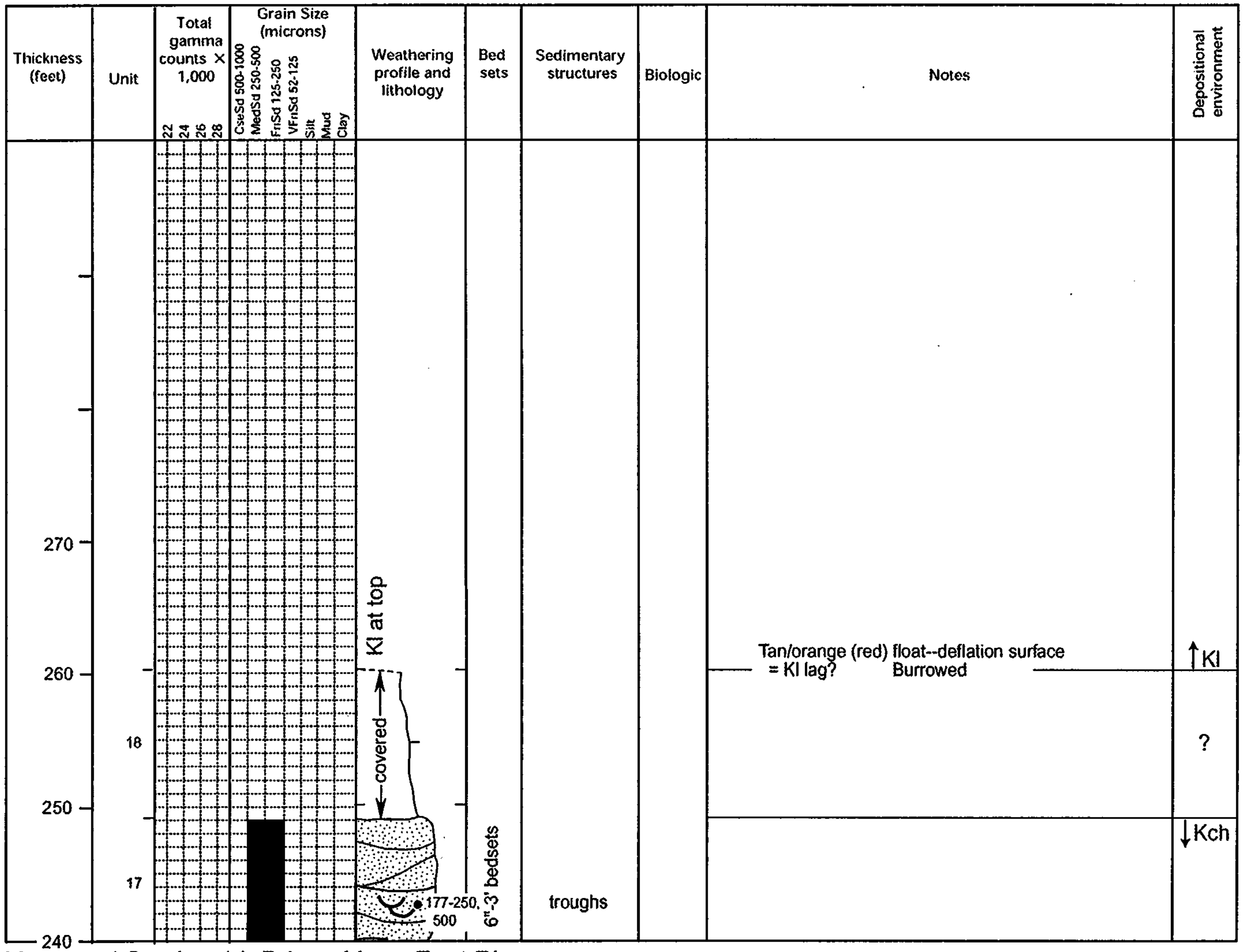
Measured Section 14: Briggs Mesa-East Rim. Measured by RWD, KO, AM, SV 36 54'38" N, 106 48'55" W Page 2



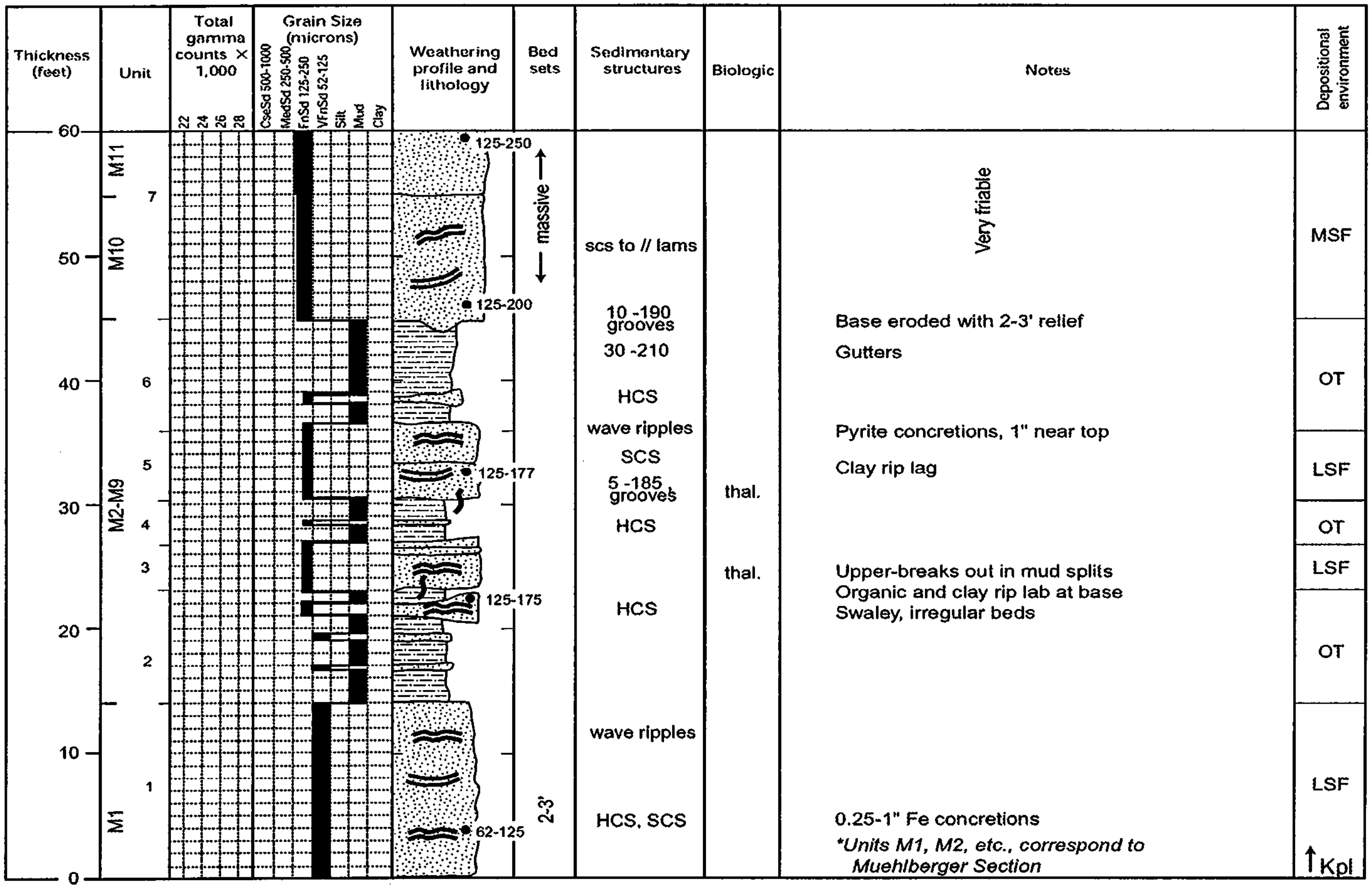
Measured Section 14: Briggs Mesa-East Rim. Measured by RWD, KO, AM, SV 36 54'38" N, 106 48'55" W Page 3



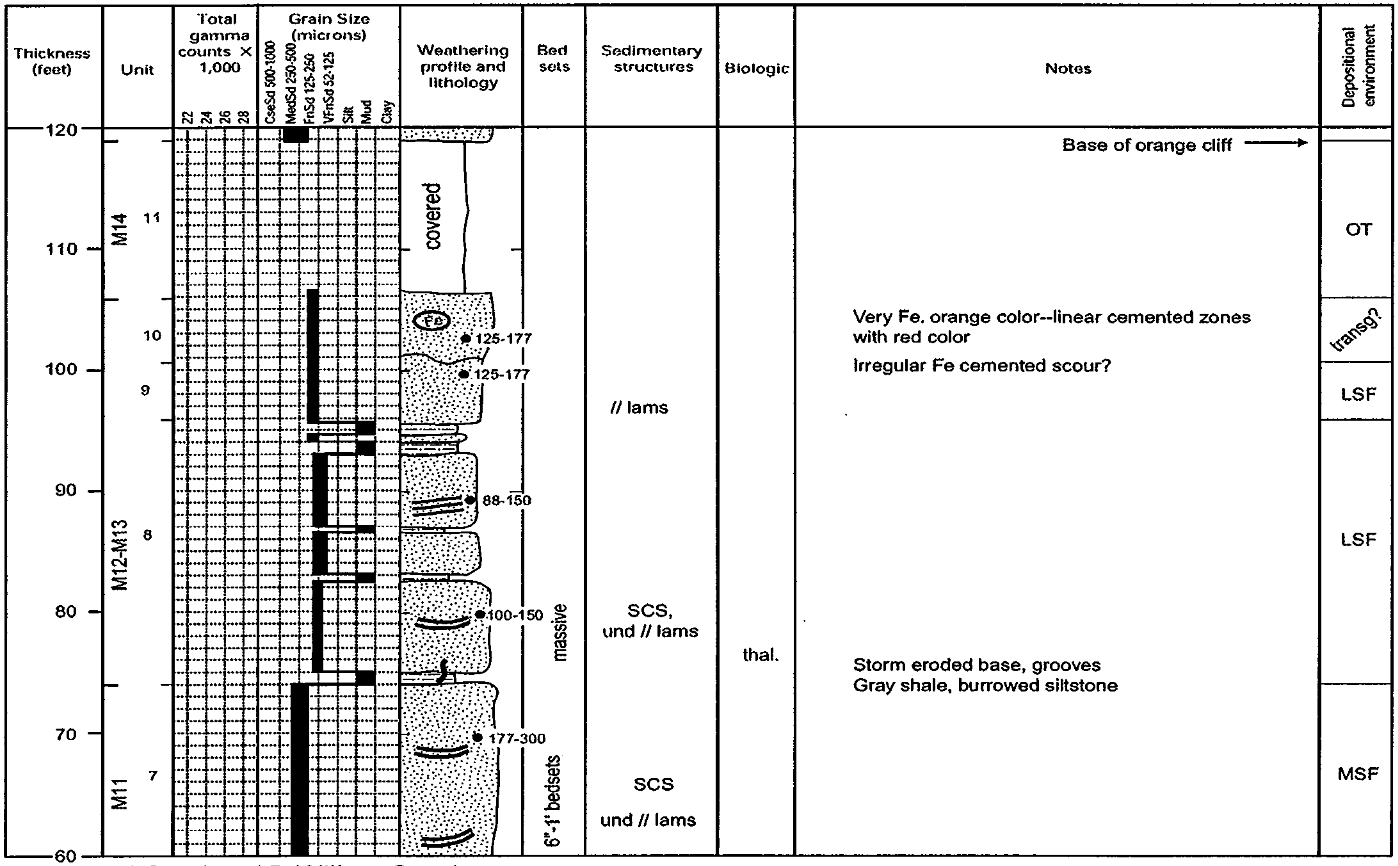
Measured Section 14: Briggs Mesa-East Rim. Measured by RWD, KO, AM, SV 36 54'38" N, 106 48'55" W Page 4



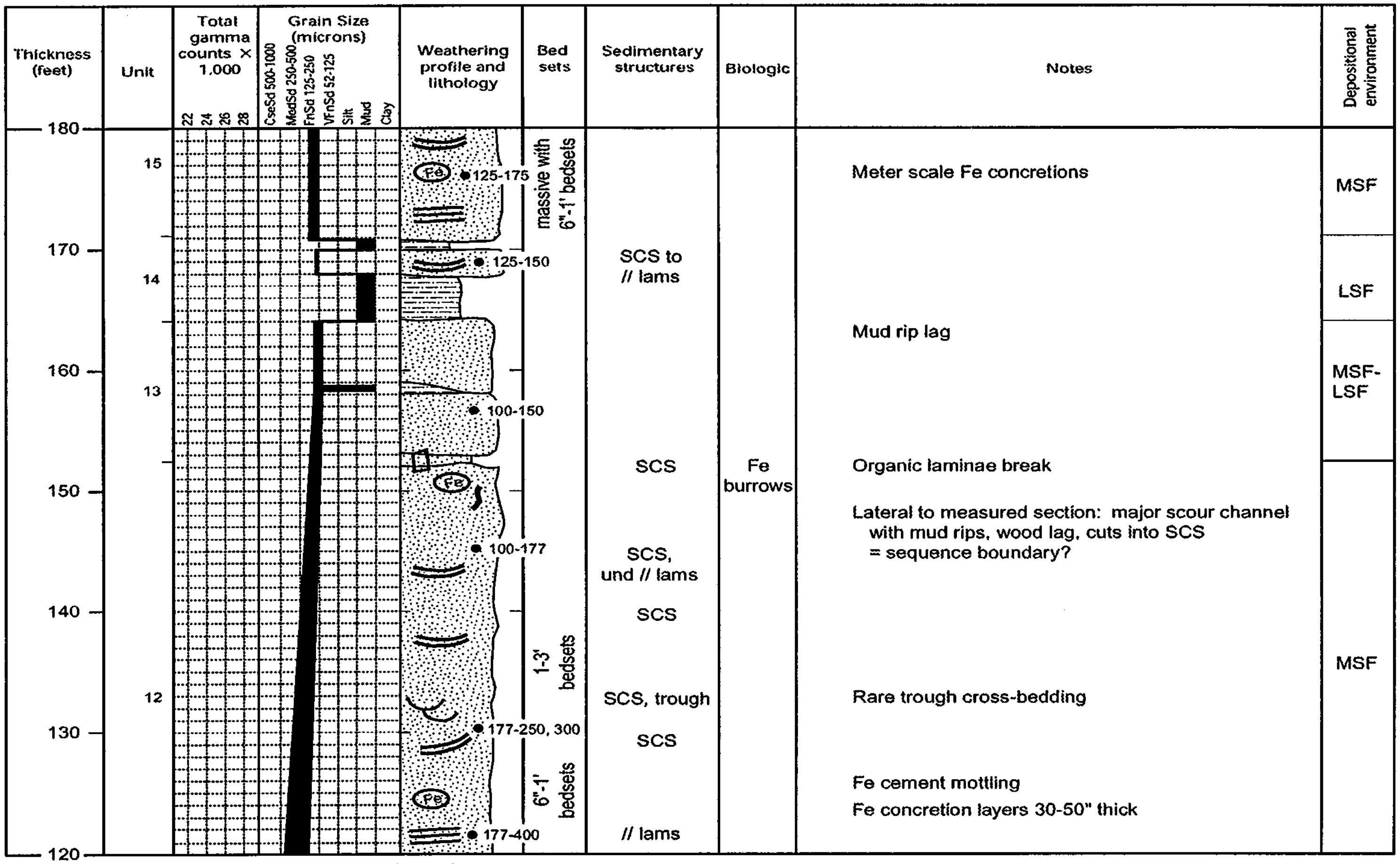
Measured Section 14: Briggs Mesa-East Rim. Measured by RWD, KO, AM, SV 36 54'38" N, 106 48'55" W Page 5



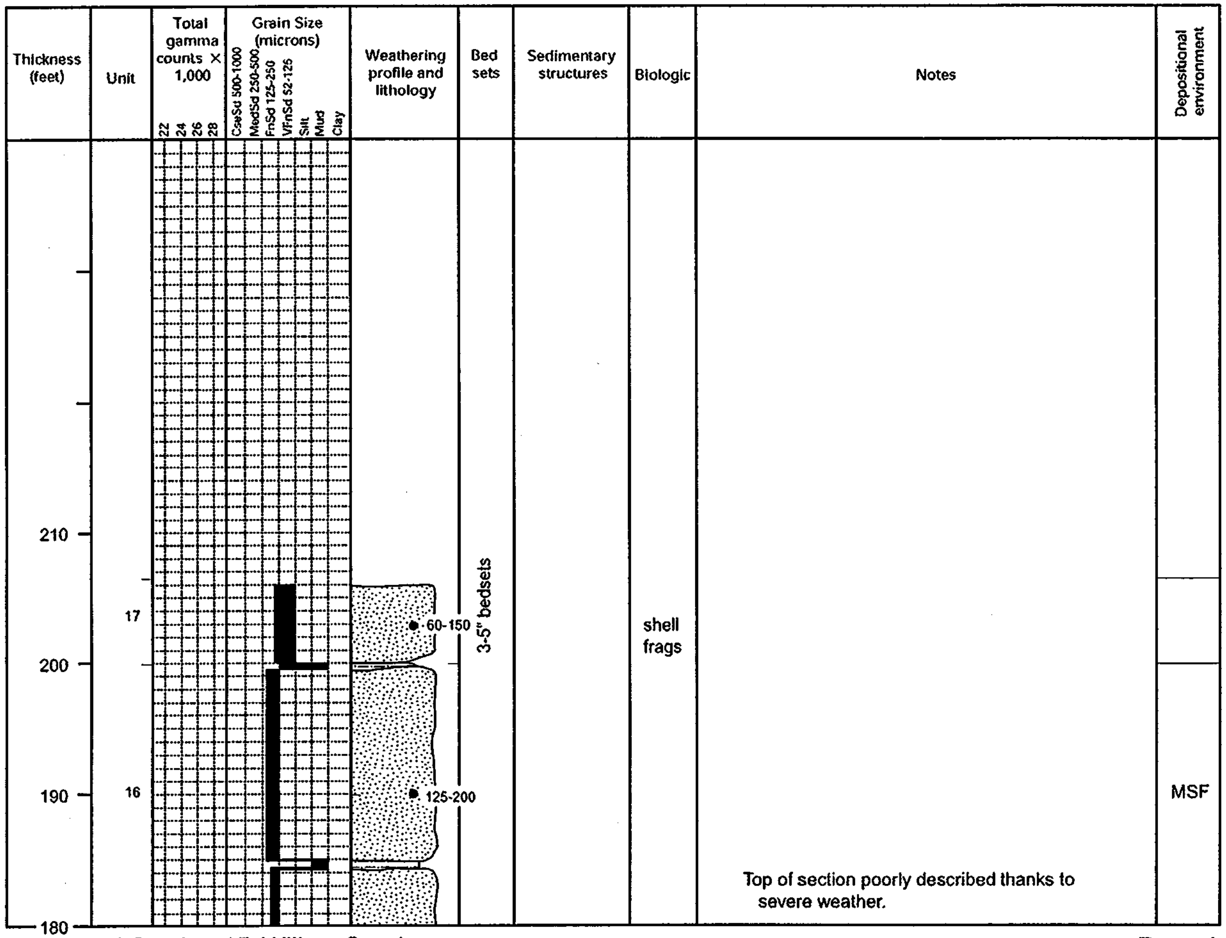
Measured Section 15: Willow Creek. Measured by RWD, KO 36 54'30" N, 106 38'27" W Page 1



Measured Section 15: Willow Creek. Measured by RWD, KO 36 54'30" N, 106 38'27" W Page 2



Measured Section 15: Willow Creek. Measured by RWD, KO 36 54'30" N, 106 38'27" W Page 3



Measured Section 15: Willow Creek. Measured by RWD, KO 36 54'30" N, 106 38'27" W Page 4

APPENDIX 2

Outcrop gamma ray data for selected measured sections (figure 1) described in this study. Data were collected using a U.S. Geological Survey GAD-6 gamma-ray spectrometer which simultaneously records total counts, potassium, uranium, and thorium. Data are reported as raw counts; count duration per sample was 90 seconds. Also shown for each section is the simplified lithology and depositional environments; ss, sandstone; org., organic; recalib., recalibrated.

Measured Section 2 - Pounds Canyon; see figure 1 for location.

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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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

Measured Section 5 - Apache Mesa South; see figure 1 for location.

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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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	891	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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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 Middle; see figure 1 for location.

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
0	5583	455	801	155	ss	upper shoreface
2.5	13770	1049	1609	518	ss	upper shoreface
5	5256	402	875	154	ss	upper shoreface
7.5	7091	564	1079	206	ss	upper shoreface
10	7223	560	1075	235	ss	upper shoreface
12.5	5061	433	899	107	ss	upper shoreface
15	6498	495	929	202	ss	upper shoreface
17.5	5368	452	930	125	ss	upper shoreface
20	7525	605	1260	230	ss	upper shoreface
gap						
27.5	5808	490	951	166	ss	upper shoreface
30	6140	481	912	212	ss	upper shoreface
32.5	9283	713	1054	310	ss	upper shoreface
35	24381	1455	227	1040	ss	upper shoreface
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

Measured Section 9 - Sulphur Canyon; see figure 1 for location.

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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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						

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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						
415	4659	837	218	172	ss	lower shoreface

Measured Section 11 - Monero Beach Roadcut; see figure 1 for location.

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(?)

Measured Section 12 - Monero Beach North; see figure 1 for location.

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	1321	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

Elevation (ft)	Total Counts	K	U	Th	Lithology	Environment
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

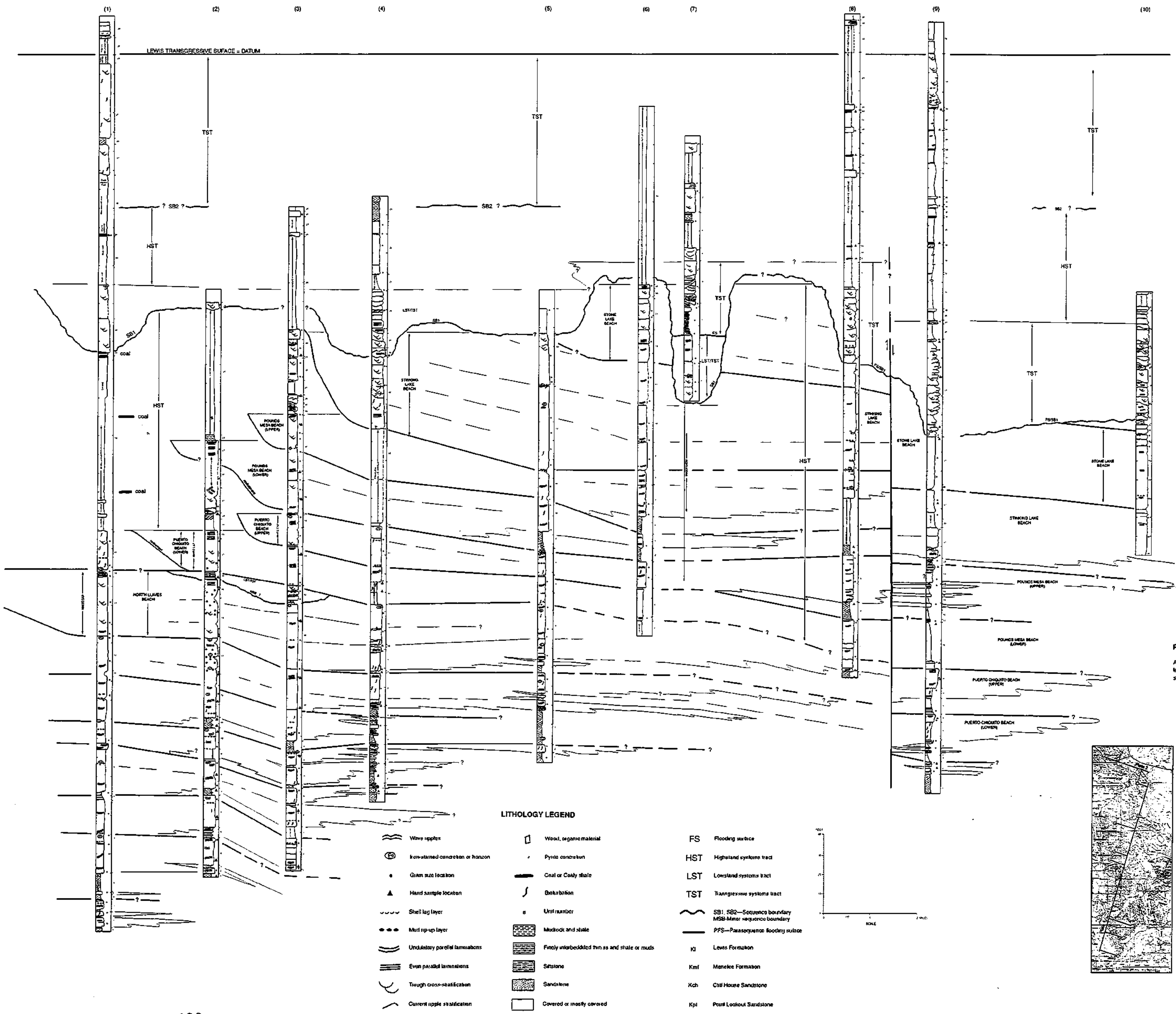


PLATE – 1

Approximate SSW NNE dip line from Puerto Chiquito to Monero N M (approx 24 Miles) See index map for section location

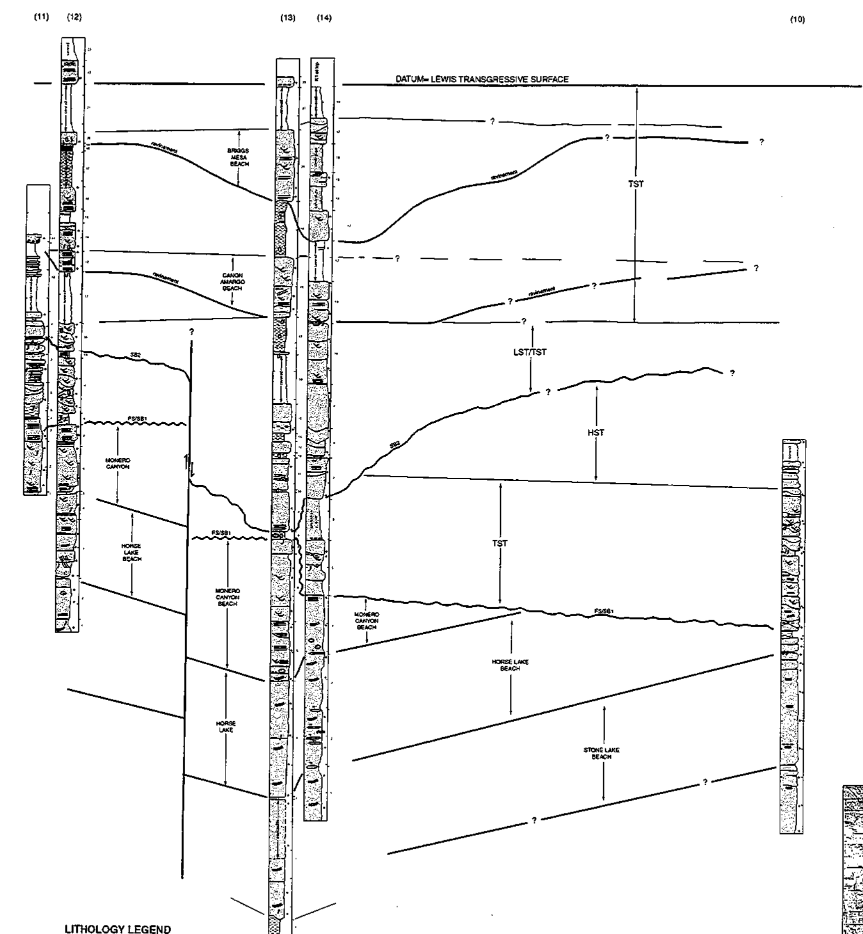


PLATE 2

LITHOLOGY LEGEND

	Wave ripples		Wood, organic material	FS	Flooding surface
	Iron-stained concretion or horizon		Pyrite concretion	HST	Highstand systems tract
	Grain size location		Coal or Coaly shale	LST	Lowstand systems tract
	Hand sample location		Bioturbation	TST	Transgressive systems tract
	Shell lag layer		Unit number		SB1, SB2—Sequence boundary MSB—Minor sequence boundary
	Mud rip-up layer		Mudrock and shale		PFS—Parasequence floodind surface
	Undulatory parallel laminations		Finely interbeddded thin ss and shale or muds	Kl	Lewis Formation
	Even parallel laminations		Siltstone	Kmf	Menefee Formation
	Trough cross-stratification		Sandstone	Kch	Cliff House Sandstone
	Current ripple stratification		Covered or mostly covered	Kpl	Point Lookout Sandstone

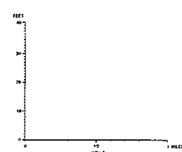


PLATE – 2

Approximate strike line for Cañon Amargo area. Note, however, that section 10 is located approx. 2-3 miles up depositional dip (landward) of sections 11-14. Section 14 is located approx. 1 mile downdip (seaward) of section 12. See index map for section location.