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Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington

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1.0 INTRODUCTION

Hanford Site activities since the end of the 1980's have focused on environmental restoration. An integral part of this, as well as any remediation effort, is accurate characterization of site geohydrologic conditions. This document addresses the geologic characteristics of the Ringold Formation and presents a compilation of Ringold Formation geologic information for the Hanford Site and much of the surrounding area.

Four main aquifer systems exist within the rocks and sediments underlying the Hanford Site (DOE 1988, Delaney et al. 1991). The three lowest systems are situated within the basalts of the Columbia River Basalt Group (CRBG). The uppermost aquifer system, commonly referred to as the suprabasalt or unconfined aquifer (DOE 1988; Connelly et al. 1992a, 1992b; Reidel et al. 1992; Lindsey et al. 1994a), occurs in the sediments overlying the CRBG. The principal stratigraphic unit within the suprabasalt aquifer is the Ringold Formation. At most locations on the Hanford Site, the top of the unconfined aquifer lies at or near the top of the Ringold Formation. Other units comprising the uppermost parts of the unconfined aquifer are the redefined Plio-Pleistocene unit and the Hanford formation (DOE 1988; Connelly et al. 1992a, 1992b; Lindsey et al. 1994a, 1994b).

2.0 SETTING

The Hanford Site is situated in part of south-central Washington referred to as the Columbia Basin. The Columbia Basin is an intermontane basin situated between the Cascade Range on the west, Okanogan Highlands to the north, Rocky Mountains to the east, and the Blue Mountains anticlinorium to the south (DOE 1988) (Figure 1). The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains physiographic region and anticlinal ridges of the Yakima Folds physiographic region (DOE 1988). Surface topography at the Hanford Site is the result of (1) Neogene-aged uplift of anticlinal ridges (DOE 1988, Reidel et al. 1994), (2) Pleistocene cataclysmic flooding (Baker et al. 1991), (3) Holocene eolian activity, and (4) landsliding.

2.1 STRUCTURAL GEOLOGY

The Columbia Basin is divided into three geologic subprovinces, the Yakima Fold Belt, Palouse Slope, and Blue Mountains (Figure 1) (DOE 1988). The Hanford Site (Figure 2) is located in the eastern Yakima Fold Belt, within the Pasco Basin (Grollier and Bingham 1978, Myers et al. 1979, Fecht et al. 1987, Smith et al. 1989, Tolan et al. 1989). The Yakima Fold Belt is characterized by a series of segmented, narrow, asymmetric, east-west trending anticlines that have wavelengths between 5 and 32 km (3.1 and 19.9 mi) and amplitudes commonly less than 1 km (0.62 mi) (Reidel 1984; Reidel et al. 1989, 1994). The northern limbs of these anticlines generally dip steeply to the north, are vertical, or even overturned. The southern limbs generally dip at relatively shallow angles to the south. Thrust and high-angle reverse faults with fault planes that generally parallel fold axial trends commonly are found on the north sides of these anticlines.

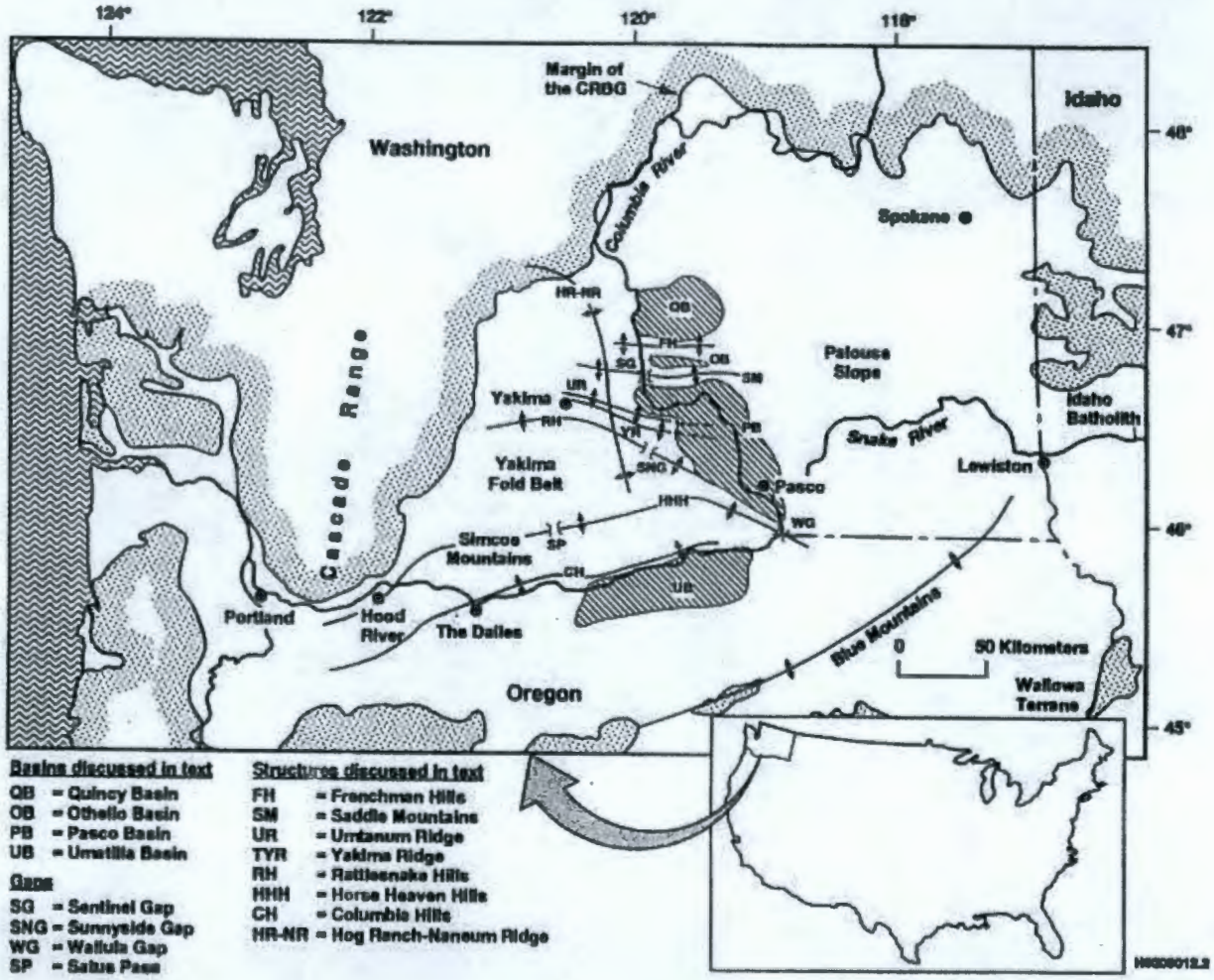
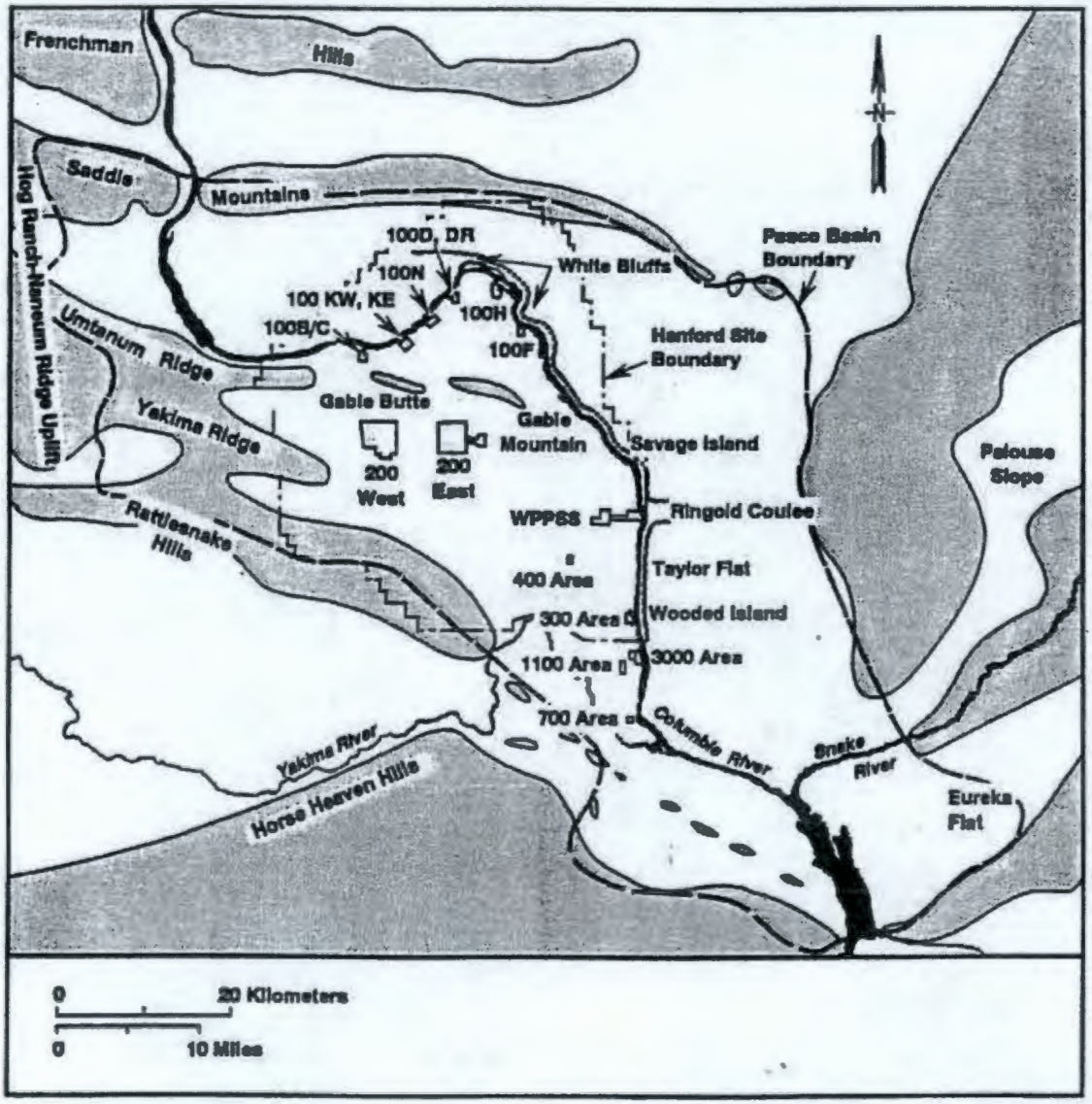


Figure 1. Regional Geologic and Geographic Setting of the Columbia Basin and Hanford Site, South-Central Washington and North-Central Washington (modified from Tolan and Reidel 1989, Tolan et al. 1989).

Figure 2. Geographic Setting of the Pasco Basin and Hanford Site, Including Study Site Locations.



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The anticlinal ridges are separated by broad synclines or basins that, in many cases, contain Neogene- to Quaternary-age sediments (Fecht et al. 1987, DOE 1988, Smith et al. 1989, Tolan and Reidel 1989). A single major north-south structure, the Hog Ranch-Naneum Ridge uplift, occurs in the western fold belt (DOE 1988, Tolan and Reidel 1989). Deformation in the Yakima Fold Belt began before the emplacement of the CRBG (beginning approximately 17 Ma), occurred throughout Columbia River basalt volcanism (which ended approximately 6.5 Ma), and continues today (Reidel et al. 1994). The Pasco Basin is one of the larger structural basins in the Yakima Fold Belt.

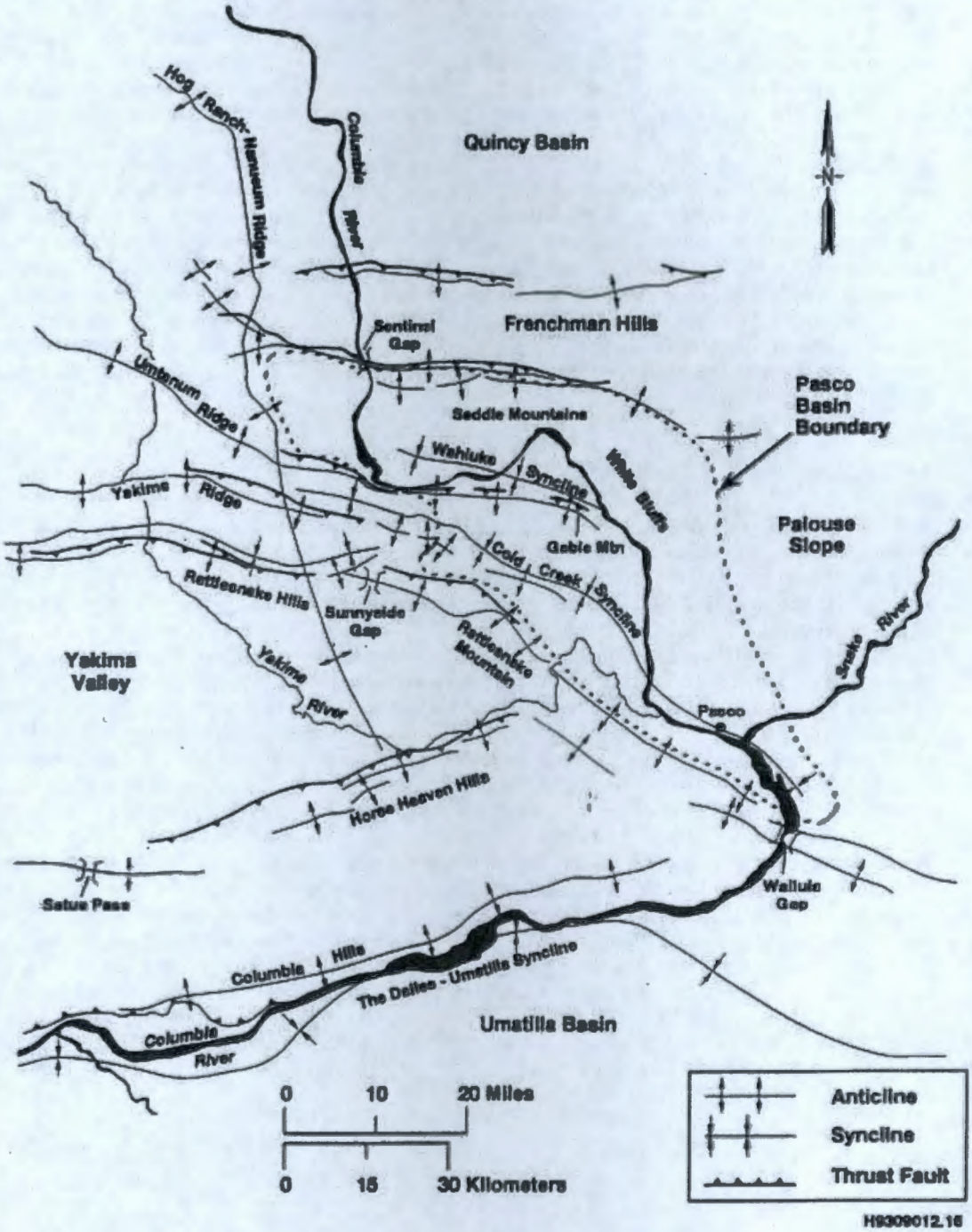
The Pasco Basin is bounded on the north by a series of anticlines forming the Saddle Mountains, on the west by the Hog Ranch-Naneum Ridge anticline, and on the south by anticlines comprising Rattlesnake Mountain and the Horse Heaven Hills (Figures 1 and 3) (Tallman et al. 1981, DOE 1988, Tolan and Reidel 1989). The Jackass monocline, a structure on the western edge of the Palouse slope, bounds the Pasco Basin on the east (Figures 1 and 3). The Pasco Basin is divided into a series of smaller synclines by east-west anticlines that project into the western Pasco Basin. From north to south, the synclines are the Wahluke syncline, Cold Creek syncline, and Bensen Ranch syncline (Figures 1 and 3). Each of these synclines is asymmetric and relatively flat bottomed with the north limbs dipping gently (approximately 5°) to the south and the south limbs dipping steeply to the north (Reidel and Fecht 1981).

2.2 DEPOSITIONAL FRAMEWORK

Late Neogene sediments (including the Ringold Formation) in the Columbia Basin were deposited in the ancestral Columbia River system (Warren 1941, Waters 1955, Newcomb 1959, Fecht et al. 1987, Baker et al. 1987, Smith 1988). The Late Neogene Columbia River in the Columbia Basin consisted of the ancestral Columbia River and three main tributaries, the ancestral Salmon-Clearwater, ancestral Yakima, and ancestral Palouse Rivers (Fecht et al. 1987). Unless otherwise stated, all rivers discussed in the report are assumed to be the Miocene-Pliocene ancestors of the modern rivers. Throughout the Late Neogene, the Columbia River maintained a north-to-south course across the Columbia Basin, while the Salmon-Clearwater and Palouse Rivers flowed to the west down the Palouse slope. The Yakima River flowed into the southwestern corner of the Columbia Basin. The Snake River did not begin to flow into the central Columbia Basin until the latest Pliocene or early Pleistocene (Baker et al. 1987). During the Pleistocene, the Columbia Basin was inundated by cataclysmic flood waters periodically released from glacial Lake Missoula (Baker et al. 1991).

Throughout the early to middle Miocene (before Ringold deposition), the Columbia River was situated along the western margin of the Columbia Basin adjacent to volcanic terranes of the ancestral Cascade Mountains (Fecht et al. 1987, Smith 1988). The Columbia River was forced into this position by the west-dipping paleoslope of the Basin and west-flowing flood basalts. As flood basalt volcanism decreased in the middle to late Miocene, continued uplift in the western basin centered on the Hog Ranch-Naneum Ridge anticline, relative to subsidence in the Pasco Basin, and began to displace the river to the east (Waters 1955, Fecht et al. 1987, Smith 1988). Near the end of flood basalt volcanism in the late Miocene (10.5 to 8.5 Ma), the Columbia River began to encroach on the central Pasco Basin, and Ringold deposition began.

Figure 3. General Geology of the Yakima Fold Belt, Pasco Basin, and Hanford Site. Map shows major structural elements in the area (modified from Reidel et al. 1989).



3.0 THE RINGOLD FORMATION

3.1 INTRODUCTION

Suprabasalt terrigenous clastic sediments assigned to the Ringold Formation are present throughout much of the central Columbia Basin south-central Washington (Warren 1941; Waters 1955; Grollier and Bingham 1971, 1978; Myers et al. 1979; Tallman et al. 1979, 1981; Fecht et al. 1987; Smith et al. 1989). Regionally, the Ringold Formation consists of interbedded, unconsolidated to cemented clay, silt, sand, and granule to cobble gravel (Newcomb 1958, Bjornstad 1985, Fecht et al. 1987, Smith et al. 1989). Exposures of the Ringold Formation are present in (1) the White Bluffs adjacent to the Columbia River (Figures 2 and 4); (2) ravines and coulees between Wallula Gap and Moses Lake; and (3) benches and slopes adjacent to basalt uplifts such as Rattlesnake Mountain, the Saddle Mountains, and the Frenchman Hills. At and near the Hanford Site, the Ringold Formation largely is restricted to the subsurface with outcrops limited to the flanks of anticlinal ridges, the White Bluffs, and Eureka Flat (Figures 2 and 4).

3.2 PREVIOUS STUDIES

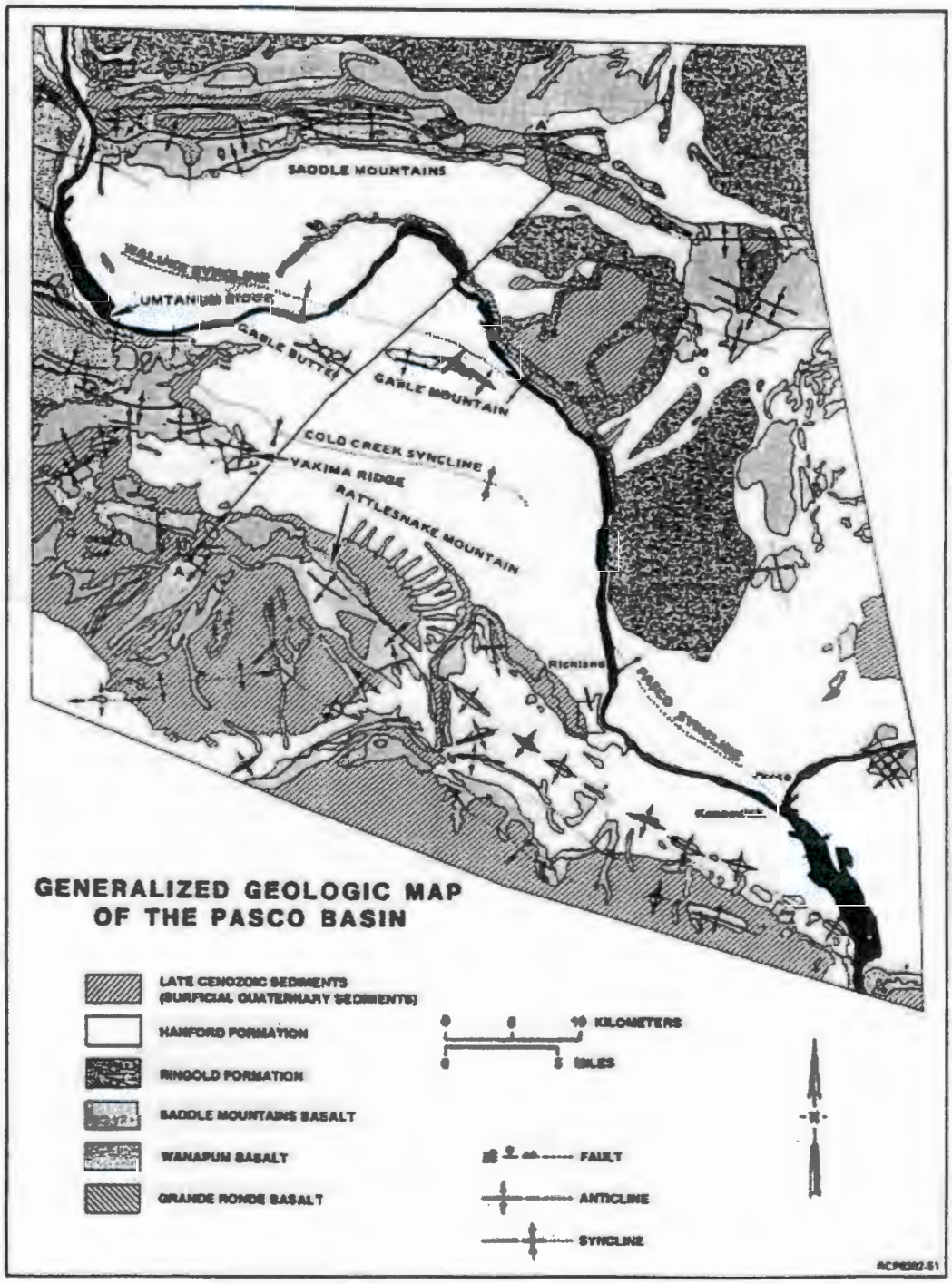
All post-Columbia River Basalt sediments (including strata now assigned to the Ringold) that occur on the central Columbia Plateau and in the eastern foothills of the southern Washington Cascades were originally assigned to the Ellensburg Formation by Smith (1901). Smith's stratigraphy was later modified by Merriam and Buwalda (1917), who assigned the fine-grained terrigenous clastic sediments exposed near Pasco, Washington and on the White Bluffs to a new unit, the Ringold Formation. Culver (1937) later mapped the Ringold Formation across the central Columbia Plateau. Both Merriam and Buwalda (1917) and Culver (1937) restricted their definition of the Ringold Formation to strata exposed at the surface.

With the establishment of the Hanford Site and increased agricultural activity in the early 1940's, numerous wells were drilled for water production, groundwater analysis, and geologic investigations. Data from these wells revealed a thick sequence (up to 175 m) of clay, silt, sand, and conglomerate overlying the Columbia River Basalt throughout the Pasco Basin. Drilling also indicated that these subsurface sediments were contiguous with Ringold exposures in the White Bluffs (Newcomb 1958). Using subsurface data and surficial exposures, Newcomb (1958) redefined the Ringold Formation to include all sediments in the Pasco Basin that overlie Columbia River Basalt and underlie Pleistocene glaciofluvial deposits.

3.3 AGE

The Ringold Formation originally was thought to be Pleistocene aged (Merriam and Buwalda 1917, Newcomb 1958, Grollier and Bingham 1971, Newcomb et al. 1972). However, detailed paleontologic investigations by Gustafson (1973, 1985) established that upper Ringold strata exposed on the White Bluffs are Pliocene aged. Paleomagnetic studies of core samples and upper Ringold exposures indicate a Miocene- to Pliocene-age range for the Ringold Formation (Packer and Johnson 1979). The Ringold Formation disconformably overlies Miocene-aged basalt dated at 8.5 to 10.5 Ma (Fecht et al. 1985). Webster and Crosby (1981) indicate Miocene pollen is present near the base of the Ringold.

Figure 4. Generalized Geologic Map of the Hanford Site. Ringold outcrops are mapped in the black-and-white mottled pattern. Note: Significant Ringold outcrops are not present on the Hanford Site (taken from Reidel et al. 1992).



Based on these data, Fecht et al. (1985) state that the Ringold Formation is no older than 8.5 Ma and no younger than 3.4 Ma, or late-Miocene to middle-Pliocene aged.

3.4 STRATIGRAPHY

The Ringold Formation (Figure 5), as currently mapped, is found throughout the Pasco Basin, between the Saddle Mountains and Moses Lake, Washington, and locally on the south side of the Horse Heaven Hills. Strata correlative to the Ringold Formation are found over a wide area between the Pasco Basin and Portland, Oregon (Smith et al. 1989). The most extensive of these units are the Snipes Mountain Conglomerate located between the Pasco Basin and Hood River, Oregon (Schminke 1964, Baker et al. 1987, Fecht et al. 1987, Anderson 1987, Smith 1988, Smith et al. 1989) and the Troutdale Formation between Hood River and Portland, Oregon (Tolan and Beeson 1984; Tolan et al. 1984a, 1984b).

Traditionally, the Ringold Formation in the Pasco Basin has been divided into several informal units. These units are (1) gravel, sand, and paleosols of the basal unit; (2) clay and silt of the lower unit; (3) gravel of the middle unit; (4) mud and lesser sand of the upper unit; and (5) basaltic detritus of the fanglomerate unit (Newcomb 1958, Newcomb et al. 1972, Myers et al. 1979, Tallman et al. 1979, Bjornstad 1985, DOE 1988). Ringold strata also have been divided on the basis of facies types (Tallman et al. 1981) and fining upward sequences (PSPL 1982). All of these stratigraphic divisions are of limited use because they are defined over large areas based on limited information or defined in detail for relatively small areas (Lindsey and Gaylord 1990).

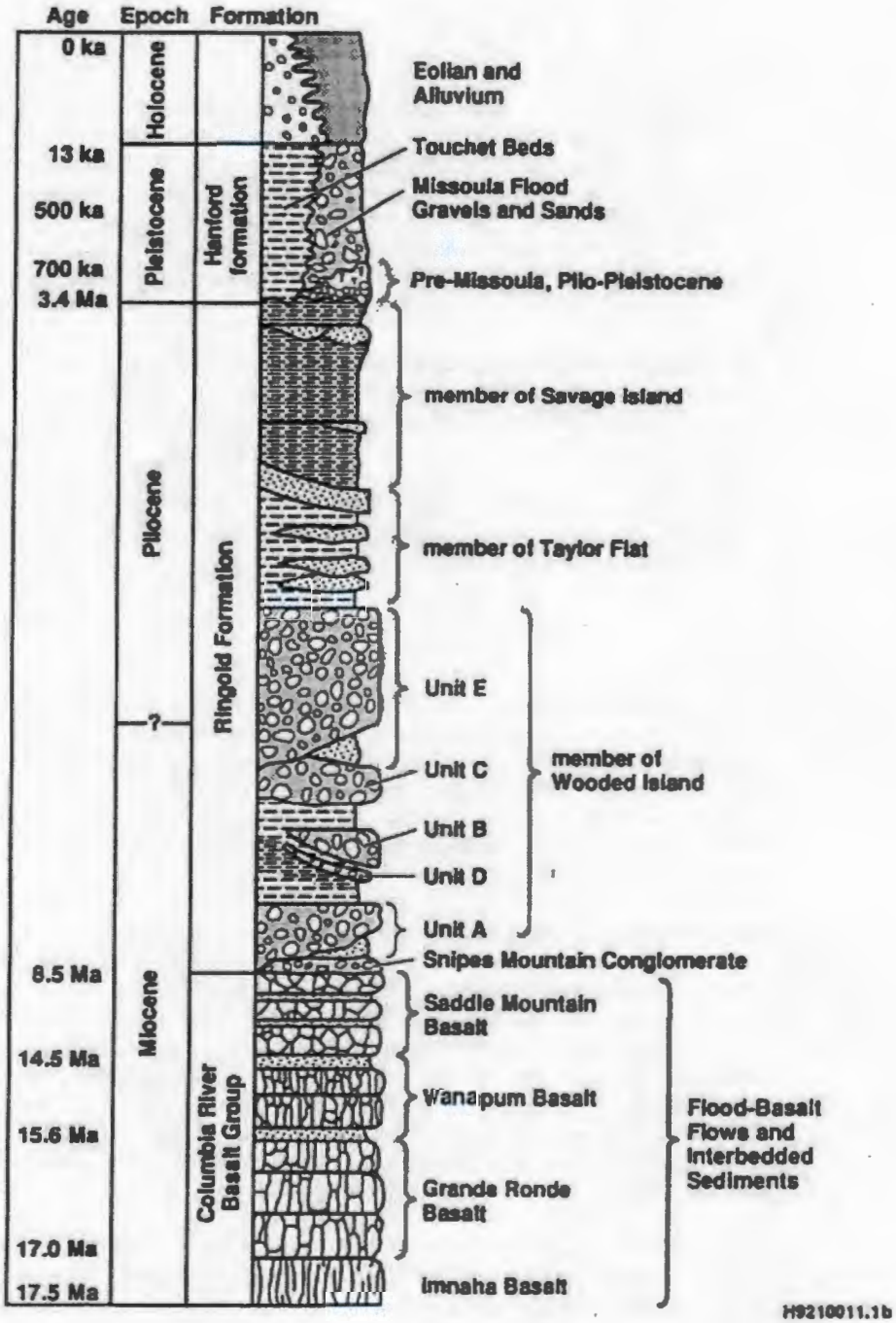
3.5 METHODS

In 1989 studies began to determine stratigraphic relationships within the Ringold Formation across the entire Hanford Site and Pasco Basin. The initial results of these studies indicated that the Ringold Formation is best described and subdivided on the basis of sediment facies associations and their distribution (Lindsey and Gaylord 1990; Lindsey 1991a, 1991b). Later studies confirmed and refined these interpretations for locations across the Hanford Site (Lindsey et al. 1991, 1992, 1994b; Lindsey and Jaeger 1993). This report presents a compilation of Ringold Formation geologic information for the Hanford Site and much of the surrounding area.

The data and interpretations presented in the remainder of this report are based largely on investigations carried out since January 1989. The primary data sources are (1) 29 measured sections from the White Bluffs (Appendix A), (2) detailed stratigraphic reconstructions based on these measured sections, (3) detailed lithologic logging of core from 28 boreholes on the Hanford Site (Appendix B), and (4) cutting-based borehole geologic logs and cutting samples from hundreds of boreholes on and near the Hanford Site. This data set is used to establish the basic geologic characteristics of the Ringold Formation, identify in detail the sedimentary facies comprising the Ringold Formation, and determine physical properties of Ringold sediments. In addition, the measured sections and cores are used to establish control points for stratigraphic interpretations and define analogues to use where core and outcrops are lacking.

The basic function of the analogues is to provide a basis of comparison for drill cuttings and cutting-based borehole logs to be evaluated against in order to determine probable subsurface geologic conditions. Conditions typically interpreted from cuttings with the aid of analogues include facies type, probable mud content, extent of interstratified lithologies, cementation and compaction, and

Figure 5. Late Neogene Stratigraphy of the Pasco Basin Emphasizing the Ringold Formation (column not to scale).



grain size range. Analogues, especially from outcrops, are used to better interpret lateral and vertical continuity of bedding and cementation in the subsurface. Use of analogues also allows identification of geologic properties fundamental to hydrologic interpretations that are otherwise incorrectly identified, or not identified at all, from borehole logs, cuttings, and the destructive sampling typical of Hanford Site drilling projects. The analogues also aid in determining sample representativeness in uncored boreholes. This is of critical importance because of the most commonly used sampling technique at the Hanford Site, driven split spoons.

Driven split-spoon sampling generates disaggregated and disrupted samples from the Ringold gravel, which is the dominant lithology in the suprabasalt aquifer. Data from such samples cannot be assumed to be representative (Reynolds and Lindsey 1994). Because of the use of inappropriate sampling techniques, characterization of the suprabasalt aquifer has been limited. The end result of this is an inability to predict accurately flow pathways and hydrologic conditions in Ringold gravels, the dominant lithology in the suprabasalt aquifer at the Hanford Site.

Additional data used to understand Ringold geology include previously published reports (referenced in text), borehole geophysics, and reconnaissance studies of Ringold correlative strata across the region. Borehole geophysics is used to verify formation and unit contacts. Reconnaissance studies provide additional analogues for interpreting geohydrologic characteristics.

4.0 SEDIMENT FACIES ASSOCIATIONS

Ringold strata are divided into five facies associations on the basis of sediment facies (Table 1) (such as defined by Miall 1977, 1978, and Rust 1978) observed in intact core and outcrops. Outcrops studied are on the Saddle Mountains, Yakima Ridge, White Bluffs, and Eureka Flat. Facies data from coreholes (Appendix B) and from drill cuttings and borehole geologic logs are from sites across the Pasco Basin. Supplemental regional data are taken from reconnaissance studies throughout the region and from previously published reports. The five Ringold facies associations are numbered I, II, III, IV, and V (Table 2).

4.1 FACIES ASSOCIATION I

Facies association I (Table 2) dominantly consists of clast- and matrix-supported, pebble to cobble gravel with a fine- to coarse-grained sand matrix (Figure 6). The degree of cementation in the facies association is variable, ranging from none to well developed. The main cements are calcium carbonate, iron oxides, and silica. Individual cemented horizons observed in outcrops generally are less than 1 m thick and rarely extend laterally more than 100 m. Evidence of cemented zones several meters thick and continuous laterally over several hundred meters can be identified from drill cuttings from several wells in the northern and southeastern part of the 200 West Area (notably wells 699-48-77A; 299-W6-3, -4, -5, -6, -7, -9, -10, -11, and -12; and W299-W7-6 and -8). Additional evidence of cementation also is found in Basalt Waste Isolation Project cores of Ringold gravel. Empirical data gathered from the wells cited above (e.g., color, hardness of drilling, well construction problems) suggest cemented intervals below the water table produce little or no water.

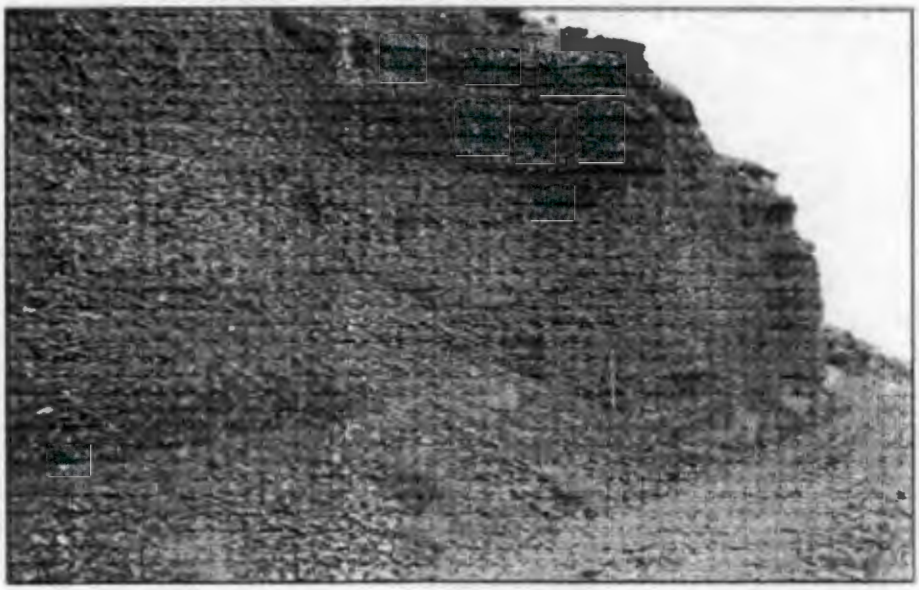
Table 1. Sediment Facies Types in Ringold Deposits (based on Miall 1977, 1978, 1985).

Facies Codes	Lithofacies	Stratification	Interpretation
Gms	Matrix-supported gravel	Massive	Debris flow deposit
Gm	Matrix- to massive to stratified clast-supported gravel	Planar to low-angle bedding 0.5 to 1.5 m thick, imbrication	Longitudinal bars, lag and sieve deposits
Gt	Matrix- to massive to stratified clast-supported gravel	Trough crossbeds up to 2 m thick, dominantly low angle	Minor channel fills
Gp	Matrix- to massive to stratified clast-supported gravel	Planar crossbeds 1 to 3 m high	Lingouid and transverse bars
Sm	Fine- to coarse-grained sand	Massive	Rapid deposition from suspension
St	Fine- to coarse-grained sand, minor pebbles	Trough crossbeds <1.5 m thick, average approximately 1 m	Dunes
Sp	Fine- to coarse-grained sand, minor pebbles	Planar cross-beds 10 cm to 1 m high	Linguoid and cross-channel bars, sand waves
Sr	Fine- to medium-grained sand, minor silt	Ripple cross-lamination	Current ripples
Sh	Fine- to coarse-grained sand, minor pebbles	Planar bedding	Planar bed flow
Sg	Silty fine-grained sand to coarse-grained sand	Normally graded beds displaying plane lamination and ripple cross-lamination	Sediment gravity flow deposits
Se	Erosional scours with intraclasts up to 3 m deep	Crude cross-bedding	Scour fills
Fl	Sand, silt, clay	Fine lamination, minor ripple cross-lamination	Waning flood and suspension deposition
Fsc	Silt, clay	Laminated to massive	Deposition from suspension
Fr	Silt, clay	Root and burrow traces, pedogenic structures	Paleosol
P	Calcium carbonate	Pedogenic structures	Paleosol

Table 2. Summary of the Characteristics and Depositional Environments of the Ringold Facies Associations.

Facies Association	Lithology	Facies	Stratification and Contacts	Bed Geometry	Depositional Environment
I	Clast-to matrix supported pebble to cobble gravel; fine to medium sand matrix; lenticular sand and silt interbeds	Gm, Gp, Gt, St, Fsc	Crudely defined Gm and low-angle Gt common; Gp locally well developed; contacts dominated by low-angle surfaces (<20°) scours <1.5 m deep and >10 m across	Gm forms lenses 0.5 to 1.5 m thick and <20 m across; Gm, Gt, and Gp form lenticular beds up to 5 m thick	Gravelly bedload deposition on braidplain dominated by shallow, shifting channels
II	Fine- to coarse-grained sand; locally pebbly; silty intervals common	Sp, St, Se, Sh, Sr, Sm	Lenticular Sp (<1 m thick) overlie scoured bases; Sh and Sr form planar sets and cosets; lenticular sands dominated by St, Sp, and Se; sheet-like sands consist of Sh and Sr; fines dominated by Sh and Sr	Channel-fills (1.5 m thick and up to 100 m across) combine to form sheet-like sand bodies <30 m thick and 0.5 km across; fines form tabular sheets that interfinger with or overlie channel fills	Sandy bedload deposition in low-sinuosity channels
IIIa	Brown to light gray, silty fine-grained sand to silt	Sr, Sh, Fl	Stratification moderately to poorly defined, disrupted beds common; mottled beds, root casts, and burrow fills locally well developed	Sands (dominated by Sr and Sh) form sheet-like and low-angle tabular intervals interfingered with associations I, II, IIIb, and IIIc	Proximal overbank, levee, and crevasse splay deposits
IIIb	Orange, red, and yellow tinted, silt to clay, rare local silty sand; peds, clay lumps, and pedogenic $CaCO_3$ also present	Fsc, Fr, P	Bedding usually disrupted; $CaCO_3$ (where present) forms irregular stringers, nodules, and concretions; root casts and burrow fills common; contacts are gradational	Form laterally persistent intervals 5 to 10 m thick; grades into and interfingers with IIIa and IIIc	Distal overbank and crevasse splay; paleosols
IIIc	$CaCO_3$ - rich clay, silt, and sand	Fr, P	Extensive $CaCO_3$; bedding very rare; root casts and burrow fills common	Laterally persistent intervals <5 m thick; grades into and interfingers with IIIb and IIIa	Calcic to silicic paleosol system
IVa	Clay, silt, and sandy silt; rare fine sand; diatomites present	Fl, Fsc, Sg	Fl form laterally persistent intervals containing normally graded intervals 2 cm to 1 m thick; contacts generally sharp and planar	Laterally continuous sand form coarsening up sequences 10 to 20 m thick; base of these commonly diatomaceous	Deposition from suspension and minor sediment gravity flow on lacustrine basin plain
IVb	Interbedded silt, silty sand, and fine- to medium-grained sand	Fsc, Fl, Sh, Sr, Sg	Laminated sand consisting of Sr, Sg, Fl, and Fsc commonly form tabular fining up beds <5 cm to 3 m thick that combine to form coarsening up intervals up to 10 m thick	Sheet-like geometries dominate; interfingers with IVa and less commonly II	Mixed deposition from suspension and by sediment gravity flow in front of prograding delta
V	Matrix and lesser clast- supported basaltic gravel with high mud content	Gms, Gm, Gp	Stratification usually lacking or poorly defined; rare Gp	Sheet-like tabular sheets dominate	Debris flow, sheet flood, and minor fluvial deposition in proximal to distal fan environment

Figure 6. Outcrop Photograph of Facies Association I. Photograph shows variable cementation (the discontinuous overhanging ledges) and grain size variations from sand to cobble rich. Jacob's staff is 1.3 m high. The outcrop is located on the eastern bank of the Columbia River opposite Wooded Island.



Wet sieve analyses of outcrop and intact core samples indicate that grain size distributions for Ringold gravel usually are bimodal (Tables 3a, 3b, and 3c). Generally, the facies association contains in excess of 67% by weight pebbles and cobbles, less than 5% by weight granules, and the remainder as medium- to fine-grained sand. Mud content is typically less than 5% by weight. This distribution differs notably from those reported from samples acquired by split-spoon sampling techniques (Last et al. 1989).

Split-spoon samples typically have lower pebble-cobble and higher granule content and contain broken pebble shards. This is the direct result of mechanical breaking of larger clasts during the driving of the sampler. The presence of broken clasts in split-spoon samples directly affects measurements for analyses requiring intact samples (e.g., hydraulic conductivity and density). Based on these recommendations, it is recommended that data acquired from analysis of split-spoon samples be used cautiously.

Gravel clasts in the association are dominated by weathered and unweathered basalt, quartzite, and intermediate to silicic volcanics (Table 4). Less common clast types include greenstone, volcanic and tectonic breccia, silicic plutonic rocks, gneiss, and mud rip-ups. Matrix sand typically is quartzo-feldspathic with a subordinate basalt fraction (Goodwin 1993) (Table 5).

Stratification ranges from massive (Gms) to planar bedded (Gm) to cross bedded (Gp, Gt). Clast imbrication is common in the stratified gravel. Low-angle cut-and-fill structures less than 1.5 m (4.9 ft) deep and at least 10 m (32.8 ft) across also are found. Facies Gms generally forms 0.5- to 1.5-m- (1.6- to 4.9-ft) thick lenses less than 20 m (65.6 ft) across that are interstratified with and grade into stratified gravels (Gp, Gt, Gm). These massive and stratified gravels commonly combine to form lenticular bodies up to 5 m (16.4 ft) thick that overlie the low-angle scours. Laterally discontinuous, fine- to coarse-grained, cross-bedded sand (Sp, St) interbeds up to 2 m (6.6 ft) thick (Figure 7) are intercalated in the gravel. The presence of these interstratified sands in the subsurface probably is the primary cause for gravelly sand lithologies commonly reported on borehole logs. Thin (usually <2 m), intercalated silty deposits displaying some mottling and bedding disruption also are present.

The features displayed by facies association I are similar to those described by Miall (1978, 1985), Rust (1978), Kraus (1984), Rust and Koster (1984), and Collinson (1986) for gravelly, bedload-dominated fluvial systems. The Ringold gravel depositional system was characterized by rapid deposition in shallow, shifting channels in braidplain settings.

4.2 FACIES ASSOCIATION II

Facies association II (Table 2) consists of fine- to coarse-grained (Tables 6a, 6b, and 6c), typically quartzo-feldspathic sand similar in composition to sand found in facies association I (Goodwin 1993). Intercalated silt and pebble beds may be present. The facies association typically is light tan to buff colored. Other colors include brown, red-brown, and yellow-brown. Salt-and-pepper colors may be present where basalt content is above approximately 20%.

Table 3a. Grain Size Distribution (wt%) for Ringold Unit E.
Samples from core.

Borehole #, Depth (ft)	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
DH-6, 178	0	74	2	0	0	9	8	5	2
DH-6, 213	0	73	1	1	1	12	8	4	0
DH-6, 227	0	82	1	5	4	4	3	1	0
DH-6, 240	0	71	1	0	1	14	12	1	0
DH-6, 270	0	64	2	1	1	8	13	11	0
DH-6, 313	0	82	4	2	2	4	3	3	0
DH-6, 316	0	73	2	4	3	12	3	2	1
DH-6, 330	0	72	1	2	1	12	8	4	0
DH-6, 393	0	72	2	4	4	12	4	2	0
DH-6, 399	0	69	3	5	4	13	5	1	0
DH-12,243	0	88	2	1	1	2	4	1	1
DH-12,285	0	76	1	1	3	12	5	1	1
DH-12,342	0	75	2	2	1	9	7	2	2
DH-12,378	0	71	2	4	3	10	6	1	3
DH-12,412	0	79	1	3	4	10	2	1	0
DH-13,284	0	88	0	0	1	3	6	2	0
DH-13,330	0	84	2	0	0	9	3	2	0
DH-13,347	0	87	2	2	2	2	3	2	0
DH-13,389	0	77	2	3	4	9	5	0	0
DH-13,398	0	80	1	4	5	8	2	0	0
DH-13,419	0	74	3	3	4	11	5	0	0
DH-13,438	0	75	1	2	2	7	7	6	0
DH-28,308	0	80	6	2	2	6	2	1	1
DH-28,429	0	79	2	1	1	9	5	3	0
DH-28,450	0	76	5	3	3	7	2	4	0
DH-28,461	0	78	4	1	5	5	4	3	0
DH-28,543	0	78	1	2	2	13	2	2	0
MEAN	0	76.9	2.1	2.1	2.4	8.6	5.1	2.4	0.4
S.DEV.	-	5.8	1.4	1.5	1.5	2.5	2.9	2.3	0.8
RANGE	-	64-88	0-6	0-5	0-5	2-14	2-13	0-11	0-3

Table 3b. Grain Size Distributions (wt%) from Outcrops of Ringold Unit E at Taylor Flat.

Sample #	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
SC-1	27	44	0	2	2	21	3	1	0
SC-2	14	62	0	2	2	16	3	1	0
SC-4	23	63	0	0	1	8	4	1	0
SC-5	10	71	0	1	1	15	1	1	0
SC-6	8	82	0	0	0	7	2	1	0
SC-7	0	69	1	2	3	20	4	1	0
SC-10	0	81	1	1	1	12	3	1	0
SC-11	8	73	1	2	1	9	5	1	0
SC-12	6	79	0	1	1	9	3	1	0
SC-15	16	74	0	0	0	6	3	1	0
SC-17	26	67	1	1	1	2	1	1	0
SC-18	0	82	2	1	1	9	3	2	0
SC-20	0	87	1	1	1	8	1	1	0
SC-21	17	70	0	1	0	9	2	1	0
SC-22	33	57	1	1	0	6	1	1	0
SC-23	8	79	1	1	1	6	3	1	0
SC-24	0	86	0	1	1	7	4	1	0
SC-25	40	56	0	0	0	2	1	1	0
MEAN	13.1	71.2	0.5	1.0	0.9	9.6	2.6	1.1	0
S.DEV	12.4	11.6	0.6	0.7	0.8	5.4	1.2	0.2	-
RANGE	0-40	44-87	0-2	0-2	0-3	2-21	1-5	1-2	-

Table 3c. Grain Size Distribution (wt%) for Ringold Unit A.
Samples from core.

Borehole #, Depth	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
DH-6, 438	0	77	2	5	6	6	2	2	0
DH-6, 448	0	78	3	3	4	6	4	2	0
DH-6, 455	0	70	5	2	2	11	7	3	0
DH-6, 464	0	67	3	4	4	12	6	4	0
DH-6, 473	0	76	3	4	3	9	3	2	0
DH-6, 503	0	78	3	4	5	7	3	0	0
DH-13,483	0	71	0	3	3	18	4	1	1
DH-13,498	0	63	0	5	6	11	12	2	1
DH-13,524	0	55	2	7	9	21	4	2	0
MEAN	0	71	2.3	4.1	4.7	11.2	5.0	2.0	0.2
S.DEV.	-	7.9	1.6	1.4	2.1	5.2	3.0	1.1	0.4
RANGE	-	55-78	0-5	2-7	2-9	6-21	2-12	0-4	0-1

Table 4. Percent Distribution of Clast Types in Ringold Unit E.

LOC	BSLT	POR	GBHC	SIV	SIP	VP	QTZ	GNS
PL12	25	9	9	10	11	13	20	2
PL13	28	21	10	11	5	6	16	3
PL11	21	16	9	16	11	7	17	4
PL14	28	11	10	16	9	7	18	1
PL9	30	10	5	22	8	4	18	2
PL6	30	15	10	16	7	7	14	2
PL15	27	18	8	13	10	7	15	1
PL16	43	15	9	13	4	3	12	1
PL10	40	7	10	10	12	5	15	1
PL4	44	2	10	10	12	4	15	2
PL1	57	9	6	7	6	3	10	2
PL17	32	13	11	10	13	7	12	1
PL18	61	13	10	7	4	1	3	1
PL8	75	2	5	4	1	2	10	1
PL5	36	5	16	13	9	5	14	1
PL7	70	8	7	4	1	2	6	0
PL3	70	2	4	5	3	0	13	3
PL2	74	1	6	2	6	2	9	1

NOTE: Lines are arranged in stratigraphic order (oldest at the bases). See Appendix A for location and stratigraphic position of specific samples.

LOC - sample number/location
BSLT - total basalt
POR - porphyritic volcanics (nonsiliceous)
GBHC - greenstone + breccia + hornfels + chert + meta seds
SIV - silicic volcanics (also flow banded tuffs)
SIP - silicic plutonics
VP - vein quartz + pegmatite
QTZ - quartzites
GNS - gneiss

Table 5. Whole Rock XRD Analysis of Ringold Unit E Sands from Coreholes near the 100-N and 200 West Areas.

Sample[a]	%qtz	%kspar	%plag	%carb	%amph	%mica	%clay
BH16/60	43	10	33	0	2	2	10
BH16/70	57	0	29	0	2	2	10
BH16/90	45	11	37	0	2	1	4
BH16/97	43	13	32	0	1	1	10
BH17/55	30	0	37	0	17	3	13
BH17/60	37	7	20	2	5	3	6
BH17/70	38	7	42	0	3	2	8
BH17/75	43	0	41	0	5	2	9
BH17/90	51	9	27	0	4	1	8
BH17/200	39	7	18	6	4	6	20
DH25/194.5	42	5	36	NA	1	2	13
DH25/391.5	55	7	18	NA	1	1	17
DH24/115.5	50	10	27	0	1	2	10
DH24/152.7	50	8	27	0	2	3	10
DH24/271.5	40	9	15	26	1	1	8
DH24/366	51	9	31	0	2	1	7
DH24/397	54	9	20	0	2	5	10
DH24/419.5	66	0	20	4	2	1	7
DH22/297	53	7	23	0	0	2	15
DH22/415.5	55	0	24	0	2	2	17
G73/302.5	69	1	10	0	0	1	20
G73/323	68	5	11	0	0	2	14
G73/348	63	4	9	4	0	3	17
G73/352	62	3	5	3	0	6	21
MEAN	50.2	5.9	24.7	2.0	2.5	2.3	11.8
S.DEV.	10.5	4.0	10.4	5.6	3.4	1.5	4.8

[a]See Appendix B for specific location information.

Figure 7. Interstratified Sand and Gravel of Facies Association I. Gravelly sand reported on borehole logs probably consists of interbedded sand and gravel such as seen here. Outcrop is located on bluffs along the eastern bank of the Columbia River opposite Wooded Island.

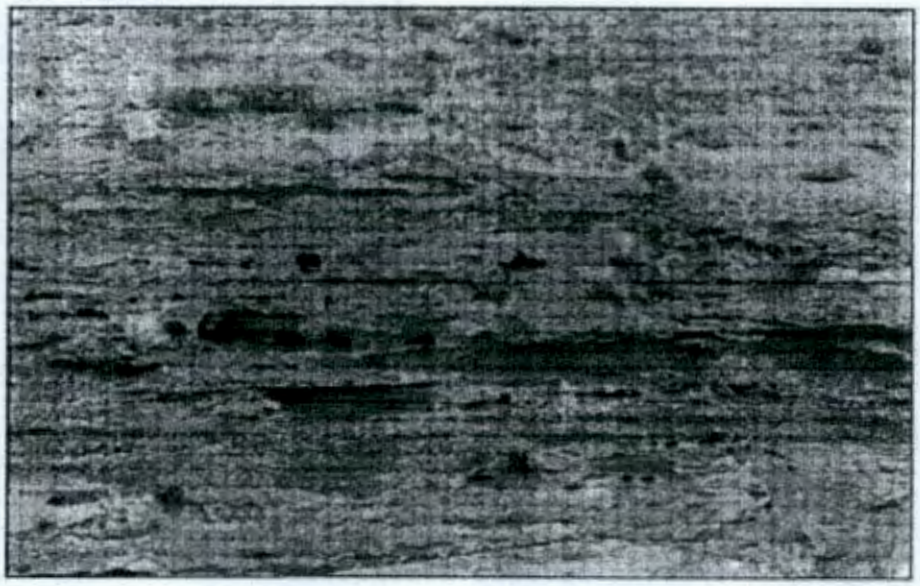


Table 6a. Grain Size Distribution (wt%) of Sand and Silty Sand Interbeds in Ringold Gravel (data acquired from core).

Sample[a]	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
DH-6, 269	0	2	4	39	42	9	4	0
DH-6, 370	0	16	18	28	16	6	13	3
DH-12,258	0	2	2	57	33	1	5	0
DH-12,369	0	6	5	49	32	4	4	0
DH-12,405	1	1	2	24	43	15	11	3
DH-13,263	0	1	1	15	49	15	16	3
DH-13,275	0	7	7	38	36	6	3	3
DH-13,280	0	6	7	74	7	1	5	0
DH-13,302	0	4	4	72	14	1	2	3
MEAN	0.1	5.0	5.6	44	30	6.4	7.0	1.7
S.DEV.	0.3	4.7	5.1	21	15	5.6	5.0	1.6
RANGE	0-1	1-16	1-18	15-74	7-49	1-15	2-16	0-3

[a]See Appendix B for specific location information.

Table 6b. Grain Size Distribution (wt%) of Sand and Silty Sand Interbeds in Outcrops of Ringold Gravel.

Sample[a]	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
SC-3	0	1	1	63	32	3	0	0
SC-8	0	12	12	64	9	1	2	0
SC-9	1	1	1	6	30	30	27	4
SC-19	0	4	4	20	50	18	4	0
MEAN	0.2	4.5	4.5	38	30	13	8.2	1.0
S.DEV.	0.5	5.2	5.2	30	17	14	13	2.0
RANGE	0-1	1-12	1-12	6-64	9-50	1-30	0-27	0-4

[a]See Appendix A for specific location information.

Table 6c. Grain Size Distribution (wt%) of Sand and Silt Bed Outcrops of the Lower Part of the Member of Taylor Flat. DH-6 is a core sample; others are outcrop samples.

Sample[a]	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
DH-6,137	0	3	4	26	19	10	15	3
SC-13	0	7	8	68	13	2	2	tr
SC-14	0	1	1	29	50	12	5	2
SC-26	0	1	1	69	25	2	2	tr
SC-27	1	2	3	21	48	20	7	tr
SC-28	0	0	1	40	51	5	3	tr
MEAN	0.17	2.3	3.0	42	34	8.5	5.7	-
S.DEV.	0.41	2.5	2.8	21	18	7.0	5.0	-
RANGE	0-1	0-7	1-8	21-69	13-51	2-20	2-15	-

[a]See Appendices A and B for specific location information.

Facies association II displays (1) sandy bedforms consisting of lenticular planar (Sp) and trough (St) cross-bedded sand overlying scoured bases (Se), (2) sandy bedforms consisting of tabular sheets and lenses of plane-laminated (Sh) to ripple cross-laminated (Sr) sand, (3) massive bedded fine-grained sand and silty sand (Sm), and (4) interstratified plane- and ripple-laminated silt and sand (Fl) (Figure 8). Deposits comprising the association commonly combine to form channel-fill sequences 1 to 5 m (3.3 to 16.4 ft) thick and up to 100 m (328 ft) across. These channel-fill sequences usually are stacked together to form sand bodies that are up to 30 m (98 ft) thick and 0.5 km (0.3 mi) or more across (Figure 9). Typical thickness-to-width ratios for these sand bodies are approximately 1:100.

Facies association II is interpreted to have been deposited in a sandy bedload-dominated fluvial system such as outlined by Cant and Walker (1976), Walker and Cant (1984), and Collinson (1986). The thickness-to-width ratios of the sand bodies indicate low-sinuosity channels similar to those outlined by Galloway (1985b). Avulsion and channel abandonment are recorded by fining upward transitions from this facies association to facies association III.

4.3 FACIES ASSOCIATION III

Facies association III is divided into three end members (IIIa, IIIb, IIIc) (Table 2), which grade into each other. The coarsest (IIIa) consists of sheets of slightly mottled and bioturbated, brown to light gray laminated sand and silt (Sr, Sh, Fl). Facies association IIIc consists of green to black, unstratified, crumbly weathering silt and clay displaying angular blocky peds, soil slickensides, and cohesive clay-rich lumps. Facies association IIIb displays features intermediate between IIIa and IIIc. Calcium carbonate is rare in facies association IIIa, while stage I and II calcium carbonate of Machette (1985) is found in facies association IIIb. Stage III, IV, and occasionally V calcium carbonate may be found in facies association IIIc. Silica cement also is occasionally found in facies association IIIc. Red-brown, massive, fine- to coarse-grained quartzo-feldspathic to slightly basaltic sand occasionally is also found in the association.

Facies association III formed in a floodplain-overbank environment where pedogenic alteration occurred. Facies association IIIa was deposited as crevasse splays in proximal overbank areas such as discussed in Bown and Kraus (1987), Kraus (1987), and Kraus and Bown (1988). Evidence of paleosols similar to that described by Collinson (1986), Kraus and Bown (1988), Miall (1978, 1985), and Retallick (1986, 1988) is seen in IIIb, which formed on the floodplain and subaerial surfaces that rarely, if ever, were submerged. The calcium carbonate-rich and silica-rich deposits of facies association IIIc are calcic and silicic paleosols.

4.4 FACIES ASSOCIATION IV

Stratified clay, silt, and sand divided into two end members (IVa and IVb) comprise facies association IV (Table 2). Laterally continuous, white diatomaceous clay gradationally overlain by gray, tan, and brown, laminated sandy silt (Fl) (Figure 10) dominates IVa. Facies association IVa grades upwards into gray, tan, and brown, plane cross-bedded sand (Sp); ripple cross-laminated sand (Sr); normally graded sand (Sg); and laminated sand, silt, and clay (Fl, Fsc) of IVb (Figures 11 and 12). Locally, facies association IVb has primary bedding dips of 5° to 10° (Figure 11). Bedding is dominated by sheet geometries continuous across tens to hundreds of meters of outcrop. Overall, strata comprising facies association IV form laterally continuous (>30 km across), coarsening upward sequences up to 40 m thick (Figures 11 and 12). Where the facies association has been encountered in the subsurface, gray to blue-gray colors predominate.

Figure 8. Facies Relationships in the Fluvial Sands (Facies Association II) of the Member of Taylor Flat. See Appendix A for locations of measured sections and Figure 12 for symbol explanation. Top of gravels corresponds to top of the Member of Wooded Island.

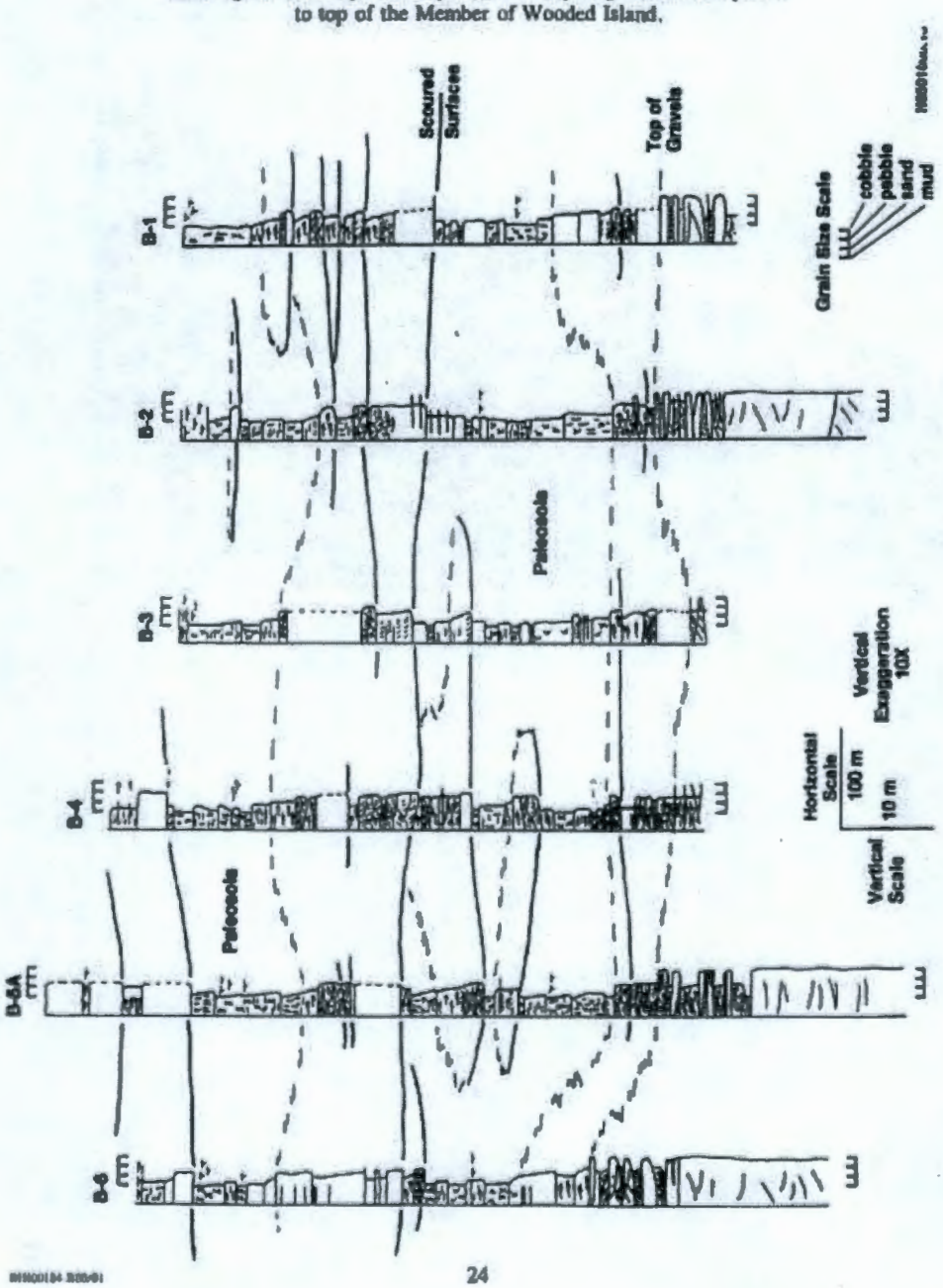


Figure 9. Facies Association II (the Three Prominent Ledges) Interbedded with Facies Association III (the Slopes). Each of the ledges consists of cross-bedded sand that fines upward and overlies a basalt scour incised into underlying strata. Jacob's staff (leaning against upper sand ledge on the right) is 1.3 m high. The outcrop lies on the eastern bank of the Columbia River opposite Wooded Island above the outcrop shown in Figures 6 and 7).

Figure 10. Closeup of Well-Stratified Diatomite (Association IVa) at the Base of One Lake-Fill Sequence. Darker colored strata near the top of the photograph are sand interbeds that mark the beginning of the coarsening upward transition from the diatomite (IVa) into clastic lake deposits (IVb). Jacob's staff is 1.3 m high. The outcrop is located approximately half way up the White Bluffs on the eastern side of the Columbia River approximately 2 km north of Savage Island.

Figure 11. Two Lake-Fill Sequences Consisting of Facies Association IV. The lower half of the slope (the darker colored area below the band of sagebrush in the middle of the slope) consists of paleosols of association III. The upper half of the slope consists of well-stratified silt and sand of facies association IV. Topographic relief between the bottom of the ravine and skyline is approximately 450 ft. The outcrop is located on bluffs east of the Columbia River and approximately 1 km north of Savage Island.

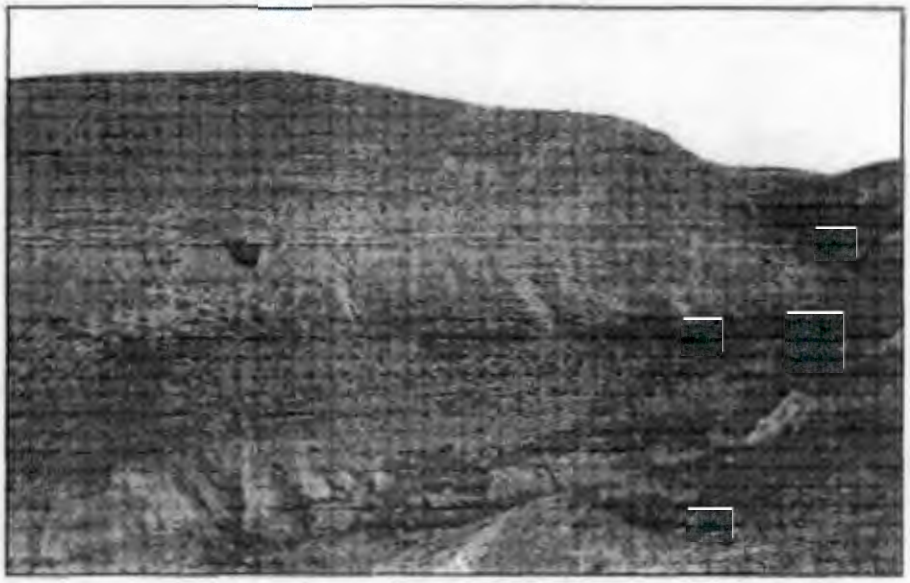
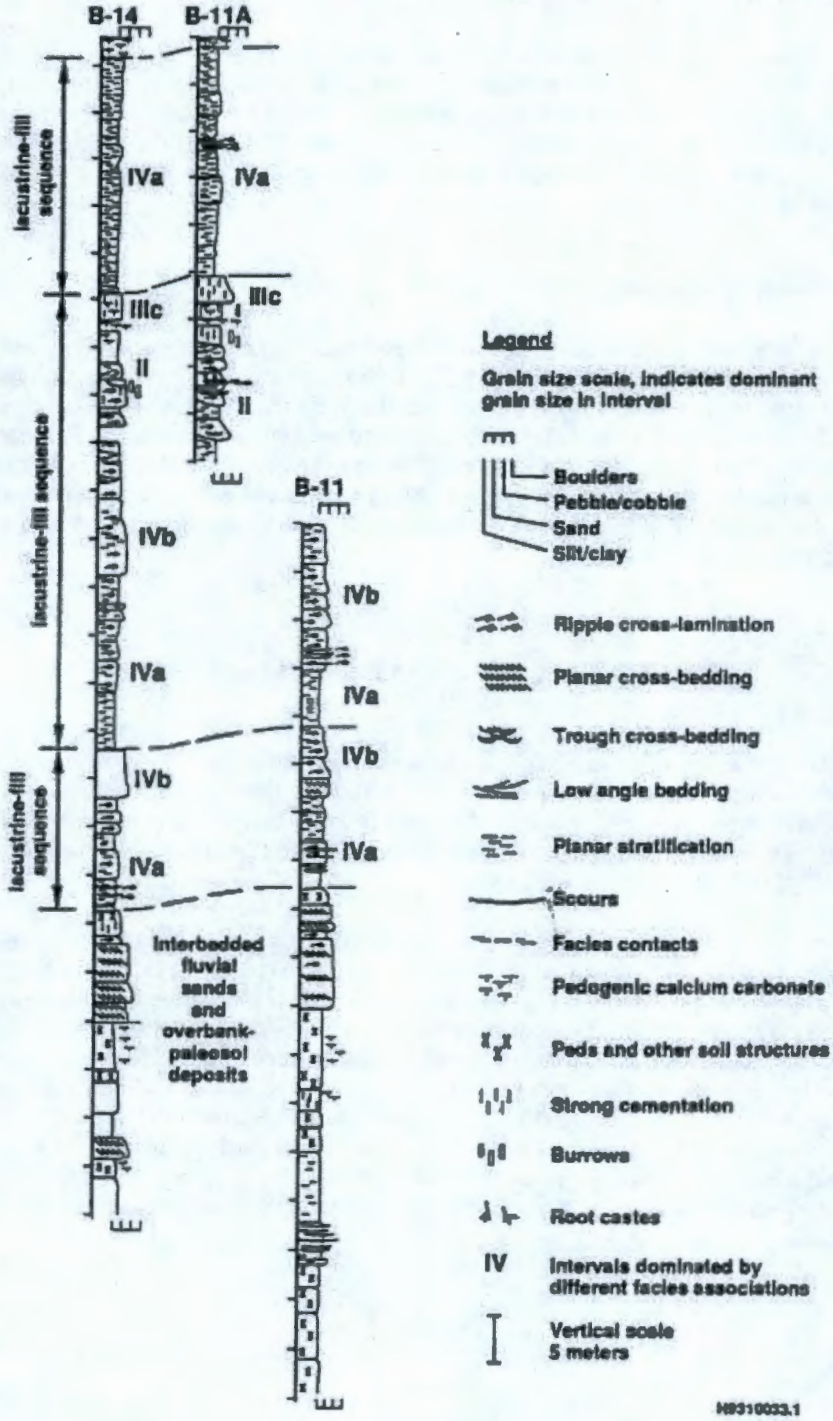


Figure 12. Measured Sections in Strata Typical of Facies Association IV. Sections show the vertical trends and characteristics of the association. See Appendix A for locations of measured sections.



Facies association IV was deposited in a hydrologically open lake such as described in Allen and Collinson (1986) with the diatomites (IVa) recording deposition in clear water, relatively distant from fluvial distributaries. Upward coarsening from IVa to IVb reflects increased detrital sedimentation as the result of fluvial-deltaic progradation.

This facies association, as well as the other mud-rich facies association (III), occurs in the subsurface as thick (>5 m) units as well as thin interbeds (see Chapter 5.0). Many borehole logs report gravelly mud for these intervals dominated by facies associations III and IV. Little evidence of gravelly mud lithologies can be found in intact cores or outcrops. In view of this and the quality of uncored samples, the presence of gravelly mud is probably the result of drilling and is not typical of facies association III or IV.

4.5 FACIES ASSOCIATION V

Massive to poorly stratified, weathered, basaltic pebble-cobble gravel (Gms, Gm) forming sheet-like bodies dominates facies association V (Table 2). Color is typically gray to black, and matrix varies from sand-sized basalt grains to clay. Stage I and II calcium carbonate development can be present. The abundance of facies Gms and Gm indicates deposition dominantly by debris flow processes such as described by Bull (1972), Rust and Koster (1984), and Galloway (1985a). Rare stratified horizons (Gp) were deposited by sheet flood and minor stream flow processes. Local pedogenic carbonate indicates that subaerial exposure occurred. Facies association V was deposited on alluvial fans that prograded into the Pasco Basin.

5.0 FACIES ASSOCIATION DISTRIBUTION

The Ringold Formation is divided into three informal members (Figure 5), each dominated by different facies associations. Data upon which the following discussion is based are found in Appendix A (outcrop measured sections), Appendix B (corehole logs), and Appendix C (basin-wide cross sections). Additional data are found in Appendix D (structure contour and isopach data) and the structure contour maps on Plates 1 through 6.

The majority of the lower half of the Ringold Formation is assigned to the member of Wooded Island. The member is divided into five stratigraphic units, designated A, B, C, D, and E, dominated by fluvial gravel (facies association I) (Appendices B and C). These units are separated by several widespread overbank/paleosol (facies association III) and lacustrine (facies association IV) intervals (Appendix C). The lowermost of these intervals, separating unit A from overlying deposits, is dominated by facies association IV and referred to as the lower mud unit. The second member, the member of Taylor Flat, is dominated by fluvial sands (facies association II) and overbank-paleosol deposits (facies association III) (Figure 9 and Appendix A). It partially interfingers with the member of Wooded Island in the northern Pasco Basin where fluvial gravels pinch out (Appendix C). Strata dominated by lacustrine deposits (facies association IV) form the third member, the member of Savage Island (Appendix A).

5.1 MEMBER OF WOODED ISLAND

The member of Wooded Island is named for the gravelly strata located on the east bank of the Columbia River, adjacent to Wooded Island. The 30- to 50-ft-high cliffs at this location contain the best exposures of Ringold gravel to be found in the Pasco Basin. The lowermost deposits of the member of Wooded Island and the Ringold Formation are the fluvial gravel and lesser fluvial sand of unit A. Unit A forms an elongated tract extending from Sentinel Gap to the east end of Rattlesnake Mountain (Plate 1). This tract crosses the Umtanum Ridge anticline at or west of Gable Mountain. Fluvial sands dominate the lower part of the unit in much of the western Pasco Basin (Appendix B). Similar sands also are exposed in Sunnyside Gap in the southwest corner of the Pasco Basin. Unit A is younger than 8.5 Ma, the age of the youngest CRBG flow underlying the Ringold Formation (Fecht et al. 1987), and older than 6.7 Ma, the approximate age of three tephra horizons (Table 7) in deposits overlying unit A. Quartz-feldspar-lithic ternary plots for unit A show higher quartz contents than the other gravel units (Goodwin 1993). In addition, volcanic lithics are less abundant (Goodwin 1993).

Unit A is overlain by a basin-wide sequence of fines consisting of a combination of paleosols (facies association III) and lacustrine deposits (facies association IV), referred to collectively as the lower mud unit (Appendices B and C). Paleosols are not found in the unit in the central Pasco Basin. The extent of interfingering between the lacustrine and overbank deposits is not known. Westward thinning sandy deposits of association IVb are present in the lacustrine strata in the east-central Pasco Basin. Argon-40/argon-39 determinations from tephra in lacustrine deposits in the central Pasco Basin yield ages of 6.62 ± 0.09 to 6.79 ± 0.13 Ma for the lower mud unit (Table 7). The lower mud unit underlies almost the entire Hanford Site and Pasco Basin (Plate 2). The only localities where it is clearly absent are the northern part of the 200 East Area, just north of the 200 West Area, and in the area between the 200 Areas and Gable Gap.

The lower mud unit is overlain in most areas by two fluvial gravel-dominated (facies association I) units, B and D (Appendices B and C), and associated overbank/paleosol deposits (facies association III). Unit B is found in the eastern to east-central Pasco Basin and thins to the west (Plate 3). Unit D is found locally in the southwestern Pasco Basin (Plate 3). It may be more extensive than currently mapped because the paleosols used to differentiate it from overlying gravel (units C and E) are discontinuous. Units B and D are absent in the Cold Creek Syncline south of the 200 Areas. In this area, overbank deposits and paleosols (facies association III) containing thin, fluvial sands (facies association II) overlie the lower mud unit. This corresponds to the easternmost extent of the sand-rich intervals in the underlying unit A and to a thinning in underlying CRBG flows described by Reidel and Fecht (1981).

The uppermost fluvial gravel-dominated units, C and E (Appendices B and C), are separated in the eastern Pasco Basin by a widespread overbank-paleosol system. In the western Pasco Basin, this intervening sequence is absent and the two units are not differentiated (Appendices B and C). Combined, the C/E interval forms a northwest to southeast linear tract stretching across the Pasco Basin (Plate 4). Basalt-rich gravels (facies association V) are found locally. Around the fringe of the Pasco Basin, especially to the north, strata laterally equivalent to units C and E consist mainly of muddy paleosols (IIIb) of the member of Taylor Flat. The C/E interval is older than 5.0 Ma (approximate age of overlying strata) (Packer and Johnson 1979). Strata near the top of unit E also have been assigned a late Hemphillian age (6.7 to 4.8 Ma) on the basis of vertebrate fauna (Gustafson 1985).

Table 7. $^{40}Ar/^{39}Ar$ Radiometric Dates for Ringold Sediments.

Borehole # / Depth (ft)	Isochron Age	Geologic Unit
Golder-E-19 / 621.7	6.79±0.13 Ma	Lower mud unit
Golder-73 / 273.9	6.62±0.09 Ma	Lower mud unit
DH-18 / 504.9	6.67±0.18 Ma	Lower mud unit

Source: $^{40}Ar/^{39}Ar$ Analysis of some Cenozoic ash/tuff samples: Final report of completed work to Rockwell Hanford Operations, Richland, Washington. Lewis G. Hogan, Ph.D., College of Oceanography, Oregon State University, Corvallis, Oregon 97331.

5.2 MEMBER OF TAYLOR FLAT

Approximately 90 m of interbedded fluvial sand (facies association II) and overbank fines (facies association III) forms the member of Taylor Flat (Appendix A). The member of Taylor Flat is named for the outcrops found above the prominent gravel-bearing cliffs at the north end of Taylor Flat on the east bank of the Columbia River. Outcrops of the member extend the length of the White Bluffs and are found on Eureka Flat (Figure 5). In the central to western part of the Pasco Basin (near the 200 West Area), most of the member has been removed by post-Ringold erosion, and all that remains is a thin (<15 m), discontinuous interval overlying unit E (Plate 5) (Appendix C). Where these thin erosional remnants occur, they are generally referred to as the Ringold upper unit (Myers et al 1979, Tallman et al. 1979, DOE 1988). Where the member of Wooded Island is absent in the northern Pasco Basin, paleosols of the member of Taylor Flat extend downward to the top of basalt (Appendix C). Consequently, the two members interfinger in the northern Pasco Basin. The member of Taylor Flat fines from south to north with sand being rare north of Gable Mountain. Based on vertebrate faunas (Gustafson 1985) and paleomagnetic data (Packer and Johnson 1979), the member is approximately 5.0 Ma where it overlies the member of Wooded Island. In the northern Pasco Basin (as well as elsewhere when the member of Wooded Island is absent), the member of Taylor Flat may be as old as 8.5 Ma.

5.3 MEMBER OF SAVAGE ISLAND

Lacustrine deposits (facies association IV) dominate the uppermost part of the Ringold Formation, the member of Savage Island (Appendix A). This member is named for the exposures found in and north of the Savage Island landslide on the east bank of the Columbia River. The member is approximately 4.8 to 3.4 Ma on the basis of paleomagnetic studies and vertebrate paleontology (Packer and Johnson 1979, Gustafson 1985, Fecht et al. 1987). Three successive lake-fill sequences are present in the member in the White Bluffs north of Ringold Coulee. South of Ringold Coulee, only two sequences are present. Each of the lake-fill sequences has a basal diatomaceous interval (facies association IVa) that grades upward into interstratified silt and sand (facies association IVb). The member has been almost completely removed by post-Ringold erosion from the central and western Pasco Basin west and south of the Columbia River (Appendix C). Small outcrops (<200 m^2) are found at a few locations at the northwestern base of Rattlesnake Mountain.

The lowest lake sequence is the most laterally restricted of the three lake-fill sequences and is only found in the northern to central White Bluffs north of Ringold Coulee (Appendix A). The lowest lake sequence interfingers to the southeast at and south of Ringold Coulee into fluvial and overbank deposits (facies associations II and III) of the member of Taylor Flat. These deposits in turn grade laterally into Salmon-Clearwater gravels of the member of Wooded Island found on Eureka Flat in the easternmost Pasco Basin. The basal diatomite for the lowest lake sequence is 0.5 to 1.0 m thick.

The second lake sequence is distinguished from the others by a thick (2 to 6 m) basal diatomite (facies association IVa) present throughout the eastern, central, and western Pasco Basin and by a capping fluvial-paleosol system (facies associations II and III). The diatomite coarsens upsection into sandy, well-stratified lacustrine deposits (facies association IVb). This well-stratified lacustrine silt and sand is in turn capped by a well-developed fluvial-paleosol system (facies associations II and III) that displays pedogenic calcium carbonate and silica development (facies association IIIc) and bioturbation extending up to 6 m into underlying strata (Appendix A).

The third lake sequence has a basal diatomite (facies association IVa) (<1 m thick), which grades upsection into well-bedded lacustrine sand and silt of facies association IVb. Post-Ringold stage IV and V pedogenic carbonate [of Machette (1985)], assigned to the informal Plio-Pleistocene unit, overlies and truncates the third lake sequence (Appendix A). This carbonate is interpreted to be correlative to the Plio-Pleistocene carbonate and silt overlying the Ringold Formation beneath the 200 West Area and the pre-Missoula gravels, which overlie the Ringold Formation southeast of the 200 East Area (Plate 6) (Appendix C).

5.4 LATE NEOGENE RINGOLD CORRELATIVES OUTSIDE OF THE PASCO BASIN

Strata assigned to the Ringold Formation also are found north of the Pasco Basin in the Quincy and Othello Basins (Reidel 1988). These strata consist of basaltic alluvial fan deposits, paleosols, lacustrine deposits, and minor fluvial sand [Packer and Johnson 1979, Reidel 1988, Smith et al. 1989, Campbell (unpub. data)] that probably are correlative to the member of Savage Island. Lacustrine deposits younger than 4.7±0.3 Ma, which make them correlative to the member of Savage Island, also are found near Yakima, Washington (Figure 4) (Smith 1988).

Post-CRBG quartzose sand and gravel, similar to that forming the member of Wooded Island, are found in a linear tract stretching from the western Pasco Basin to Hood River, Oregon (Schmincke 1964, Fecht et al. 1987, Smith 1988). Sand mineralogy and clast types in these clastics, the Snipes Mountain Conglomerate, are similar to those in unit A of the member of Wooded Island (Goodwin 1993). The Snipes Mountain Conglomerate is younger than 10.5 Ma, the age of the underlying Elephant Mountain Member of the Saddle Mountains Basalt. South of Satus Pass, the Snipes Mountain Conglomerate is overlain by the 4.5- to 1.0-Ma Simcoe Volcanics (Anderson 1987). The Snipes Mountain Conglomerate is at least in part correlative to unit A of the member of Wooded Island.

Additional Ringold-aged deposits are found west of the Snipes Mountain outcrops. Throughout the late Miocene and Pliocene, the Columbia River cut a series of canyons through the ancestral Cascade Range between The Dalles and Portland, Oregon (Tolan and Beeson 1984; Tolan et al. 1984a, 1984b; Beeson et al. 1989). The Troutdale Formation (<12 to 2 Ma) fills one of these paleocanyons (Tolan and Beeson 1984; Tolan et al. 1984a, 1984b). Tolan and Beeson (1984) divide the Troutdale Formation into a lower member dominated by Columbia River clastics (similar to Snipes Mountain

and Ringold sand and gravel) and an upper member dominated by ancestral Cascade-derived volcaniclastic sediments. An early Pliocene age of approximately 5 Ma is placed on this contact.

Ringold-aged sedimentary units also occur south of the Pasco Basin. These units are the Alkalai Canyon Formation in the Umatilla Basin and the correlative Mackay Creek Formation near Pendleton, Oregon. The Alkalai Canyon Formation ranges from less than 14.5 Ma (age of underlying Priest Rapids Basalt) to Late Hemphillian age (6.7 to 4.8 Ma) (Martin 1979, Farooqui et al. 1981). Locally derived basaltic gravel dominates the Alkalai Canyon Formation in the eastern Umatilla Basin and the Mackay Creek Formation (Farooqui et al. 1981). Quartzite-bearing mixed lithology gravel is common in the Alkalai Canyon Formation in the western Umatilla Basin, although lithologies indicative of the Columbia River are not present (Lindsey et al. 1993). The minimum age for the Alkalai Canyon Formation (4.8 Ma) indicates that it is older than the member of Savage Island.

6.0 TOP OF THE RINGOLD FORMATION

The nature of the contact between the Ringold Formation and overlying strata varies from location to location (Appendices A, B, and C). Marker strata of various kinds define the contact in the vicinity of the 200 West Area, between the Wye Barricade and the 200 East Area, and in parts of the 100 Areas. Beneath the northwestern part of the Hanford Site, in the vicinity of the 200 East Area, and in the southern Pasco Basin, distinctive marker strata are lacking. This chapter presents guidelines and criteria to be used to locate the top of the Ringold Formation.

The top of the Ringold Formation is easily recognized where distinctive marker strata are encountered. In the vicinity of the 200 West Area, marker strata are paleosols and quartzo-feldspathic fluvial sand comprising localized erosional remnants of the member of Taylor Flat overlain by pedogenic calcium carbonate and basaltic gravel and sand of the Plio-Pleistocene unit (Appendices B and C) (Tallman et al. 1979, 1981; DOE 1988; Last et al. 1989; Lindsey et al. 1991). Where the member of Taylor Flat is absent, the Plio-Pleistocene unit directly overlies unit E of the member of Wooded Island. Because the pedogenic calcium carbonate is commonly superimposed directly onto Ringold strata, the contact may appear transitional. Where this occurs, the contact generally is placed at the base of the lowest carbonate greater than 2 to 3 cm thick. Because individual carbonate beds are discontinuous, the contact will not be at the same horizon at every location.

The member of Taylor Flat also is found in the east-central Cold Creek syncline, between the 200 East Area and the Wye Barricade. Here, it is overlain by the quartzo-feldspathic sand and granitic to gneissic gravel of the pre-Missoula gravel (PSPL 1982) (correlative to the Plio-Pleistocene unit) (Appendices B and C). Near the fringes of the syncline, the member pinches out and pre-Missoula gravel directly overlies fluvial-gravel-dominated deposits of Ringold unit E (Appendices B and C). The abundance of granitic and gneissic clasts, a relative decrease in the percentage of basalt, lesser compaction and cementation, and a white to very light gray color distinguishes pre-Missoula gravel from more oxidized-appearing Ringold gravel.

Hanford formation gravel overlies Ringold paleosol-overbank deposits in the vicinity of the 100-H and 100-F Areas (Lindsey 1992, Lindsey and Jaeger 1993, Raidl 1993), as well as in the area east of the 200 East Area (Lindsey et al. 1992) (Appendix C). At these locations, basalt-rich sand and gravel of the Hanford formation are easily distinguished from pedogenically altered silt- and clay-rich

overbank-paleosol (facies association III) deposits of the Ringold Formation. North of Gable Mountain, this stratigraphic relationship persists throughout the area north and east of Gable Gap and as far west as the 100-D Area.

Gravelly Hanford deposits are less common southwest of the 200 East Area, where the formation is dominated by interstratified silt and sand. These strata, deposited by Pleistocene-aged cataclysmic flood water, are described in Last et al. (1989), Baker et al. (1991), and Lindsey et al. (1992, 1994b). Where these silty deposits overlie the Ringold Formation, they generally lie directly over Ringold gravel, making identification of the Ringold Formation relatively easy.

At and west of the 100-D Area and in the Gable Gap area (Lindsey 1992), as well as in much of the 200 East Area and surrounding vicinity (Lindsey et al. 1992, 1994b), Hanford gravel commonly overlies Ringold gravel. This situation also occurs throughout much of the Hanford Site south of the Wye Barricade (including the 300 and 1100 Areas). Where Ringold gravel is overlain by Hanford gravel, a variety of criteria, including mineralogy, grain size, compaction and cementation, and carbonate content, need to be examined to identify the contact. It is best to use these criteria together, because used alone, they may not prove to be diagnostic.

Matrix sand in Ringold gravel contains a higher proportion of quartz and feldspar versus basalt than Hanford formation matrix sand. In hand samples, Ringold sand usually contains less than 20%, basalt, is tan, brown, and reddish colored, and iron staining can be observed. This differs from Hanford formation matrix sand where gray colors dominate because of the high basalt content, typically greater than 50%. However, exceptions to this are found in parts of the 100-B/C, 100-K, and 100-F Areas where Hanford sand is generally quartzo-feldspathic, yielding a strikingly Ringold-like appearance. This mineralogy probably is due to the presence of Ringold rip-up material. Where this occurs, induration is a more useful tool for differentiating the two units.

Ringold gravel is partially to well indurated, while Hanford gravel usually is not. Evidence of this commonly can be found in drill cuttings and recorded drilling rates. Indurated Ringold gravel drill cuttings can consist of cemented conglomerate pieces and gravel clasts coated with sand and mica. Color changes to more red-browns, browns, and yellow-browns are commonly associated with cemented Ringold gravel. Drilling rates with cable tool rigs usually are lower when in Ringold gravels, and drilling is generally done using a hard tool rather than a drive barrel. The opposite usually occurs where air rotary drill rigs are used. Calcium carbonate rinds on gravel clasts are rare in Ringold gravel (even in cemented gravel), although they can be found on Hanford gravel.

Where intact core samples are recovered, grain size distribution also can be used to differentiate Ringold gravel from Hanford gravel. Ringold gravel, as previously discussed, generally has a bimodal size distribution (Tables 3a, 3b, and 3c), coarse sand (0.5 to 2 mm) and granules (2 to 4 mm) being rare in Ringold deposits. Examination of Hanford gravel reveals an abundance of granule-sized grains. In addition, the granules consist predominantly of basalt.

7.0 CONCLUSIONS

The Miocene-Pliocene Ringold Formation in the Pasco Basin and at the Hanford Site in south-central Washington consists of a variety of interstratified alluvial-lacustrine sediments. Ringold alluvial-lacustrine sediments comprise the majority of the suprabasalt "unconfined" aquifer at the Hanford Site. Previous work in the Ringold Formation was to generalize or localize to adequately document the character and distribution of these sediments across the entire Hanford Site. This document presents a stratigraphic interpretation for the Ringold Formation that fills that gap. The data presented here show that Ringold sediments can be grouped into five facies associations which, in turn, comprise three informal members.

The Ringold facies associations, I, II, III, IV, and V, are summarized as follows.

I. Fluvial gravel - Clast-supported and lesser matrix-supported pebble to cobble gravel with a sandy matrix characterizes the association. Localized intercalated sand and mud also are found. Clast composition is variable, with basalt, quartzite, porphyritic volcanics, and greenstone being the most common types. Sand in the association is quartzo-feldspathic. Low-angle to planar stratification; massive bedding; wide, shallow channels; and large-scale cross-bedding are found in outcrops. The association was deposited in a gravelly fluvial braidplain characterized by wide, shallow, shifting channels. Calcium carbonate, iron, and silica are present, but highly variable. This variability probably accounts for much of the variability seen in aquifer properties.

II. Fluvial sand - Quartzo-feldspathic sand displaying cross-bedding and cross-lamination dominates this association. Intercalated strata consist of lenticular silty sand and clay up to 3 m thick and thin (<0.5 m) gravels. Fining upward sequences less than 1 m to several meters thick are common in the association. Strata comprising the association were deposited in wide, shallow fluvial channels. Thin sand interbedded in gravel in the saturated zone is uncemented and caves into uncased borings.

III. Overbank-paleosol - This association dominantly consists of laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic calcium carbonate. Overbank-paleosol deposits occur as thin (<0.5 to 2 m) lenticular interbeds in the fluvial gravel and fluvial sand associations and also as thick (up to 10 m), laterally continuous stratigraphic sequences. These sediments record deposition on floodplains and the formation of paleosols.

IV. Lacustrine - Plane-laminated to massive clay with thin, ripple cross-laminated and normally graded silt and silty sand interbeds displaying some soft sediment deformation characterizes this association. Coarsening upward packages less than 1 to 10 m thick are common. Strata comprising the association were deposited in lakes under standing water to deltaic conditions.

V. Basaltic alluvium - Massive to crudely stratified, weathered to unweathered basaltic detritus dominates this association. These basaltic deposits generally are found around the periphery of the basin. The association records deposition by debris flows in alluvial fan settings and in sidestreams draining into the Pasco Basin.

Sediments comprising the Ringold Formation are divided into three informal members. The lowest member, the member of Wooded Island, contains five separate stratigraphic intervals, designated units A, B, C, D, and E, dominated by fluvial gravel. These units are separated by intervals containing deposits typical of the overbank-paleosol and lacustrine facies associations. The lowermost of the fine-grained sequences, overlying unit A, is designated the lower mud unit. The member of Wooded Island is overlain by the member of Taylor Flat, which is dominated by interbedded fluvial sands and overbank-paleosol deposits. Around the periphery of the Pasco Basin and in the northern Hanford Site, the member of Wooded Island pinches out, interfingering with the member of Taylor Flat. The third member, the member of Savage Island, consists dominantly of lacustrine deposits that are basin-wide in extent. This lacustrine package sharply overlies underlying deposits.

The contact between the Ringold Formation and overlying deposits varies across the Hanford Site. At many locations, especially in the 200 West Area and around the 100-H and 100-F Areas, marker strata are found. Where marker strata are absent, a variety of criteria are used. These criteria include mineralogy, compaction and cementation, and carbonate distribution.

It cannot be emphasized enough that the data and interpretations presented in this document are the result of an integrated study of outcrops, cores, and cuttings, and the available literature. Without such a study, much of the data necessary to begin to interpret the geologic characteristics that influence groundwater flow in the suprabasalt aquifer at the Hanford Site would not be available. This interpretation is especially important in utilizing to the greatest extent the voluminous drill cutting data sets available for the site.

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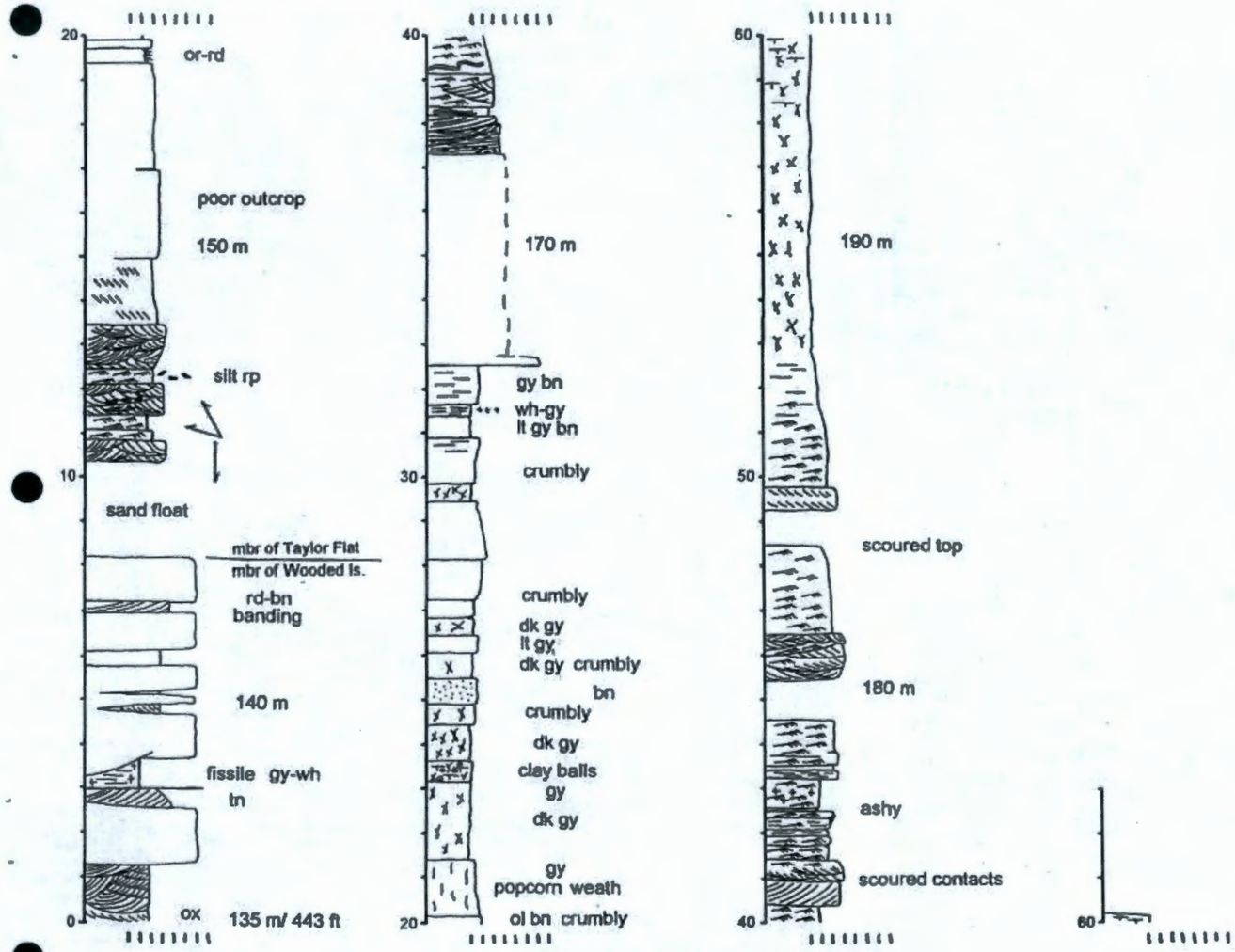
APPENDIX A
MEASURED SECTIONS FROM OUTCROPS

Sec B-1 Top Elev 640 ft (195 m)



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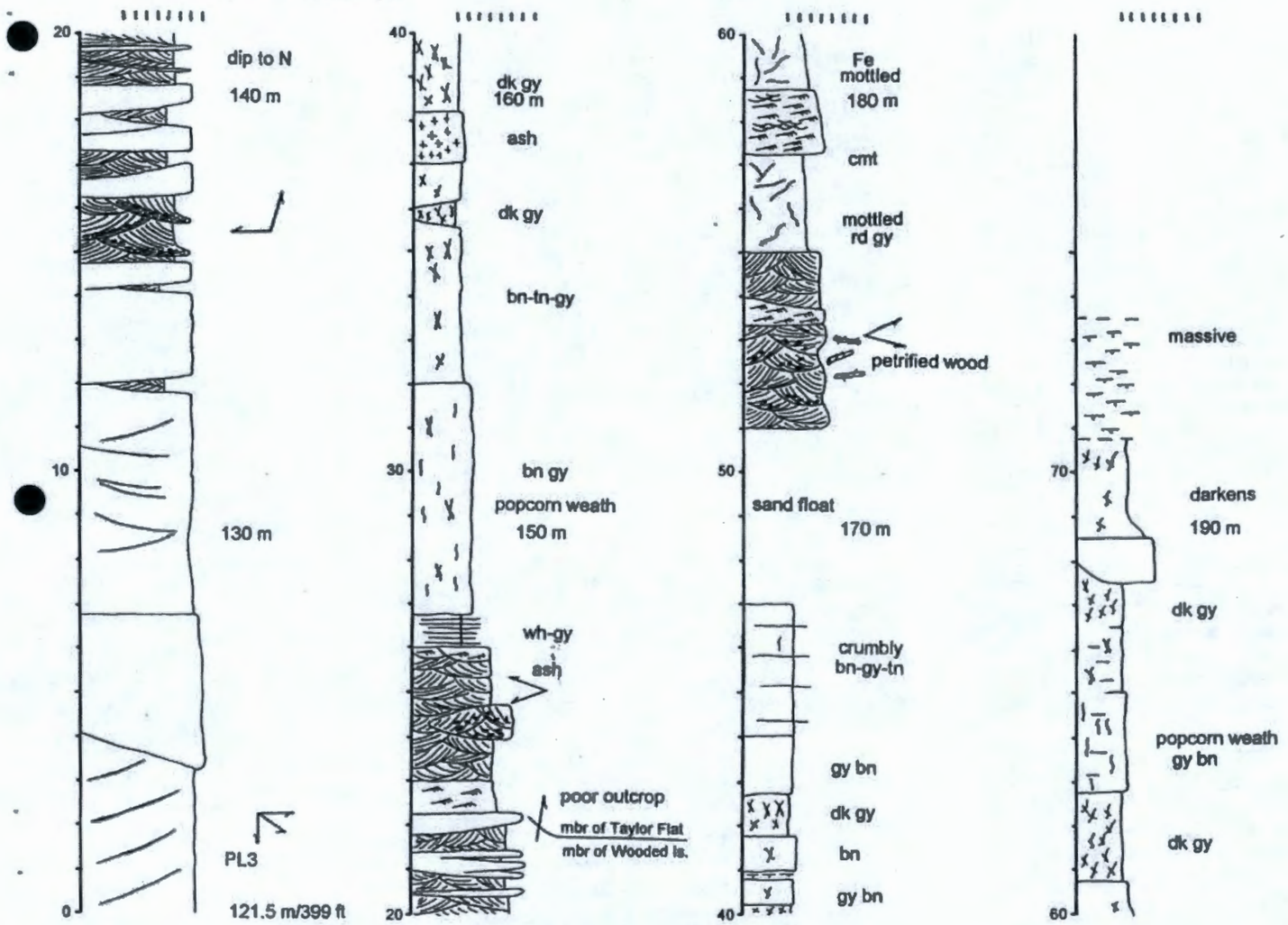

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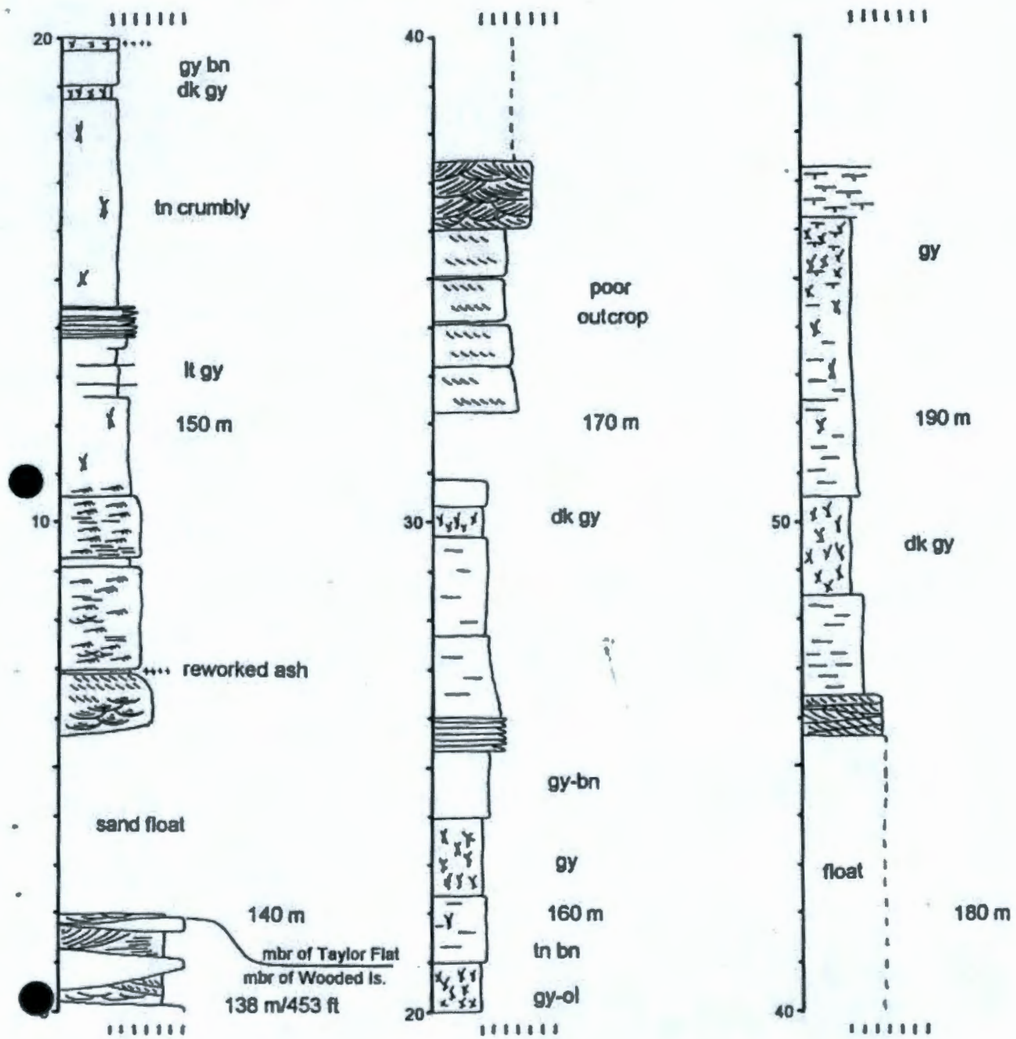
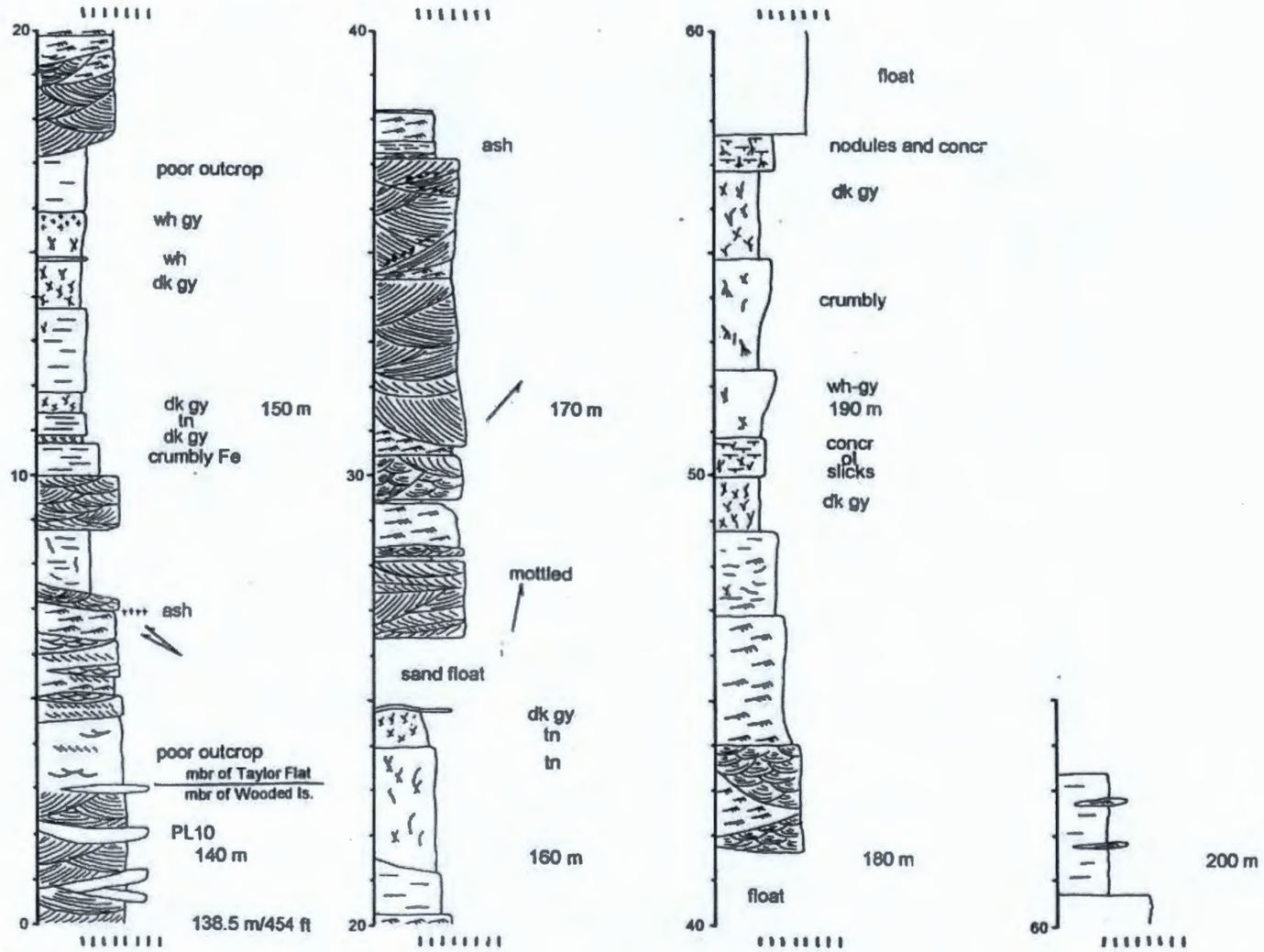
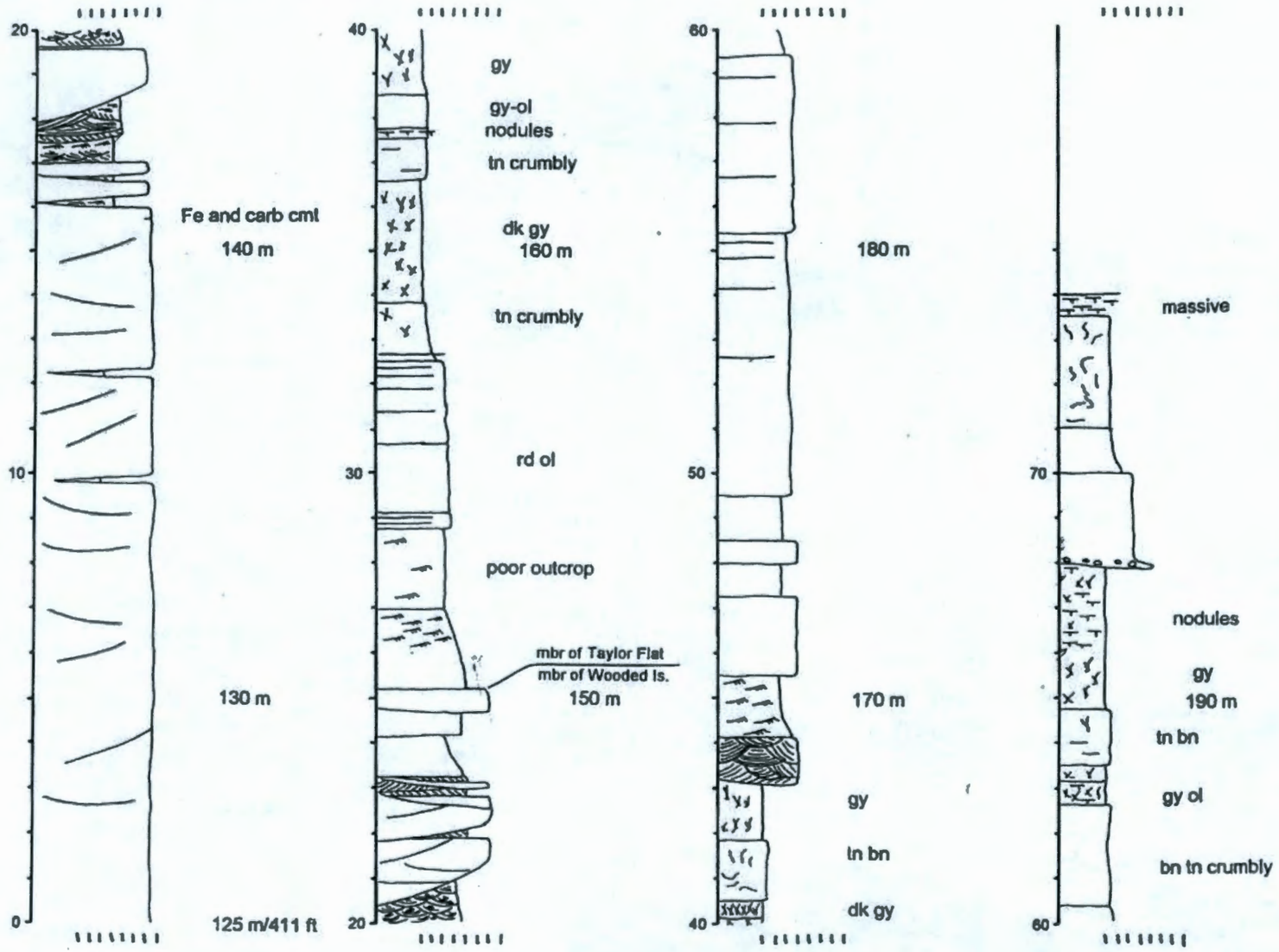


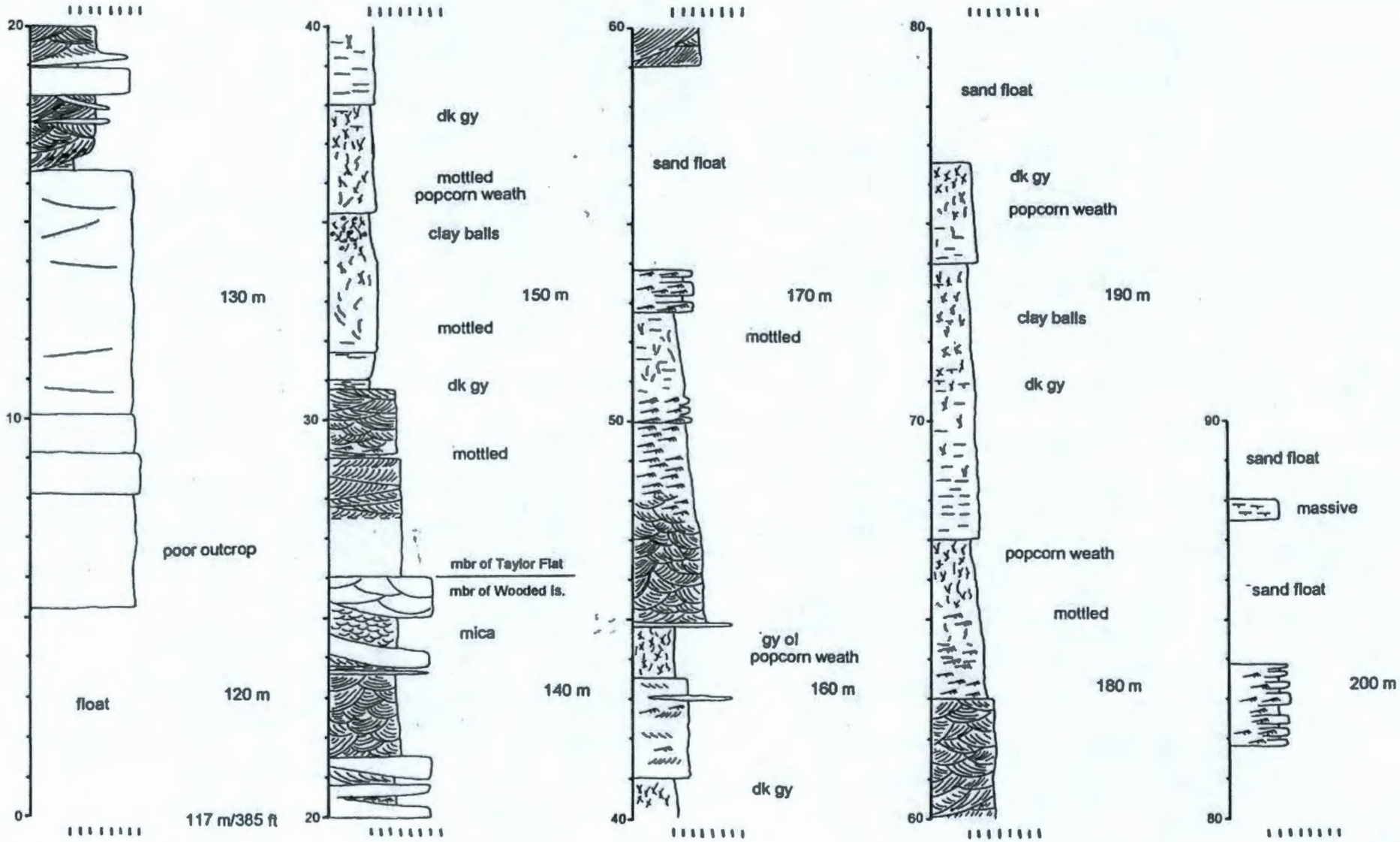
Sec B-4 Top Elev 661 ft (202 m)



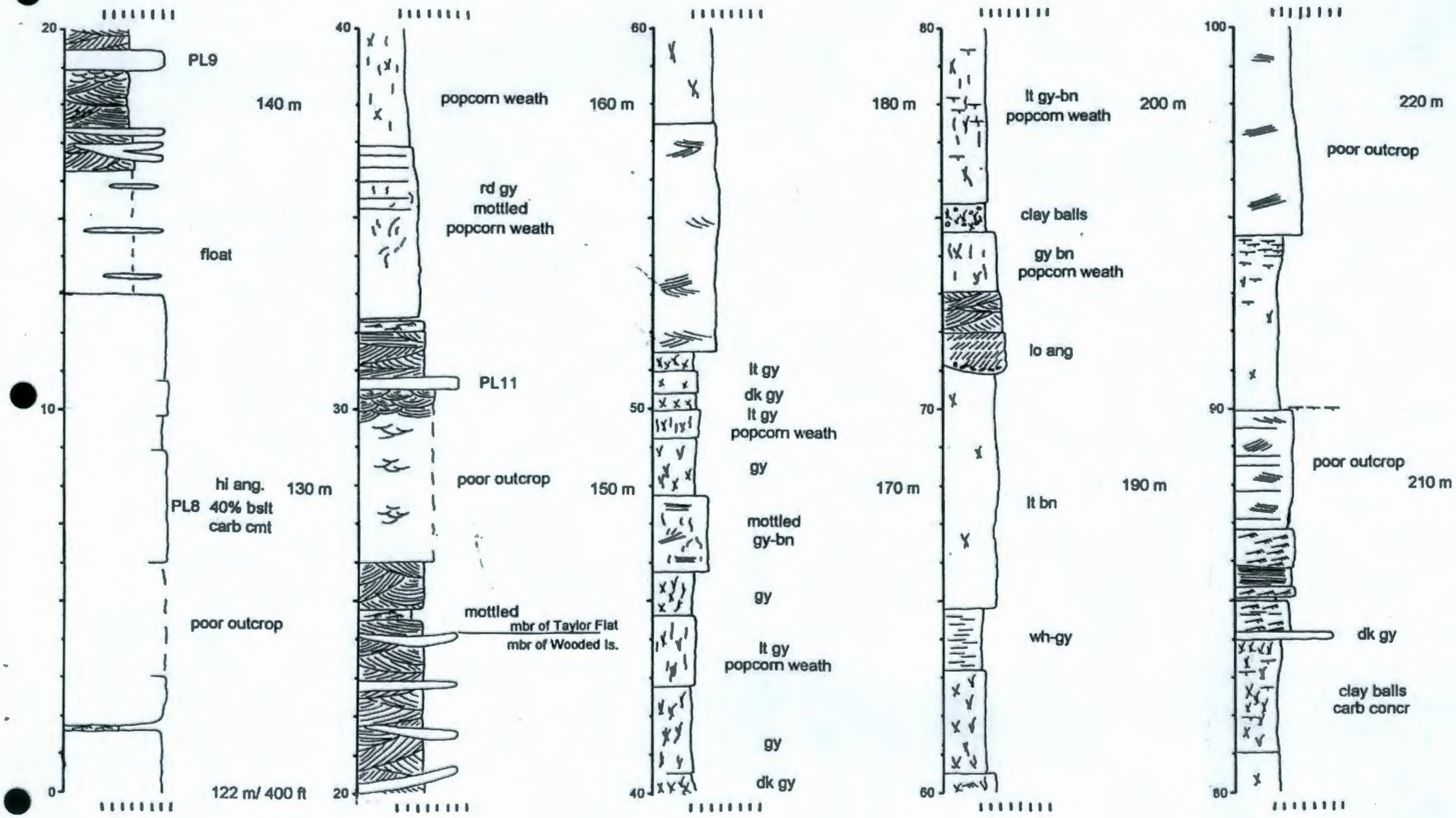
Sec B-5 Top Elev 653 ft (199 m)



Sec B-5A Top Elev 686 ft (209 m)



Sec. B-6 Top Elev 796 ft (243 m)



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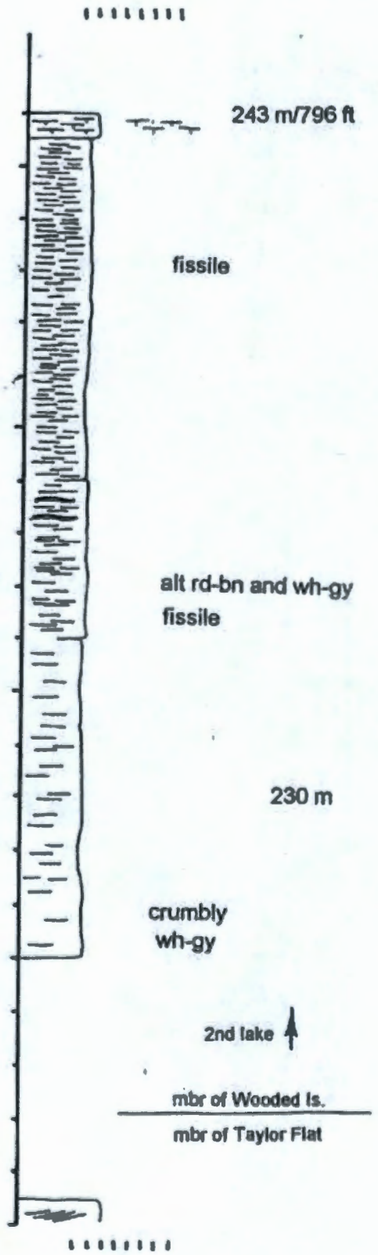
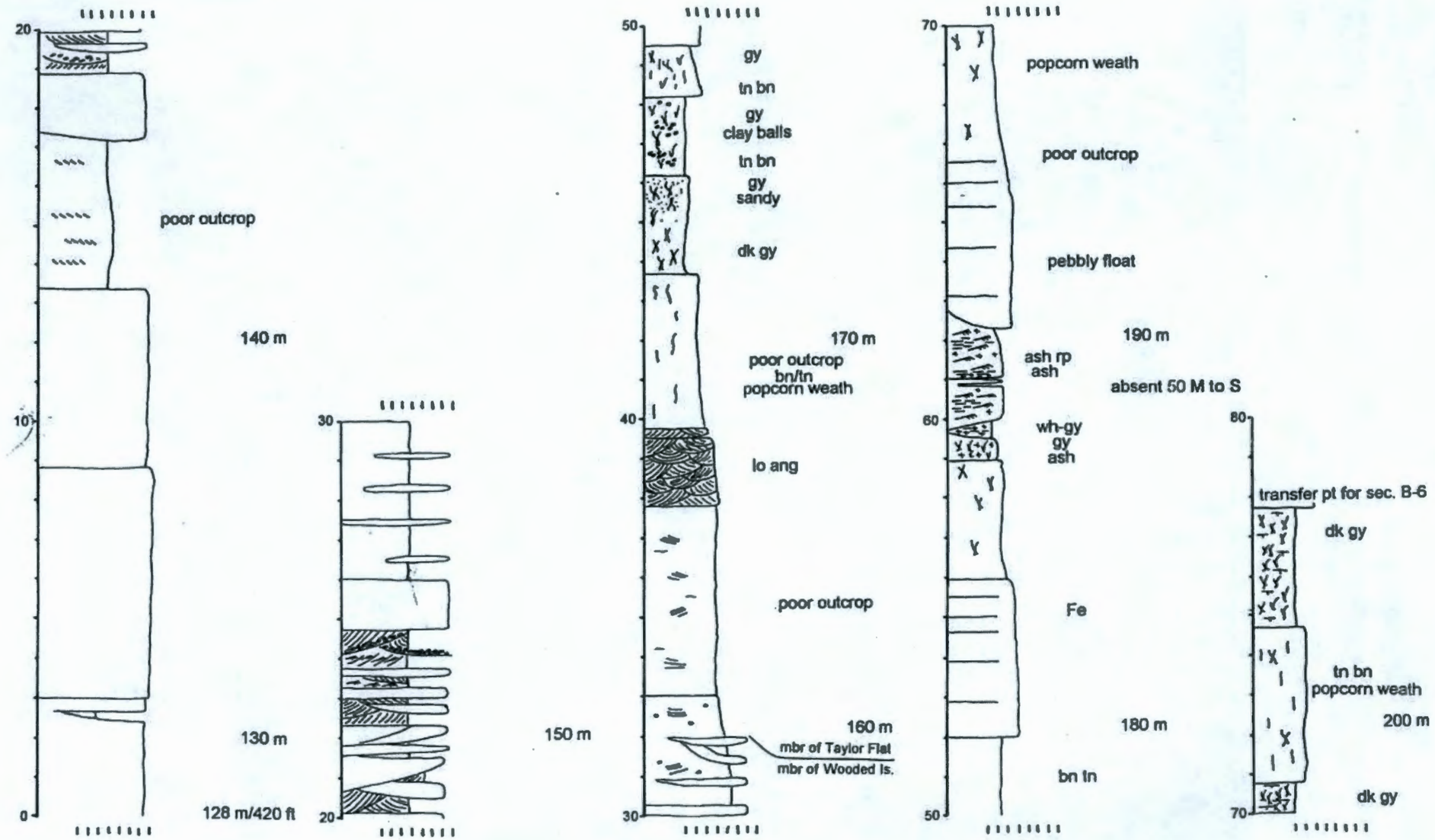
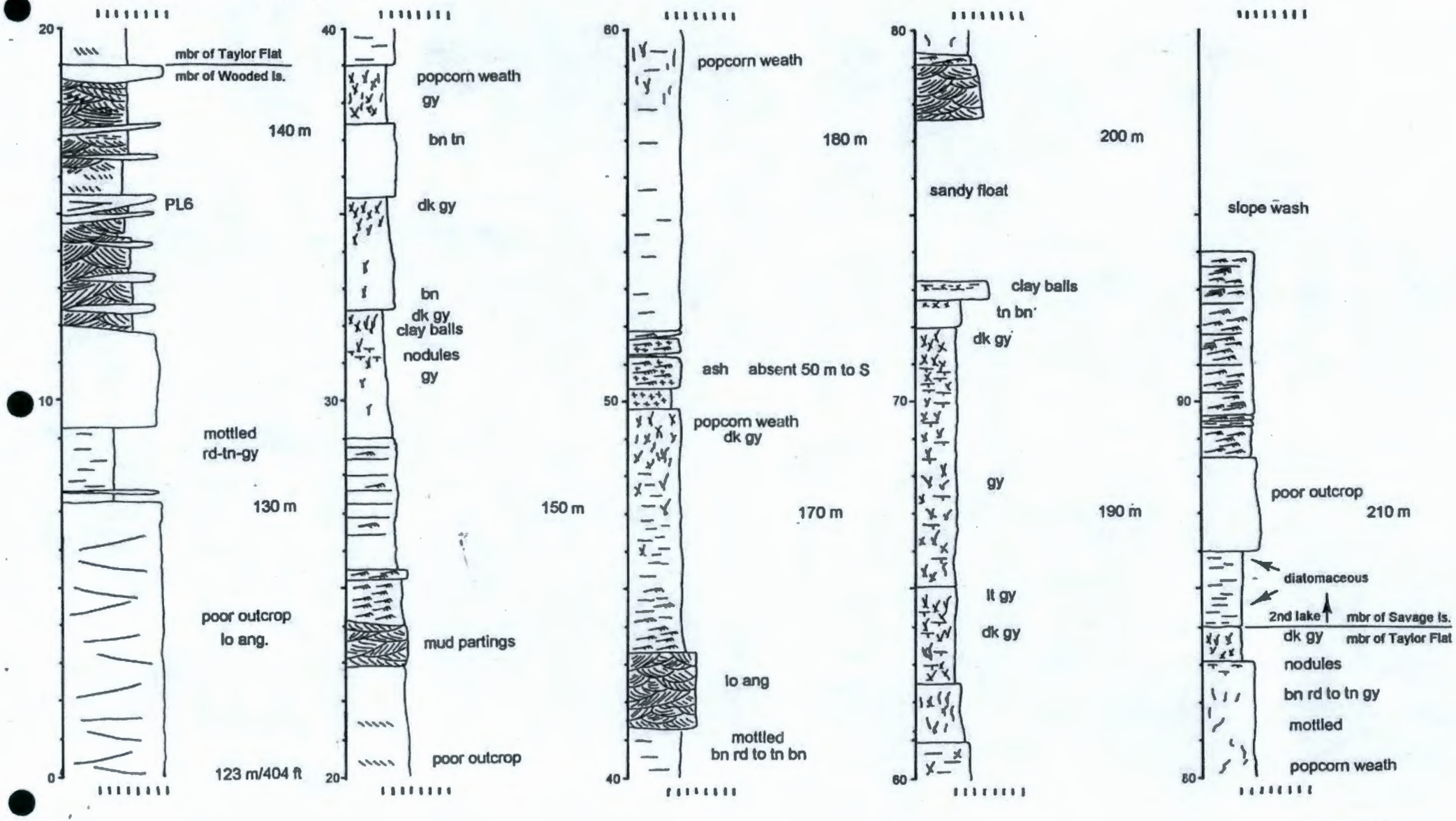

243 m/796 ft
fissile
alt rd-bn and wh-gy
fissile
230 m
crumbly
wh-gy
2nd lake
mbr of Wooded Is.
mbr of Taylor Flat

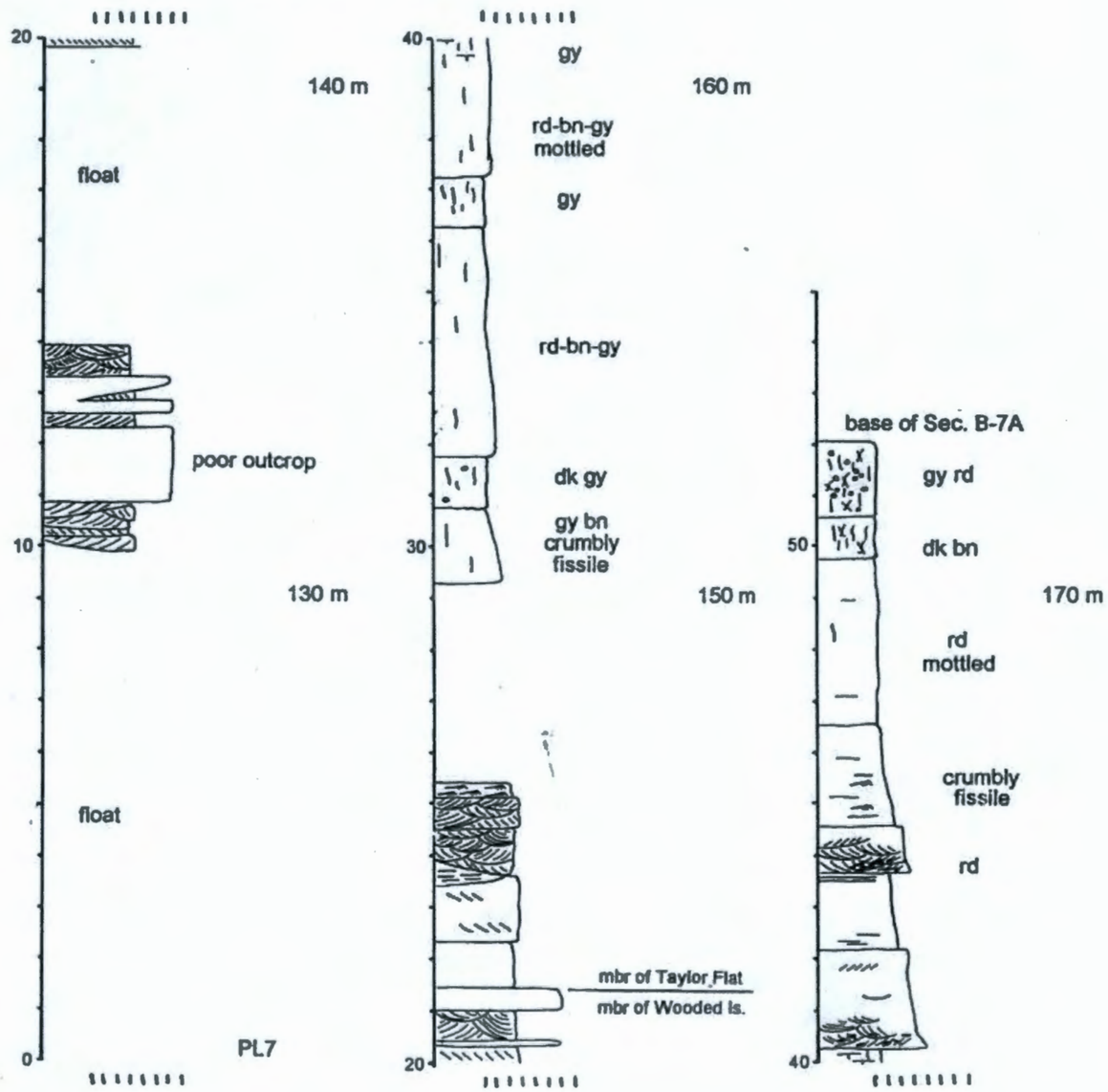
Sec. B-6A Top Elev 675 ft (206 m)



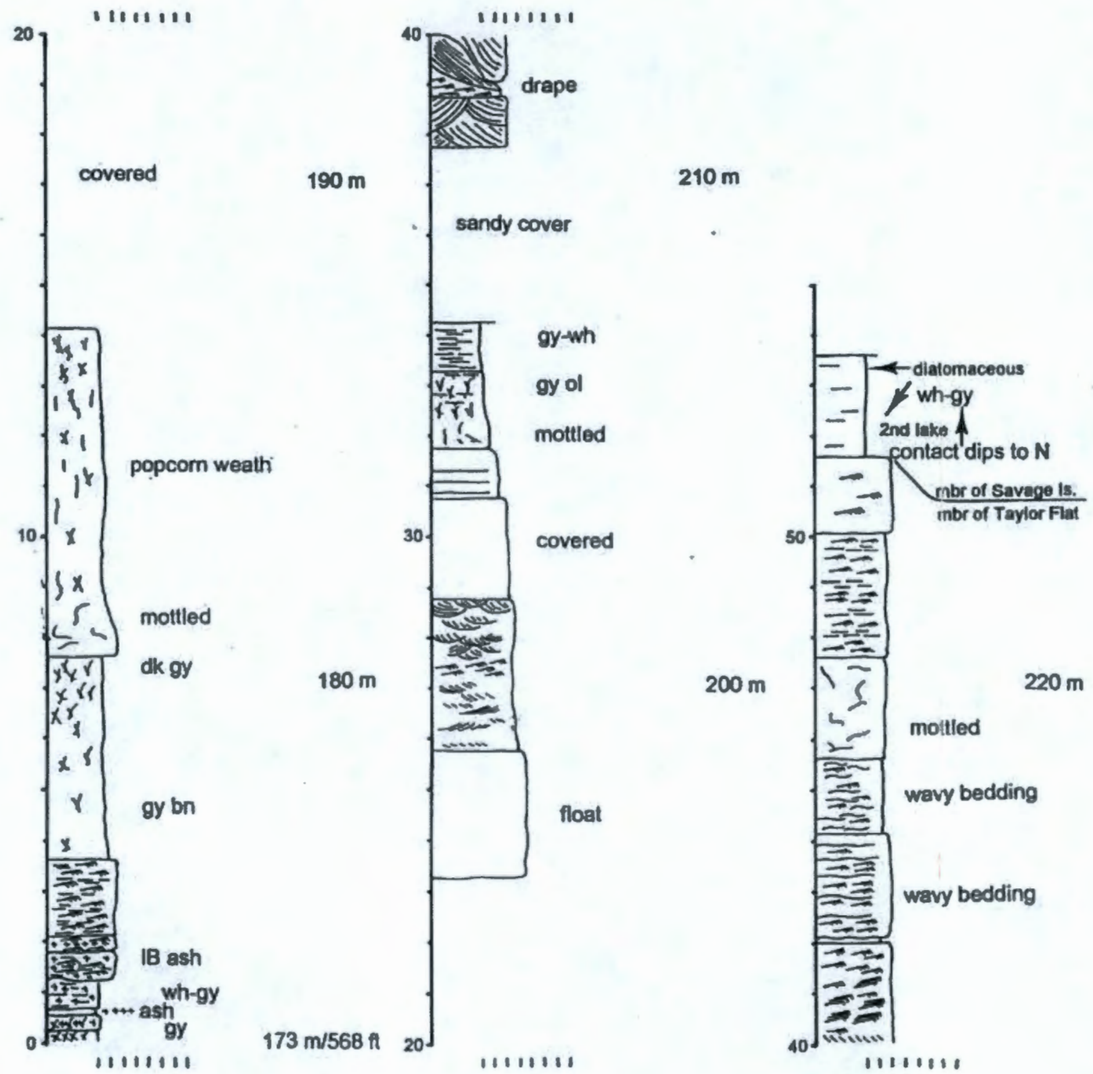
Sec B-7 Top Elev 712 ft (217 m)



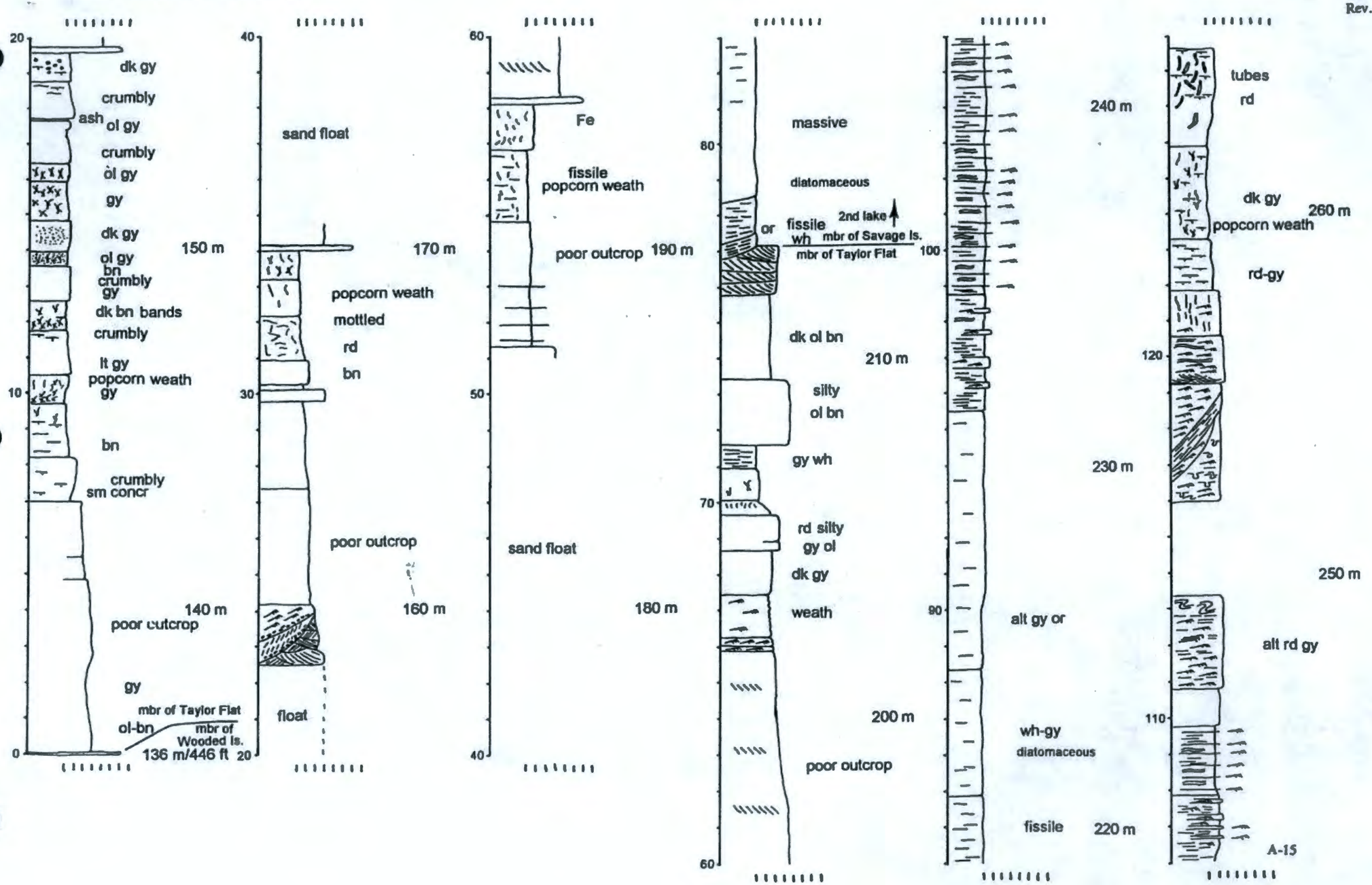
Sec B-7 Extension Top Elev 567 ft (173 m)



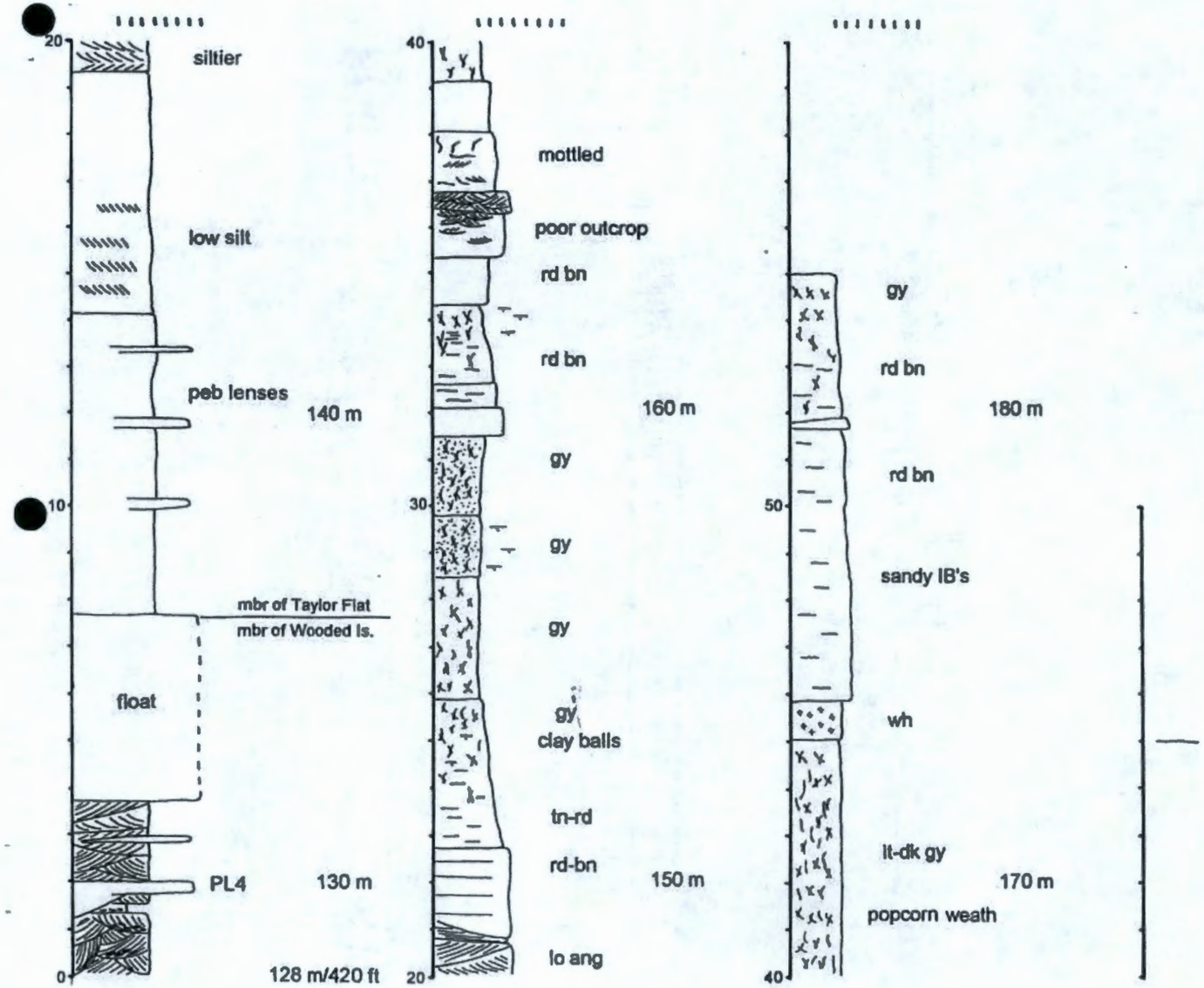
Sec B-7A Top Elev 742 ft (227 m)



Sec. B-8 Top Elev 879 ft (265 m)



Sec. B-9 Top Elev 600 ft (183 m)



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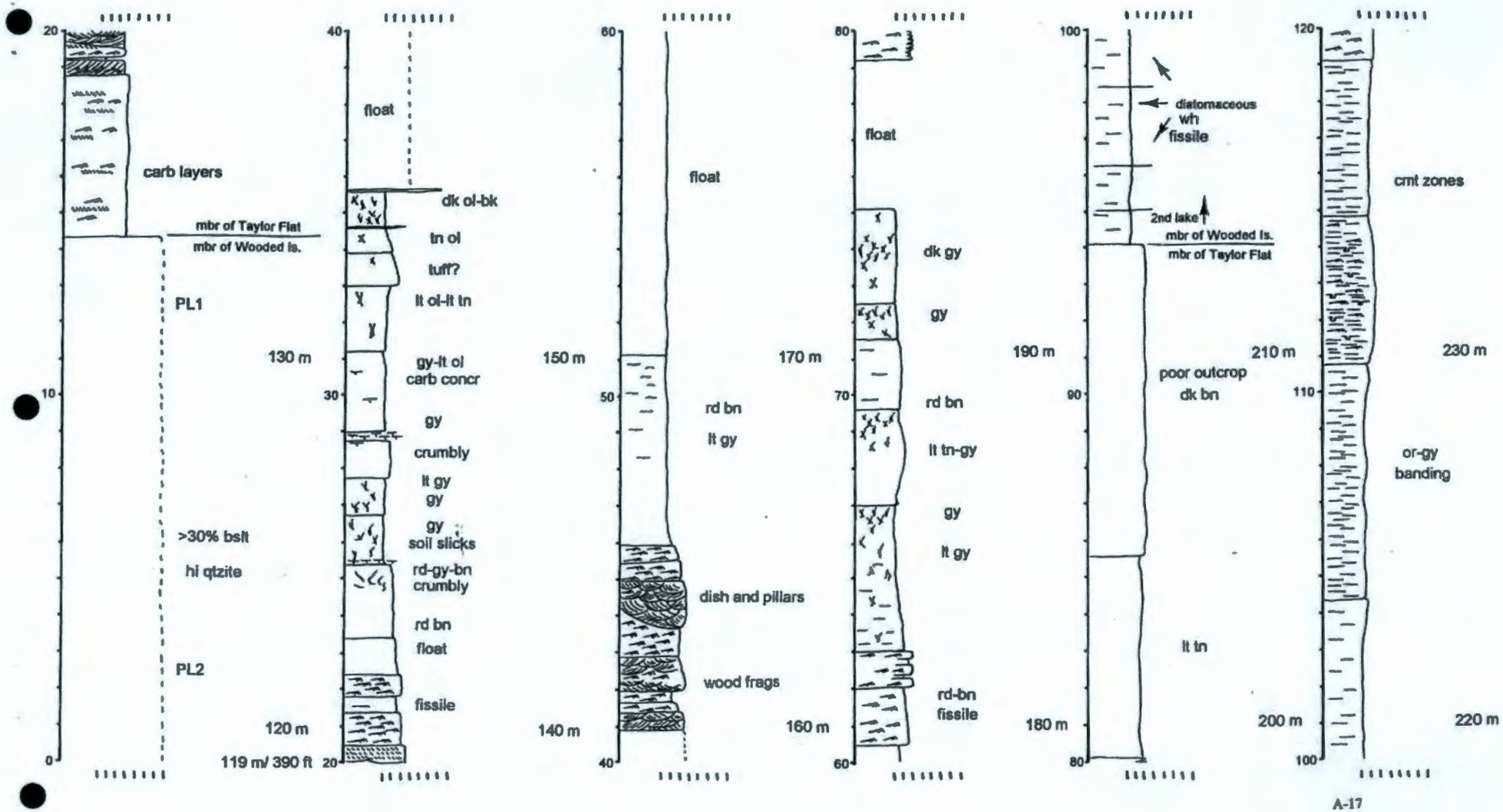

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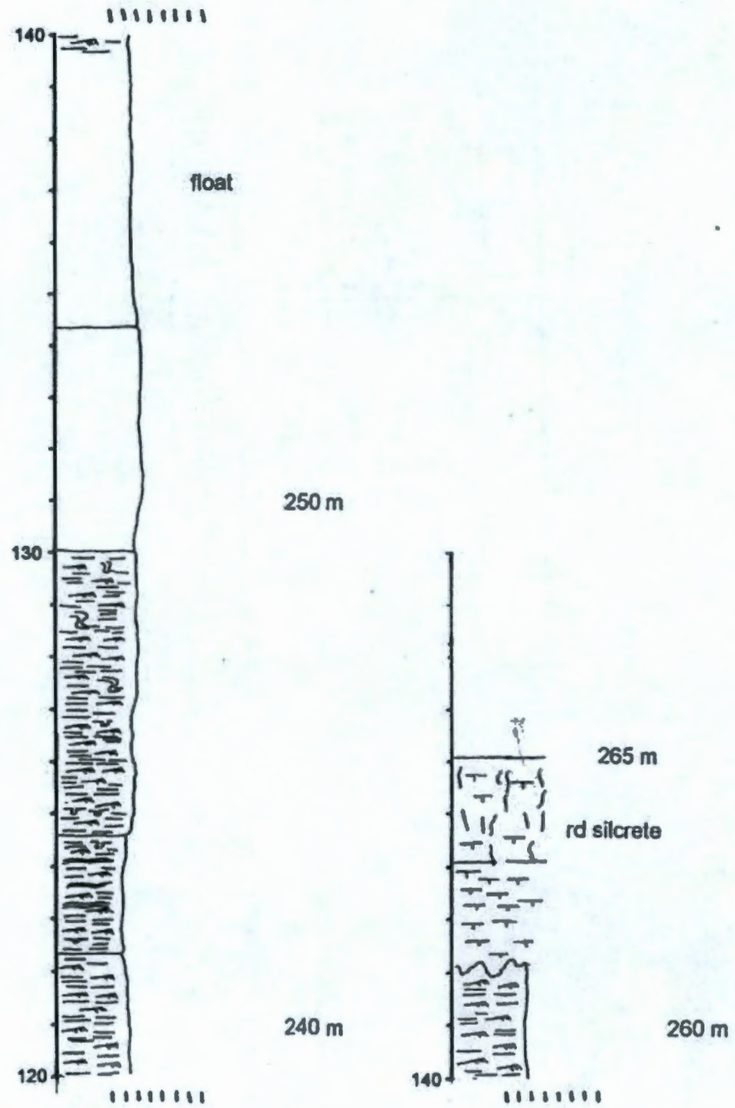
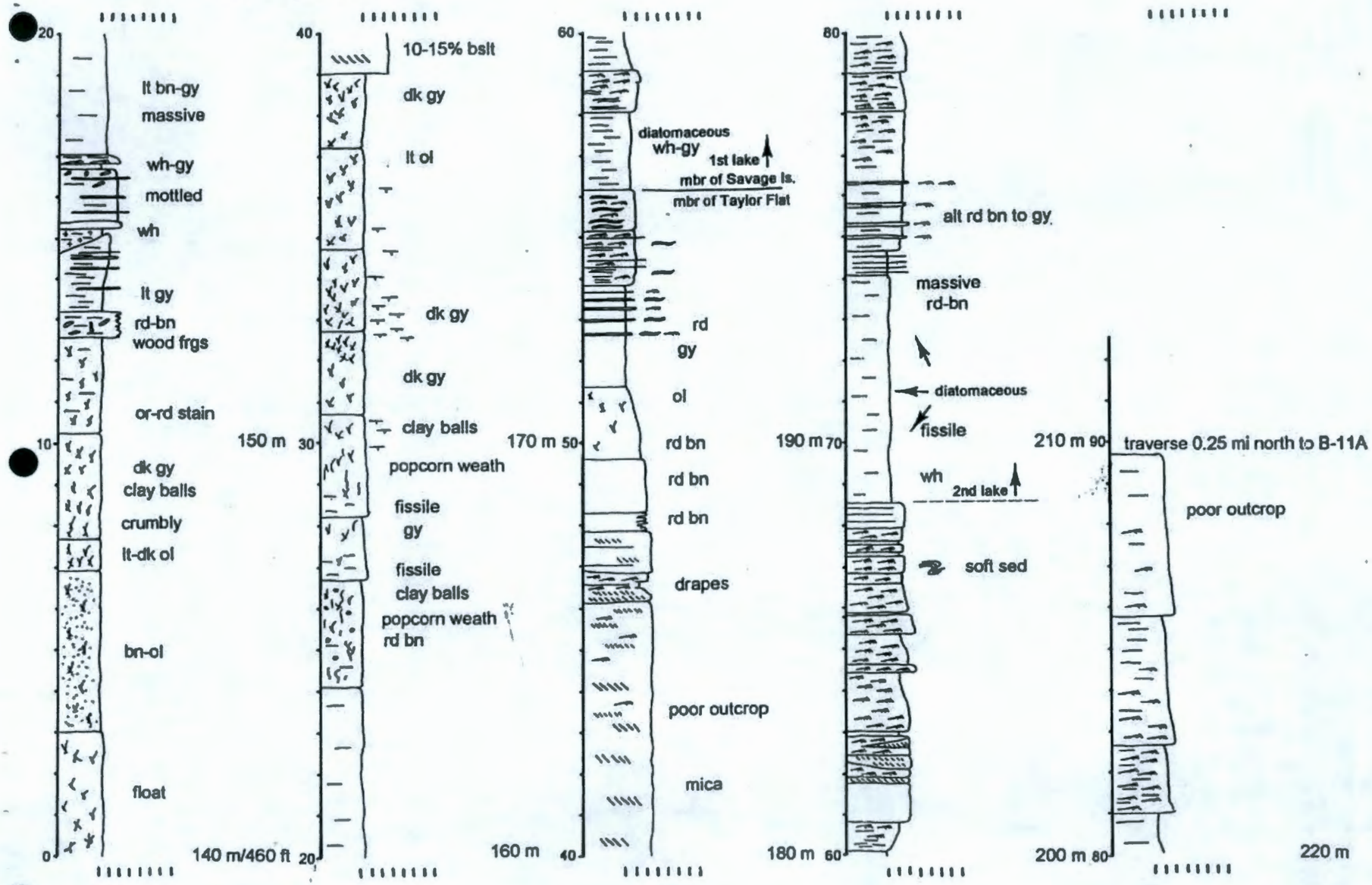
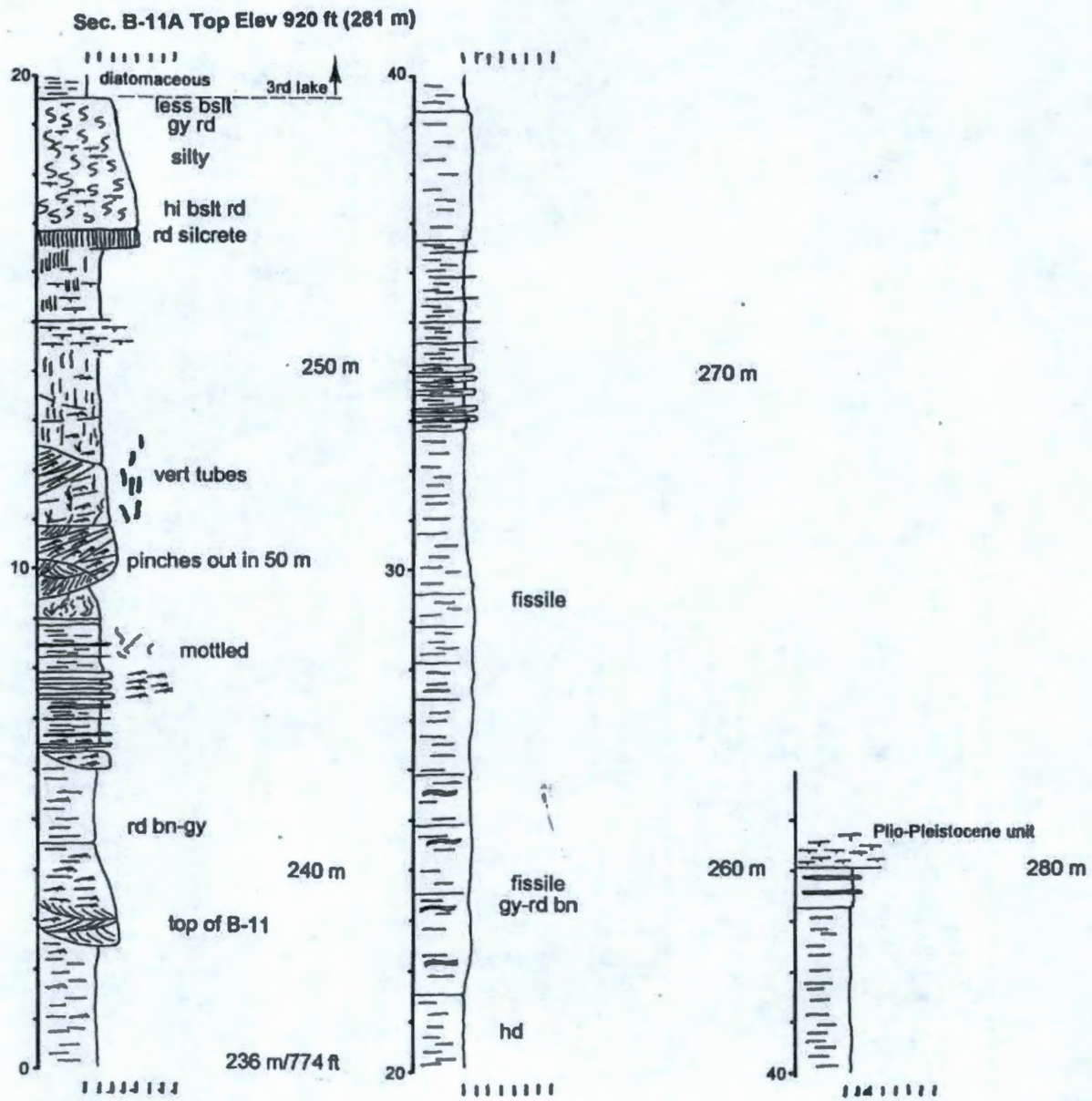


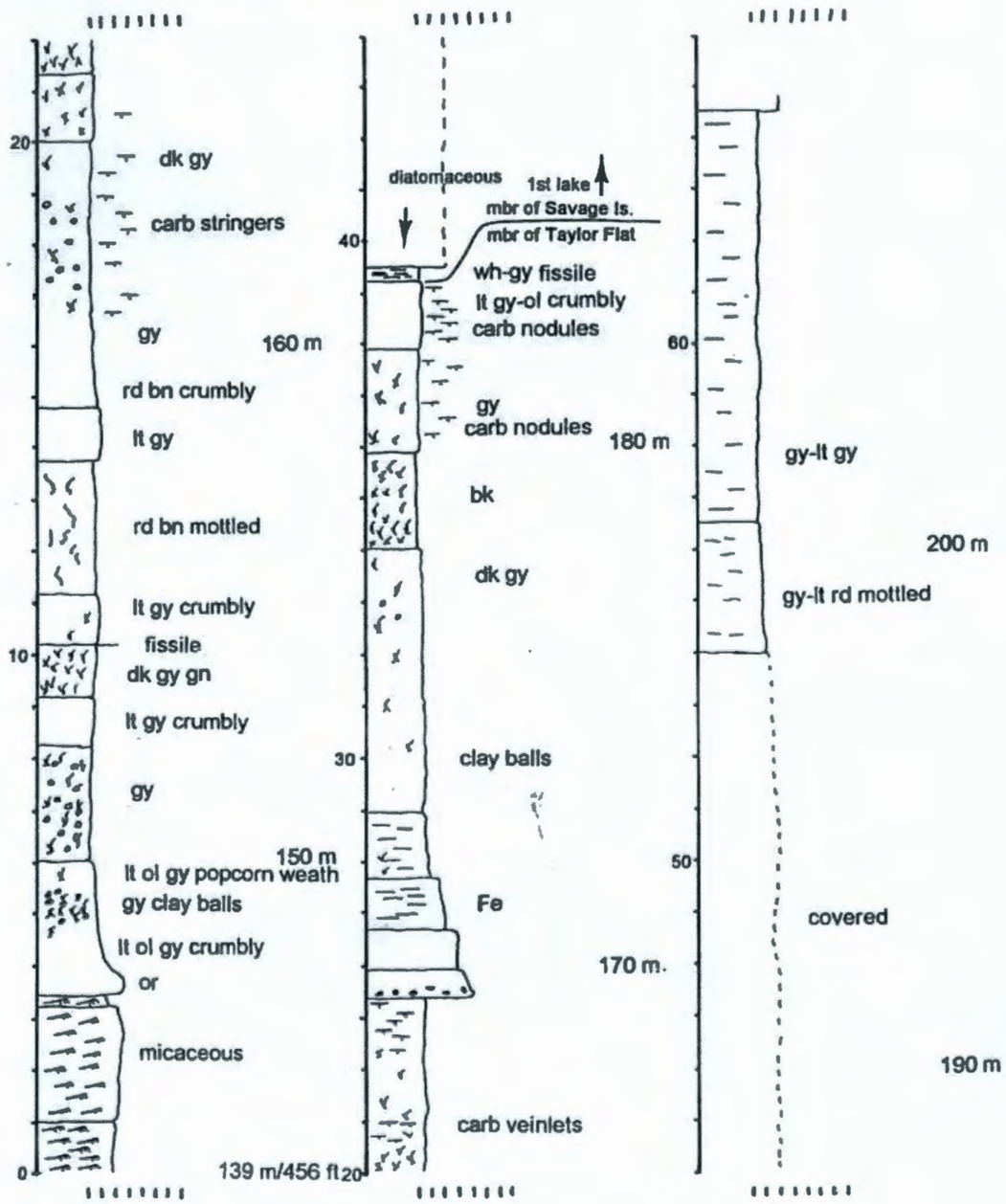
Sec. B-11 Top Elev 754 ft (230 m)



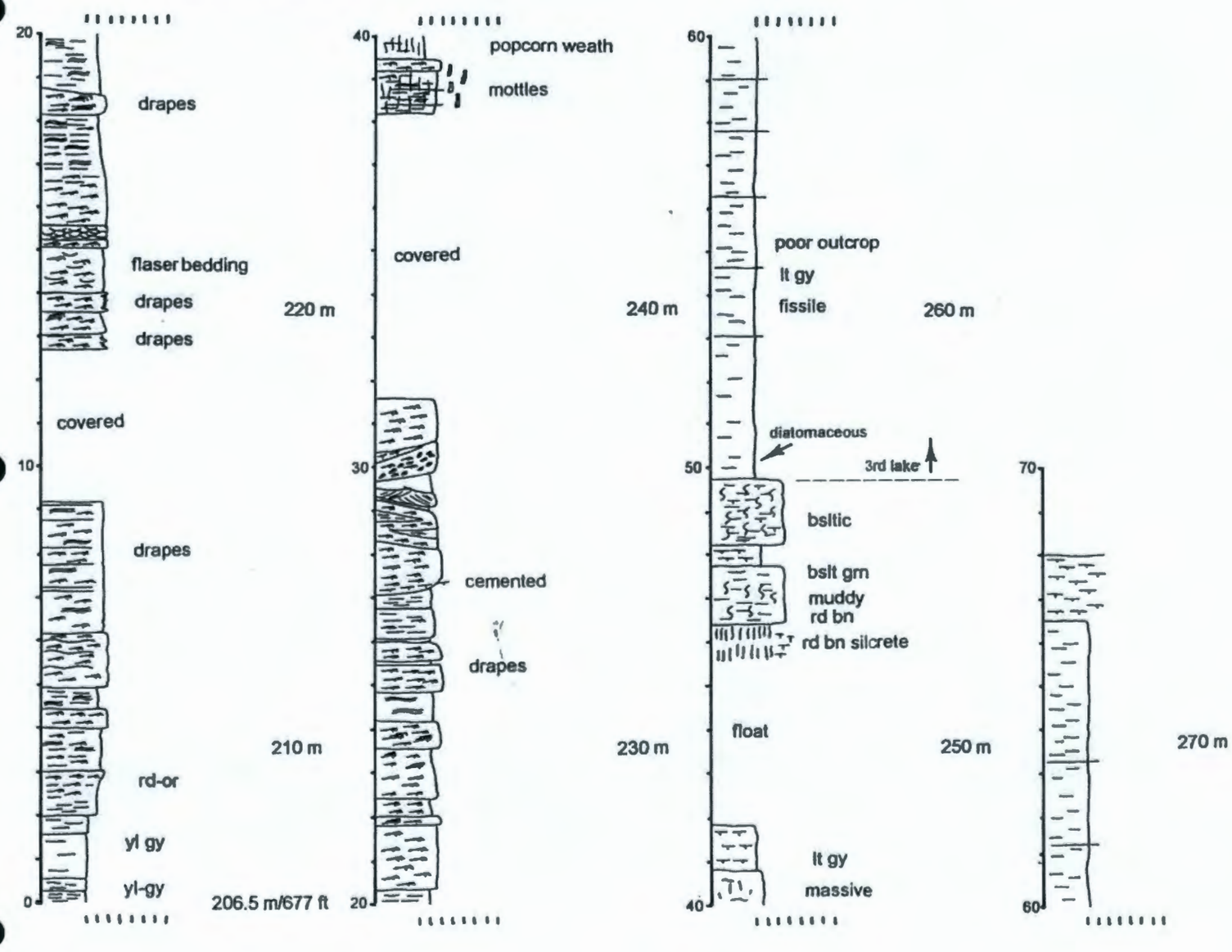

Sec. B-11A Top Elev 920 ft (281 m)
20
diatomaceous
3rd lake
less bslt
gy rd
silty
hi bslt rd
rd silcrete
250 m
vert tubes
10
pinches out in 50 m
mottled
rd bn-gy
240 m
top of B-11
0
236 m/774 ft
40
270 m
30
fissile
fissile
gy-rd bn
hd
20

Plio-Pleistocene unit
260 m
280 m
40

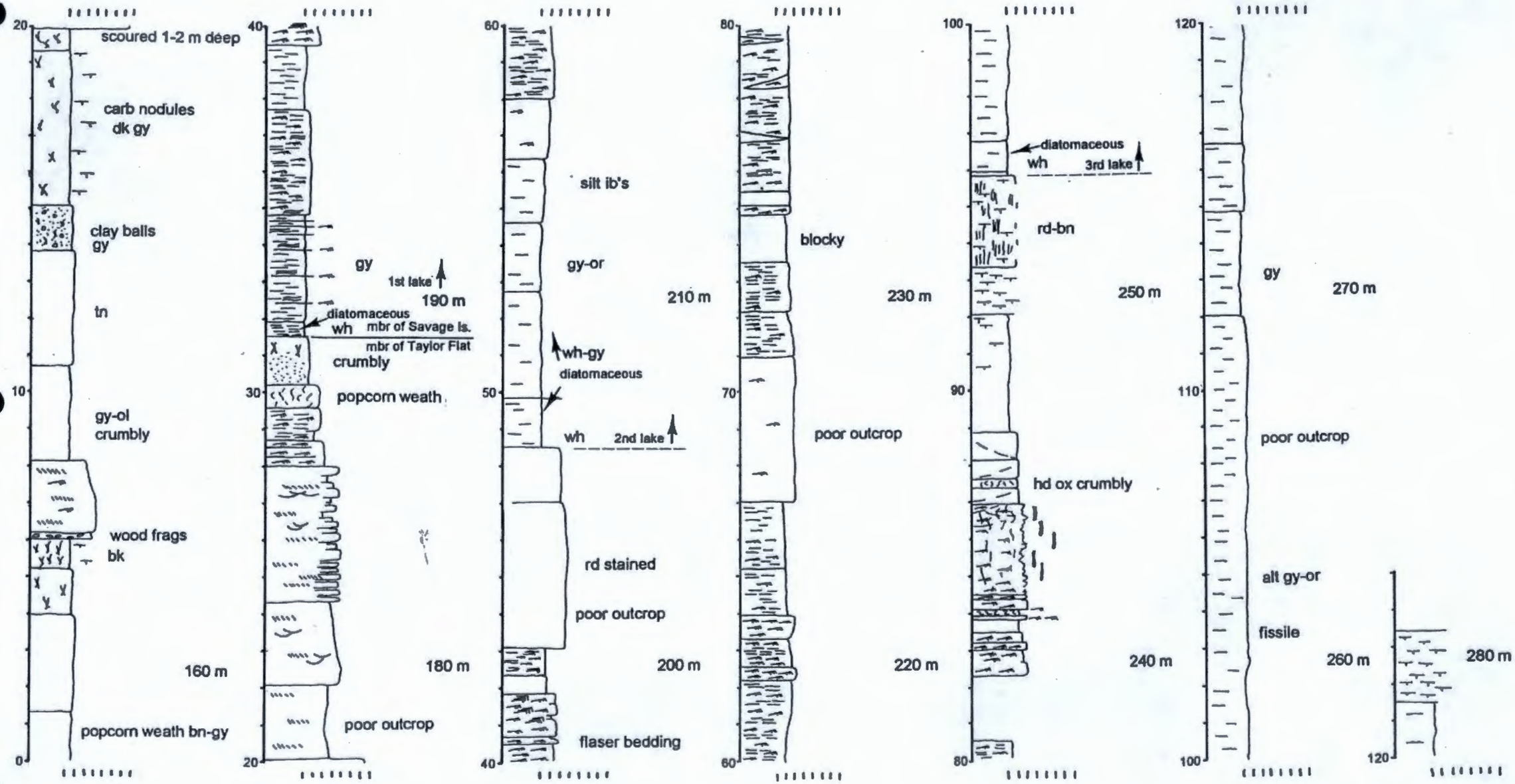
Sec. B-12 Top Elev 669 ft (204 m)



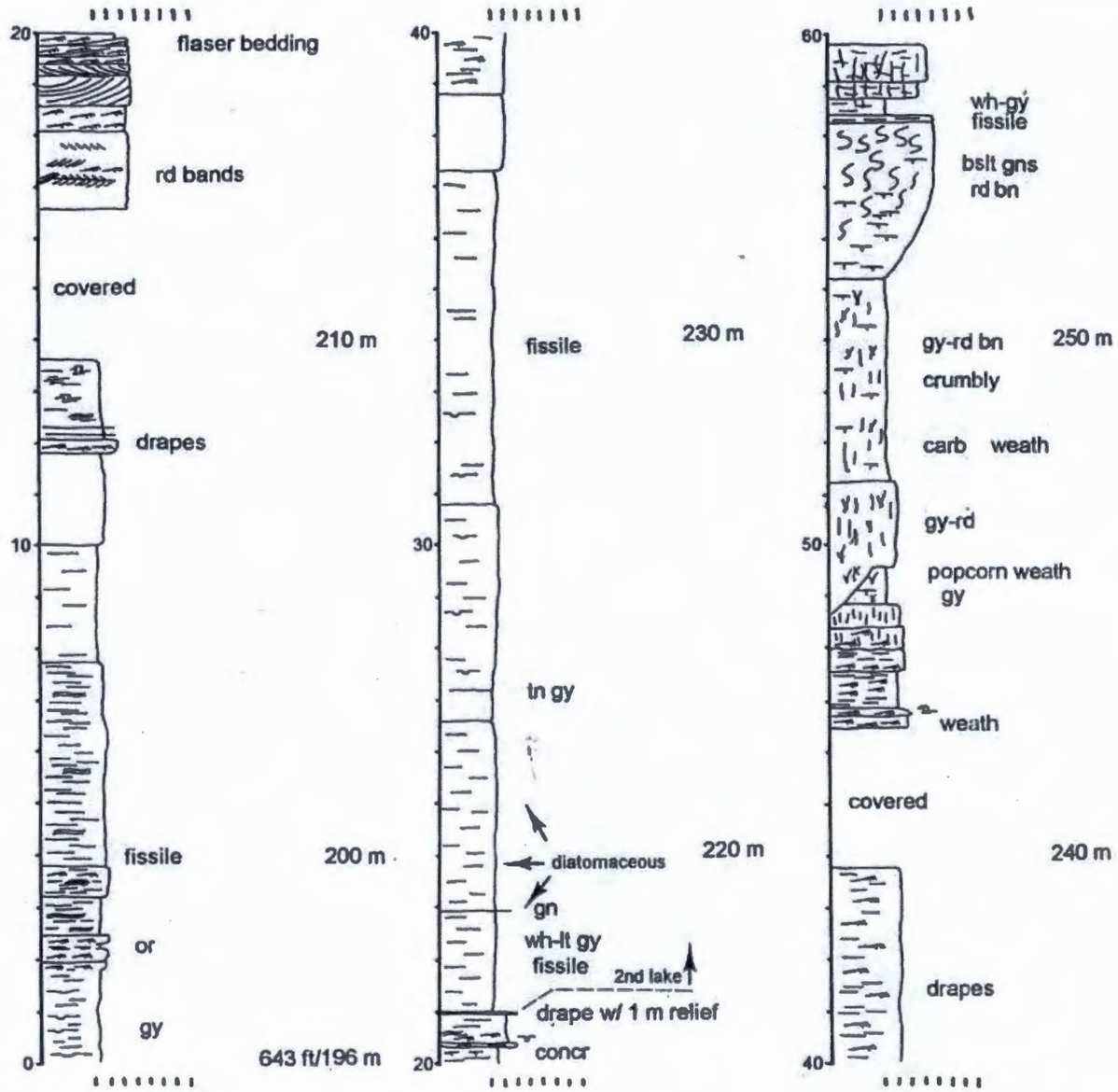
Sec. B-13 Top Elev 900 ft (274 M)



Sec. B-14 Top Elev 920 ft (281 m)



Sec. B-15 Top Elev 840 ft (256 m)



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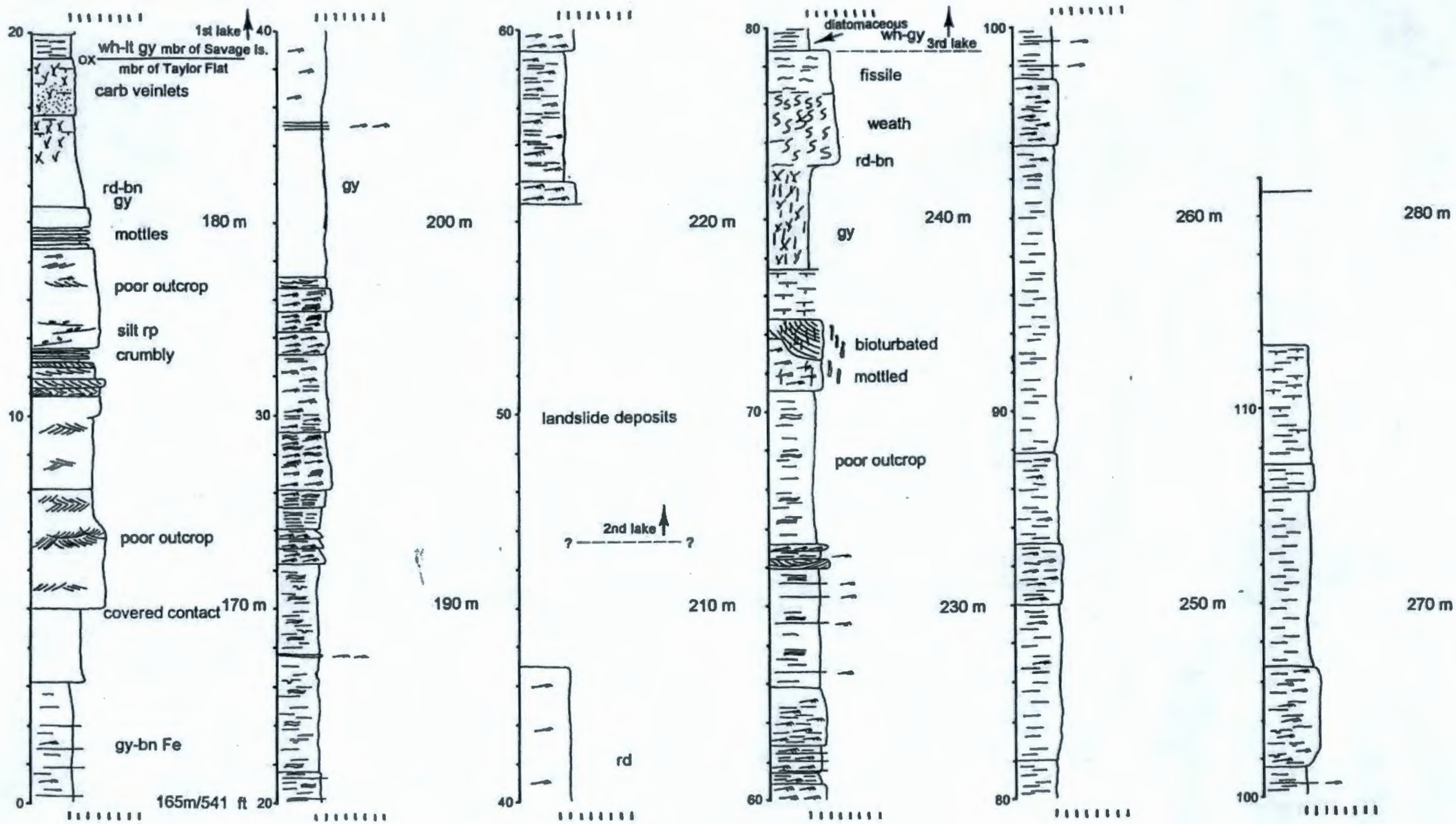
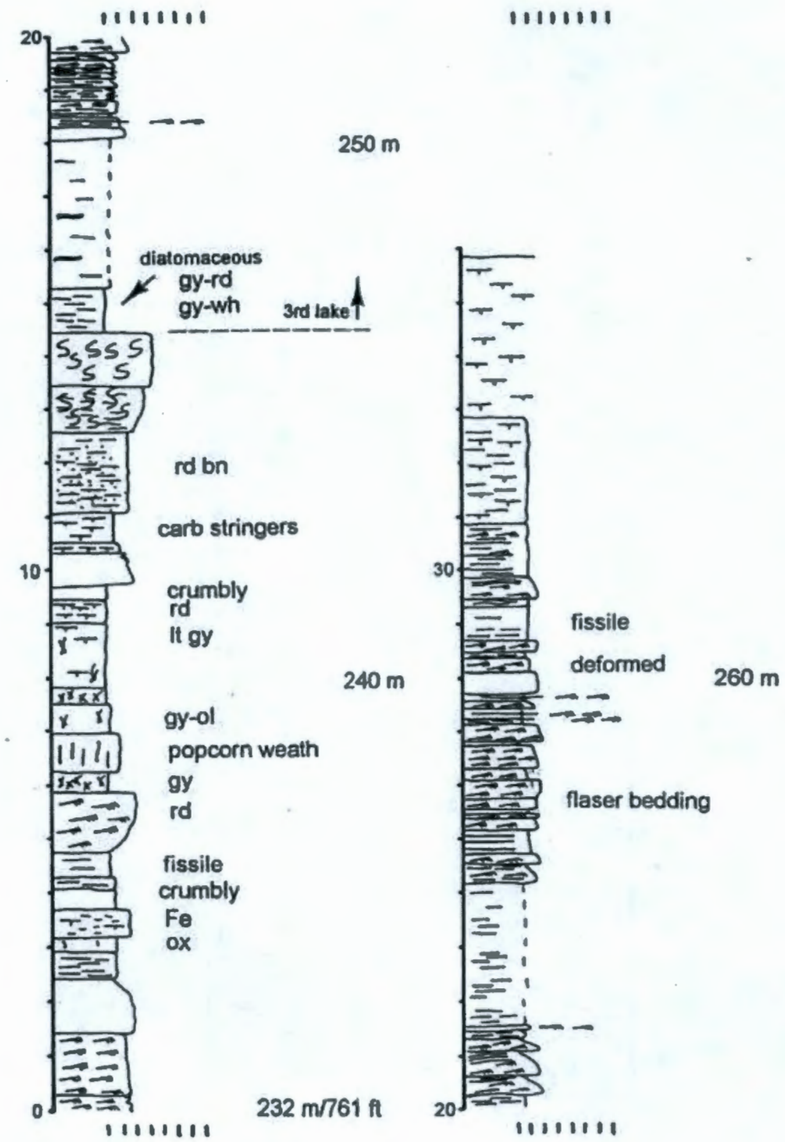
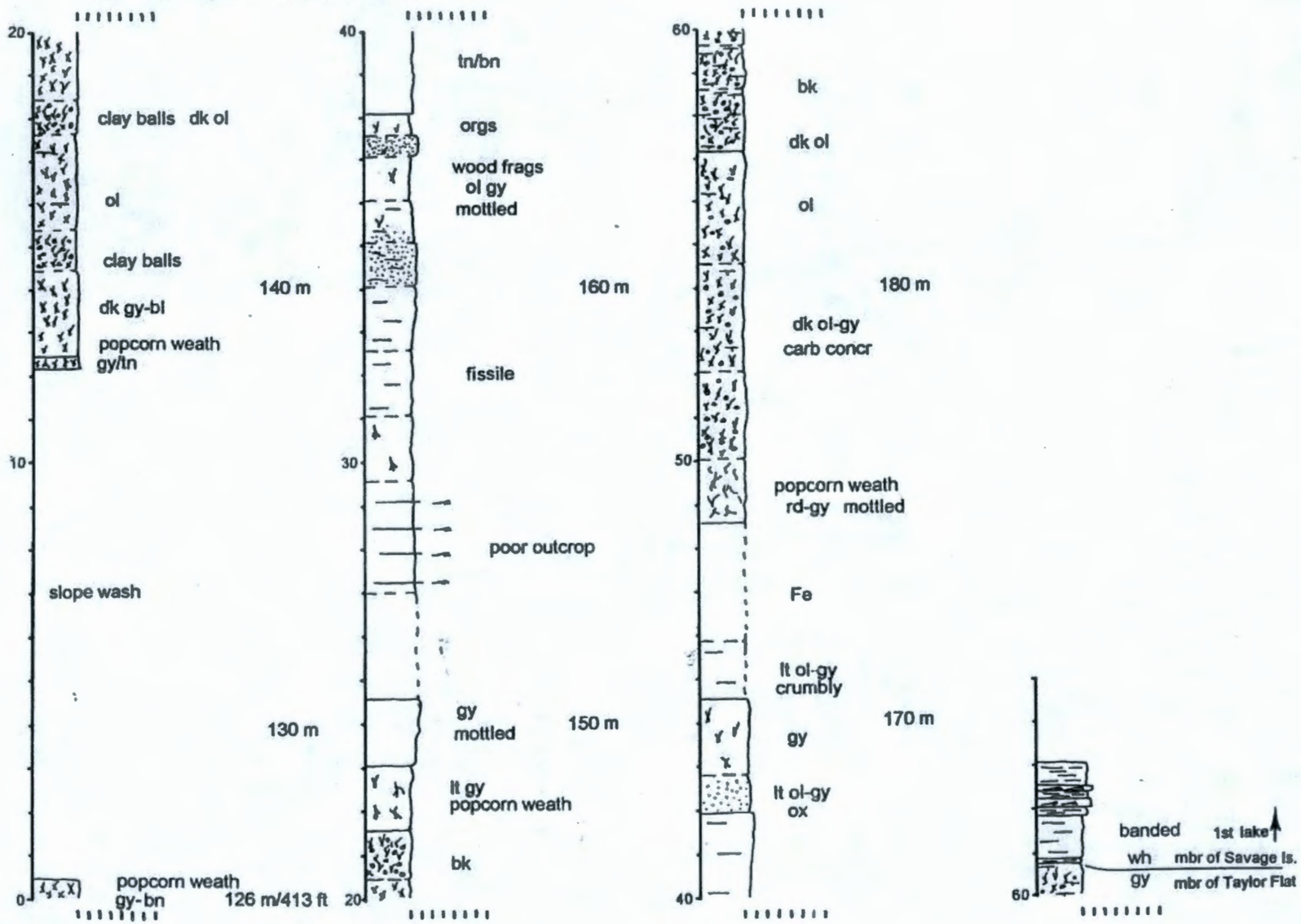


Sec. B-17 Top Elev 890 ft (268 m)



Sec. B-18 Top Elev 620 ft (189 m)



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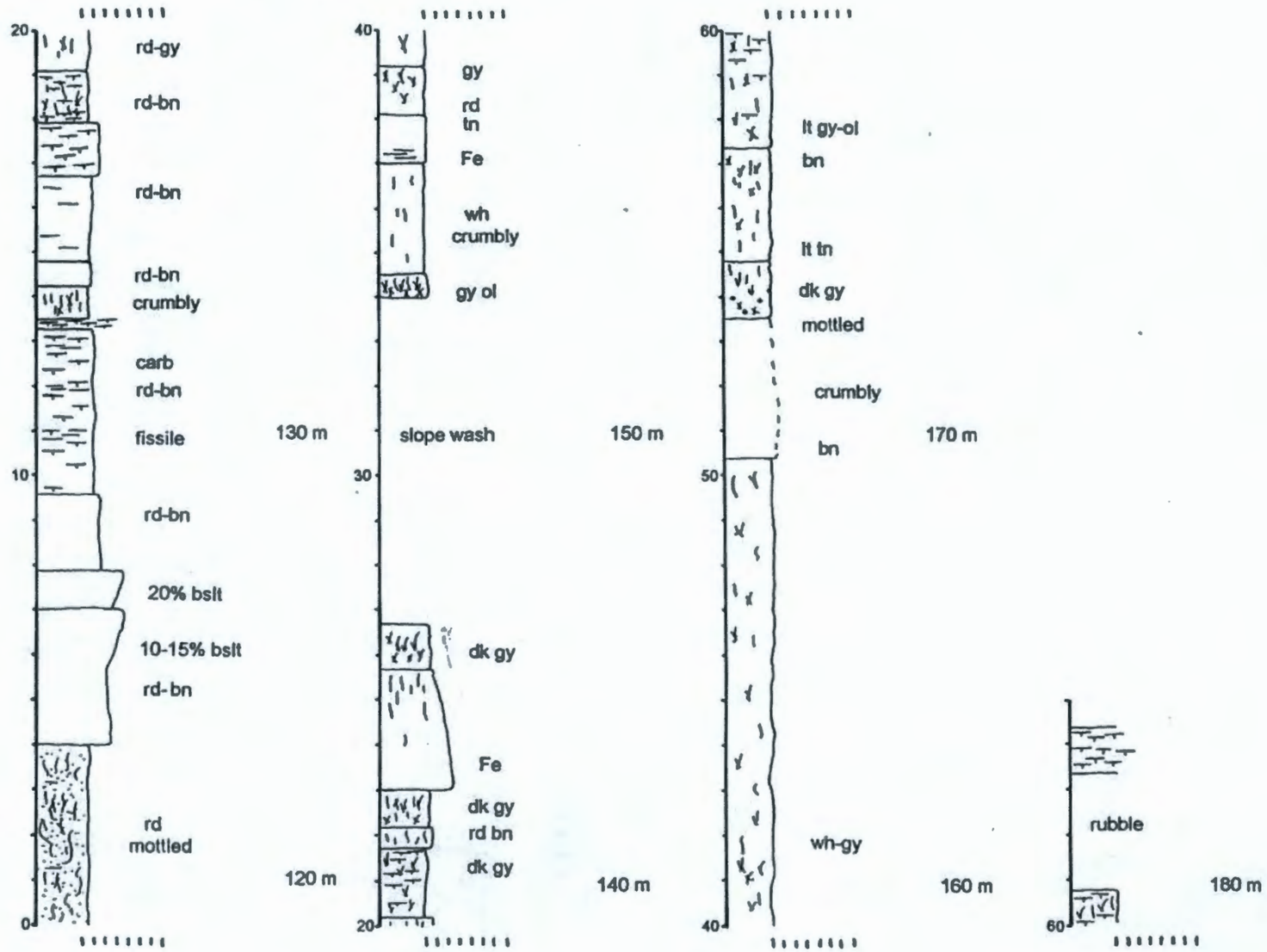
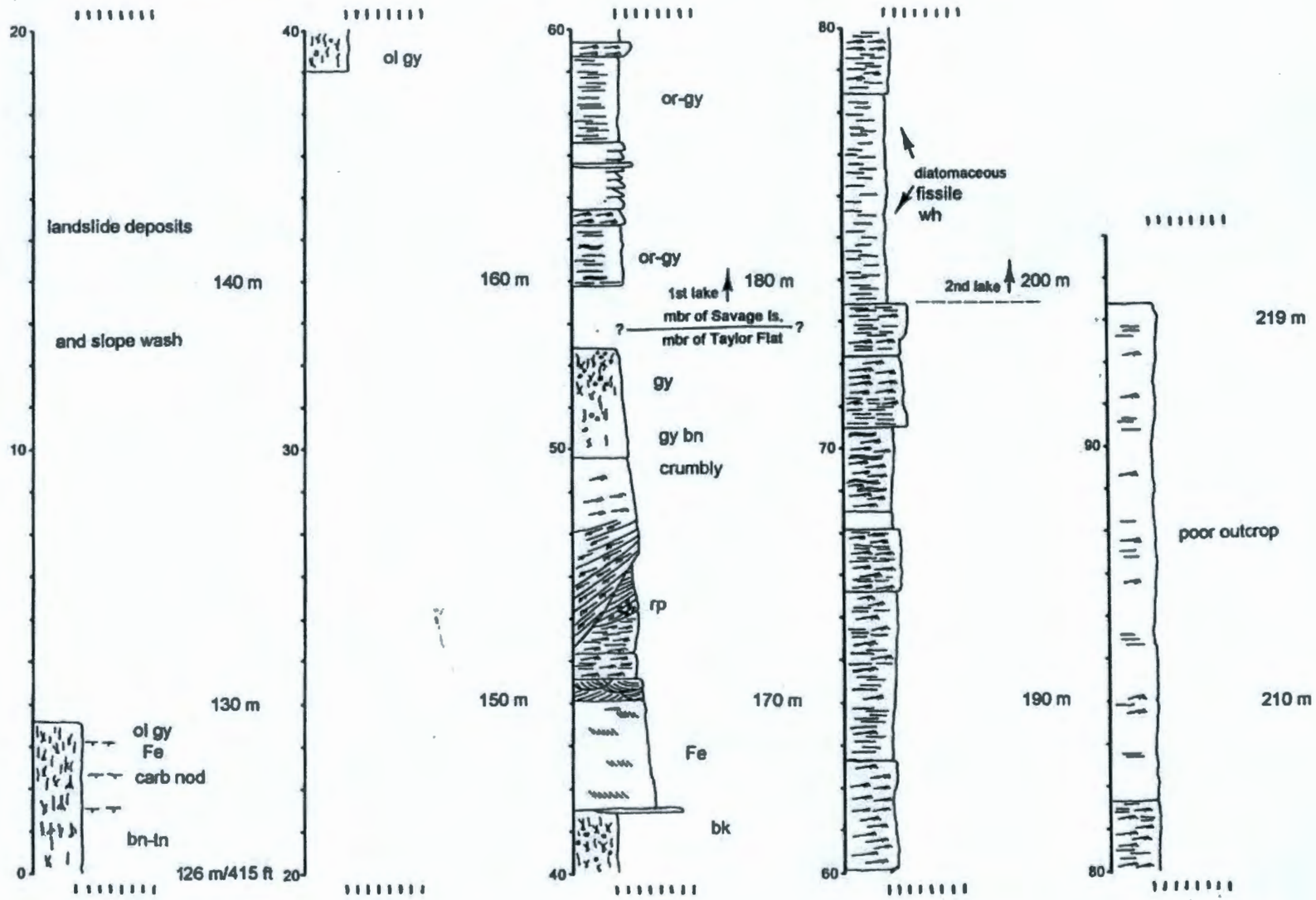


Sec. B-20 Top Elev 720 ft (220 m)



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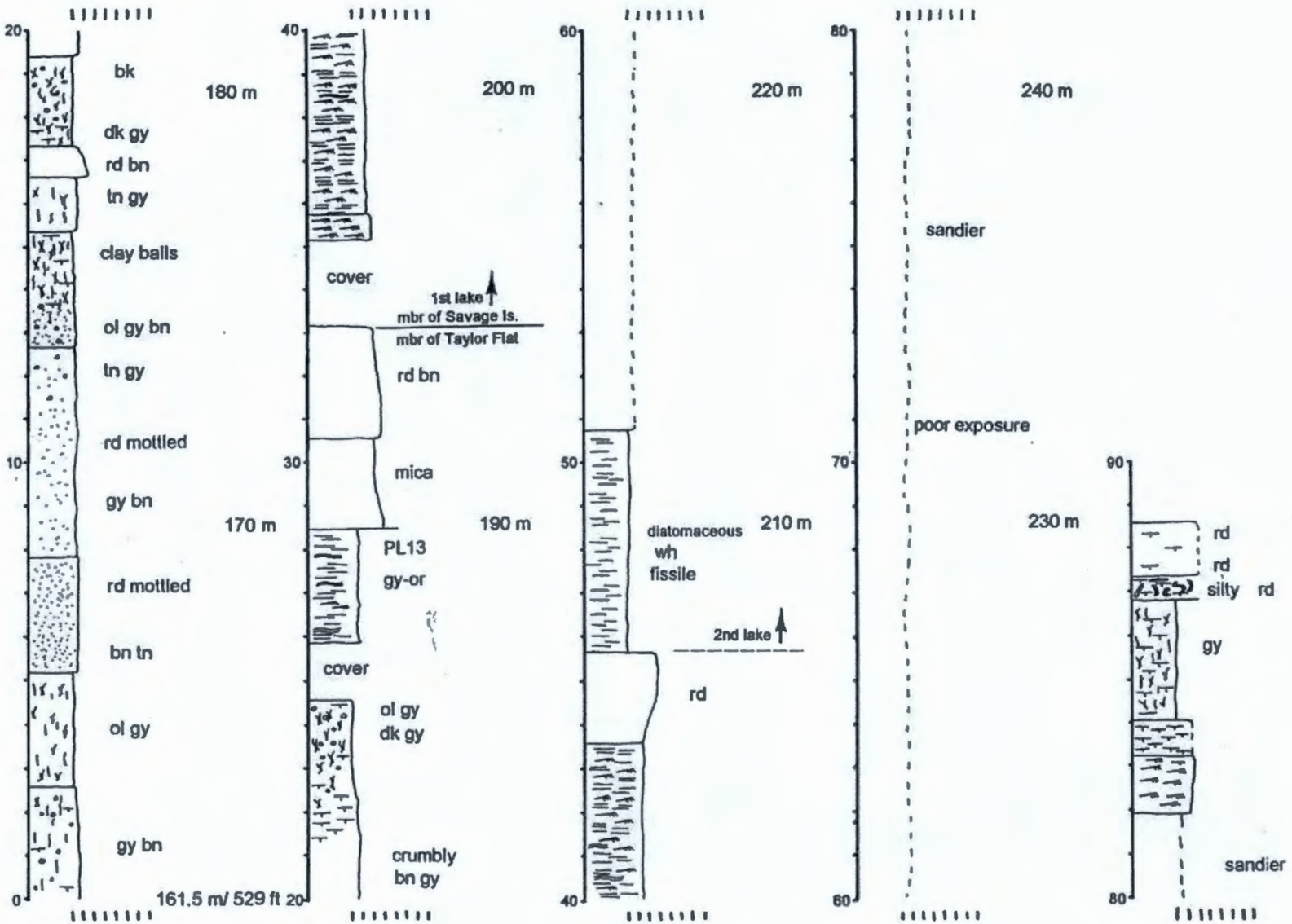
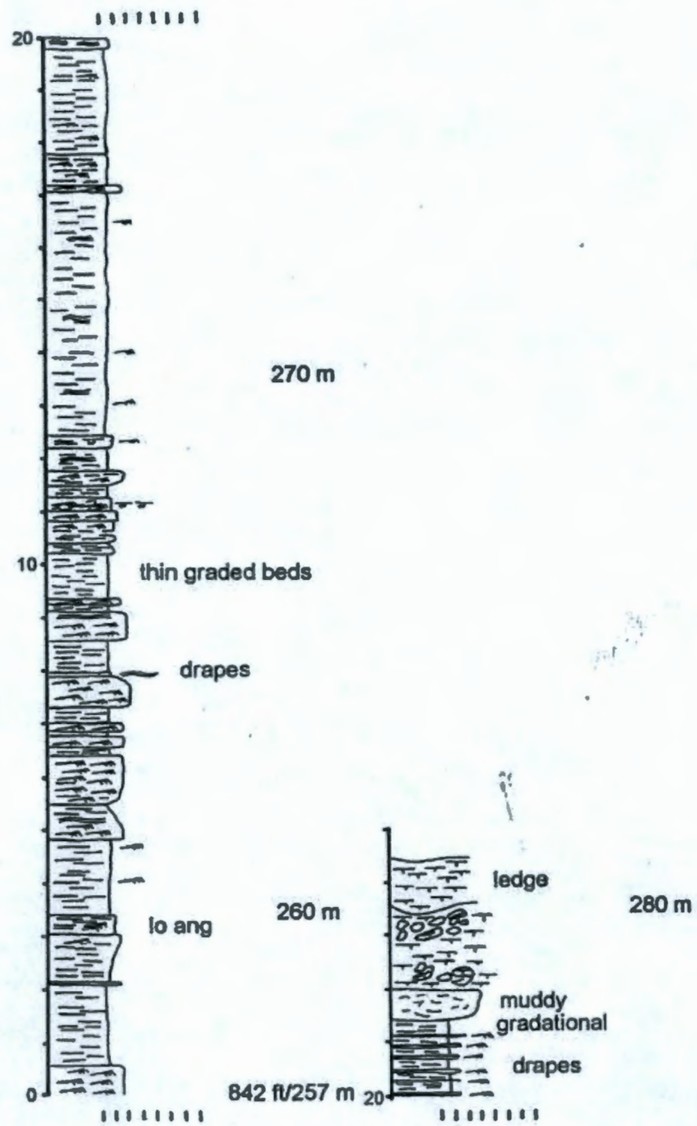
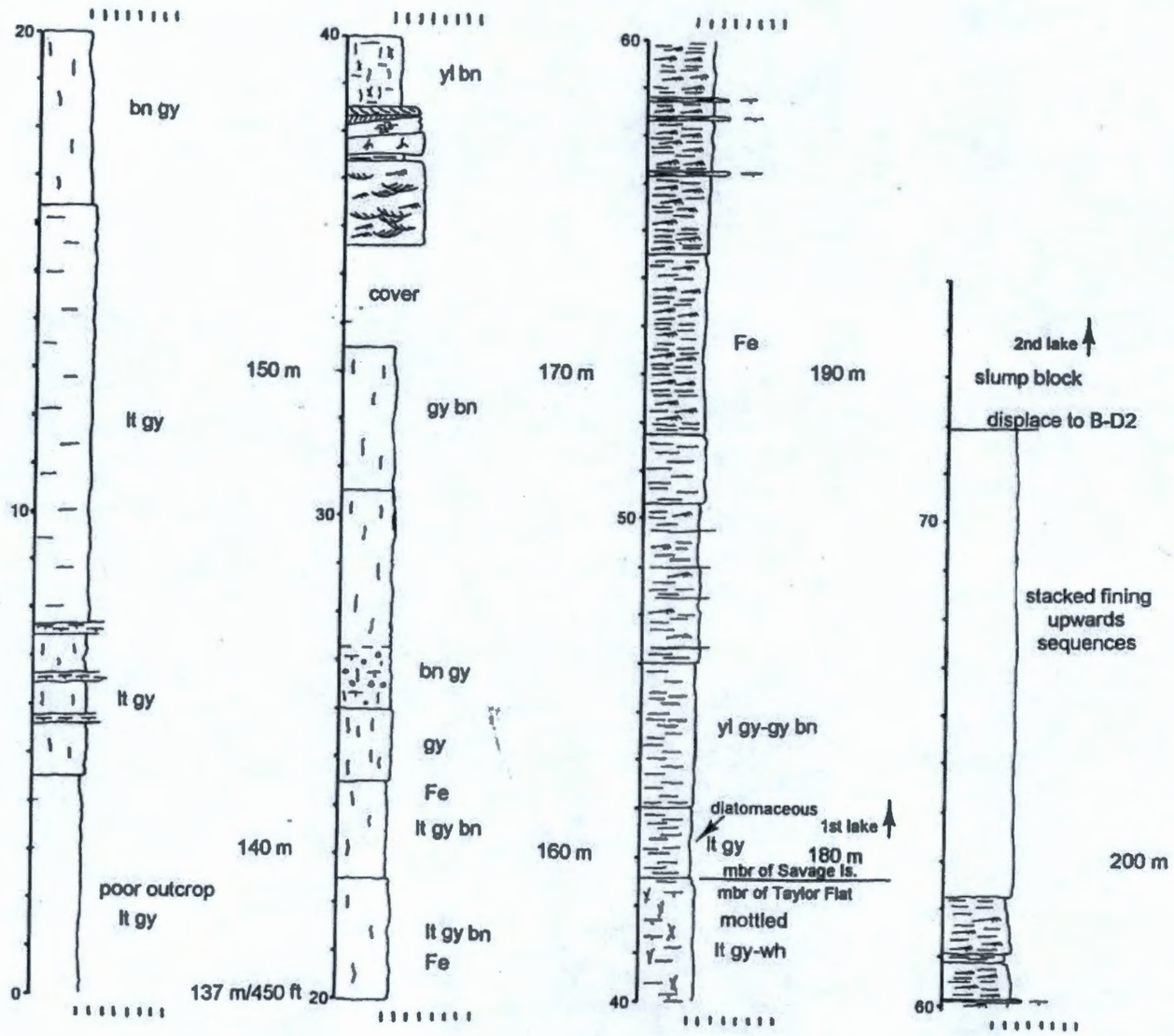


Sec. B-22 Top Elev 920ft (281 m)



Sec B-D1 Top Elev 685 ft (209 m)



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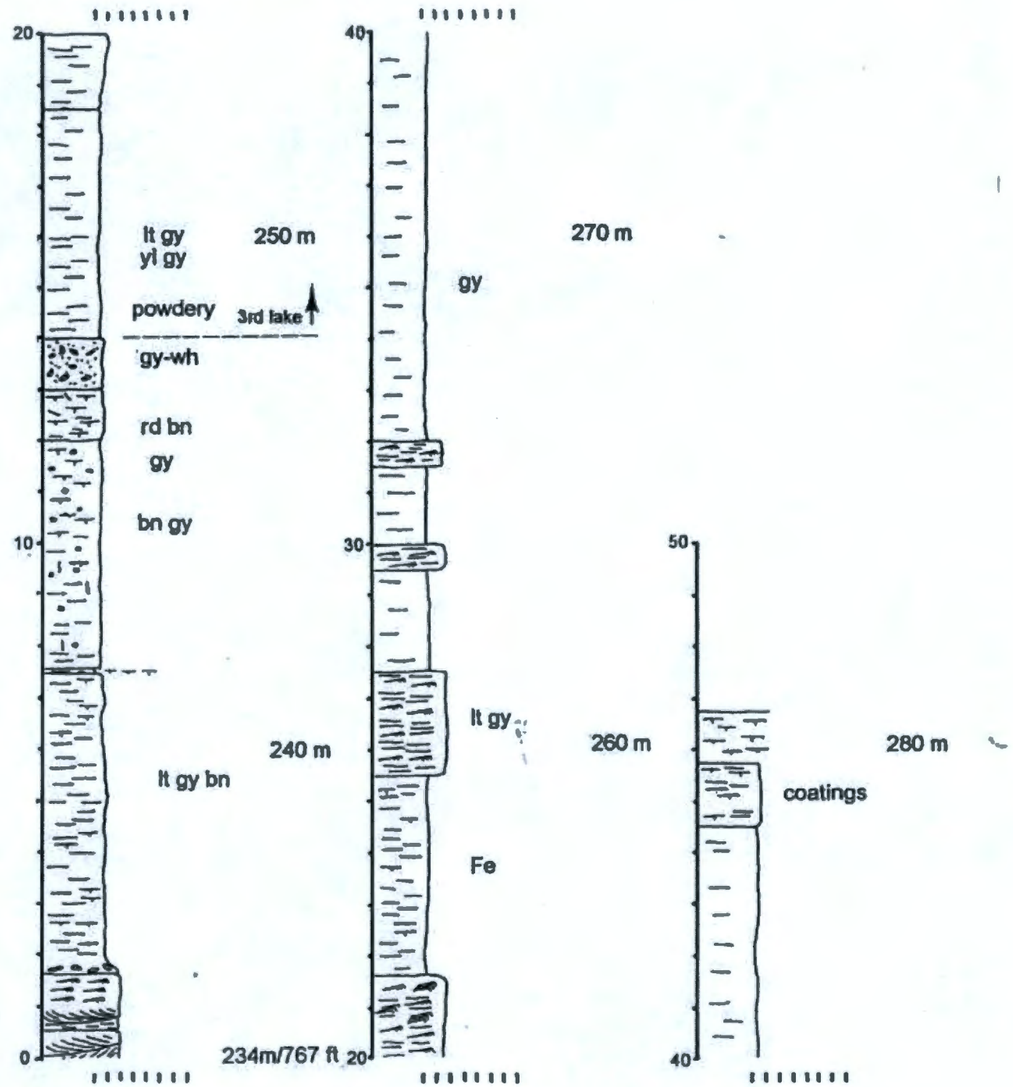


APPENDIX B
CORE MEASURED SECTIONS

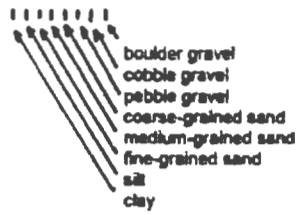
APPENDIX B
CORE MEASURED SECTIONS

LOCATIONS OF CORE HOLES

Corehole #	Hanford well number	Northing (WSC82S)	Easting (WSC82S)
Golder 1	699-40-13	135649.9	585839.4
Golder 73	699-42-30	136213.8	580785.9
Golder 78	699-30-25C	132593.5	582358.4
Golder E-19/E-1	699-17-26	128581.9	581882.4
DH-6	299-W11-26	135563.7	567044.7
DH-9B	699-54-16C	139996.7	584471.6
DH-11	299-W15-14	135647.9	568092.9
DH-12	299-W14-7	135654.5	567034.2
DH-13/13A	299-W14-8/8A	135688.0	568012.0
DH-17	299-E19-1	135085.9	572819.9
DH-18	699-26-15C	131330.3	585472.4
DH-19	699-70-17	144960.8	584592.0
DH-20	699-29-83	132372.6	564510.1
DH-22	699-37-92	134697.4	561920.7
DH-24	699-43-84	136856.5	564184.7
DH-25	699-40-84	135751.6	564246.2
DH-28	699-50-96	138598.9	560496.9
DH-33	699-34-98		

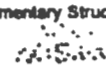
EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED ON CORE GEOLOGIC LOGS

Grain Size Scale, indicates dominant grain size



Vertical scale is in feet below ground surface

Sedimentary Structures and Subordinate Lithologies


normally graded

small-scale planar cross-bedding

ripple cross-lamination

plane bedding

root and burrow trace fossils

soil peds and slickensides

calcium carbonate

silty

silt and clay rip up clasts

pebbly

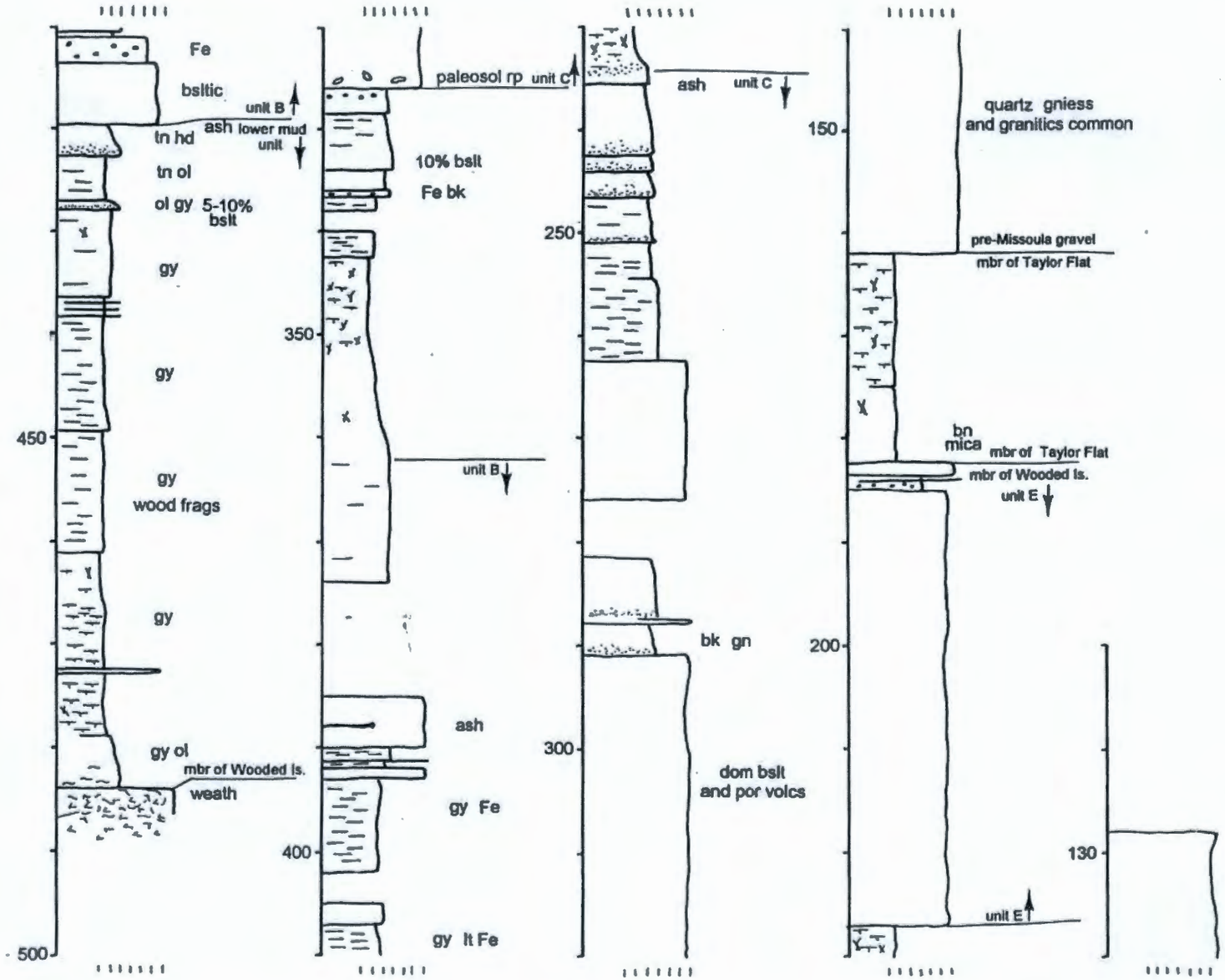
pebbly to cobbly

basalt

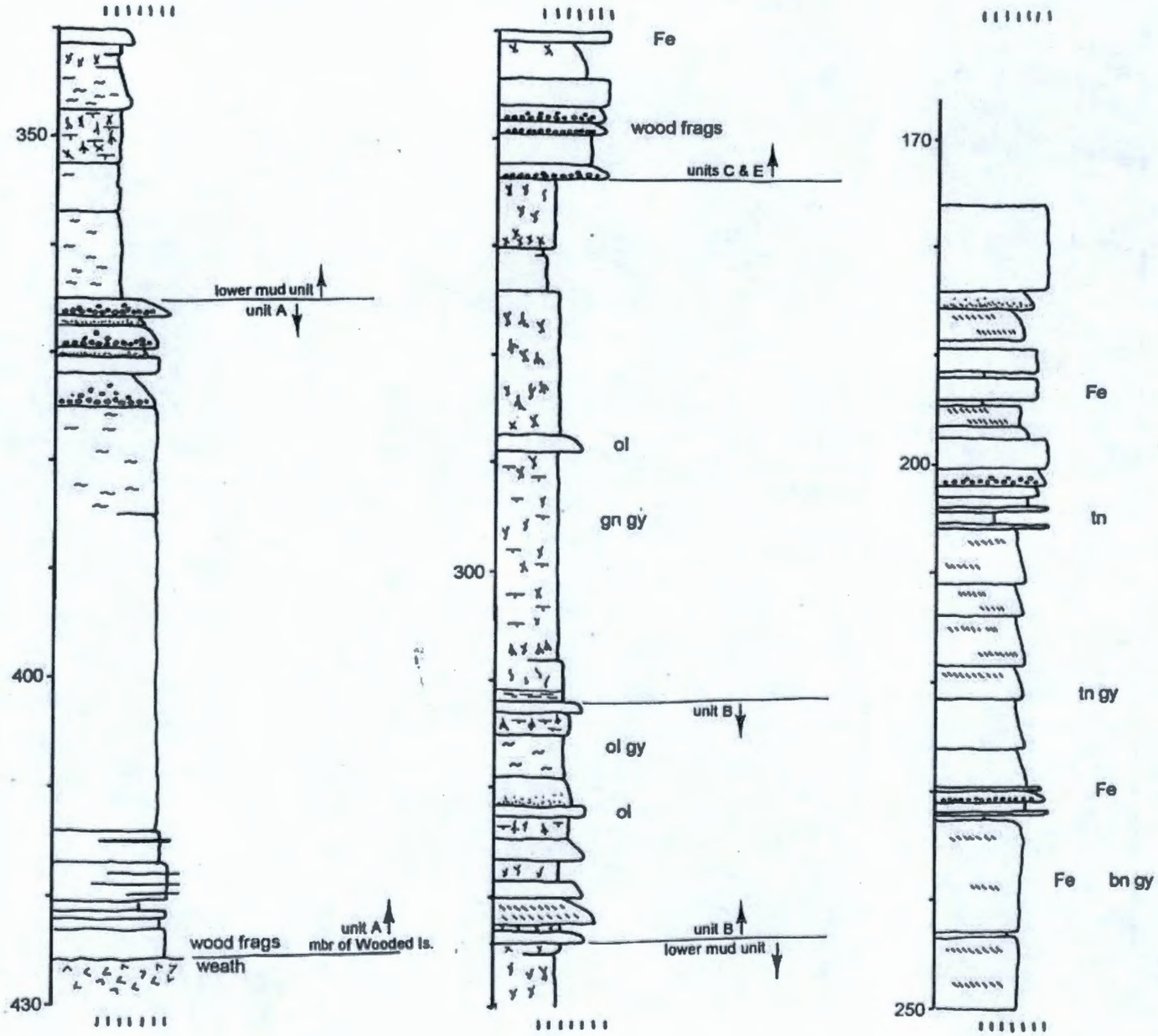
Abbreviations

wh - white; gy - gray, rd - red, bn - brown, ol - olive, tn - tan, bk - black, Fe - iron stains, rp - rip up clasts; lt - light; dk - dark; hd - hard; gn - green; weath - weathered; bslt - basalt, org - organic debris; R - reversed magnetic polarity; N - normal magnetic polarity.

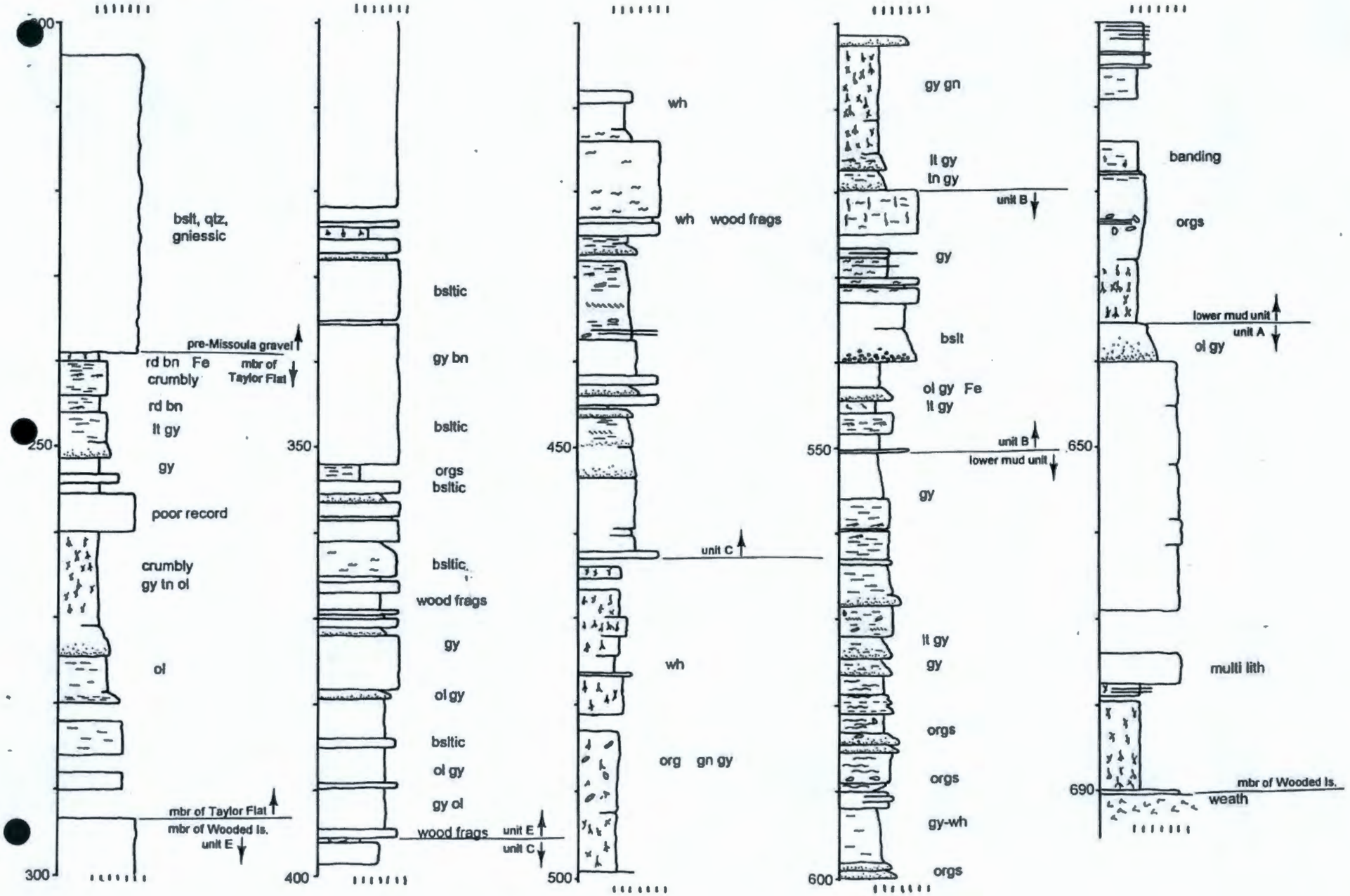
G-1 699-40-13 Elev 507 ft (155 m)



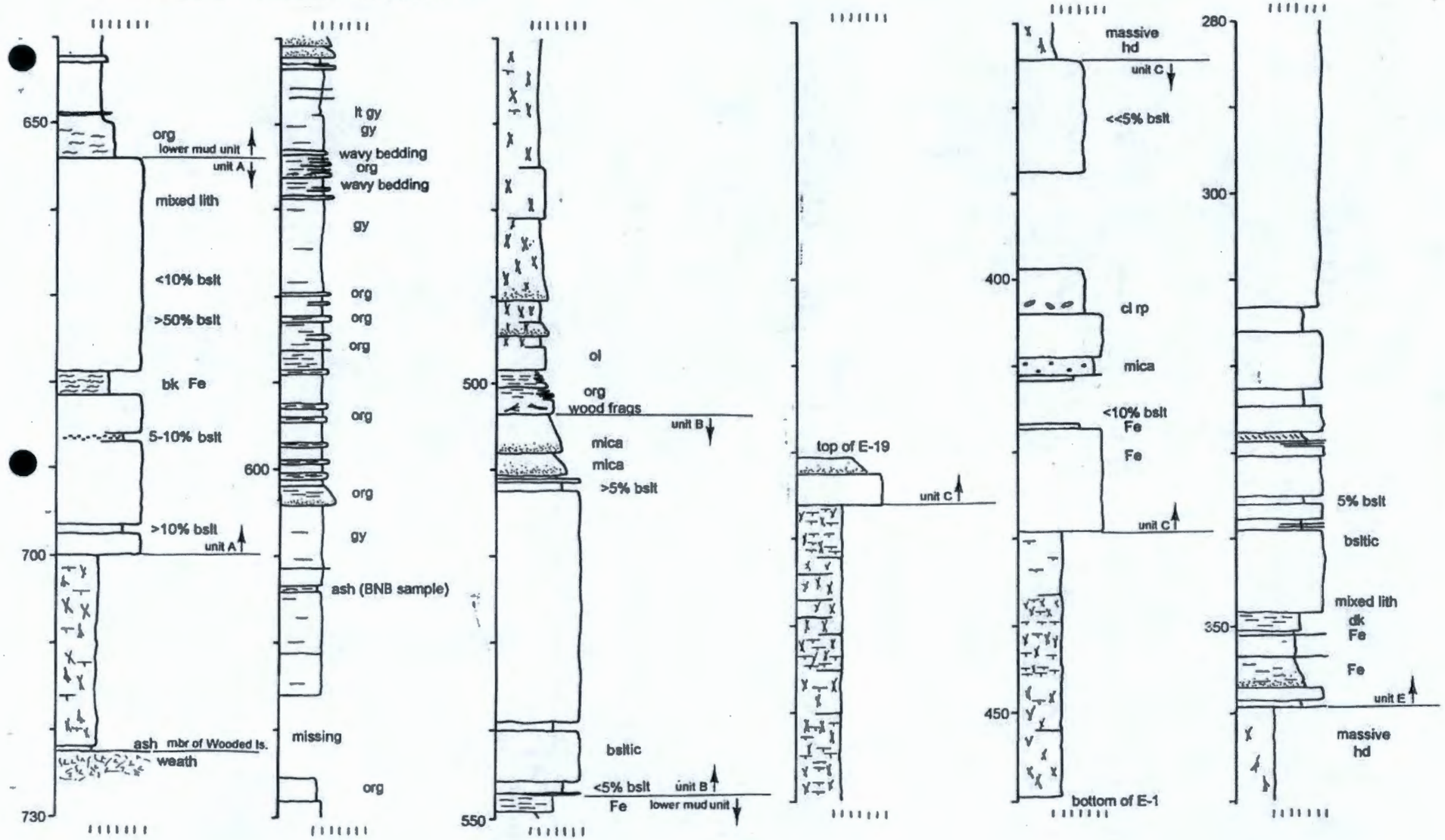
G-73 699-42-30 Elev 481 ft (147 m)

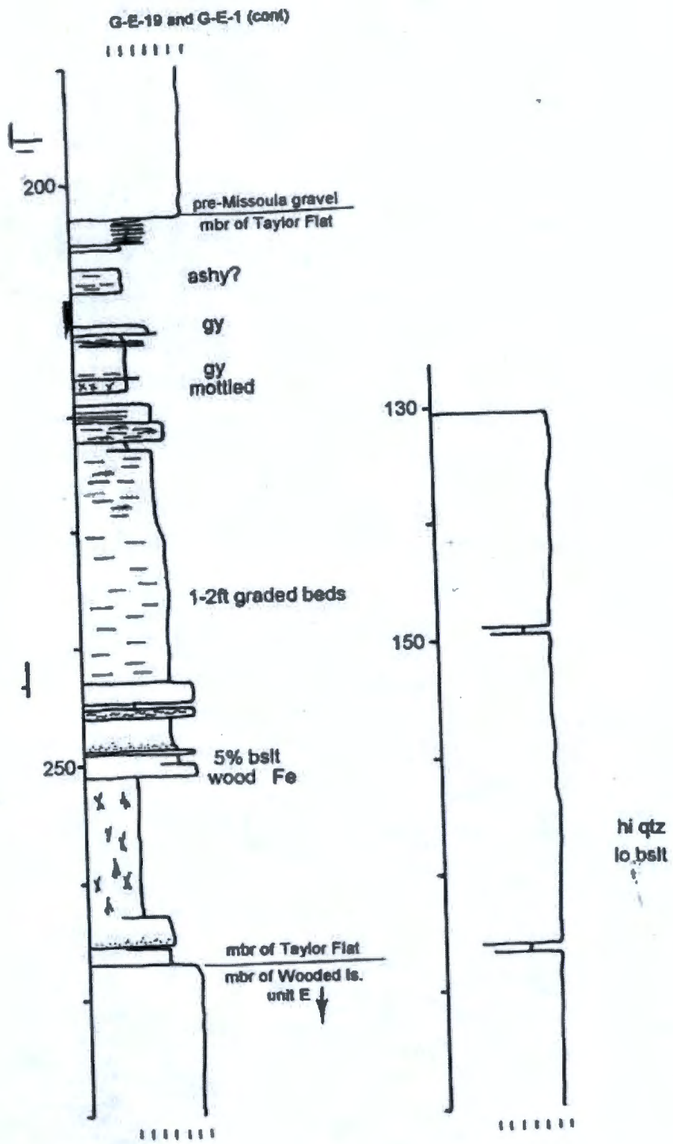


G-78 699-30-25C Elev 543 ft (166 m)



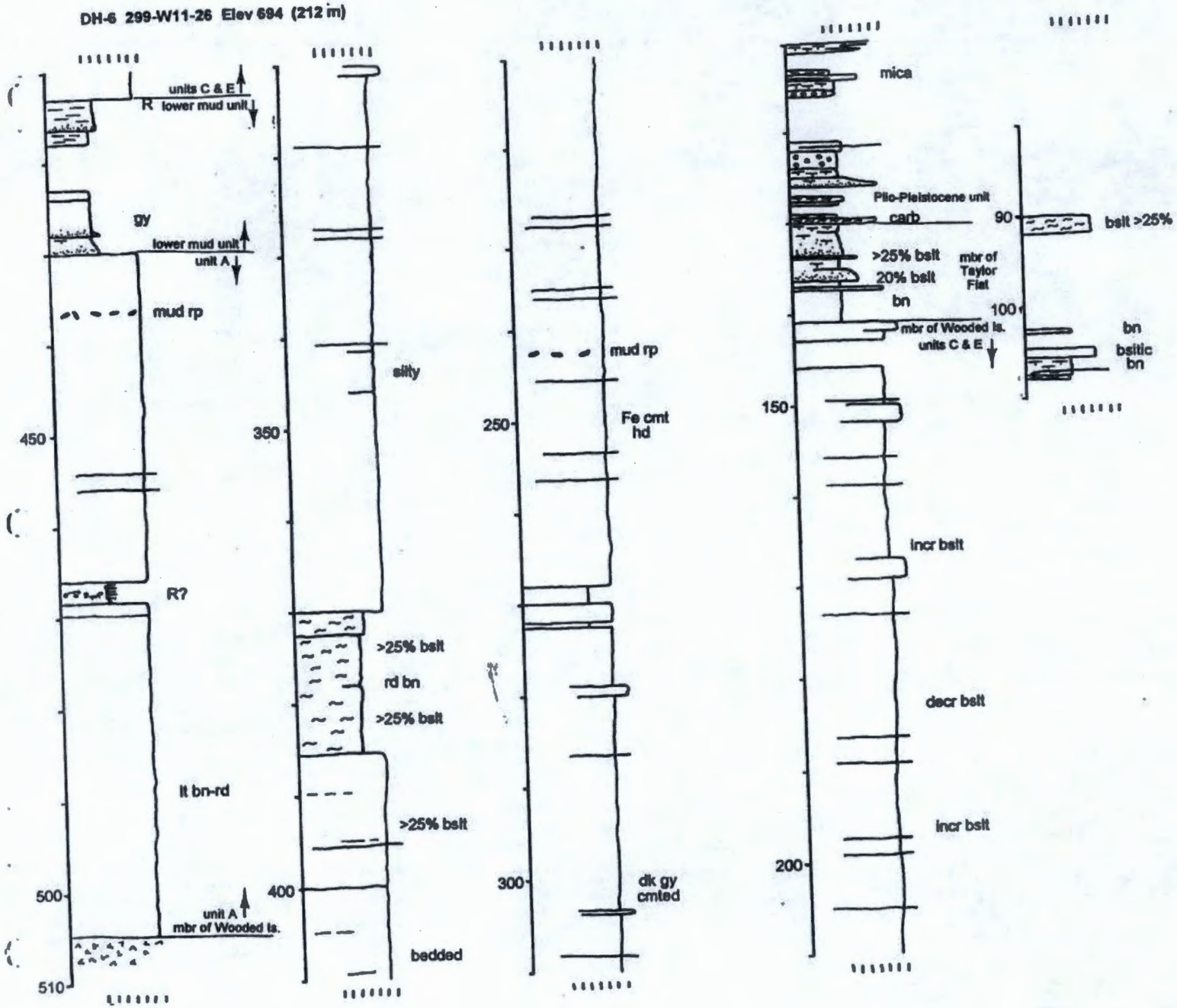
G-E-19 and G-E-1 699-17-26 Elev 525 ft (est.) (160 m)



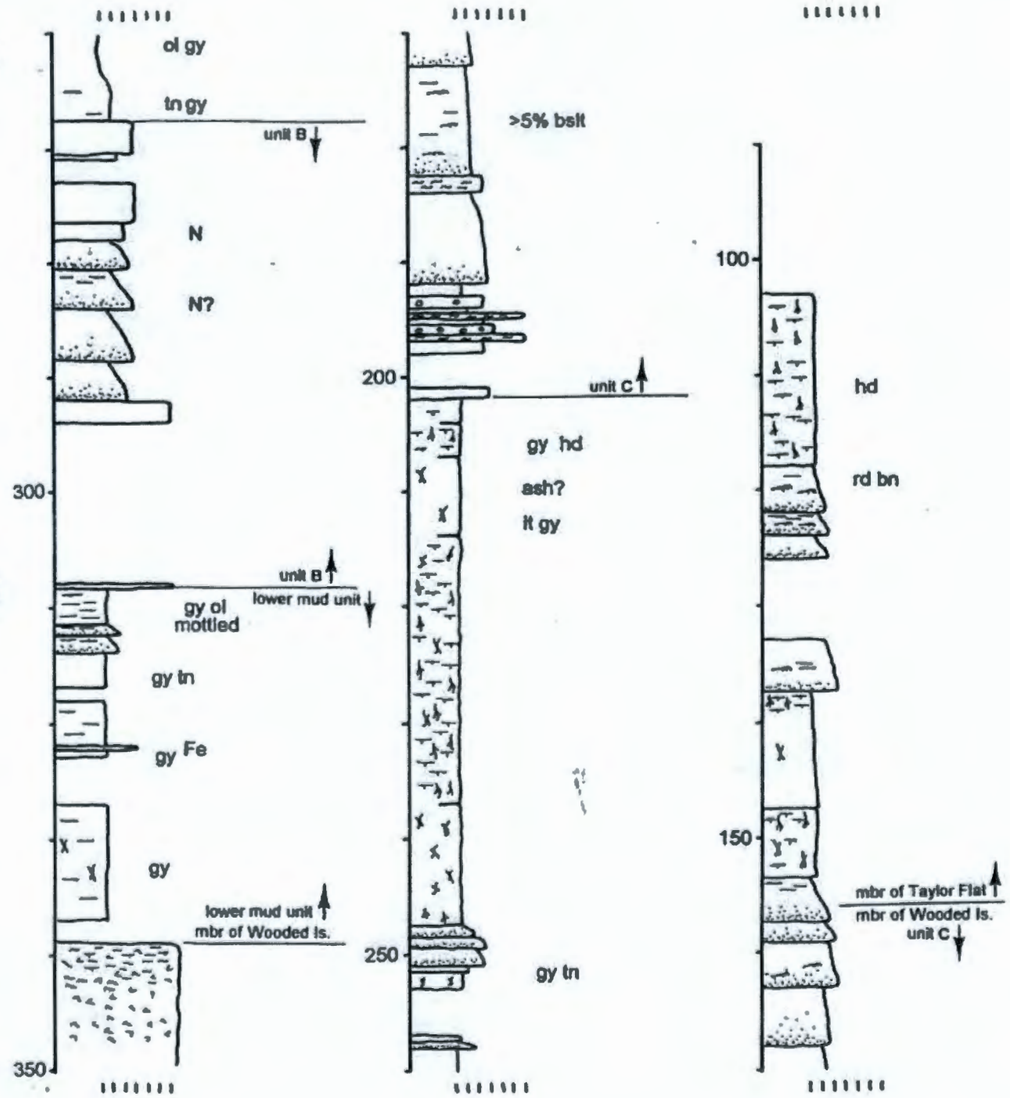

G-E-19 and G-E-1 (cont)
200
pre-Missoula gravel
mbr of Taylor Flat
ashy?
gy
gy
mottled
1-2ft graded beds
250
5% bslt
wood Fe
mbr of Taylor Flat
mbr of Wooded Is.
unit E

130
150
hi qtz
lo bslt

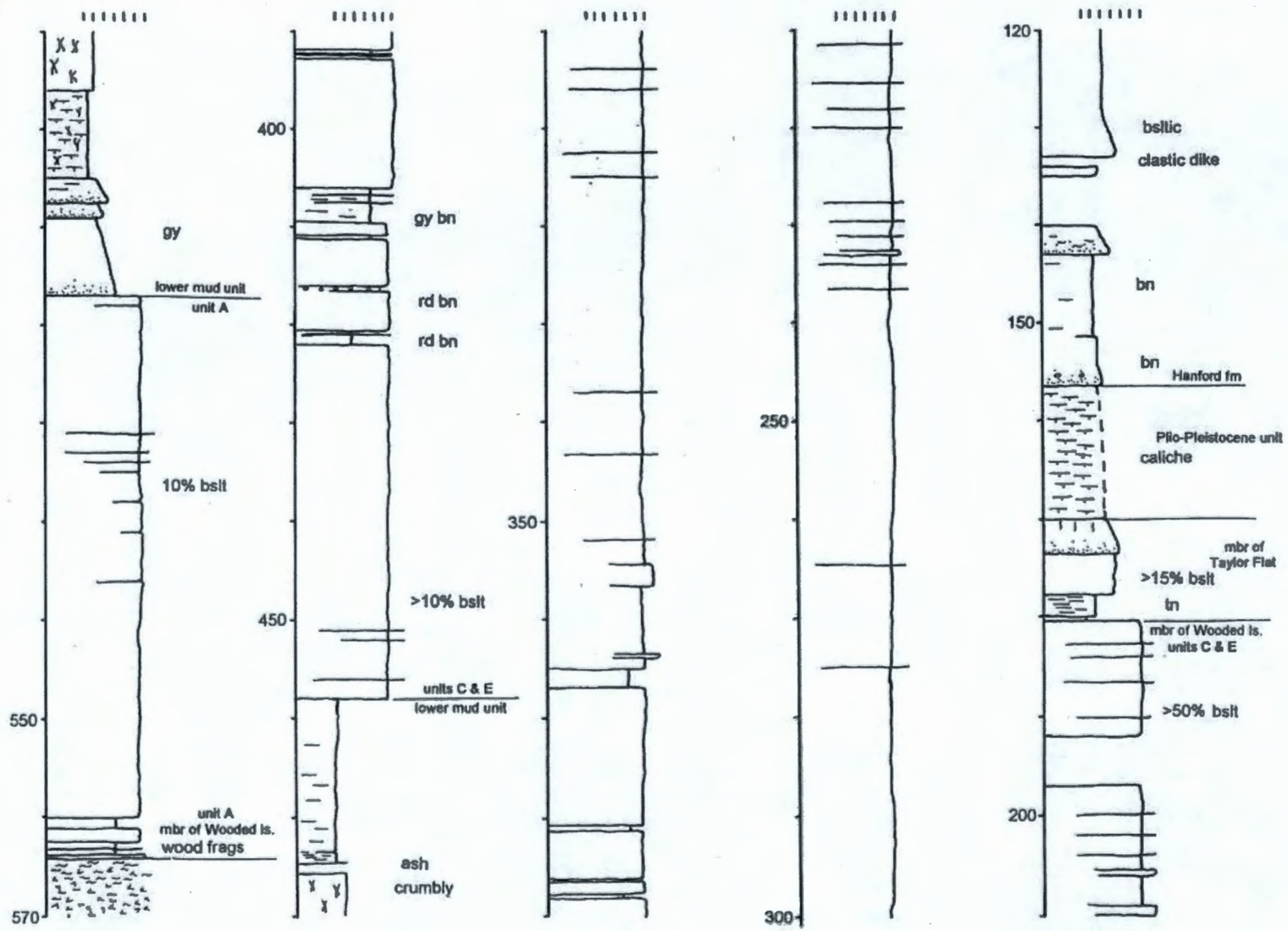
DH-6 299-W11-26 Elev 694 (212 m)



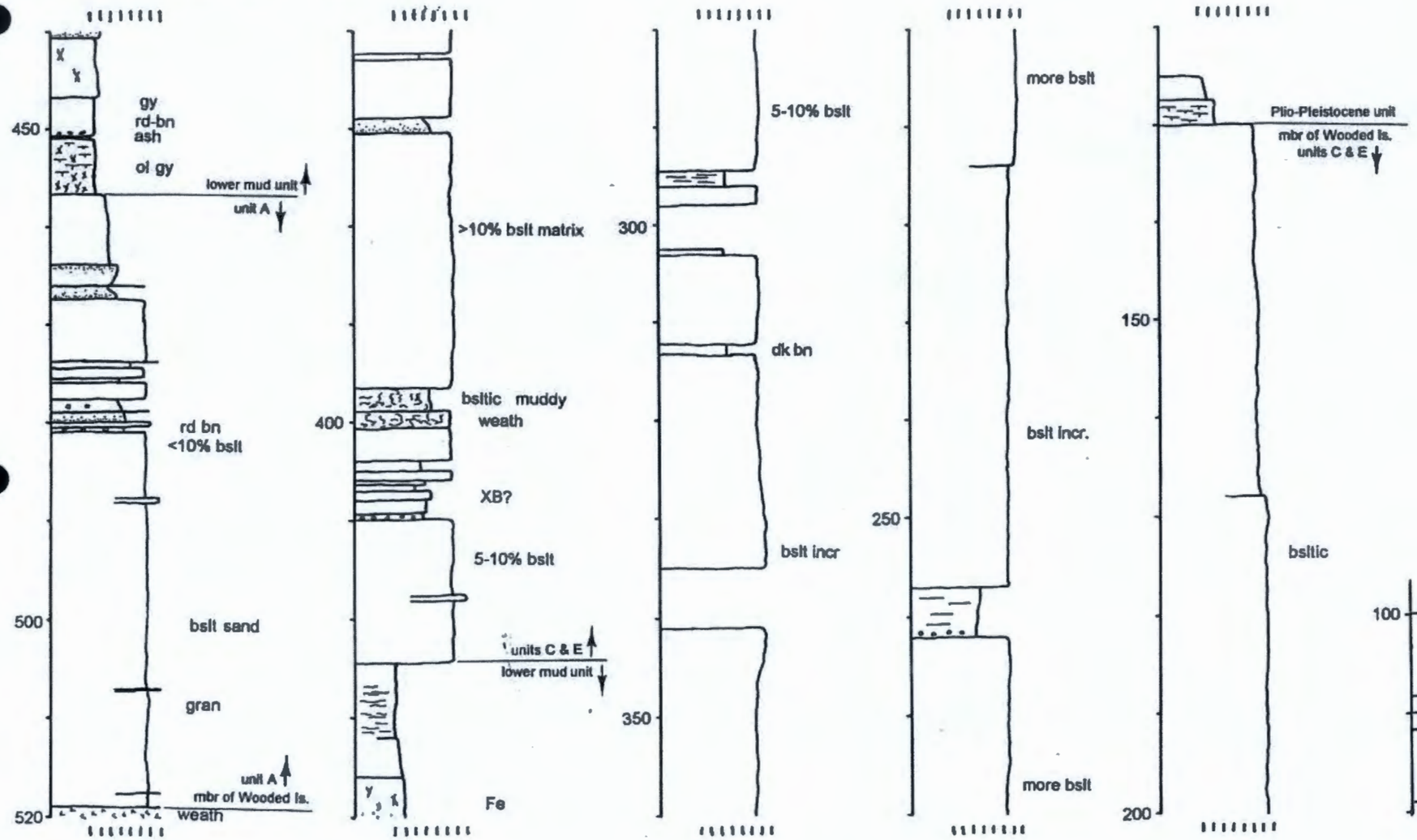
DH-9B 699-54-18C Elev 404 ft (123 m)



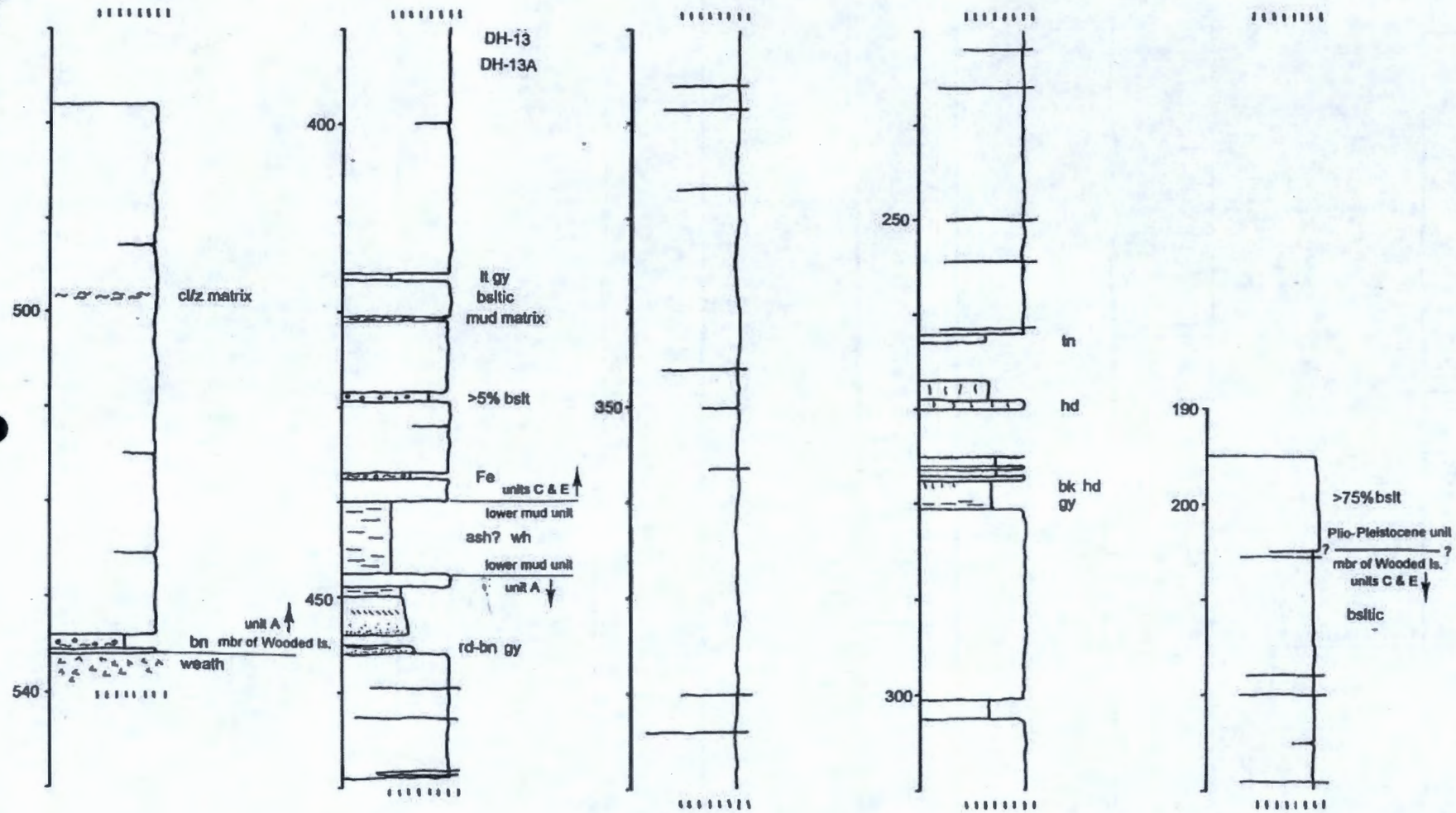
DH-11 299-W15-14 Elev 698 ft (212 m)



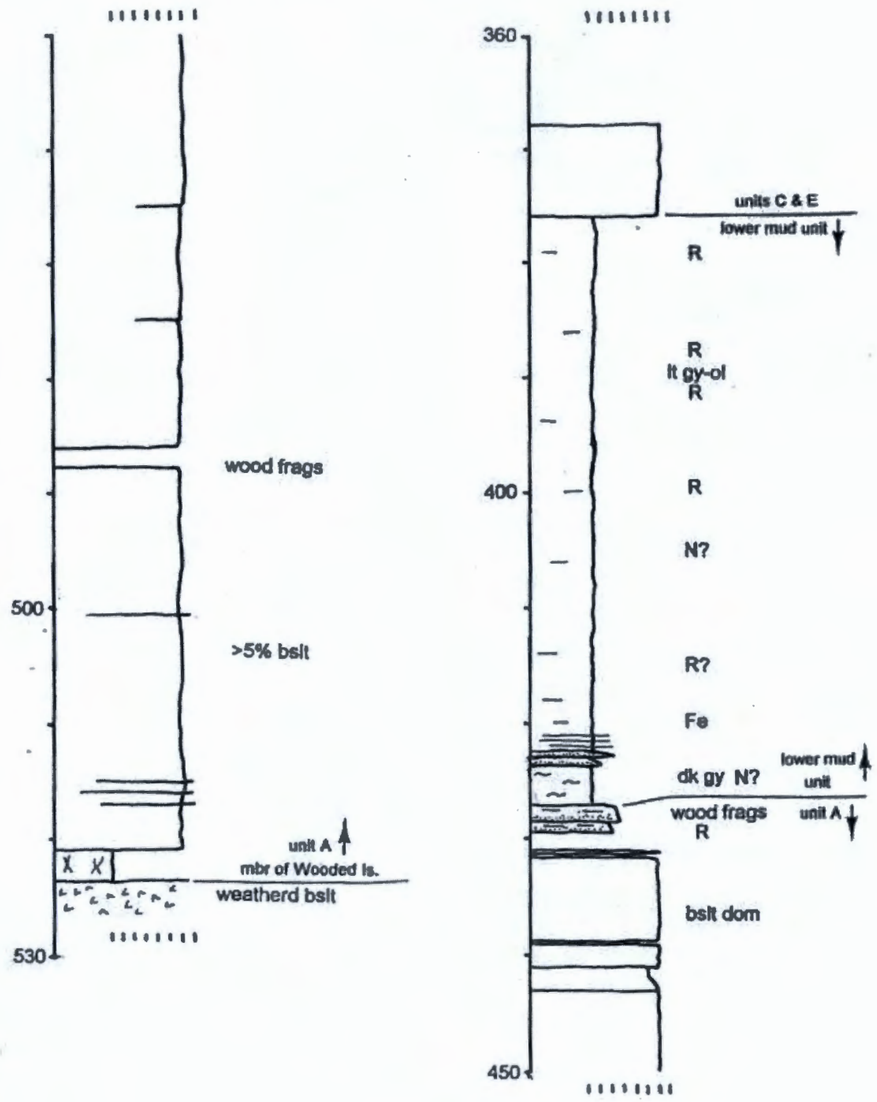
DH-12 299-W14-7 Elev. 677 ft (206 m)



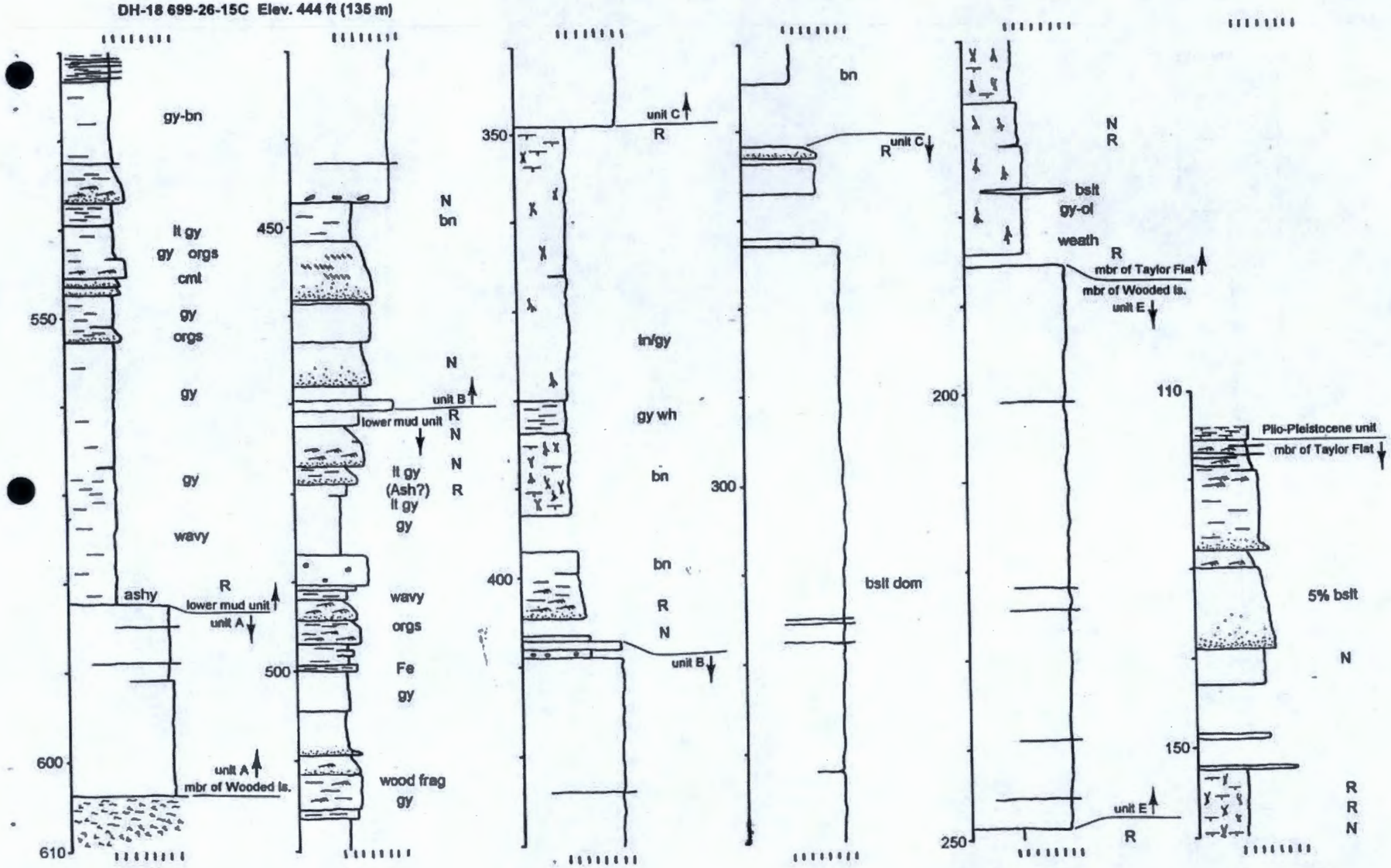
DH-13/13A 299-W14-8/8A Elev. 725 ft (221 m)



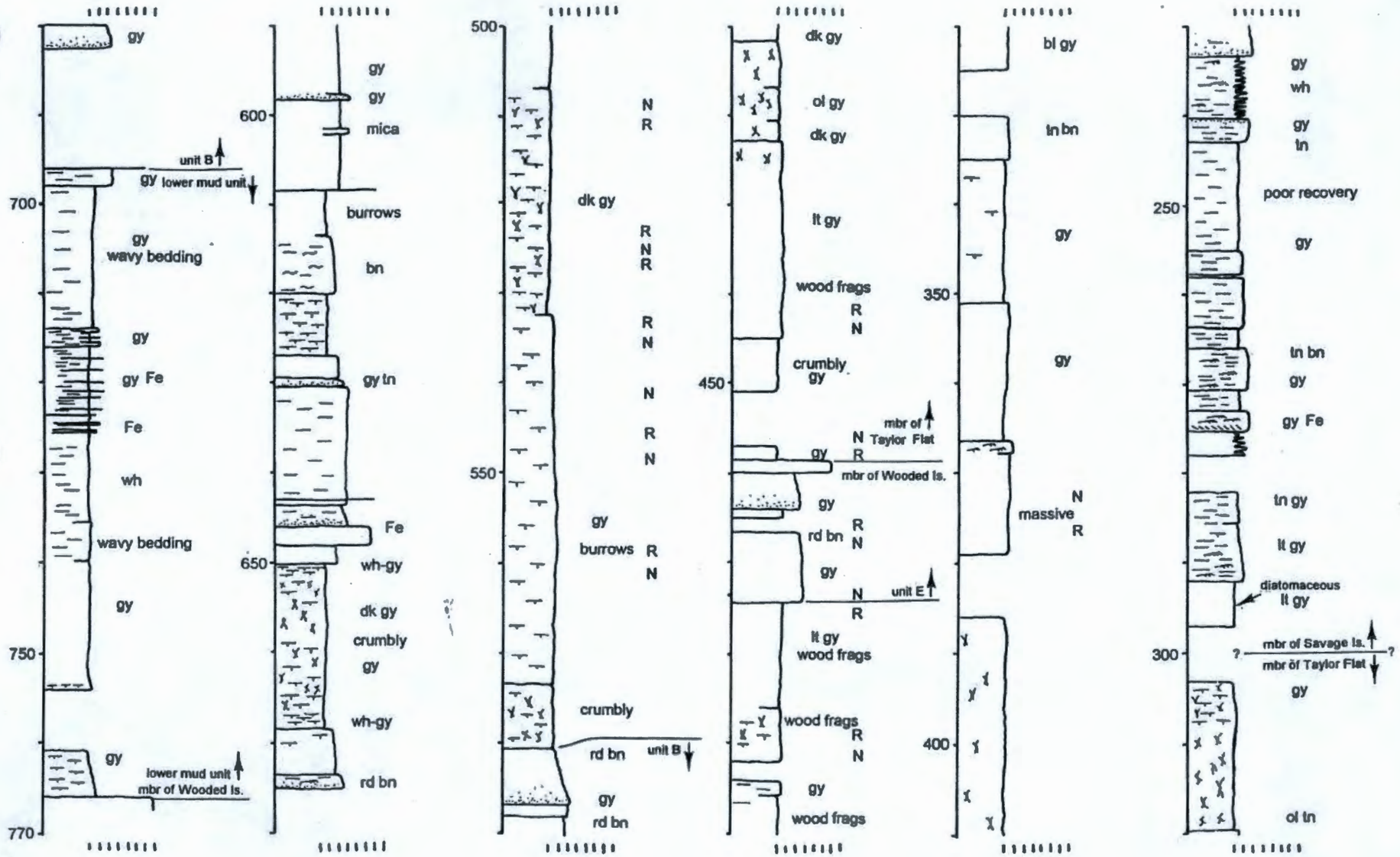
DH-17 299-E19-1 Elev. 736 ft (224 m)

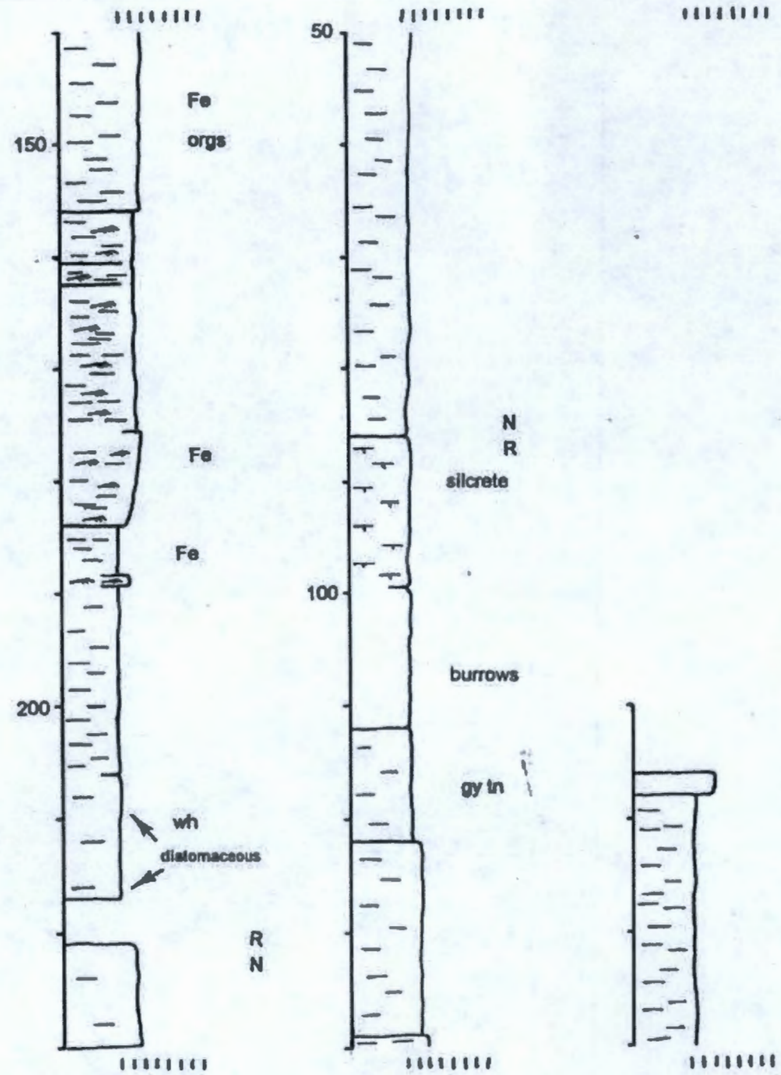


DH-18 699-26-15C Elev. 444 ft (135 m)

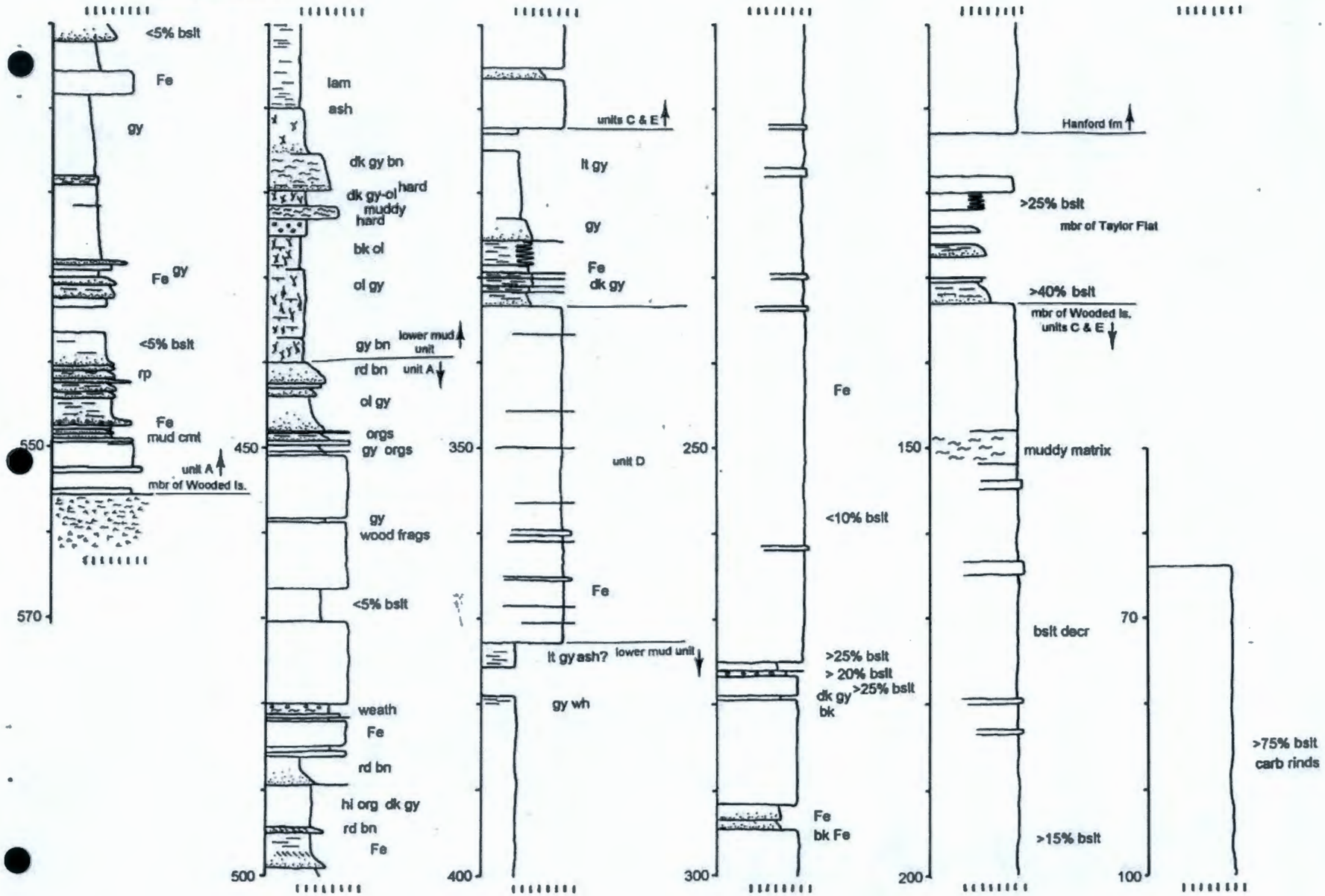


DH-19 699-70-17 Elev 875 ft (est.) (267 m)

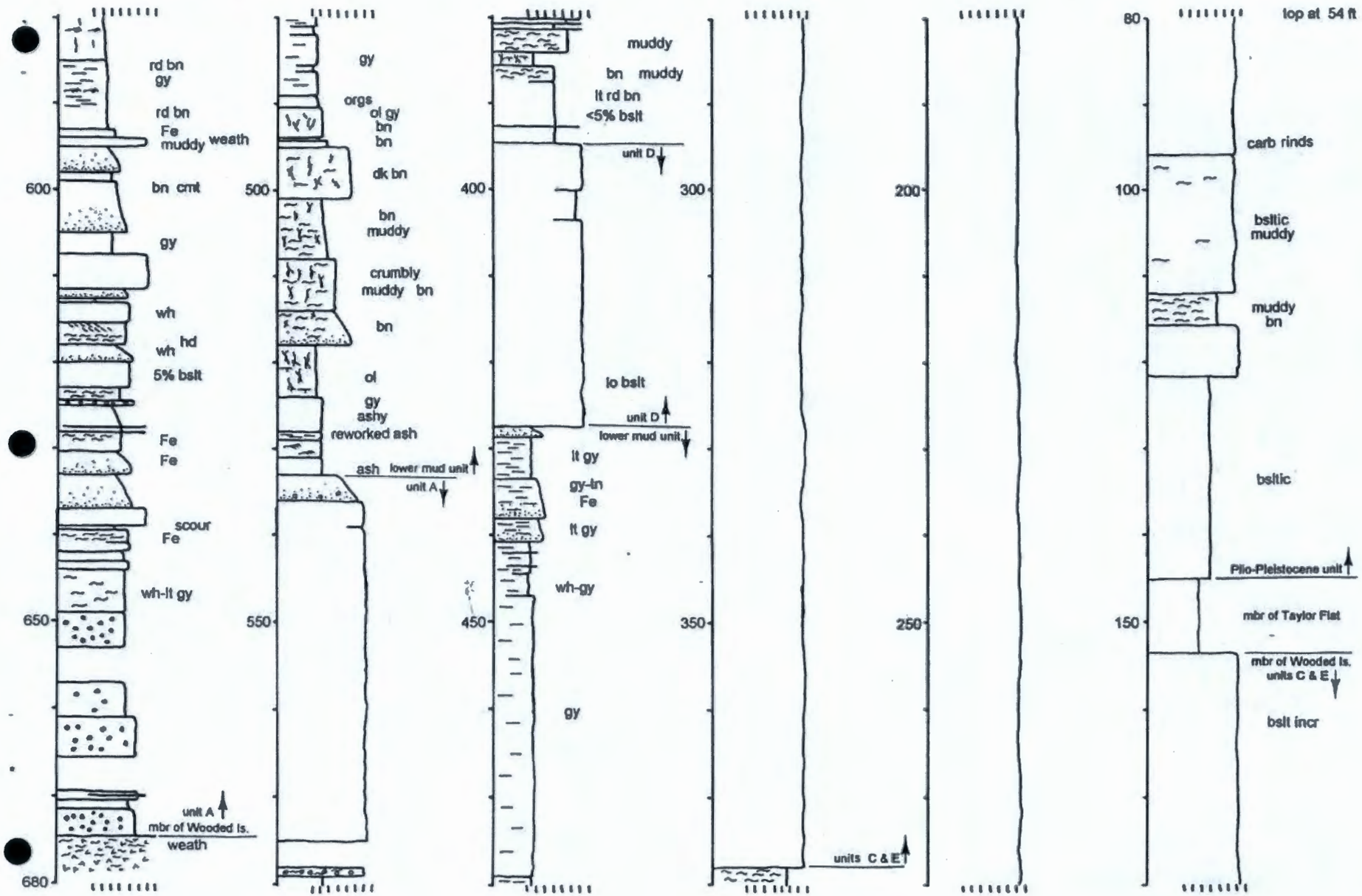



150
200
Fe
orgs
Fe
Fe
wh
diatomaceous
R
N
50
100
N
R
silcrete
burrows
gy tn

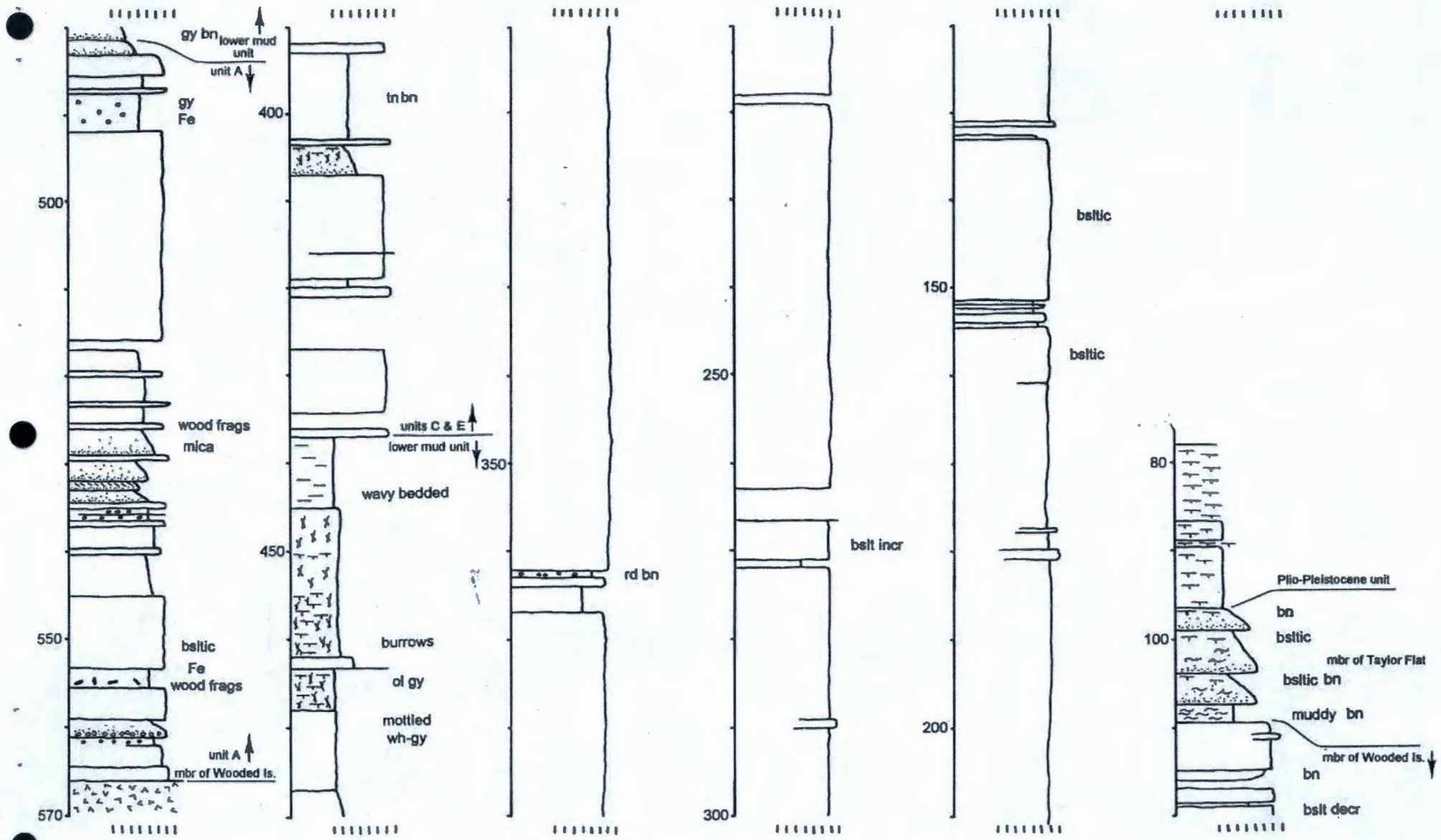
DH-20 699-29-83 Elev. 623 ft (190 m)



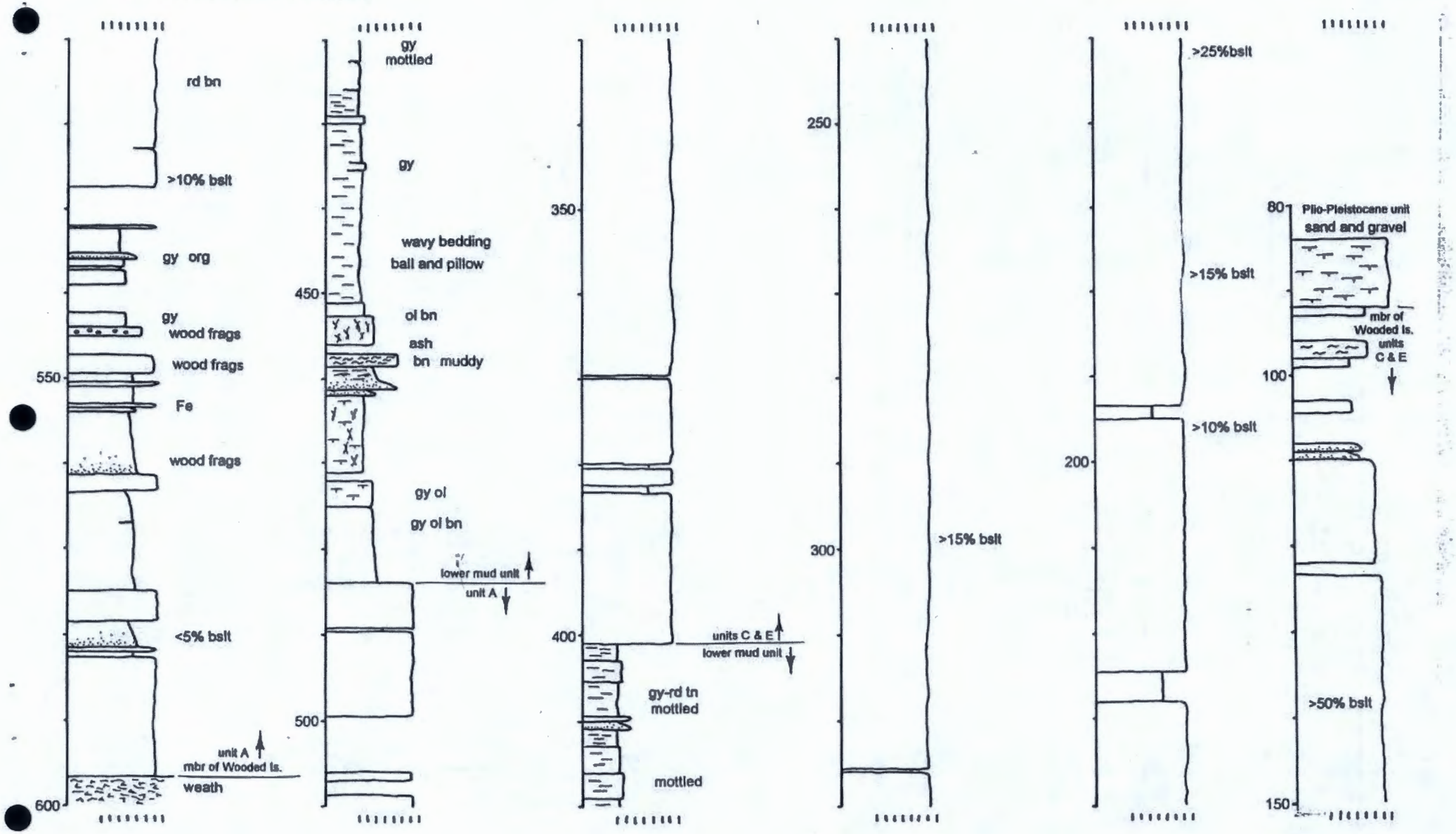
DH-22 699-37-92 Elev 645 (197m)



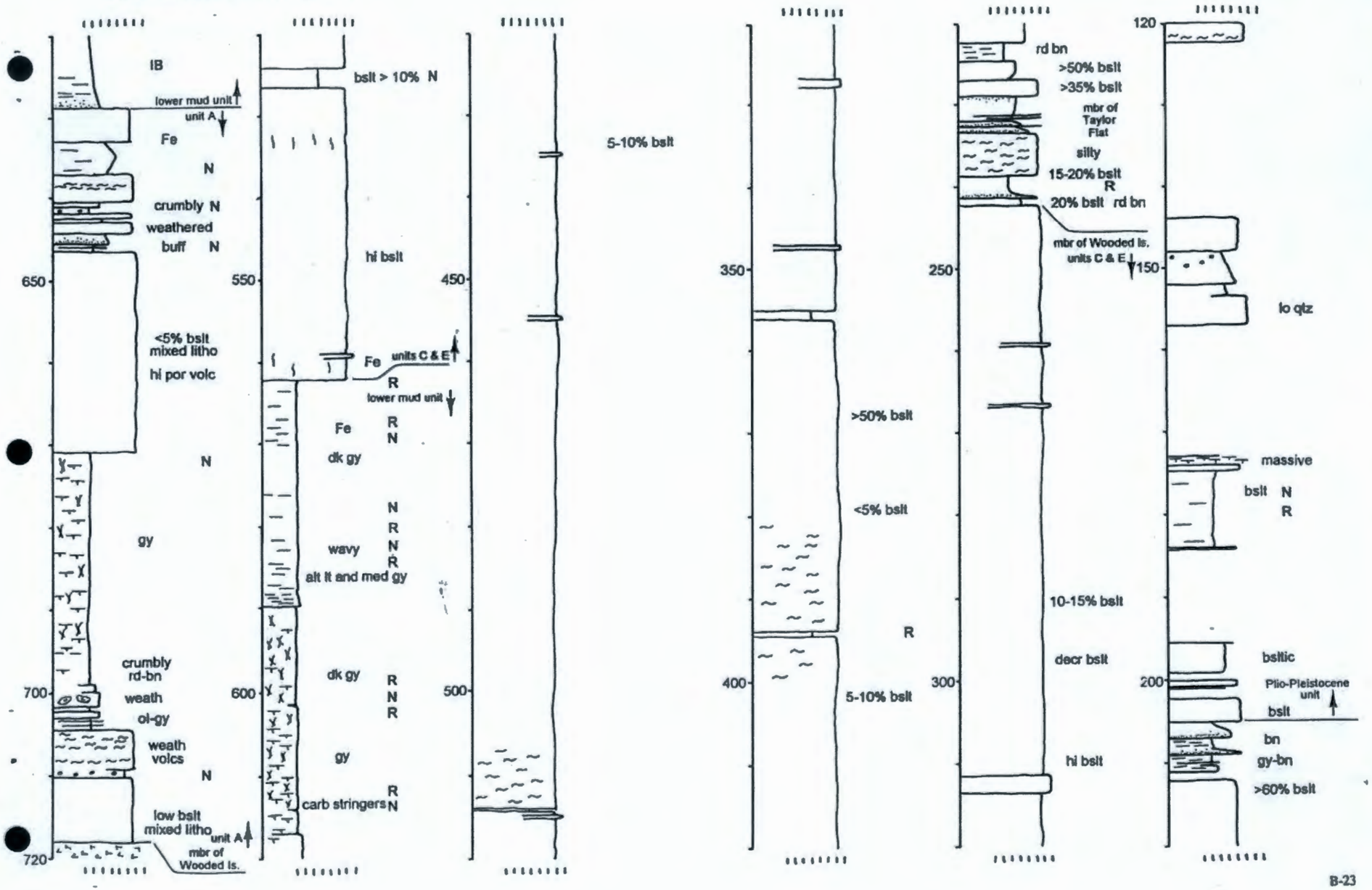
DH-24 699-43-84 Elev 634 ft (193 m



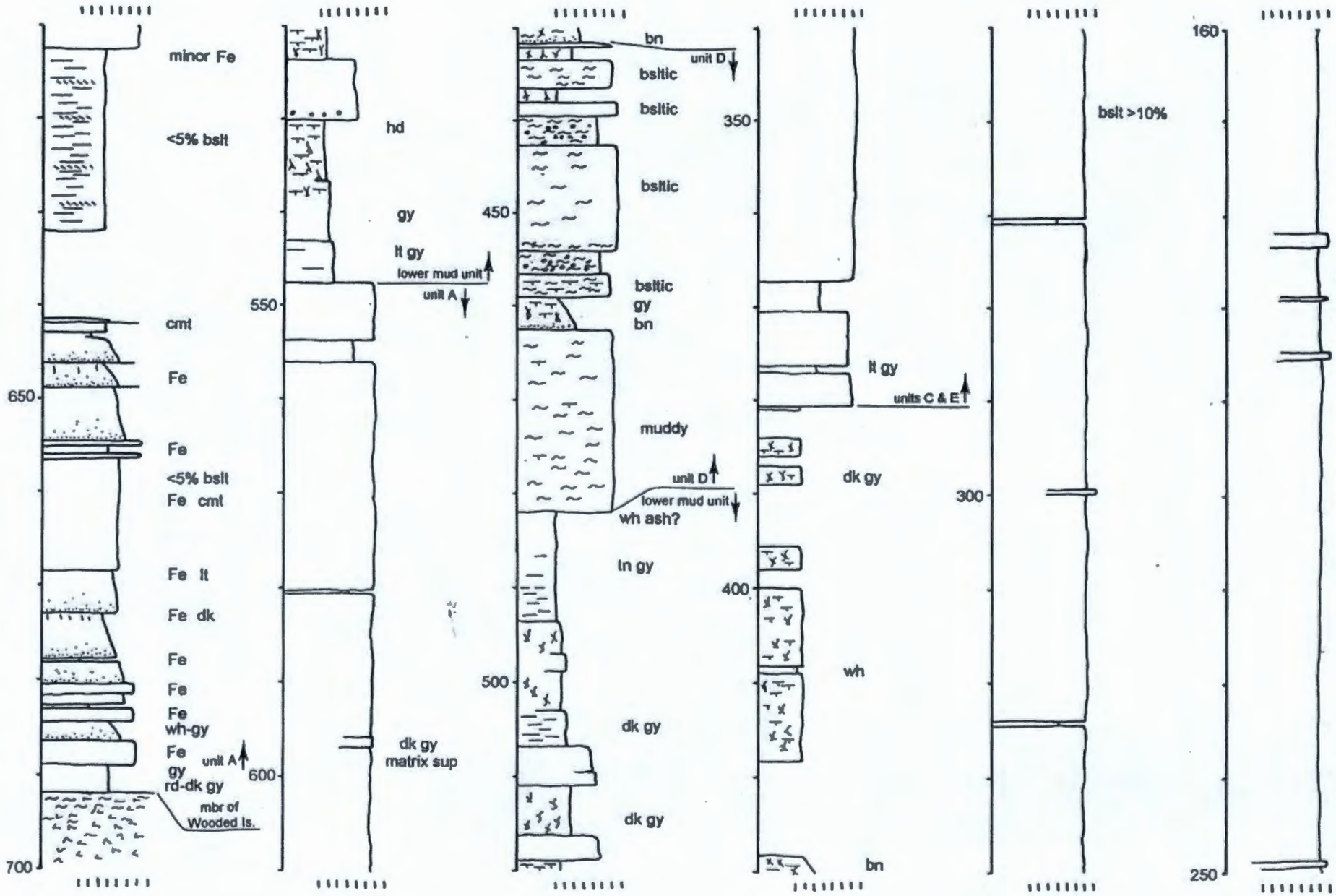
DH-25 699-40-84n Elev 638 ft (1[illegible] 4 m)

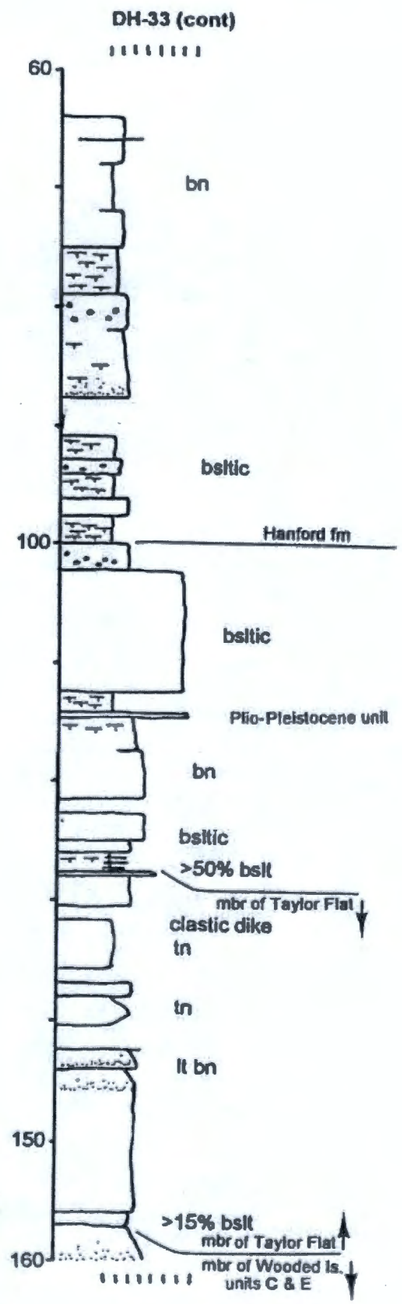


DH-28 699-50-96 Elev. 800 ft (245 m)



DH-33 699-34-98 Elev 670 ft (204 m)




DH-33 (cont)
60
bn
bsltic
100
Hanford fm
bsltic
Plio-Pleistocene unit
bn
bsltic
>50% bslt
mbr of Taylor Flat
clastic dike
tn
tn
lt bn
150
>15% bslt
mbr of Taylor Flat
160
mbr of Wooded Is.
units C & E

APPENDIX C
GEOLOGIC CROSS SECTIONS

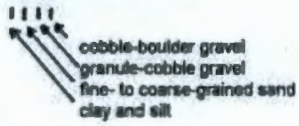
APPENDIX C

GEOLOGIC CROSS SECTIONS SHOWING DISTRIBUTION OF RINGOLD FORMATION STRATIGRAPHIC UNITS

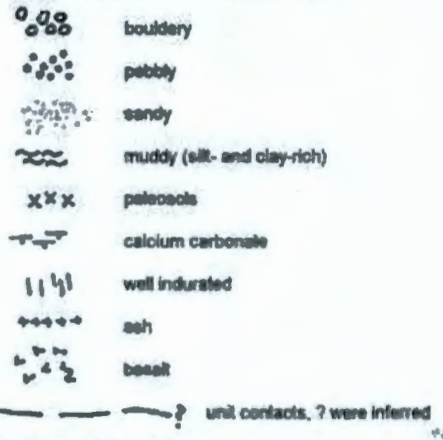
Locations of cross sections are shown on inset maps of the Hanford Site on each cross-section page.

EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED IN CROSS SECTIONS

Grain Size Scale, indicates dominant grain size



Subordinate lithologies and other lithologic symbols



Stratigraphic unit abbreviations

PM - pre-Missoula gravel of Plio-Pleistocene interval

UR - upper Ringold, Ringold Formation member of Taylor Flat

E - unit E, Ringold Formation member of Wooded Island

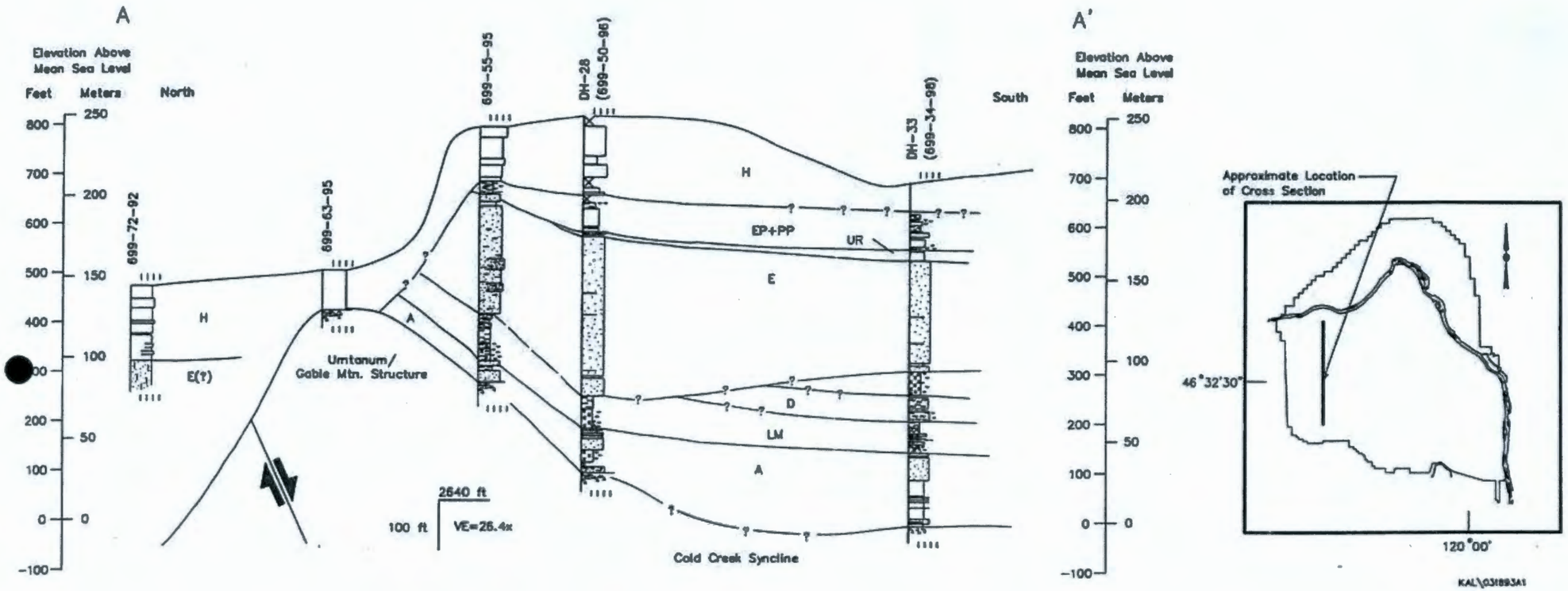
C - unit C, Ringold Formation member of Wooded Island

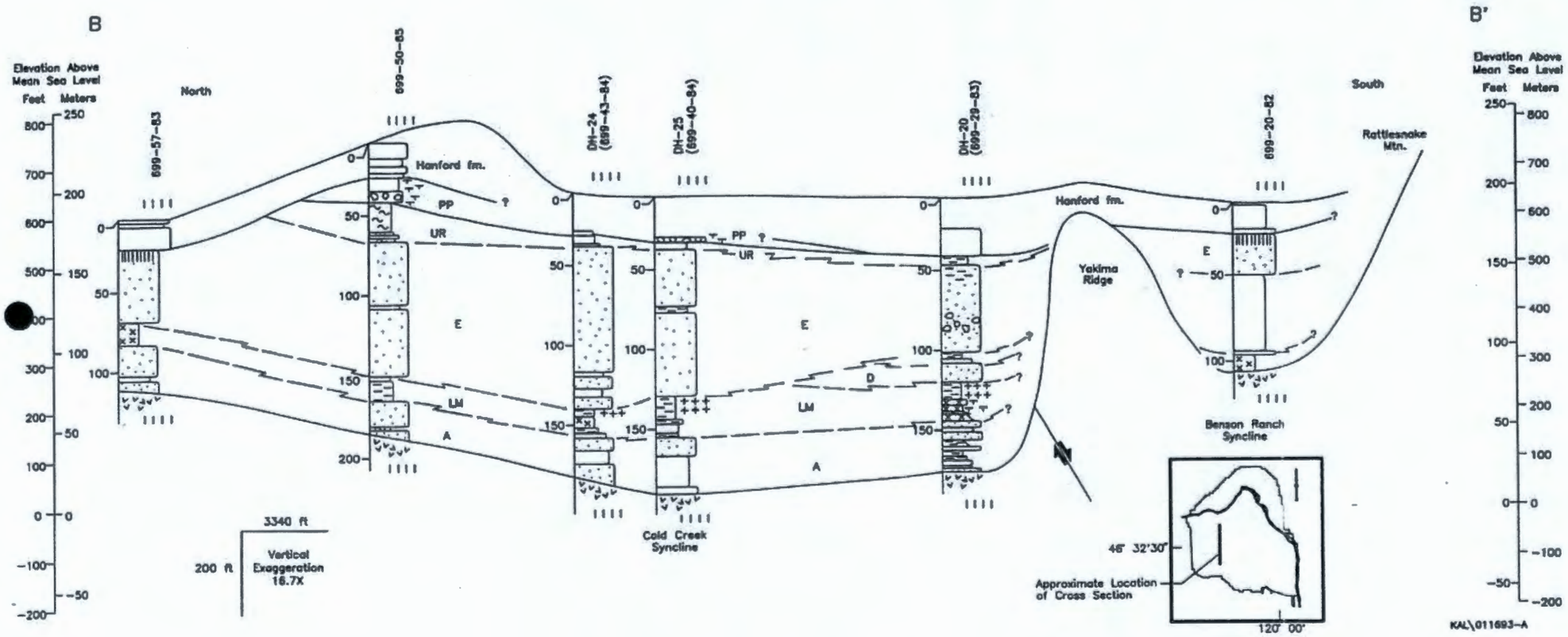
B - unit B, Ringold Formation member of Wooded Island

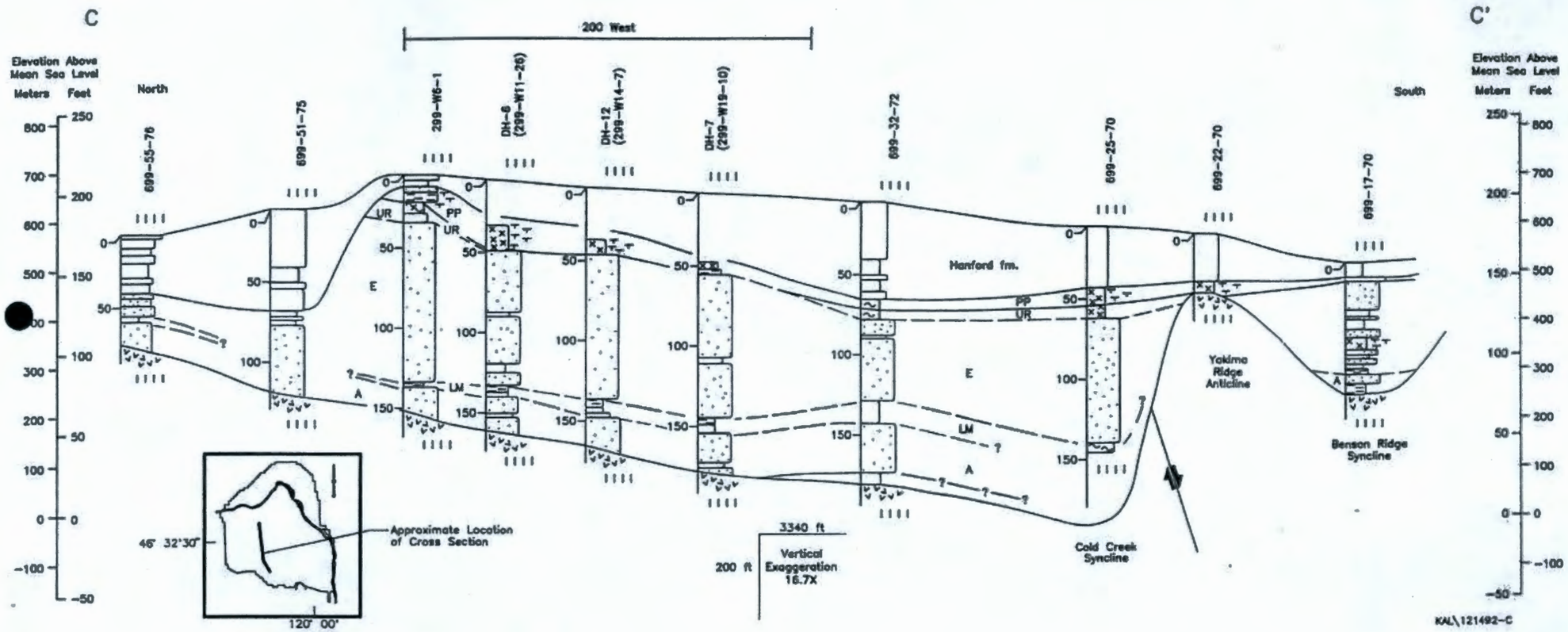
D - unit D, Ringold Formation member of Wooded Island

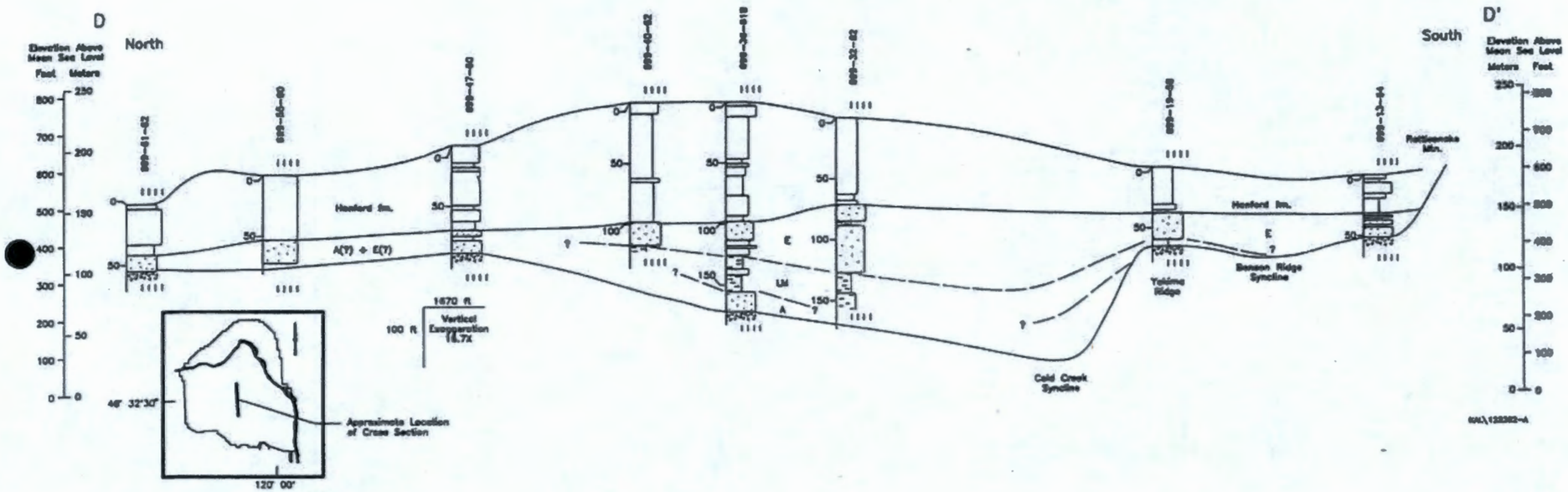
LM - lower mud unit, Ringold Formation member of Wooded Island

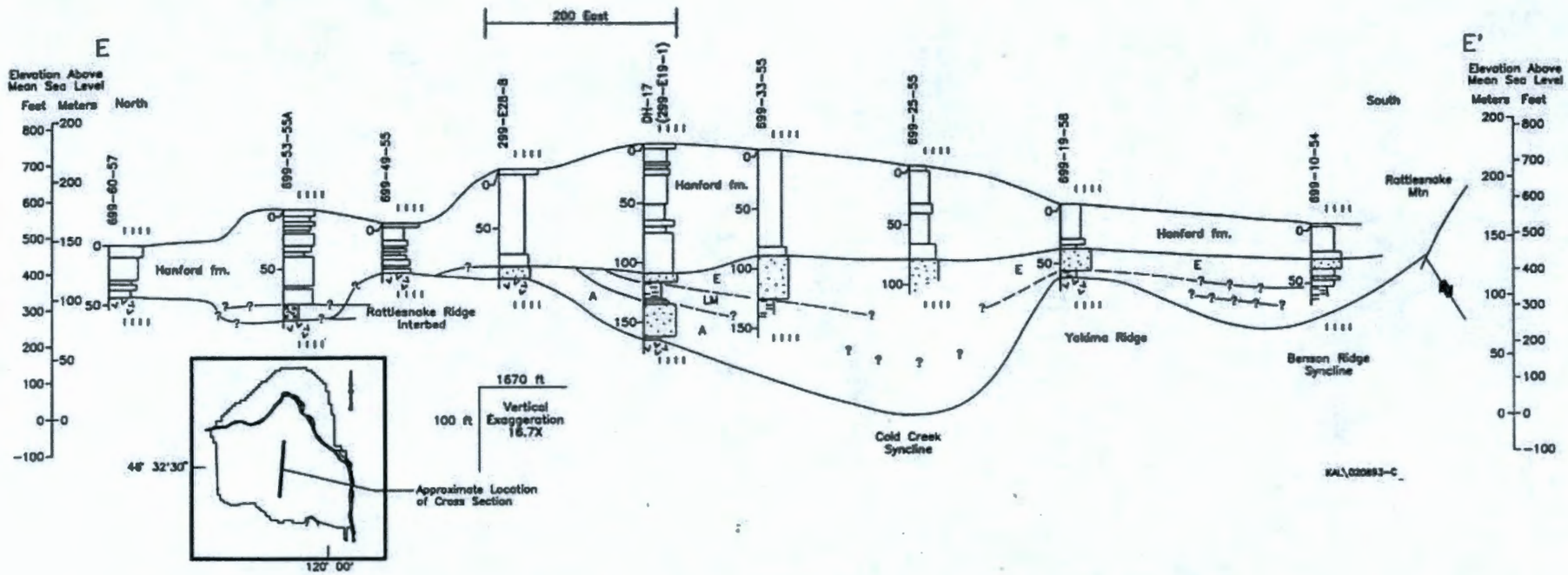
A - unit A, Ringold Formation member of Wooded Island

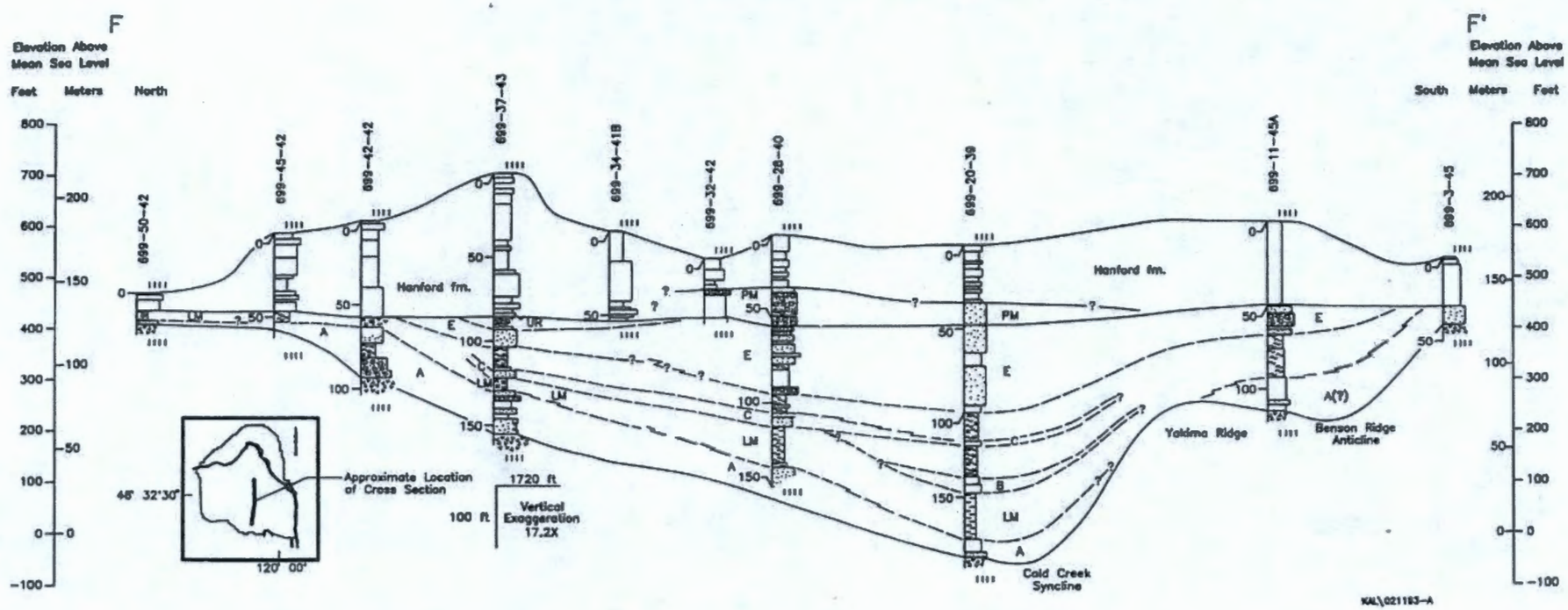

A
Elevation Above Mean Sea Level
Feet
Meters
North
South
699-72-92
699-63-95
699-55-95
DH-28 (699-50-96)
DH-33 (699-34-96)
H
E(?)
A
Umtanum/ Gable Mtn. Structure
EP+PP
UR
E
D
LM
A
Cold Creek Syncline
2640 ft
100 ft
VE=26.4x
A'
Approximate Location of Cross Section
46°32'30"
120°00'
KAL\031893A1

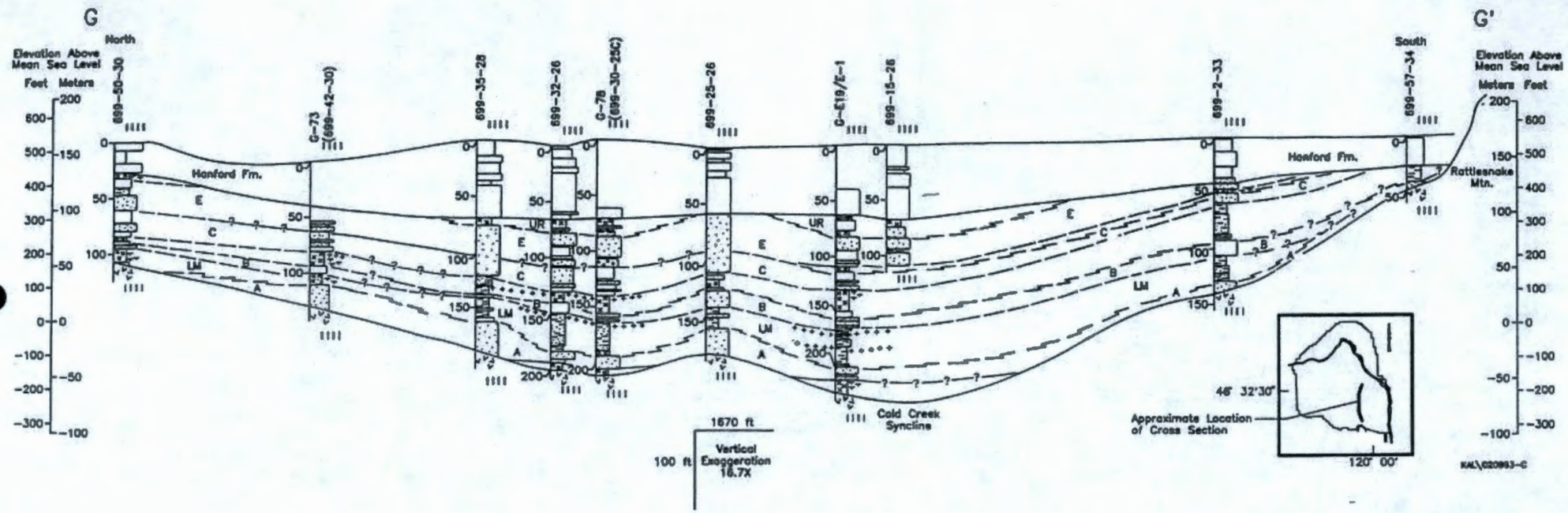

B
B'
Elevation Above Mean Sea Level
Feet Meters
North
South
699-57-83
699-50-85
DH-24 (699-43-84)
DH-25 (699-40-84)
DH-20 (699-29-83)
699-20-82
Hanford fm.
Rattlesnake Mtn.
Yakima Ridge
Benson Ranch Syncline
Cold Creek Syncline
PP
UR
E
LM
A
D
3340 ft
200 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section
KAL\011693-A

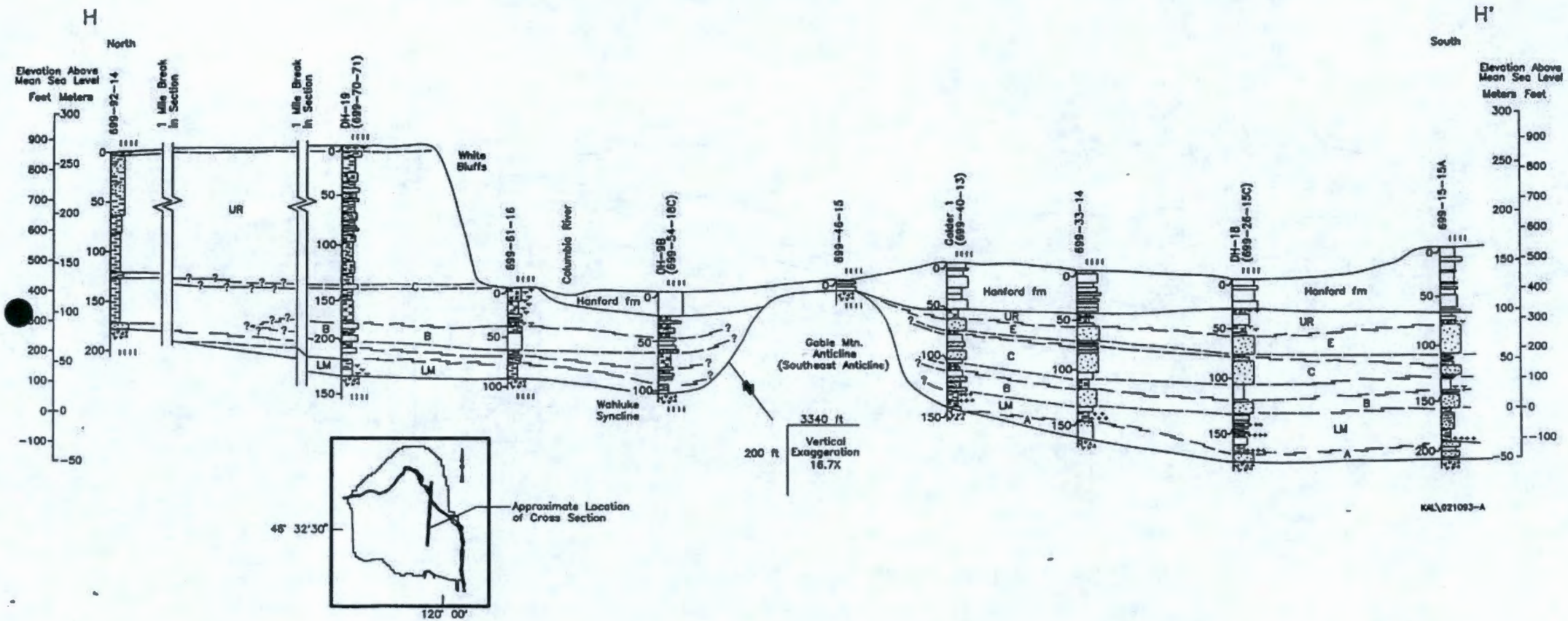

C
C'
200 West
Elevation Above Mean Sea Level
Meters Feet
North
South
699-53-76
699-51-75
299-W5-1
DH-6 (299-W11-26)
DH-12 (299-W14-7)
DH-7 (299-W19-10)
699-32-72
699-25-70
699-22-70
699-17-70
Hanford fm.
Yakima Ridge Anticline
Benson Ridge Syncline
Cold Creek Syncline
UR
PP
E
LM
A
Approximate Location of Cross Section
46° 32'30"
120° 00'
3340 ft
200 ft
Vertical Exaggeration 16.7X
KAL\121492-C

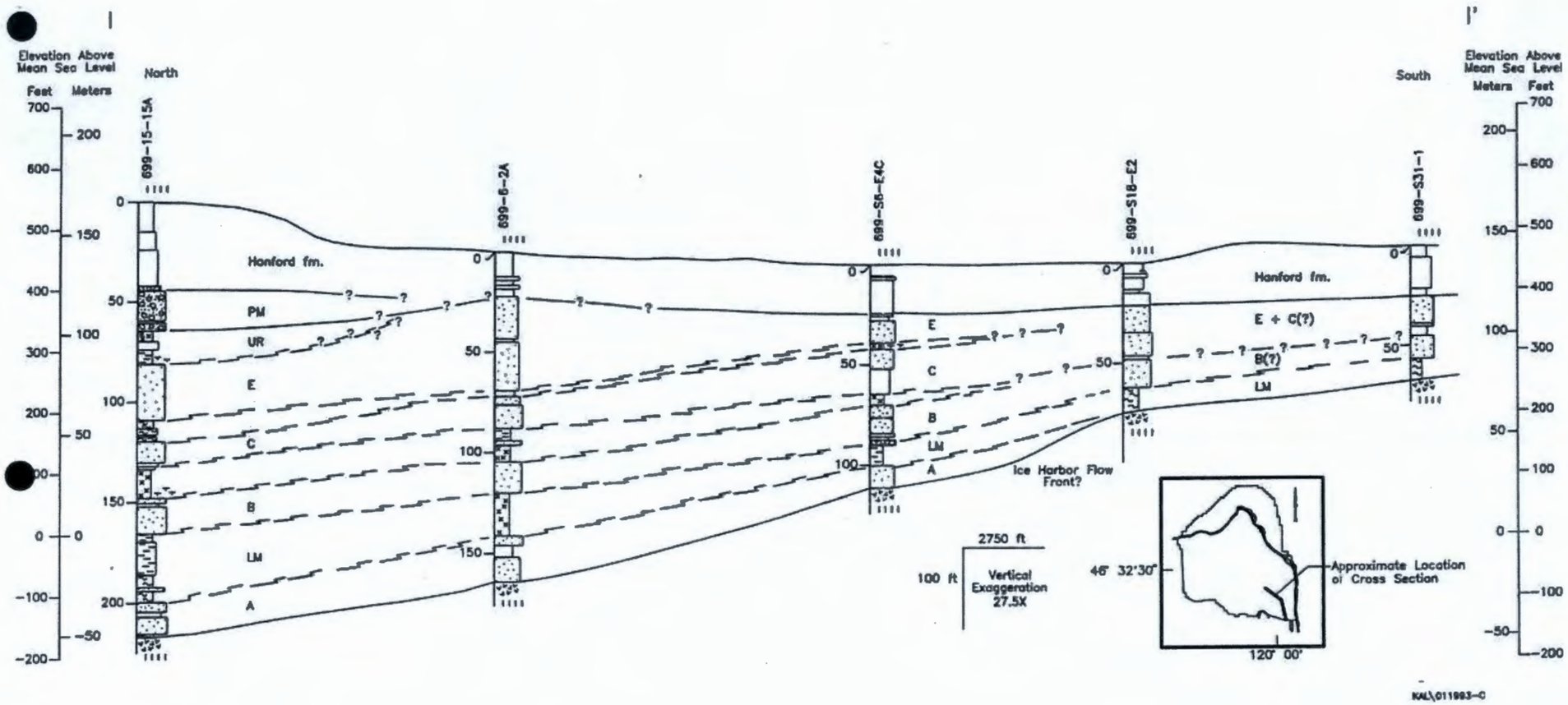

D
North
D'
South
Elevation Above Mean Sea Level
Feet
Meters
Hanford fm.
A(?) + E(?)
Rattlesnake Mtn.
Yakima Ridge
Benson Ridge Syncline
Cold Creek Syncline
1670 ft
100 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section

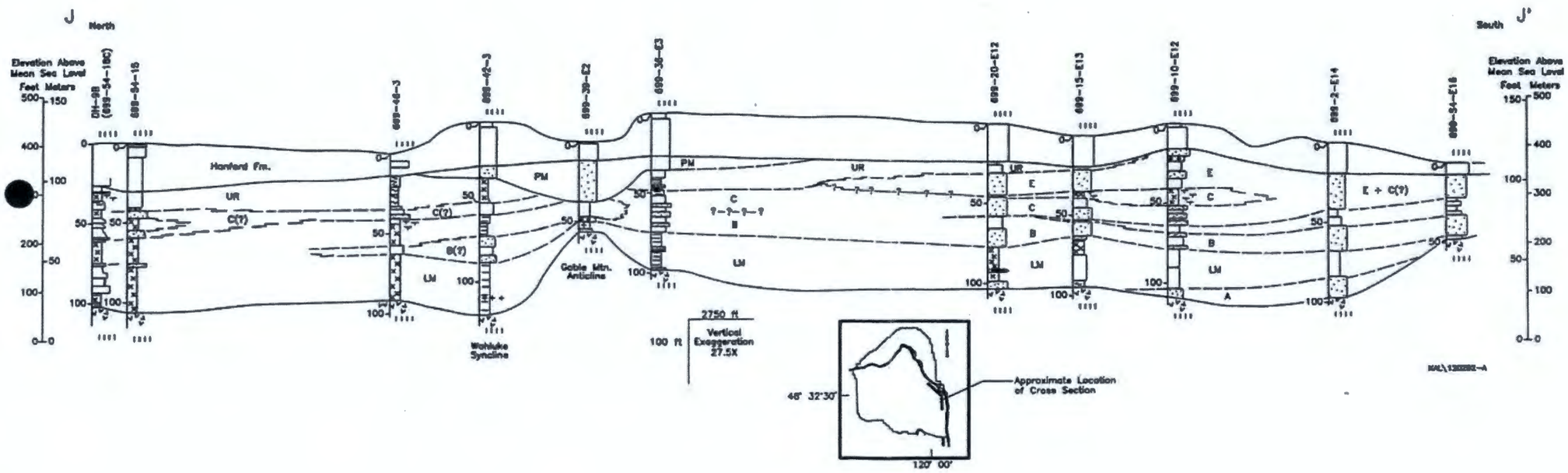

E
E'
Elevation Above Mean Sea Level
Feet Meters
North
South
200 East
699-60-57
699-53-55A
699-49-55
299-E28-8
DH-17 (299-E19-1)
699-33-53
699-25-55
699-19-58
699-10-54
Hanford fm.
Rattlesnake Ridge Interbed
Rattlesnake Mtn
Yakima Ridge
Benson Ridge Syncline
Cold Creek Syncline
1670 ft
100 ft
Vertical Exaggeration 16.7X
48° 32'30"
120° 00'
Approximate Location of Cross Section

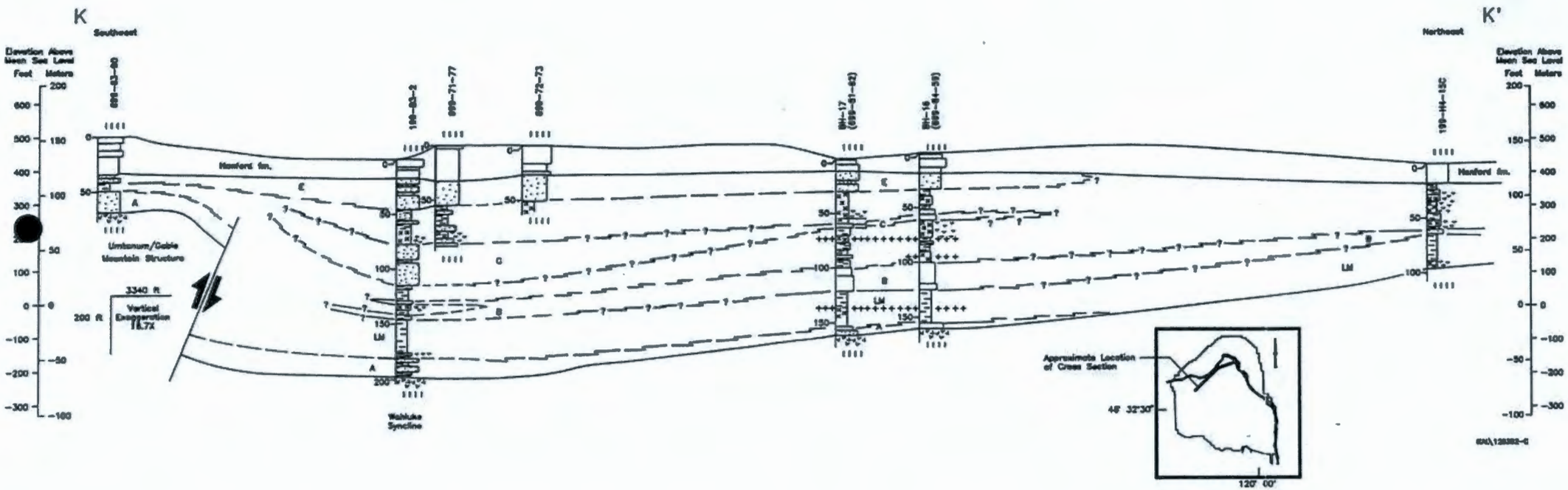

F
F'
Elevation Above Mean Sea Level
Feet
Meters
North
South
699-50-42
699-45-42
699-42-42
699-37-43
699-34-41B
699-32-42
699-28-40
699-20-39
699-11-45A
699-3-45
Hanford fm.
Hanford fm.
Yakima Ridge
Benson Ridge Anticline
Cold Creek Syncline
Approximate Location of Cross Section
46° 32'30"
120° 00'
1720 ft
100 ft
Vertical Exaggeration 17.2X
KAL\021193-A

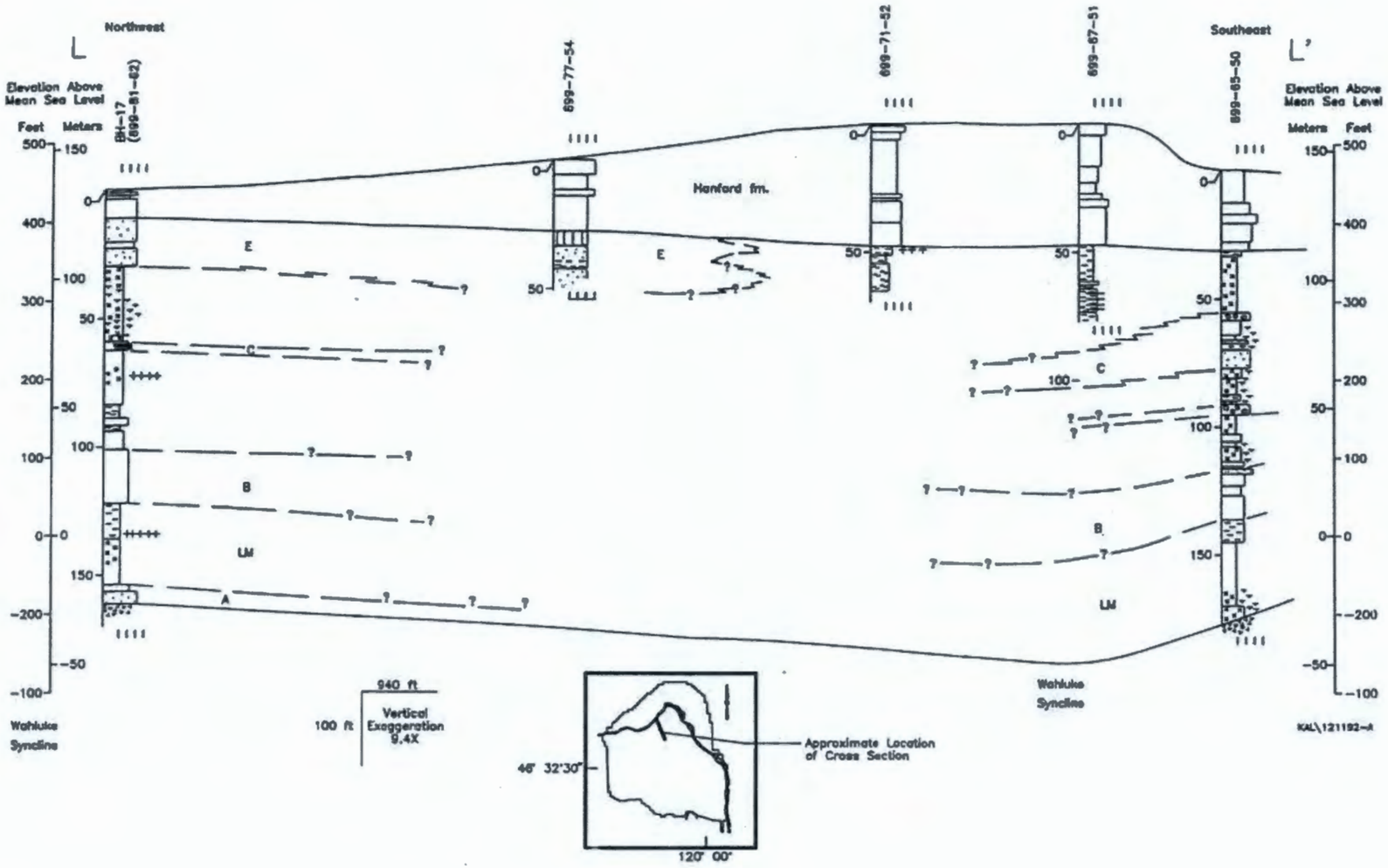

G
G'
North
South
Elevation Above Mean Sea Level
Feet Meters
Meters Feet
699-50-30
G-73 (699-42-30)
699-35-28
699-32-26
G-78 (699-30-25C)
699-25-26
C-E19/E-1
699-15-26
699-2-33
699-57-34
Hanford Fm.
Rattlesnake Mtn.
Cold Creek Syncline
1670 ft
100 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section
KAL\G20993-C

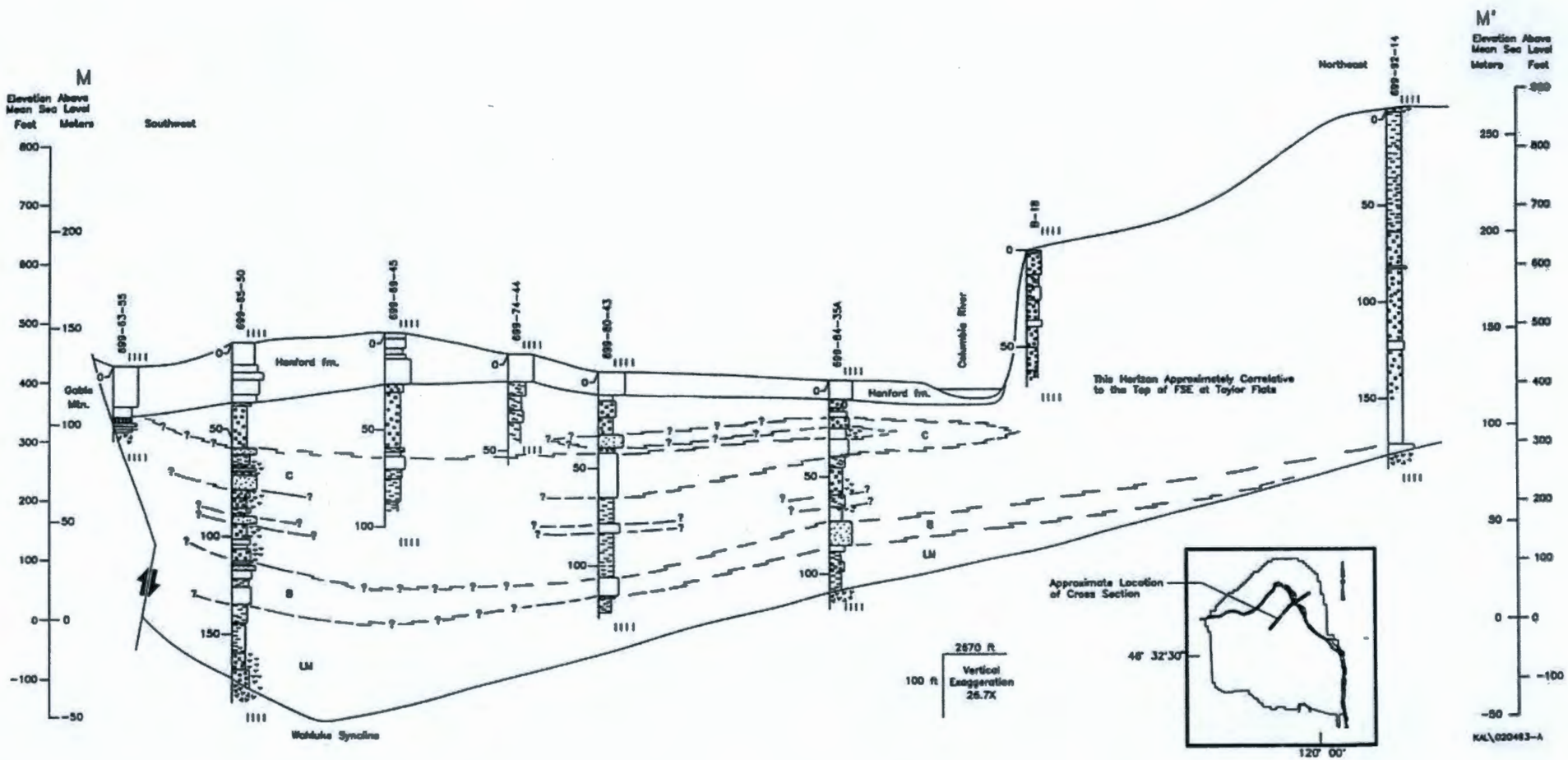

H
H'
North
South
Elevation Above Mean Sea Level
Feet Meters
Meters Feet
699-42-14
1 Mile Break in Section
DH-19 (699-70-71)
White Bluffs
699-51-16
Columbia River
DH-9B (699-54-18C)
699-46-15
Calder 1 (699-40-13)
699-33-14
DH-18 (699-26-15C)
699-15-15A
Hanford fm
UR
E
C
B
LM
A
Gable Mtn. Anticline (Southeast Anticline)
Wahluke Syncline
3340 ft
200 ft
Vertical Exaggeration 16.7X
Approximate Location of Cross Section
46° 32'30"
120° 00'
KAL\021093-A

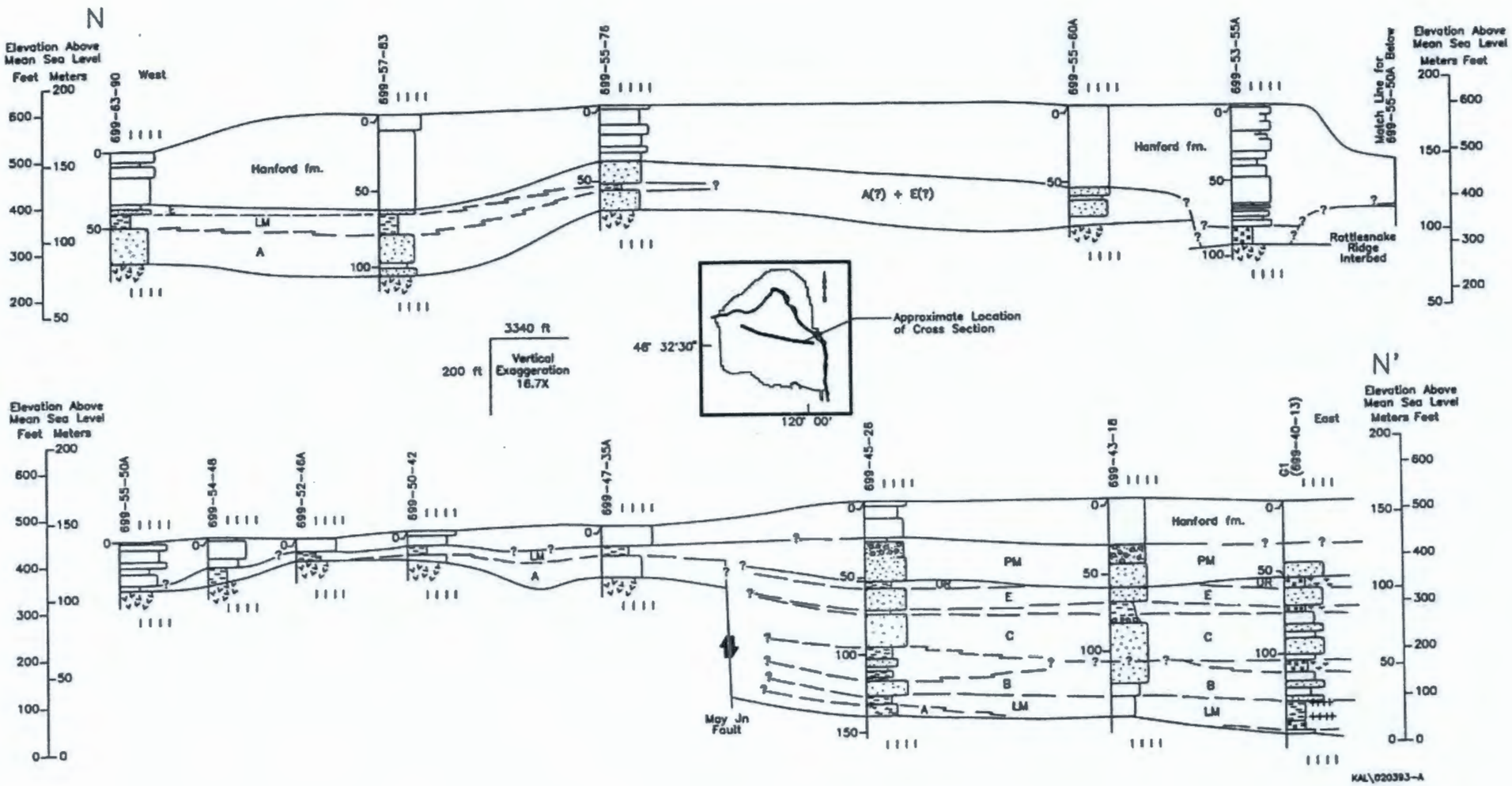

I
I'
Elevation Above Mean Sea Level
Feet
Meters
North
South
699-15-15A
699-6-2A
699-S6-E4C
699-S18-E2
699-S31-1
Hanford fm.
PM
UR
E
C
B
LM
A
E + C(?)
B(?)
Ice Harbor Flow Front?
2750 ft
100 ft
Vertical Exaggeration 27.5X
46° 32'30"
120° 00'
Approximate Location of Cross Section
KAL\011993-C

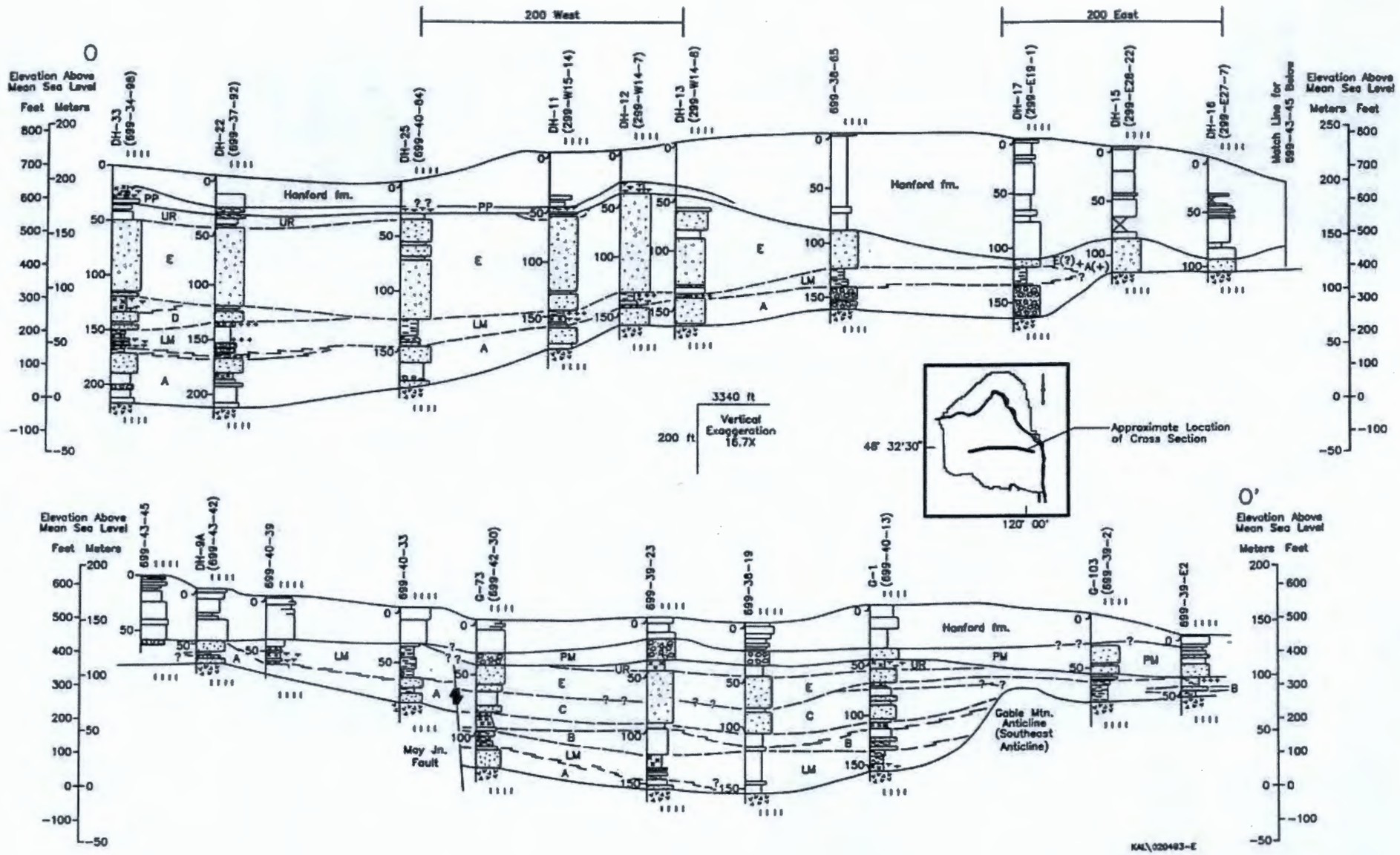

J
North
J'
South
Elevation Above Mean Sea Level
Feet Meters
Hanford Fm.
UR
PM
C(?)
B(?)
LM
E
C
B
A
E + C(?)
Gable Mtn. Anticline
Wahluke Syncline
2750 ft
100 ft
Vertical Exaggeration 27.5X
Approximate Location of Cross Section
46° 32'30"
120° 00'

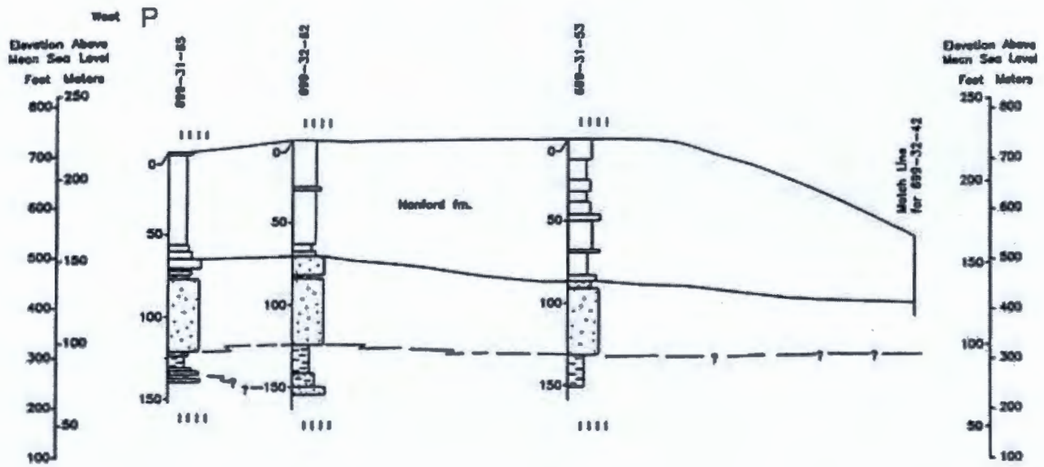

K
K'
Southwest
Northeast
Elevation Above Mean Sea Level
Feet
Meters
Hanford fm.
Umtanum/Gable Mountain Structure
3340 ft
200 ft
Vertical Exaggeration 16.7X
Wahluke Syncline
Approximate Location of Cross Section
46° 32'30"
120° 00'

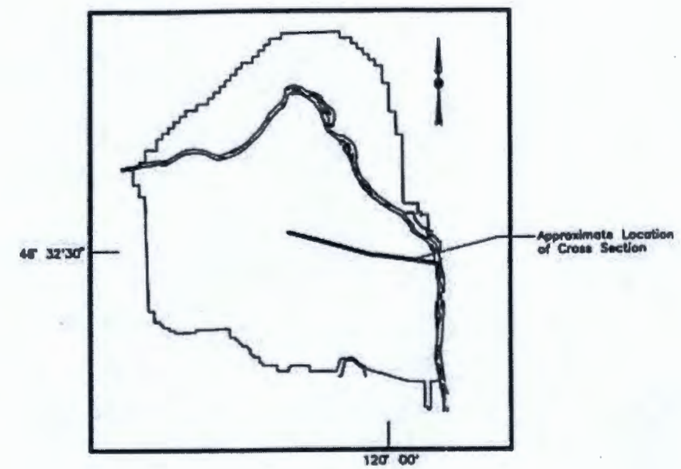

Northwest
L
Elevation Above Mean Sea Level
Feet
Meters
BH-17 (699-81-62)
699-77-54
699-71-52
699-67-51
Southeast
L'
699-65-50
Elevation Above Mean Sea Level
Meters
Feet
Hanford fm.
E
C
B
LM
A
Wahluke Syncline
940 ft
100 ft
Vertical Exaggeration 9.4X
46° 32'30"
120° 00'
Approximate Location of Cross Section
KAL\121192-A

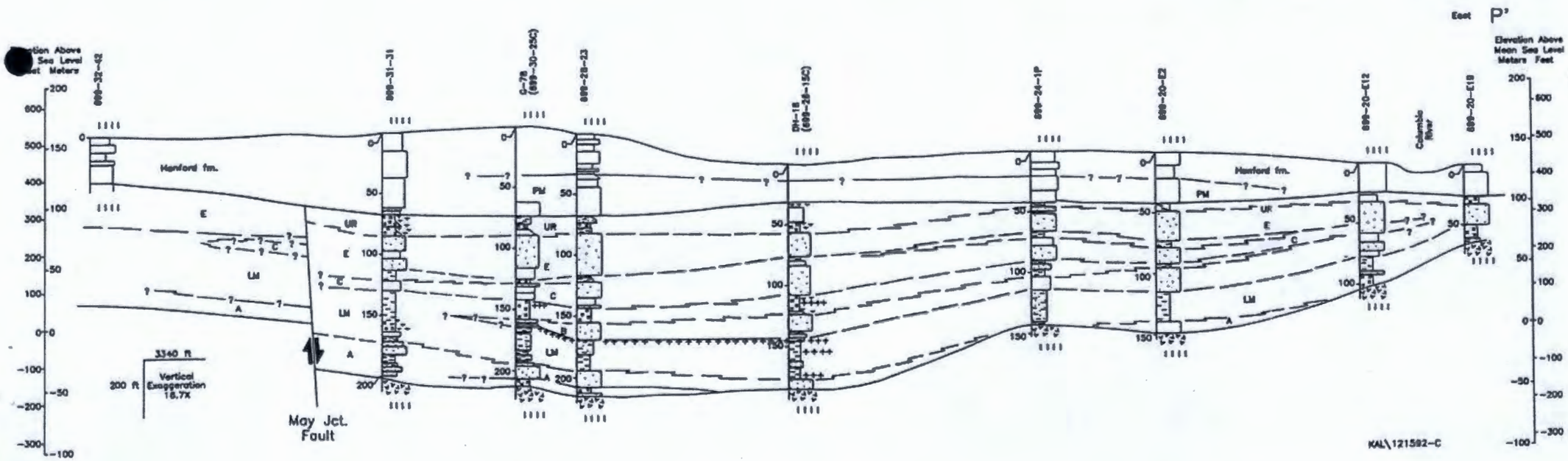

M
Elevation Above Mean Sea Level
Feet
Meters
Southwest
Northeast
M'
Elevation Above Mean Sea Level
Meters
Feet
699-63-55
699-65-50
699-69-45
699-74-44
699-80-43
699-84-35A
B-18
699-92-14
Hanford fm.
Columbia River
Gable Mtn.
This Horizon Approximately Correlative to the Top of FSE at Taylor Flats
Wahluke Syncline
Approximate Location of Cross Section
46° 32'30"
120° 00'
2870 ft
100 ft
Vertical Exaggeration 26.7X
KAL\020483-A

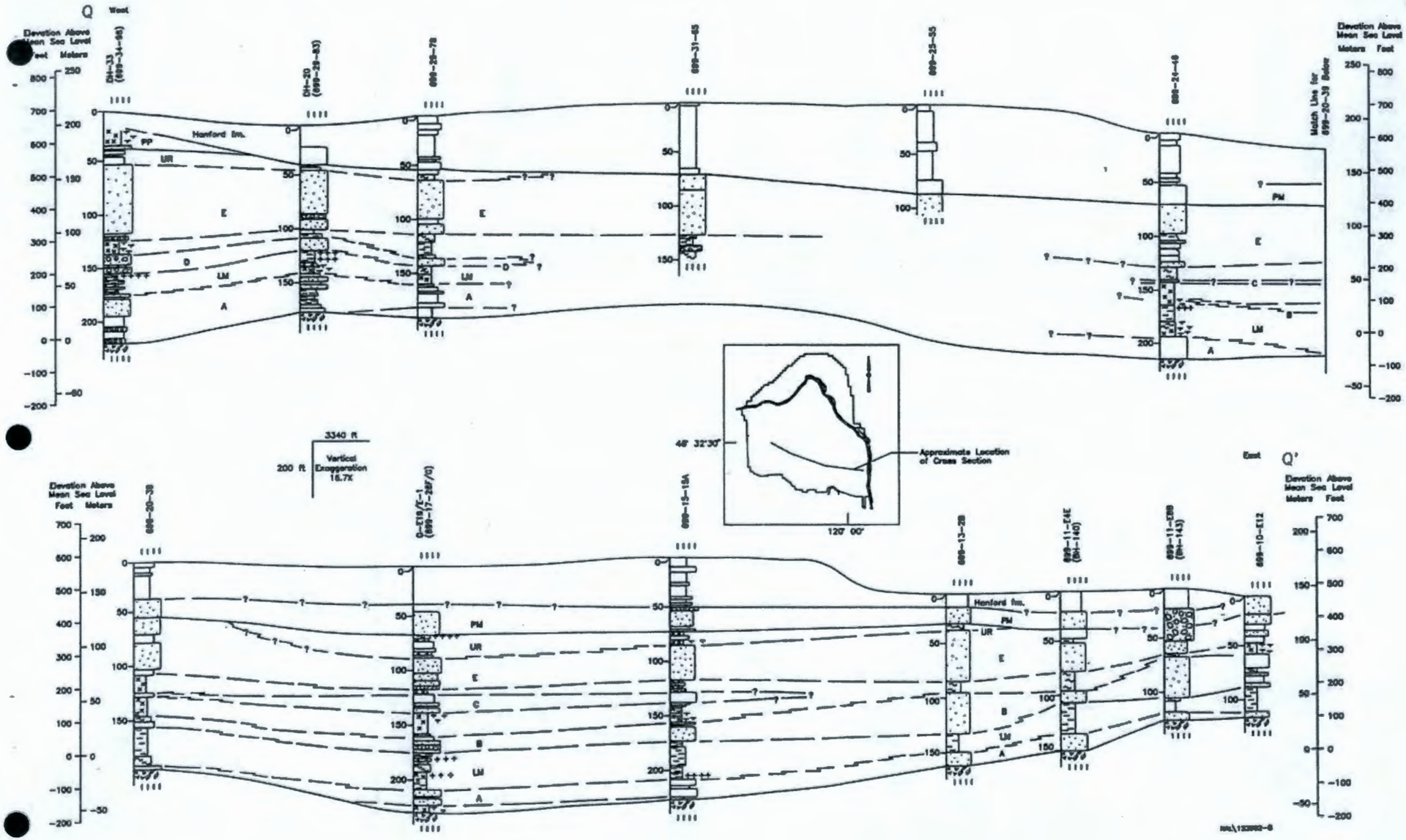

N
Elevation Above Mean Sea Level
Feet Meters
West
699-63-90
699-57-83
699-55-76
699-55-60A
699-53-55A
Match Line for 699-55-50A Below
Hanford fm.
LM
A
A(?) + E(?)
Rattlesnake Ridge Interbed
3340 ft
200 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section
N'
East
699-55-50A
699-54-48
699-52-46A
699-50-42
699-47-35A
699-45-26
699-43-18
C1 (699-40-13)
PM
UR
E
C
B
LM
May Jn Fault
KAL\020393-A

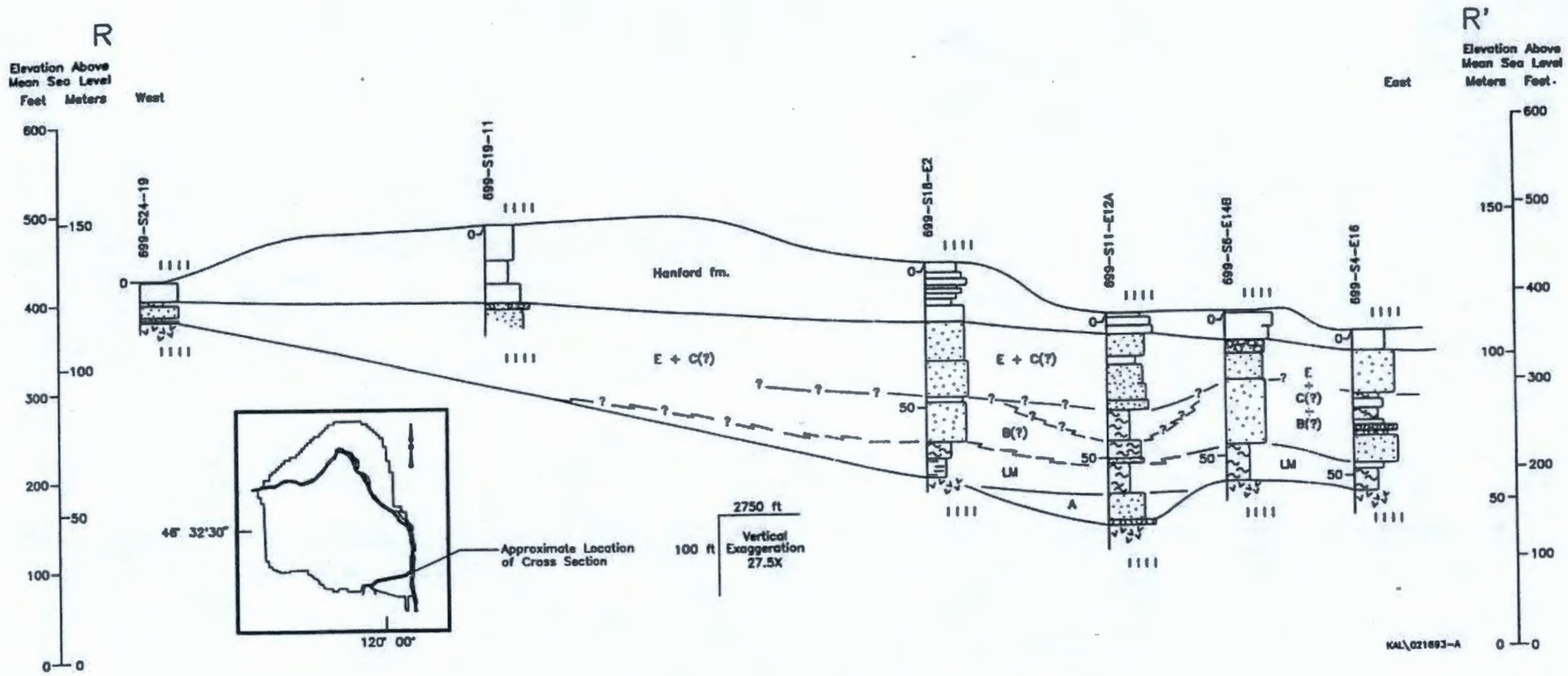

O
O'
200 West
200 East
Elevation Above Mean Sea Level
Feet Meters
Meters Feet
DH-33 (699-34-96)
DH-22 (699-37-92)
DH-25 (699-40-84)
DH-11 (299-W15-14)
DH-12 (299-W14-7)
DH-13 (299-W14-8)
699-38-65
DH-17 (299-E19-1)
DH-15 (299-E28-22)
DH-16 (299-E27-7)
Match Line for 699-43-45 Below
Hanford fm.
PP
UR
E
D
LM
A
E(?)+A(+)
3340 ft
200 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section
699-43-45
DH-9A (699-43-42)
699-40-39
699-40-33
G-73 (699-42-30)
699-39-23
699-38-19
G-1 (699-40-13)
G-103 (699-39-2)
699-39-E2
PM
C
B
May Jn. Fault
Gable Mtn. Anticline (Southeast Anticline)
KAL\020493-E

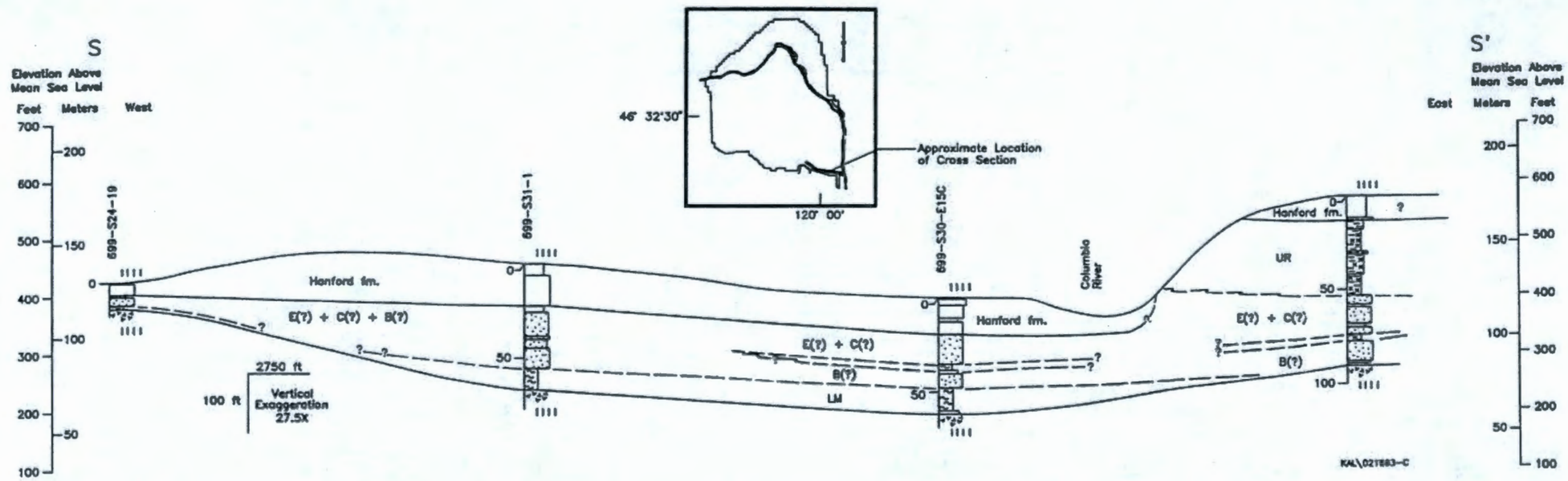

West
P
Elevation Above Mean Sea Level
Feet Meters
699-31-53
Hanford fm.
Match Line for 699-32-42

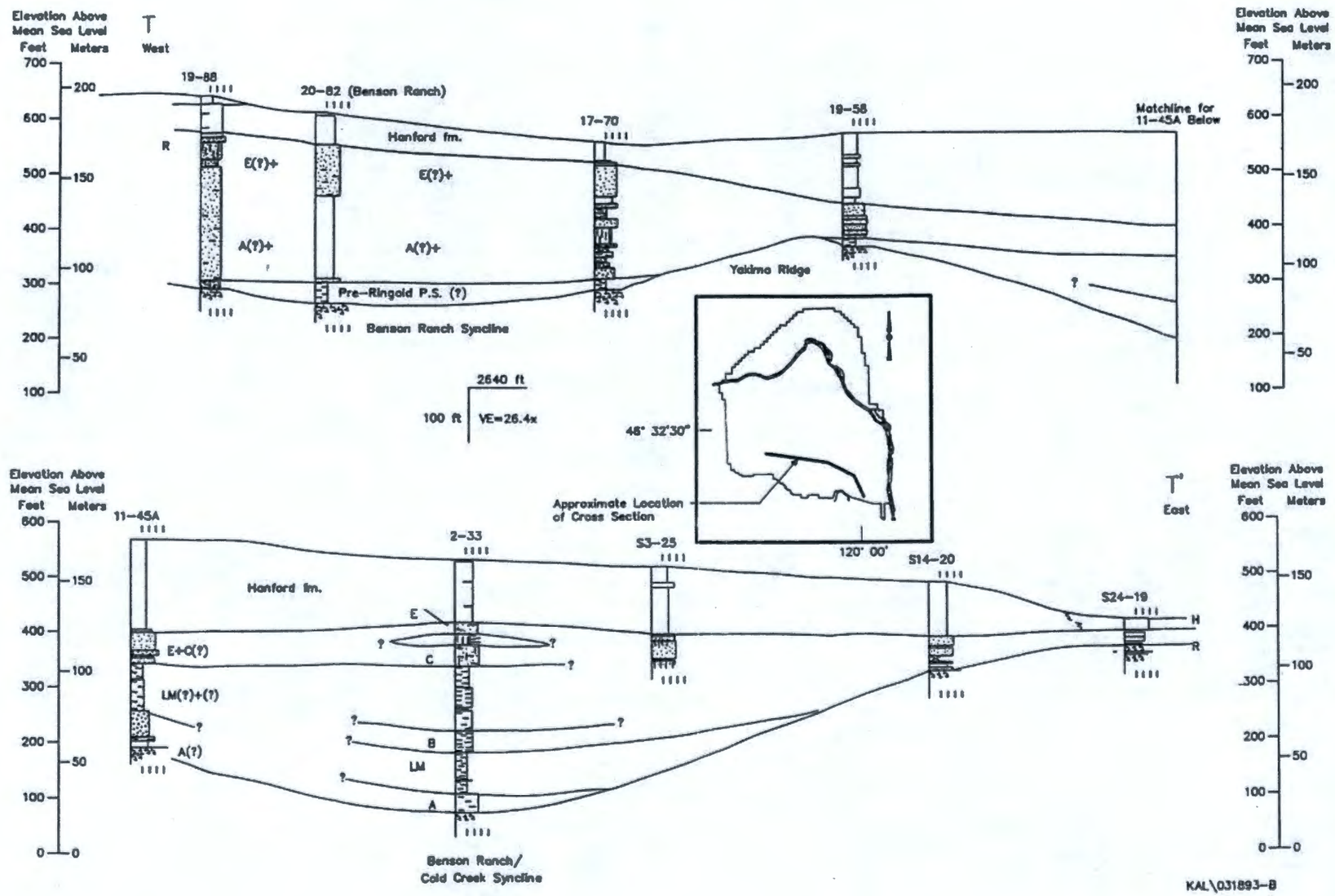

46° 32'30"
120° 00'
Approximate Location of Cross Section


East
P'
Elevation Above Mean Sea Level
Meters Feet
699-32-42
699-31-31
C-78 (699-30-25C)
699-28-23
DH-18 (699-28-15C)
699-24-1P
699-20-E2
699-20-E12
Columbia River
699-20-E18
Hanford fm.
UR
E
C
LM
A
PM
3340 ft
200 ft
Vertical Exaggeration 16.7X
May Jct. Fault
KAL\121582-C


Q
West
Q'
East
Elevation Above Mean Sea Level
Feet
Meters
Hanford fm.
PP
UR
E
D
LM
A
PM
C
B
Match Line for 699-20-39 Below
3340 ft
200 ft
Vertical Exaggeration 16.7X
46° 32'30"
120° 00'
Approximate Location of Cross Section


R
R'
Elevation Above Mean Sea Level
Feet Meters
West
East
Elevation Above Mean Sea Level
Meters Feet
699-S24-19
699-S19-11
699-S18-E2
699-S11-E12A
699-S6-E14B
699-S4-E16
Hanford fm.
E + C(?)
B(?)
LM
A
E + C(?) + B(?)
46° 32'30"
120° 00'
Approximate Location of Cross Section
2750 ft
100 ft
Vertical Exaggeration 27.5X
KAL\021693-A


S
Elevation Above Mean Sea Level
Feet
Meters
West
700
200
600
500
150
400
100
300
200
50
100
699-S24-19
699-S31-1
699-S30-E15C
46° 32'30"
120° 00'
Approximate Location of Cross Section
Hanford fm.
E(?) + C(?) + B(?)
2750 ft
100 ft
Vertical Exaggeration 27.5x
E(?) + C(?)
B(?)
LM
Columbia River
Hanford fm.
UR
E(?) + C(?)
B(?)
S'
Elevation Above Mean Sea Level
East
Meters
Feet
KAL\021883-C


Elevation Above Mean Sea Level
Feet Meters
West
19-88
20-82 (Benson Ranch)
17-70
19-58
Matchline for 11-45A Below
Hanford fm.
E(?)+
A(?)+
Pre-Ringold P.S. (?)
Benson Ranch Syncline
Yakima Ridge
2640 ft
100 ft
VE=26.4x
46° 32'30"
120° 00'
Approximate Location of Cross Section
East
11-45A
2-33
S3-25
S14-20
S24-19
E+C(?)
LM(?)+(?)
A(?)
LM
Benson Ranch/
Cold Creek Syncline
KAL\031893-B

APPENDIX D
STRUCTURE CONTOUR AND ISOPACH DATA FOR THE RINGOLD FORMATION AT SELECTED BOREHOLES AT THE HANFORD SITE

Borehole #	Easting	Northing	Top Dev	Top Sub A	Inc Sub A	Top A	Inc A	Top LM	Inc LM	Top BD	Inc BD	Top Sub C	Inc Sub C	Top C	Inc C	Top Sub E	Inc Sub E	Top E	Inc E	Inc C+E	Top UK	Inc UK	Top PMPP	Inc PMPP	Top HZ	Inc HZ	Inc Zn	Dev
101-03C	570237.00	159411.01																			238 +20		238	0	307	49	0	307
103-25	562318.00	158886.00	343																									
107-79	563779.00	158071.00	300																									
107-83	564464.70	158308.00	340																									
109-46	565325.40	158600.30	430																									
15-3	569660.00	129960.00	-64																									
10-36	569747.30	139573.40	-43																									
10-34A	573597.40	129572.00	366													335 +60		400	77	77	400	0	400	0	397	60	0	516
10-E12	563675.00	129577.00	72		0	45	16	170	68	300	16	220	16	260	48	300	36	356	36	72	356	28	356	0	426	36	4	428
111-34	562536.00	157331.00	488																									
112-37	570835.00	157540.00	455																									
113-38	570308.40	158105.20	457																									
114-60	571642.00	158540.00	357																									
115-61	571379.00	159413.00	494																									
115-7	567430.00	158888.00	380																									
115-77	568361.00	158842.00	390																									
117-11	569418.00	159113.00	392																									
119-11	568483.00	159868.20	381																									
13-29	561154.00	129928.00	-164																									
13-40	570270.00	129888.00	300		0	248	66	300	66	300	0	300	0	300	0	300	0	400	68	68	400	0	400	0	372	72	0	72
13-E4E	569864.85	128730.23	-23	-26	0	28	68	116	88	146	30	146	0	146	0	286	68	286	68	136	286	0	286	0	446	72	0	446
13-E8B	562319.31	128749.12		64	0	68	36	156	48	216	60	216	0	216	37	254	16	254	68	136	314	0	314	0	446	72	0	446
123-11	568436.30	160855.00	1023																									
13-1	568881.00	127939.30	-41																									
13-10	568314.50	127197.90	-688																									
13-26	561664.10	127961.70	-230																									
13-29	569001.85	127336.10		48	0	48	36	84	36	144	60	144	0	144	0	204	20	204	60	140	264	0	264	0	396	48	0	396
13-64	570410.00	127300.00		300	0	300	0	300	0	300	0	300	0	300	0	300	0	400	60	60	400	0	400	0	532	60	0	532
14-36	570411.00	127702.00	60																									
14-E3E	569878.70	127837.00	0	0	0	36	47	156	70	156	0	156	0	156	0	216	31	286	68	168	346	0	346	0	468	72	0	468
14-E8P	569563.80	127703.47			0	60	43	168	36	216	36	216	0	216	0	252	36	288	68	168	288	0	288	0	468	72	0	468
15-15A	568293.00	128923.00		-108	7	108	65	0	110	60	36	156	60	156	0	192	36	288	68	168	288	0	288	0	468	72	0	468
15-36	569875.94	128954.00																243			243	0	243	0	423	72	0	423
15-E12	568766.00	128200.00		184	7	170	69	354	34	240	60	240	2	242	46	241	0	241	46	64	241	0	241	0	424	60	0	424
16-23	567942.00	129373.00	-188																									
16-35A	566605.00	129449.00	-188																									
16-64A	571905.91	129299.37		186	0	174	18	246	72	246	60	246	0	232	38	242	10	270	28	94	270	0	270	0	408	60	0	408
17-13	565418.00	130546.00	-197																									
17-28	561250.00	129790.00		-170	22	-102	48	48	108	36	48	84	60	144	24	194	16	236	51	165	288	0	288	0	552	136	0	552
17-47	573408.00	128783.00		243	0	260	7	276	36	288	12	288	0	288	0	288	60	288	48	108	288	0	288	0	552	132	0	552
17-79	568578.00	128647.00		313	16	288	36	288	36	288	0	288	0	288	0	288	60	288	48	108	288	0	288	0	552	132	0	552
17-80	561585.00	128839.00			0	720	0	720	0	720	0	720	0	720	0	720	0	720	0	0	720	0	720	0	720	96	0	720
18-21	563738.79	128705.20	-140																									
18-28	559427.10	128931.40	-344																									
18-35	562985.40	128315.00	-441																									
18-37	561080.00	128329.40	-184																									
18-38	560100.10	128585.10	-172																									
18-88	572153.00	128357.00		300	0	300	0	300	15	302	0	300	0	300	0	300	0	424	41	41	424	0	424	0	573	140	0	573
18-90	563183.30	128235.20	203																									
1-10	564329.00	129948.00														317 +30		412	95	95	412	0	412	0	552	140	0	557
20-19	564464.00	129419.50	-75																									
20-25	562666.40	129880.80	-646																									
20-79	577008.00	129729.00			0	84	15	88	110	70	14	140	70	140	0	210	35	300	170	170	300	0	420	0	555	0	0	555
20-80	569042.00	129465.20	480																									
20-80	569012.00	129508.00		300	0	300	0	300	0	300	0	300	0	300	0	300	0	424	57	57	424	0	424	0	572	0	0	572
20-E12	568673.00	128738.00		112	15	112	0	168	70	252	84	252	0	252	42	252	0	252	68	168	252	0	372	84	492	60	0	492
20-E2	569903.00	128722.00		-13	0	71	24	91	60	180	82	181	0	251	42	236	35	241	57	97	241	21	300	84	480	60	0	480
20-E3	571301.00	129811.00	147																									
21-17	564789.00	129893.00	-62																									
21-[illegible]	569918.00	129982.00	-100																									
22-23	562992.00	130342.00	-129																									
23-70	569800.00	129804.00		400	0	400	0	400	0	400	0	400	0	400	0	400	0	400	0	0	400	0	400	0	532	60	0	532
23-33	570934.00	130600.00		172	0	213	65	280	42	113	36	153	36	153	0	153	0	216	15	15	216	0	216	0	372	60	0	372
24-19	569494.13	130705.16		30	10	30	0	110	70	140	30	150	40	224	0	300	30	324	24	24	324	0	324	0	432	60	0	432
24-33	572732.70	130756.00		0	0													300 +30			300	0	324	0	432	60	0	432
24-48	570888.00	130700.00		-70	0	-1	65	65	110	160	15	160		160		160	30	241	66	66	241	0	241	0	361	60	0	361
25-29	563890.00	130090.00	-101																									
25-28	562044.00	131002.00		48	0	18	72	60	36	120	36	156	36	216	60	300	0	300	12	12	300	0	300	0	432	60	0	432
25-31	560460.00	131176.00		84	0	21	63	63	36	135	36	135	36	201	60	300	0	321	63	63	321	0	321	0	453	60	0	453
25-55	573062.51	131290.00																438 +45			438	0	438	0	558	60	0	558
25-70	560544.00	131172.00						180 +18		180	0	180	0	180	0	180	0	442	204	204	442	0	442	0	558	60	0	558

D-4

Borehole #	Easting	Northing	Top Bas	Top Sub A	Iso Sub A	Top A	Iso A	Top LM	Iso LM	Top BD	Iso BD	Top Sub C	Iso Sub C	Top C	Iso C	Top Sub E	Iso Sub E	Top E	Iso E	Iso C+E	Top LR	Iso LR	Top PMPP	Iso PMPP	Top Hf	Iso Hf	Iso Eo	Elev
25-80	585875.00	131108.00		505	0	515	10	515	0	515	0	515	0	515	0	515	0	575	60	60	575	0	582	7	600	18	15	615
26-15C	585472.44	131330.29	-180	-180	0	-130	22	-35	180	57	72	96	56	182	67	195	13	258	63	163	330	70	330	0	442	112	2	644
26-29B	581883.00	131328.00	-193																									
26-63A	584532.90	131300.00	290																									
26-69	583779.50	131375.20		182	0	187	33	233	38	303	70	303	0	303	0	343	40	513	170	170	544	31	544	0	643	99	10	669
27 8	587480.70	131742.30	101																									
28 27	582807.00	132084.00		-172	0	107	65	-32	75	10	90	50	48	135	75	143	20	263	110	106	308	49	418	110	528	110	0	528
28-30	580010.00	131991.00			0	-48	134	33	80	32	0	33	0	32	0	32	0	262	230	230	322	60	437	115	532	95	0	532
28-40	577821.40	131992.13				112 >22		182	70	182	0	182	0	208	27	247	38	379	132	130	379	0	448	70	588	110	0	584
28-52A	574108.00	132111.00			0	90	180	274	175	274	0	274	0	274	0	274	0	420	140	140	420	0	438	19	604	245	0	684
28-78	588212.90	132414.00	90	81	73	153	73	208	55	228	20	217	0	217	0	290	71	458	180	158	485	25	488	0	647	164	0	647
29-81	584910.00	132373.00	97	97	0	183	116	290	87	290	40		0		0	311	13	480	170	170	503	73	597	94	88	823		823
2-3	588910.91	124098.21																382 >57		0	382	0	382	0	489	87	8	477
2-33A	579919.00	124047.00		84	0	118	32	191	73	231	49	348	114	371	38	381	10	412	31	57	412	0	412	0	531	119	5	536
2-E13-14	573118.10	134216.00				273 >15		328	55	328	0	328	0	328	0	328	0	388	60	60	388	0	388	0	728	340		728
2-E13-20	573802.60	134312.80	158	158	6	271	116	331	60	331	0	331	0	331	0	331	0	426	95	95	426	0	426	0	738	310	3	741
2-E14	584081.00	134020.00	88	88	0	108	40	158	60	213	55	313	0	213	0	248	35	320	75	75	323	0	323	0	388	68	0	388
2-E17-4	579118.20	135370.30																410 >98		>85	410	0	410	0	715	305	0	715
2-E19	686400.00	124133.00		104	0	139	35	199	60	234	35	234	0	234	0	274	40	324	50	50	324	0	324	0	380	46	16	386
2-E19-1	572920.20	139865.29	219																									
2-E24-T	574408.80	136190.90	271	271	0	391	110	391	0	391	0	391	0	391	0	391	0	391	0	0	391	0	391	0	710	336	0	710
2-E24-8	574547.00	136371.70	336	336	0	408	102	408	0	408	0	408	0	409	0	408	0	408	0	0	408	0	408	0	600	200	20	600
2-E25-1	575336.10	136031.30				408 >40		418	10	418	0	418	0	418	0	418	0	418	0	0	418	0	418	0	663	245	20	680
2-E25-12	575576.80	136491.30				367 >35		383	5	382	0	382	0	382	0	382	0	382	0	0	382	0	382	0	673	311	5	678
2-E25-13	675382.90	136138.90				388 >34		427	28	427	0	427	0	427	0	427	0	427	0	0	427	0	427	0	677	250	5	681
2-E25-17	575695.40	136703.20						407 >18		407	0	407	0	407	0	407	0	407	0	0	407	0	407	0	687	280	0	687
2-E25-18	575838.10	136088.70				386 >10		391	5	391	0	391	0	391	0	391	0	391	0	0	391	0	391	0	676	285	0	676
2-E25-19	575855.00	135857.00				388 >25		399	0	399	0	399	0	399	0	399	0	399	0	0	399	0	399	0	670	271	4	674
2-E25-2	575514.00	136082.00	310	310	0	406	98	420	15	420	0	420	0	420	0	420	0	420	0	0	420	0	420	0	663	243	12	675
2-E25-20	576011.80	136111.90	310	310	0	407	98	413	5	413	0	413	0	413	0	413	0	413	0	0	413	0	413	0	655	242	1	660
2-E25-32P	576352.20	136044.70	323	323	0	375	82	375	0	375	0	375	0	375	0	375	0	375	0	0	375	0	375	0	663	288	5	668
2-E25-33	575932.20	135713.20	291	291	0	384	93	403	19	403	0	403	0	403	0	403	0	403	0	0	403	0	403	0	672	269	0	672
2-E26-1	575251.90	137130.70	394	394	0	394	0	394	0	394	0	394	0	394	0	394	0	394	0	0	394	0	394	0	616	222	0	616
2-E26-10	575588.30	137025.90	384	384	0	384	0	384	0	384	0	384	0	384	0	384	0	384	0	0	384	0	384	0	588	204	0	588
2-E26-11	575188.20	137134.00	389	389	0	389	0	389	0	389	0	389	0	389	0	389	0	389	0	0	389	0	389	0	586	197	0	586
2-E26-6	575884.10	137129.40	388	388	0	388	0	388	0	388	0	388	0	388	0	388	0	388	0	0	388	0	388	0	591	206	0	599
2-E27-1	574615.00	136917.10				420 >70		426	0	428	0	426	0	424	0	428	0	426	0	0	420	0	420	0	681	253	0	681
2-E27-10	575100.00	137052.00	382	382	0	382	0	382	0	382	0	382	0	382	0	382	0	382	0	0	382	0	382	0	622	240	0	622
2-E27-11	574833.20	137083.20	378	378	0	378	0	378	0	378	0	378	0	378	0	378	0	378	0	0	378	0	378	0	643	262	0	643
2-E27-6	574808.00	136309.50				435 >70		440	5	440	0	440	0	440	0	440	0	440	0	0	440	0	440	0	685	245	0	685
2-E28-17	673492.00	135331.00				415 >50		415	0	415	0	415	0	415	0	415	0	415	0	0	415	0	415	0	708	293	0	708
2-E28-10	573098.20	136707.70				430 >40		438	0	438	0	430	0	430	0	430	0	430	0	0	430	0	430	0	682	254	0	682
2-E29-3	573700.00	136987.30				371 >5		371	0	371	0	371	0	371	0	371	0	371	0	0	371	0	371	0	692	321	0	692
2-E29-5	574033.00	136898.00	365	365		366	0	383	17	380	0	382	0	383	0	382	0	382	0	0	382	0	368	0	672	290	0	672
2-E33-10	573788.30	137388.00	388	391	0	402	7	441	36	441	0	441	0	441	0	441	0	441	0	0	441	0	441	0	643	202	0	643
2-E30-57	574001.90	137966.00	382	382	0	382	0	382	0	382	0	382	0	382	0	382	0	382	0	0	383	0	382	0	653	271	0	653
2-E33-4	573017.00	137903.00	399	399	0	399	0	399	0	390	0	399	0	390	0	399	0	399	0	0	399	0	399	0	629	230	0	629
2-E33-41	573797.38	137376.00	389	389	0	411	22	433	22	433	0	432	0	433	0	433	0	433	0	0	433	0	433	0	618	185	34	652
2-E34-2	574836.10	137221.00	388	388	0	388	0	388	0	388	0	388	0	388	0	388	0	388	0	0	388	0	388	0	629	241	0	629
2-E34-8	574289.50	137290.00	383	383	0	383	0	383	0	383	0	383	0	383	0	383	0	383	0	0	383	0	383	0	640	257	0	640
2-E35-1	575400.00	137405.20	402	402	0	402	0	402	0	402	0	402	0	402	0	402	0	402	0	0	402	0	402	0	586	185	0	586
2-E35-3	575570.36	137299.30	399	399	0	399	0	399	0	399	0	399	0	399	0	399	0	399	0	0	399	0	399	0	599	200	0	599
30-25C	583260.41	132993.31	-147	-135	12	92	41	3	88	73	70	88	37	129	40	129	0	258	171	170	384	54	388	86	543	145	0	543
31-31	582568.00	132674.00						-71 >50		38	35	104	140	124	50	158	3	274	115	165	329	55	408	80	510	110	10	520
31-33A	573754.90	132082.41														281 >37		423	142		423	0	423	0	790	365	0	790
31-65	588881.00	127777.00				290 >11		291	36	291		291		291		291		471	180	180	471	0	471	0	676	205	5	681
31-8	587288.00	132838.00	-94	-94	0	-34	30	11	46	81	70	118	38	216	100	226	10	276	50	150	321	41	401	80	460	60	10	470
31-84A	584381.00	132808.00	21																									
32-22	581190.71	133257.40																330 >10			330	0	350	0	510	160	0	510
32-28	581891.00	133144.00	-140	-115	25	-90	25	25	115	55	30	90	16	106	75	186	0	360	180	175	315	80	480	140	510	90	10	520
32-32	580297.00	133208.00	-200	-200	0	-80	140	15	75	15	0	-5	0	140	126	140	0	385	145	270	262	0	440	125	505	65	15	520
32-42	570861.37	133368.30																387			387	0	387	0	487	80	25	
32-62	571080.41	133217.00						302 >97		302	0	302	0	302	0	302	0	462	180	180	462	0	505	23	785	300	0	786
32 72	567643.00	133383.00	86	86	0	217	111	257	40	257	0	257	0	257	0	257	0	427	170	170	472	0	468	43	688	200	0	687
33-14	565534.00	133907.00	-77	-77	0	-37	30	3	30	83	88	113	30	220	115	238	10	288	60	175	330	40	423	68	463	40	10	473
33-21A	583372.00	133474.00	-115	115	0	-60	50	-25	40	60	85	60	20	115	36	145	30	288	140	175	330	41	436	105	466	50	15	500
33-42	577820.24	133404.38																401 >10			401	0	401	0	480	85	20	510
33-88	572831.88	133338.58						316 >90		316	0	316	0	316	0	316	0	431	115	116	431	0	431	0	711	280	9	710
33-8	588013.00	133420.00	-41																									
34-20	583053.00	133722.00	-118	-118	0	-80	33	0	66	75	75	75	0	180	80	175	29	279	100	100	380	25	384	85	475	120	25	500
34-41B	577738.20	133813.01																400 >10			400	0	400	0	579	170	0	

Borehole #	Easting	Northing	Top Res	Top Sub A	Bot Sub A	Top A	Bot A	Top LN	Bot LN	Top BD	Bot BD	Top Sub C	Bot Sub C	Top C	Bot C	Top Sub E	Bot Sub E	Top E	Bot E	Top C-E	Bot C-E	Top LR	Bot LR	Top PBPP	Bot PBPP	Top HI	Bot HI	Top Dr	Elev
34-0	521524.00	133800.00	-31																										
34-08	503035.29	133874.70	-10	-10	0	160	123	209	120	204	0	204	0	204	0	205	0	204	205	205	341	36	341	0	410	70	10	401
34-0W	502925.00	133963.00	-4																										
34-80	500760.74	134103.00	-22																										
35-10	505109.00	134124.00	-46																										
35-19A	504005.00	134000.00	-17																										
35-21	505514.00	134522.30	-20	-20	2	11	79	91	80	125	20	170	20	270	80	270	0	251	70	150	291	0	420	83	211	80	0	371
35-27	504000.80	134003.30	-24	-24	0	11	85	200	80	100	20	140	20	140	0	140	0	201	100	120	201	20	201	0	201	200	0	
35-30	501287.00	134019.00	-47	-47	0	0	85	72	80	70	0	150	80	150	80	150	0	221	80	150	270	20	400	100	400	0	0	400
35-3	500003.00	134190.00	20	20	0	25	0	151	100	101	0	151	0	200	80	200	20	210	80	150	251	0	451	100	400	80	10	400
35-8	500020.00	134321.00	5																										
35-00	505000.10	134004.00				273 +1		320	30	323	0	305	0	305	0	300	0	402	30	30	403	0	403	0	710	200	0	
35-70	500000.40	135007.71																402 +05			444	22	424	30	400	270	0	300
35-T90	500007.00	134273.00	70	69	5	100	80	240	72	240	0	240	0	240	0	240	0	400	200	200	400	0	503	80	400	150	0	300
35-0	507102.23	134000.57																	0	0	323 +111		324	40	400	110	0	300
36-1	509400.00	134010.00	210																									
36-10	500773.00	134000.00	-32																									
36-17	504700.00	134013.00																										
36-2	500225.00	134401.00	100																									
36-27	501600.00	134440.00	-24	-24	0	4	70	100	100	110	15	140	20	210	80	210	0	202	70	100	321	20	400	140	321	45	0	321
36-40P	575004.70	134010.25	102	102	0	200	84	241	70	241	0	241	0	241	0	241	0	410	40	40	410	0	410	0	721	251	0	721
36-010	574400.80	134000.00	201	201	0	201	85	240	40	240	0	240	0	240	0	240	0	400	50	50	400	0	400	0	720	200	0	720
36-02	501000.00	134400.00																			200 +1		210	50	200	170	0	
36-03	501151.00	134420.00	-40	-20	0	101	100	100	10	230	30	230	0	230	0	200	20	400	200	240	400	0	200	0	402	100	0	400
36-03	500777.00	134340.00	140	140	0	140	0	220	40	300	30	200	0	200	40	340	30	340	0	40	340	0	370	30	400	80	0	400
37-30	570973.00	134722.07	1322																									
37-4	500000.00	134741.00	200																									
37-03	574004.40	134785.10	100	100	0	204	84	300	30	300	0	300	0	304	40	300	40	300	40	80	400	10	404	0	400	100	0	400
37-0200	504023.71	134733.44	10	10	0	120	100	240	100	240	0	240	0	240	0	240	0	300	200	200	300	0	340	0	400	60	10	400
37-04	504247.00	134700.00	14	14	0	120	110	210	67	210	0	210	0	210	0	210	0	300	210	200	321	1	300	0	324	60	0	324
37-02	501021.00	134507.00	-29																									
37-01	500000.00	134700.00																										
38-10	504000.00	135100.00	-40	-40	0	40	0	91	110	101	10	130	30	200	67	200	0	201	60	100	201	30	411	60	401	40	10	401
38-3	500025.00	135121.00																										
38-344	570400.70	138140.73	174	174	0	254	80	304	10	304	40	304	0	304	0	304	0	370	15	20	400	30	410	0	210	40	10	300
38-00	570001.10	135041.00	200	200	0	300	77	300	80	300	0	300	0	300	0	300	0	420	110	110	400	0	420	0	721	201	0	721
38-70	500000.04	135000.30						314 +00		314	4	314	0	314	0	314	0	402	60	100	300	4	324	0	721	100	0	300
38-0	507507.00	135241.00	70																									
38-0	507202.07	138022.00	41																									
38-E0	500159.10	135000.90	207																									
399-1-16C	594312.30	119410.00	200	200	0	200	0	270	80	270	0	270	0	270	0	270	0	200	80	80	200	0	200	0	200	60	0	
399-1-17C	594104.00	119400.00	200	200	0	200	0	201	36	201	0	201	0	201	20	201	0	200	40	60	200	0	200	0	201	40	0	
399-1-20	594257.00	119500.00	207																									
399-6-5	604130.00	119000.00	202	200	0	200	0	220	12	221	11	221	0	221	0	207	20	240	60	80	340	0	340	0	400	60	0	
3b-100	604401.00	136431.00	172																									
39-23	502983.40	136047.20	-10	-10	0	36	40	91	10	101	70	100	10	230	60	200	0	201	60	100	201	30	401	0	470	0		470
39-3A	503372.00	136401.00	213																	0								
39-70	500000.00	136411.07																			300 +00		300	0	300	120	20	270
39-74	507016.53	136440.73	330	330	0	300	0	302	10	302	0	300	0	300	0	300	0	302	0	0	302	0	302	0	402	100	0	
39-0W3	504230.00	136440.00	20																									
39-02	500532.00	136431.00	210	210	0	210	0	230	30	240	60	240	0	240	0	270	30	270	0	0	270	0	304	60	400	40	0	400
3-45	570205.00	124401.00	373	373	0	373	0	373	0	373	0	373	0	373	0	373	0	373	0	0	373	0	373	0	390	170	0	390
3-0-9C	503300.00	116574.00	200	200	0	200	0	230	32	200	20	200	0	200	30	200	70	200	0	0	200	0	200	0	201	100	0	200
40-130	500325.30	130837.23	32	32	0	32	0	160	60	160	20	160	0	200	30	200	70	200	0	100	200	0	200	0	200	100	0	200
40-13	500000.00	130000.00	20	20	0	20	0	60	30	80	80	104	30	270	80	200	7	202	40	100	240	20	304	40	400	110	0	300
40-2	500132.00	130000.00	100																									
40-20	500000.00	136070.00	-14	-14	0	16	80	101	80	140	40	150	10	210	60	220	10	221	80	100	300	10	400	80	470	10	0	
40-02	500007.00	136070.00	100	100	0	273	70	300	110	300	0	300	0	300	0	300	0	300	0	0	300	0	300	0	310	110	0	
40-204	570704.61	135011.00	240	240	0	210	70	400	10	400	0	400	0	400	0	400	0	400	0	0	400	0	400	0	410	110	0	
40-30	570700.30	136833.00	202	202	0	220	70	410	30	410	0	410	0	410	0	410	0	410	0	0	410	0	410	0	400	100	0	400
40-30	577000.30	135040.20				210 +10		410	30	410	0	410	0	410	0	410	0	410	0	0	410	0	410	0	400	100	0	300
40-4	504101.00	135070.00	200																									
40-02	571140.90	135755.00						370 +10		370	0	370	0	370	0	370	0	400	61	61	400	0	400	0	700	200	0	
40-00	500417.00	135040.00	107	107	0	104	67	210	30	210	0	210	0	210	0	210	0	200	200	200	200	0	340	30	400	110	0	400
40-04	504246.00	135751.00	40	40	0	100	110	207	31	207	0	207	0	207	0	207	0	200	201	201	200	0	200	7	400	60	0	400
41-10	500002.00	130100.00	200																									
41-11	500000.00	130024.40	130																									
41-20	500000.00	130100.00	15	15	0	25	30	110	40	100	45	100	0	240	60	200	10	200	60	140	200	0	200	20	400	100	0	400
41-23	502023.00	130000.00																371			371	0	400	0	400	100	0	
41-31	500625.00	130000.00	104	100	0	202	77	300	100	300	0	300	0	300	0	300	0	300	30	30	300	0	400	20	400	120	0	300
41-35	570070.00	130047.40	270	270	0	302	62	417	35	417	0	417	0	417	0	417	0	417	0	0	417	0	417	0	317	60	0	317

Borehole #	Easting	Northing	Top Elev	Top Sub A	Ins Sub A	Top A	Ins A	Top LM	Ins LM	Top BD	Ins BD	Top Sub C	Ins Sub C	Top C	Ins C	Top Sub E	Ins Sub E	Top E	Ins E	Ins C+E	Top UR	Ins UR	Top PMPP	Ins PMPP	Top HT	Ins HT	Ins BD	Elev
41-4	[illegible]	[illegible]	[illegible]																									
41-40	[illegible]	[illegible]				[illegible]	>10	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
41-42	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	51	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
41-5	[illegible]	[illegible]	[illegible]																									
42-10	[illegible]	[illegible]	[illegible]																									
42-12A	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42-21	[illegible]	[illegible]			0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42-29	[illegible]	[illegible]			0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42-3	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42-30	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42-37	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
42-40C	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
42-42A	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
42-42B	[illegible]	[illegible]				[illegible]	>10	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
42-48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
43-10	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	0	[illegible]
43-2	[illegible]	[illegible]	[illegible]																									
43-21	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
43-41B	[illegible]	[illegible]				[illegible]	>10	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	
43-41F	[illegible]	[illegible]				[illegible]	>10	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	
43-42	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	46	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
43-42J	[illegible]	[illegible]				[illegible]	>10	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	
43-43	[illegible]	[illegible]				[illegible]	>10	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
43-45	[illegible]	[illegible]																							[illegible]	[illegible]	0	[illegible]
43-6	[illegible]	[illegible]	[illegible]																									
43-51	[illegible]	[illegible]																										
43-54	[illegible]	[illegible]			0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
43-55	[illegible]	[illegible]																										
43-6	[illegible]	[illegible]			0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
43-51A	[illegible]	[illegible]																										
43-51B	[illegible]	[illegible]																										
44-11B	[illegible]	[illegible]	[illegible]																									
44-15	[illegible]	[illegible]																										
44-42	[illegible]	[illegible]				[illegible]	>10	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
44-42B	[illegible]	[illegible]				[illegible]	>10	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
44-50	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	16	[illegible]	17	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	16	[illegible]	0	[illegible]	[illegible]	0	[illegible]
44-7	[illegible]	[illegible]	[illegible]																									
44-70	[illegible]	[illegible]	[illegible]																									
45-54	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
45-55	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
45-62	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
45-64A	[illegible]	[illegible]	[illegible]																									
45-70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
45-72	[illegible]	[illegible]	[illegible]		0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
46-2	[illegible]	[illegible]	[illegible]																									
46-6	[illegible]	[illegible]	[illegible]																									
46-60B	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
47-11B	[illegible]	[illegible]	[illegible]																									
47-24	[illegible]	[illegible]	[illegible]																									
47-40	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
47-40A	[illegible]	[illegible]	[illegible]																									
47-40B	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
47-43	[illegible]	[illegible]	[illegible]																									
47-48A	[illegible]	[illegible]	[illegible]		0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
47-48B	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
47-49	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
47-49A	[illegible]	[illegible]	[illegible]																									
47-49B	[illegible]	[illegible]	[illegible]																									
47-49C	[illegible]	[illegible]	[illegible]																									
47-49D	[illegible]	[illegible]	[illegible]																									
47-52	[illegible]	[illegible]	[illegible]																									
48-52	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	46	[illegible]	46	[illegible]	0	[illegible]	45	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	40	[illegible]	[illegible]	0	[illegible]
48-57	[illegible]	[illegible]	[illegible]																									
48-59	[illegible]	[illegible]	[illegible]																									
48-71	[illegible]	[illegible]	[illegible]																									
49-70B	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
49-100C	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
49-51	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]
49-51	[illegible]	[illegible]	[illegible]																									
49-100B	[illegible]	[illegible]	[illegible]																									
49-30	[illegible]	[illegible]	[illegible]																									
49-40	[illegible]	[illegible]			0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	[illegible]	0	[illegible]

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Borehole #	Easting	Northing	Top Bas	Top Sub A	Ins Sub A	Top A	Ins A	Top LM	Ins LM	Top BO	Ins BO	Top Sub C	Ins Sub C	Top C	Ins C	Top Sub E	Ins Sub E	Top E	Ins E	Ins CrE	Top UP	Ins UP	Top PUPP	Ins PUPP	Top H	Ins H	Ins Es	Elev
49-51A	573148.30	139351.76	305	325	0	325	0	325	0	325	0	325	0	325	0	325	0	325	0	0	325	0	325	0	325	136	0	136
49-55B	573139.00	139351.00	304																									
49-57B	573530.40	139391.40			0	309	0	309	0	309	0	309	0	309	0	309	0	309	0	0	309	0	309	0	347	100	4	351
49-61B	573617.00	139406.00	120																									
49-95	560930.69	139903.03				296 +26		310	33	310	0	310	0	310	0	310	0	307	321	321	307	0	307	0	352	345	5	357
50-30	567790.00	139007.00	159	120	0	159	0	314	55	324	0	300	15	300	0	300	15	415	115	100	445	31	445	0	329	35	0	329
50-42	577111.10	139701.40	400	400	0	400	0	420	15	420	0	420	0	420	0	420	0	420	0	0	420	0	420	0	420	35	0	420
50-45	576172.00	139772.00	412	412	0	412	0	412	0	412	0	412	0	412	0	412	0	412	0	0	412	0	412	0	412	35	0	412
50-49A	573150.00	139885.00	430	430	0	430	0	430	0	430	0	430	0	430	0	430	0	430	0	0	430	0	430	0	340	111	0	340
50-53B	573600.50	139950.00	350																									
50-99	564130.00	139875.00	164	104	0	310	35	307	40	307	0	307	0	307	0	307	0	304	307	307	300	55	374	35	720	65	0	720
50-99	563790.00	139900.00	352																									
51-30B	579921.41	139886.17	479	479	0	479	0	479	0	479	0	479	0	479	0	479	0	479	0	0	479	0	479	0	515	35	0	515
51-40	575736.00	139804.00			0	430	0	430	0	430	0	430	0	430	0	430	0	430	0	0	430	0	430	0	443	13	0	443
51-93	570864.00	139452.00	300	300	0	300	0	300	0	300	0	300	0	300	0	300	0	300	0	0	300	0	300	0	575	275	0	575
51-75	569980.00	139404.00			0	355	41	355	4	355	0	355	0	355	0	355	0	475	155	155	455	0	455	0	511	212	0	511
53-107	554323.00	139275.00	935																									
53-110	553012.00	139355.00	1110																									
53-98A	570952.30	139594.60	400	400	0	400	0	410	15	410	0	410	0	410	0	410	0	410	0	0	410	0	410	0	464	35	0	464
52-64	573254.00	139194.00	355																									
52-67	572702.00	139115.00	407																									
53-100	560364.00	139513.00	259																									
53-111	555020.00	139580.00	712																									
53-114	555122.00	139478.00	940																									
53-55A	573114.80	139032.00	274	310	0	310	0	310	0	310	0	310	0	310	0	310	0	310	0	0	310	0	310	0	574	300	0	574
54-15	588187.00	138833.00			0	97	0	150	55	150	0	210	55	355	35	355	0	355	0	35	355	45	355	0	555	55	15	555
54-18C	584471.84	139098.69	65	65	0	65	0	105	40	154	35	355	40	357	42	357	0	357	0	42	357	55	357	0	402	75	0	404
54-34	579497.10	140026.00	402																									
54-37A	578671.00	139981.00	397																									
54-42	579660.00	140098.00			0	370	0	370	0	370	0	370	0	370	0	370	0	370	0	0	370	0	370	0	310	140	0	310
54-49A	578317.00	140098.00						380 +5		380	0	380	0	380	0	380	0	380	0	0	380	0	380	0	434	65	0	434
54-49	575367.00	139823.00			0	380	0	384	32	391	0	391	0	391	0	391	0	391	0	0	391	0	391	0	449	30	0	449
55-44	576889.00	140392.00			0	370 +55		410	42	410	0	410	0	410	0	410	0	410	0	0	410	0	410	0	513	55	0	513
55-50A	574642.00	140247.30	343	343	0	343	0	343	0	343	0	343	0	343	0	343	0	343	0	0	343	0	343	0	438	95	0	443
55-56	573227.10	140130.00	370																									
55-57	572445.00	140119.80	304	300	0	304	0	304	0	304	0	304	0	304	0	304	0	304	0	0	304	0	304	0	352	48	2	354
55-60A	571582.95	140287.37																							360 +230		4	
55-60B	571560.40	140300.40																							372 +189		0	372
55-61B	569953.60	140323.70	440	440	0	440	0	440	0	440	0	440	0	440	0	440	0	440	0	0	440	0	440	0	575	135	2	555
15-70	566601.00	140324.00	356	356	0	357	15	400	15	400	0	400	0	400	0	400	0	356	115	115	355	0	356	0	364	30	0	355
15-79	566750.00	140227.00	355	355	0	355	55	410	15	410	0	410	0	410	0	410	0	405	0 +0	0 +0	405	0	405	0	385	155	0	385
55-55	560942.30	140210.00			0	305	35	455	35	455	0	455	0	455	0	455	0	640	185	305	545	0	555	55	775	155	0	775
56-26A	582030.00	140598.00	495																									
56-40A	577561.31	140466.19	595	595	0	595	0	595	0	595	0	595	0	595	0	595	0	595	0	0	595	0	595	0	606	21	0	606
56-42	577280.80	140360.80	547																									
56-43	576784.00	140826.00	407																									
56-53	573793.10	140662.40	332	332	0	332	0	332	0	332	0	332	0	332	0	332	0	332	0	0	332	0	332	0	432	100	0	432
57-41	577580.90	141099.40	661																									
57-42	577175.10	141048.20	641																									
57-63A	564083.00	140825.00	330	330	0	321	65	357	65	357	0	357	0	357	0	357	0	372	0	0	372	0	372	0	477	105	0	477
58-40	577774.30	141193.70	742																									
58-41A	577931.00	141153.00	862																									
59-101	560190.00	141400.00	465	465	0	465	0	465	0	465	0	465	0	465	0	465	0	465	0	0	465	0	465	0	560	115	0	560
59-44	579618.00	141534.00	840																									
59-30	573048.00	141844.20																							485 +135		0	485
59-60B	568837.87	141374.96	410	410	0	400	30	430	0	430	0	430	0	430	0	430	0	360	55	55	355	0	355	0	355	75	0	355
60-32	580419.00	141903.00	340																									
60-57	572624.00	141871.00	325	325	0	325	0	325	0	325	0	325	0	325	0	325	0	325	0	0	325	0	325	0	475	145	0	475
60-60	571569.00	141764.00	901																									
61-18A	585101.00	142243.00	112	112	0	112	0	170	35	195	10	200	10	200	64	200	0	200	0	64	412	145	412	0	412	0	0	412
61-53	573714.00	141876.00	684																									
61-62	570915.00	141422.00	310	310	0	310	0	310	0	310	0	310	0	310	0	310	0	310	0	0	354	40	354	0	400	134	2	402
61-66	569700.00	142000.00	307	307	0	307	0	307	0	307	0	307	0	307	0	307	0	307	0	0	307	0	307	0	522	215	0	522
62-95	572964.00	142452.00	442																									
63-31	573596.00	142582.00	314	314	0	314	0	314	0	314	0	314	0	314	0	314	0	314	0	0	314	0	314	0	425	111	1	426
63-58	572383.00	140583.00	372																									
63-60	562587.00	140812.00	374	374	0	347	73	375	55	375	0	375	0	375	0	375	0	355	15	15	355	0	355	0	355	117	0	355
63-65	560915.00	140651.00	407	407	0	407	0	407	0	407	0	407	0	407	0	407	0	407	0	0	407	0	407	0	483	75	0	483
63-80	574594.00	143188.00	-155	-155	0	-50	21	22	155	10	35	217	155	357	35	357	0	357	0	35	355 +157	75	355	0	407	155	0	407
65-55	560915.00	143183.00	355	355	0	432	35	432	1	435	0	435	0	435	0	435	0	435	0	0	435	0	435	0	482	55	0	482
66-30	576204.92	143657.67																			455 +157		455	0	455	57	0	455

Borehole #	Easting	Northing	Top Bas	Top Sub A	Iso Sub A	Top A	Iso A	Top LM	Iso LM	Top BD	Iso BD	Top Sub C	Iso Sub C	Top C	Iso C	Top Sub B	Iso Sub B	Top E	Iso F	Iso C+E	Top UR	Iso UR	Top PdPp	Iso PdPp	Top [illegible]	Iso [illegible]	Iso Eo	Elev
66-61	562175.00	143476.00	389	389	0	410	21	411	1	411	0	411	0	411	0	411	0	411	0	0	411	0	411	0	487	38	0	487
67-61	574178.03	143033.22												324 >30		324	0	324	0		360	45	369	0	524	158	0	
67-88	568944.00	143715.00	288																									
68-45	578157.41	144588.31								195 >5		236	41	305	70	308	0	305	0	30	303	130	303	0	404	88	2	488
8-24	588311.74	125194.38	-78	-78	0	-3	78	87	88	177	50	175	58	233	88	335	0	388	163	213	388	6	388	0	487	88	4	481
70-11	584958.80	144481.00	110																									
71-30	585003.35	145226.91												276 >23		276	0	276	0		388	88	388	0	401	38	0	401
71-82	573887.74	145215.10														388 >36		388	30		388	0	398	0	520	122	3	
71-77	588401.85	145098.61												187 >23		287	100	387	70		387	0	387	0	472	105	0	472
71-78	585418.00	145349.00	213	213	0	-153	80	-28	127	13	30	83	50	183	120	282	108	387	66	118	387	0	387	0	442	56	0	442
72-72	587581.54	146418.79														318 >38		388	80		388	0	388	0	482	65	0	
72-92	581838.42	146358.75																300 >80			300	0	300	0	488	150	0	488
74-44	576385.09	146098.70														373 >80		400	25		400	0	400	0	443	43	2	
74-48	575237.72	146037.71														382 >25		430	50		430	0	430	0	487	87	8	487
77-38	576847.85	146888.58												277 >15		277	0	277	0		387	88	387	0	418	43	2	
77-94	573385.67	146854.85																380 >80			380	0	380	0	488	98	0	488
78-02	576877.38	147185.22														344 >26		426	81		426	0	425	0	488	43	1	
80-43P	578703.83	147729.91						38 >30		68	38	303	133	308	105	308	0	308	0	105	373	65	373	0	412	38	1	413
81-58	572185.94	148173.60												294 >5		340	55	374	25		374	0	374	0	438	65	0	
81-62	578843.00	148183.60	-88	-88	0	45	22	40	105	110	70	335	135	248	10	341	88	408	66	75	408	0	408	0	440	34	0	440
83-1	588817.80	148725.00	388																									
83-47	576402.94	148785.25																			355 >75		356	0	436	80	0	436
83-88	571948.00	148874.00	-88																									
84-36A	570483.40	149083.75	45	45	0	45	0	118	74	195	38	193	0	150	0	155	0	165	0		385	218	385	0	420	35	0	488
84-38	571731.00	149170.00			0	-53	52	58	110	174	88	288	141	288	15	353	73	403	50	88	403	0	403	0	458	53	4	488
86-88	671875.00	148887.00	-78																									
88-94	570334.00	149618.00	53																									
87-88	572889.75	148803.87																418 >80			418	0	418	0	458	41	0	488
88-36	570121.74	148549.51																			342 >21		342	0	388	54	0	
8-17	584898.84	128008.11																		0	322 >10		388	64	500	112	13	422
8-29	582788.20	125837.78																404			404	0	404	0	404	88	25	
93-14	588588.00	151148.00	274	274	0																							
95-46	575084.32	151788.52																			388 >11		388	0	428	83	0	
95-93	561824.00	151800.10	170																									
96-43	576781.88	152088.64																			377 >6		377	0	421	44	1	
96-48	574851.58	152088.31																			388 >40		388	0	418	88	0	418
97-43	576872.00	153090.52																			377 >56		377	0	422	45	0	
8-E2	188829.08	128138.00	-4																									
8-E3A	581479.81	128312.20	-23	-23	0	7	30	153	148	218	86	218	0	318	0	248	38	383	108	108	383	0	388	31	455	67	0	453
83-2	588840.00	145328.00	208	208	0	-152	54	-8	143	15	24	63	48	183	120	243	88	384	141	281	384	0	384	0	440	38	0	448
D8-5	573812.47	151148.41														388 >7		408	48		408	0	408	0	458	88	0	
D8-12	573838.01	151587.51														379 >3		418	38		418	0	418	0	468	58	0	468
D8-20	573238.97	152030.15														385 >3		412	48		412	0	412	0	490	48	0	
E13-1	572884.21	134381.22																380 >10			380	0	380	0	740	330	0	740
E13-13	573409.07	134888.72																380 >30			388	0	388	0	734	334	0	
E13-18	573118.98	134219.97				273 >16		328	55	328	0	328	0	328	0	328	0	443	115	114	443	0	443	0	727	284	0	727
E13-20	573809.57	134312.73	198	198	0	270	114	331	81	331	0	331	0	331	0	331	0	428	95	98	428	0	429	0	741	315	0	
E17-4	575118.16	135370.35						330 >13		330	0	330	0	330	0	330	0	410	80	80	410	0	410	0	717	307	0	717
E18-1	572298.00	138000.37																388			388	0	388	0	718	330	0	
E19-1	572918.87	135086.00	215	215	0	320	84	388	81	380	0	380	0	380	0	380	0	385	23	25	385	0	385	0	734	348	0	734
E24-7	574400.76	135580.71	271	271	0	381	110	381	0	381	0	381	0	381	0	381	0	381	0	0	381	0	381	0	714	333	0	
E24-8	576547.00	138271.00	308	308	0	408	102	408	0	408	0	408	0	408	0	408	0	408	0	0	408	0	408	0	608	200	0	608
E25-2	575613.98	138002.15	318	318	0	405	88	418	14	418	0	418	0	418	0	418	0	418	0	0	418	0	418	0	675	258	0	
E26-1	575281.94	137130.71	383	383	0	388	6	383	0	383	0	383	0	383	0	383	0	383	0	0	383	0	383	0	618	223	0	615
E26-8	575676.37	137123.48	387	387	0	387	0	387	0	387	0	387	0	387	0	387	0	387	0	0	387	0	387	0	608	203	0	
E27-10	575100.71	137052.00	382	382	0	382	0	382	0	382	0	382	0	382	0	382	0	382	0	0	382	0	382	0	627	248	0	622
E27-11	574083.20	137083.00	378	378	0	378	0	378	0	378	0	378	0	378	0	378	0	378	0	0	378	0	378	0	640	262	0	
E27-13	575885.10	138400.00																							608 >270		0	608
E27-8	573245.00	136332.47	336	336	0	404	68	414	10	414	0	414	0	414	0	414	0	414	0	0	414	0	414	0	671	257	0	
E28-2	573764.48	138083.88	373	373	0	402	29	402	0	402	0	402	0	402	0	402	0	402	0	0	402	0	402	0	679	277	0	679
E28-22	574041.35	136320.85	337	337	0	430	93	430	0	430	0	430	0	430	0	430	0	430	0	0	430	0	430	0	700	270	0	
E29-3	573728.00	138807.32				388 >6		388	0	388	0	388	0	388	0	388	0	388	0	0	388	0	388	0	693	327	0	693
E29-5	574034.10	138880.00	383	383	0	380	17	380	0	380	0	380	0	380	0	380	0	380	0	0	380	0	380	0	688	308	3	
E33-16	573778.39	137388.32	388	388	0	404	18	433	29	433	0	433	0	433	0	433	0	433	0	0	433	0	433	0	643	210	0	648
E33-29	573838.13	137231.47	389	389	0	433	48	433	0	433	0	433	0	433	0	433	0	433	0	0	433	0	433	0	671	238	0	
E33-37	574081.71	137188.78	385	388	0	385	0	388	0	386	0	385	0	388	0	385	0	385	0	0	388	0	386	0	663	288	0	663
E33-4	573818.97	137881.40	387	387	0	387	0	387	0	387	0	387	0	387	0	387	0	387	0	0	387	0	387	0	612	215	18	
F33-41	573767.19	137388.84	388	388	0	411	22	433	22	433	0	433	0	433	0	433	0	433	0	0	433	0	433	0	652	219	0	652
E34-2	574838.18	137220.82	388	388	0	388	0	388	0	388	0	388	0	388	0	388	0	388	0	0	388	0	388	0	629	241	0	
E34-4	574825.29	137744.76	408	408	0	408	0	408	0	408	0	408	0	408	0	408	0	408	0	0	408	0	408	0	588	178	0	583
F34-8	574208.88	137249.00	381	381	0	381	0	381	0	381	0	381	0	381	0	381	0	381	0	0	381	0	381	0	638	257	0	

Borehole #	Easting	Northing	Top Bas	Top Sub A	Iso Sub A	Top A	Iso A	Top LM	Iso LM	Top BD	Iso BD	Top Sub C	Iso Sub C	Top C	Iso C	Top Sub E	Iso Sub E	Top E	Iso E	Iso C+E	Top UR	Iso UR	Top PNPP	Iso PNPP	Top H	Iso H	Iso Ex	Elev
H3-2C	577632.23	152732.54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H4-10C	578011.07	153330.19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H4-13C	577907.08	153080.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H4-2	578004.00	153003.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
K-20	568520.32	147017.34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
K-24	568533.05	148034.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N-2	571478.21	149853.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N-6	571488.72	149873.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N-8	571483.03	149934.66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N-80	571477.78	149951.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S11-E12A	563579.40	120172.86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S12-20	560953.00	119732.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S12-3	560113.03	119751.78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S14-20A	563021.00	119087.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S16-24	562785.00	118540.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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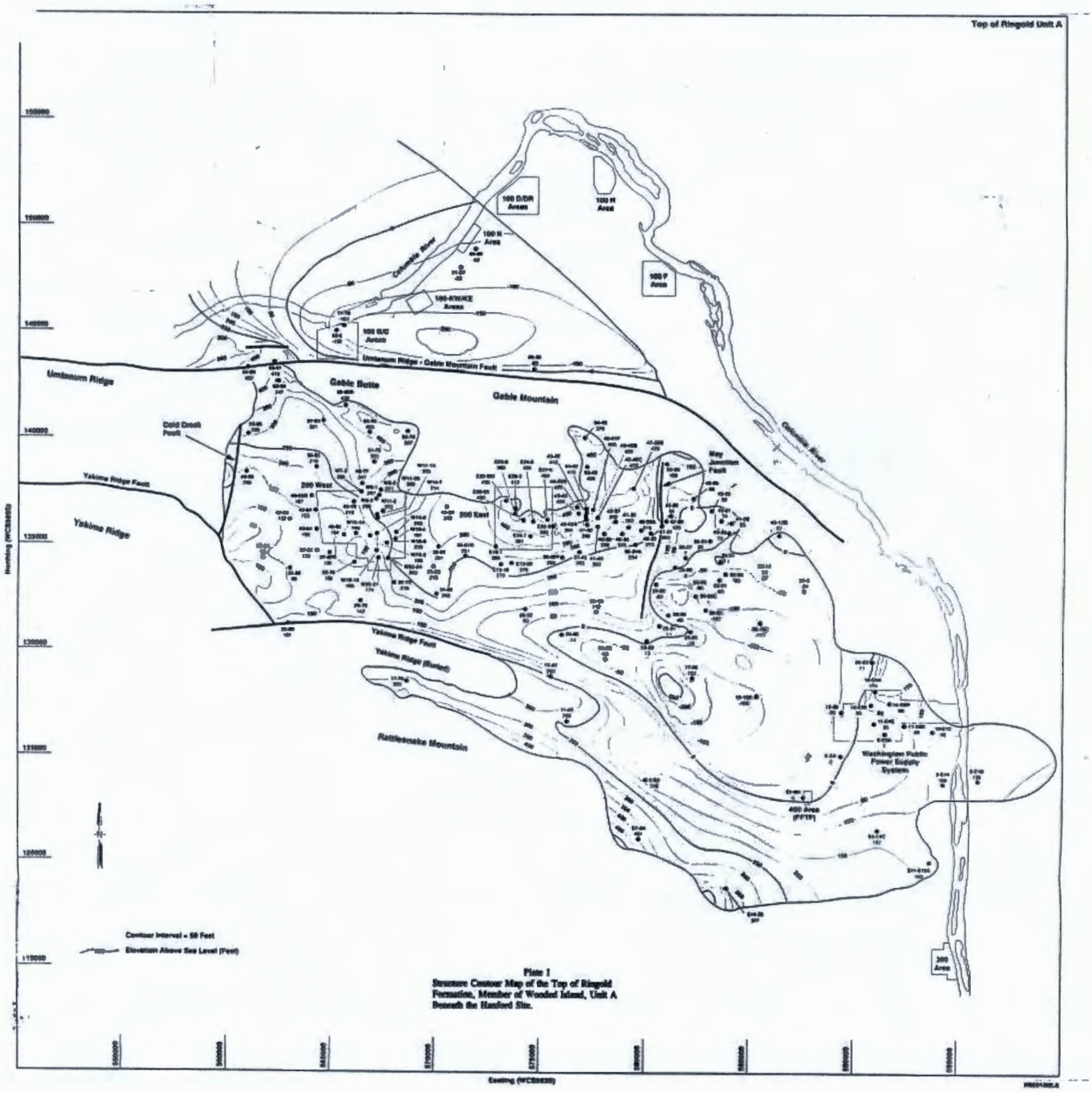

Plate 1
Structure Contour Map of the Top of Ringold Formation, Member of Wooded Island, Unit A Beneath the Hanford Site.

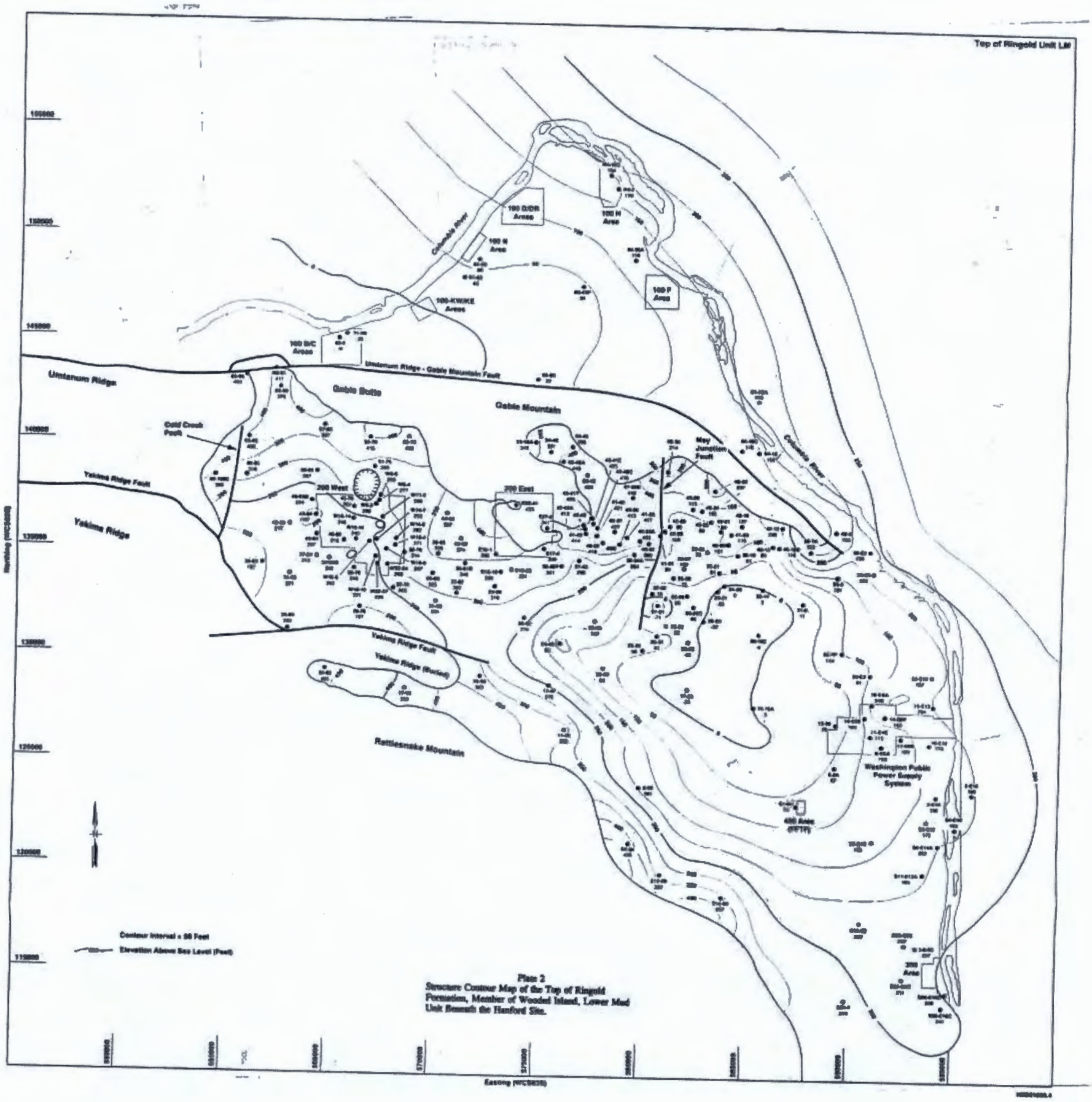

Plate 2
Structure Contour Map of the Top of Ringold Formation, Member of Wooded Island, Lower Mud Unit Beneath the Hanford Site.

Plate 3
Structure Contour Map of the Top of Ringold Formation, Member of Wooded Island, Unit B/D Beneath the Hanford Site.

Plate 4
Structure Contour Map of the Top of Ringold Formation, Member of Wooded Island, Unit C/E Beneath the Hanford Site.

Plate 5
Structure Contour Map of the Top of Ringold Formation, Member of Taylor Flat in the Subsurface Beneath the Hanford Site. Map does not include occurrences of the member outside of the Hanford Site.

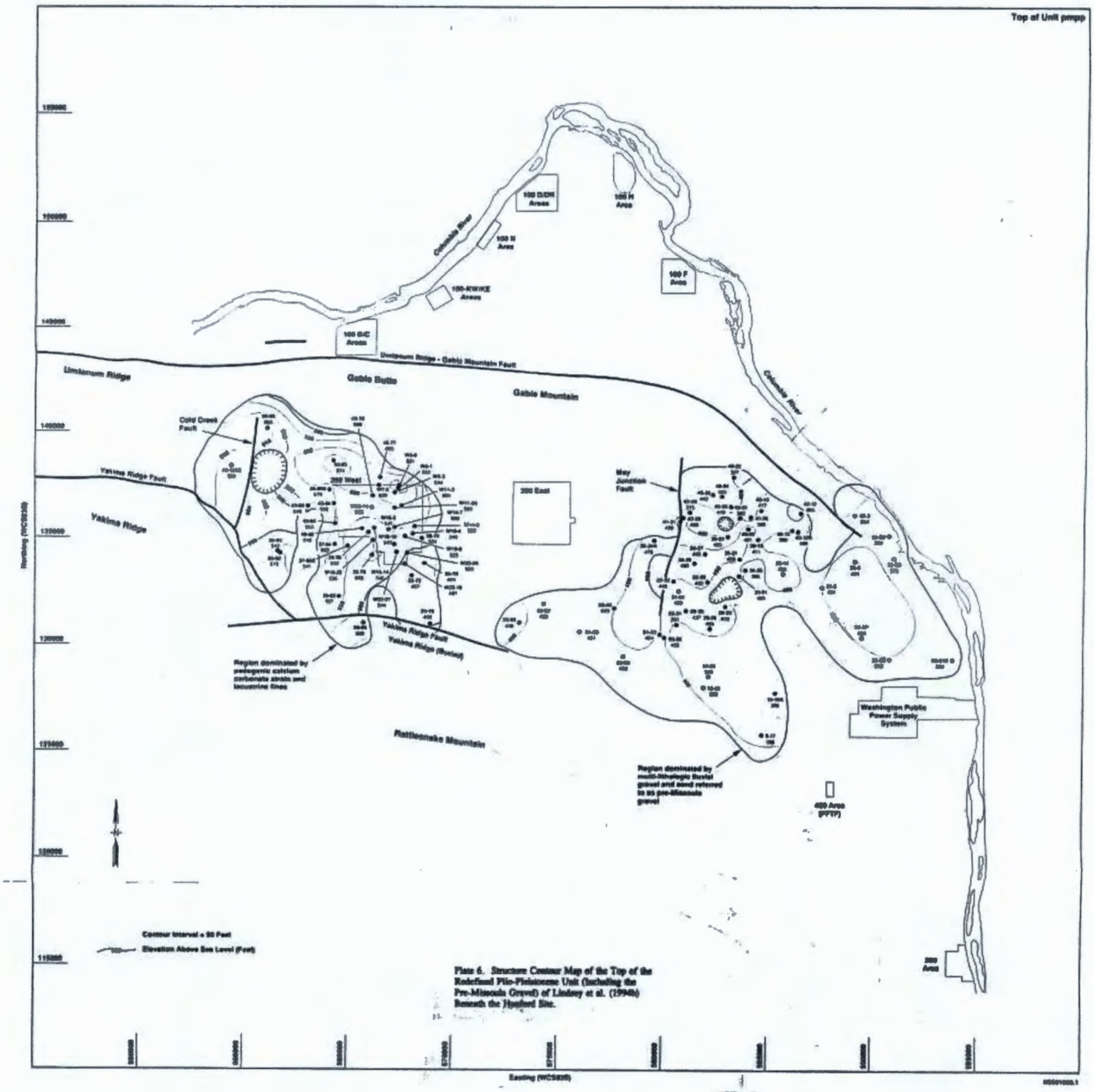

Plate 6. Structure Contour Map of the Top of the Redefined Plio-Pleistocene Unit (Including the Pre-Missoula Gravel) of Lindsey et al. (1994b) Beneath the Hanford Site.

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