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Stratigraphic analysis of the Albian through Campanian Colorado Group within the Garrison Depression, West-Central Montana

by

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Abstract

O'Brien, Matthew W., M.S. Geology

STRATIGRAPHIC ANALYSIS OF THE ALBIAN THROUGH CAMPANIAN COLORADO GROUP WITHIN THE GARRISON DEPRESSION, WEST-CENTRAL MONTANA.

Committee Chair: Marc S. Hendrix, Ph.D. MSH

The Garrison Depression is a small basin within the northern Rocky Mountain thrust belt. Measuring forty kilometers long and twenty-five kilometers wide, this basin contains the greatest thickness of Upper Cretaceous strata anywhere in the Montana foreland. To investigate the record of Cretaceous sedimentation, I studied the stratigraphy and detailed sedimentology of the Albian through Campanian strata of the Colorado Group. These strata appear to record two transgressive/regressive cycles that I interpret as stratigraphic sequences.

The three members of the Blackleaf Formation (Flood, Taft Hill, and Dunkelberg Members) compose the first stratigraphic sequence. The lower sequence boundary consists of a coquina lag that lies directly on lacustrine limestone of the Aptian-Albian Kootenai Formation. The lag is overlain by quartzite, which is overlain by organic-rich open marine shale that comprises the bulk of the Flood Member. This shale grades upsection to coarse-grained, cross-bedded sandstone of the Taft Hill member, which I infer to represent a shoreface and marsh environment. The overlying Dunkleberg Member consists mainly of interbedded porcellanite, argillite, and sandstone. I interpret the Dunkleberg as a fluvial and deltaic sequence. Within the porcellanitic strata of the Dunkleberg is the second inferred sequence boundary. Consisting of interbedded marine siltstone, sandstone, and abundant coquina beds, the overlying Coberly fines upward into gray shale of the Jens, which I infer to have been deposited below wave base. Overlying the Jens, fluvial sandstone of the Carten Creek marks the upper portion of the second inferred sequence and the final regression of the Cretaceous Sea from the Garrison Depression. An angular unconformity separates the Carten Creek from the overlying Campanian Golden Spike Formation and is responsible for dramatic thinning of the Carten Creek across the study area.

The results of this study suggest that both eustacy and tectonism were the primary depositional controls on the accumulation and preservation of this great thickness of sediment. Further, I infer that the Garrison Depression was located in the wedge-top portion of the foreland basin during deposition of this Cretaceous strata, as suggested by the immaturity of the sediments and the eastward thinning of the Colorado Group in the Garrison Depression.

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Introduction

The Colorado Group of the Clark Fork Valley is a westward thickening sedimentary wedge that was deposited during Albian through Campanian time in the Montana foreland basin. The Clark Fork Valley, located between Drummond and Garrison, Montana, contains the thickest section of Colorado Group found anywhere in the state (Gwinn, 1960). In the Clark Fork Valley, the Cretaceous foreland strata thin eastward where they are intruded by the Boulder Batholith. This thesis presents the results of a detailed stratigraphic study conducted on Colorado Group strata between Garrison and Avon, Montana.

Regional Geology

Located within the Cordilleran fold and thrust belt, the Cretaceous Colorado Group (Figure 1) near Garrison, MT is part of the Garrison Depression, a structural depression containing a six kilometer thick accumulation of Cretaceous Strata. Presently, three regional uplifts, the Lewis and Clark Line, the Sapphire Plate, and the Purcell Anticlinorium surround the Garrison Depression. To the north is the Lewis and Clark Line, also known as the Lewis and Clark Shear Zone and the Montana Lineament (Blackstone, 1956; Weidman, 1965). The Lewis and Clark Line is a transpressional uplift zone interpreted as a crustal weakness (Sears, 1988). The western boundary of the Garrison Depression is the Sapphire Thrust Plate and Flint Creek Range. East of the Garrison Depression, the Purcell Anticlinorium represents the inverted Precambriam Belt

Basin, emplaced during the Late Cretaceous as part of the Lewis-Eldorado-Hoadley Thrust Plate (Sears, et. al., 2000).

Up to six kilometers of Cretaceous sediment occurs in the middle of the Garrison Depression, near Drummond, Montana. This thickness diminishes to approximately 3 kilometers in the eastern Garrison Depression near Garrison, Montana, where the Cretaceous Strata are gently folded into a southeast plunging syncline (Figure 2) (Webb, 1999; Sears et. al., 1999). The study area for this thesis is located in the eastern Garrison Depression near Garrison.

Previous Research

Before the 1950's Emmons and Calkins (1913), and Pardee (1917, 1938) made limited reference to the Colorado Group in the Clark Fork Valley. Later, McLaughlin and Johnson (1955), McGill (1958), and Kaufman (1963) described selected Colorado Group sections from the region and McGuire (1957) completed an extensive study on the underlying Kootenai Formation in Powell County, Montana. It was not until 1958 that Fotouhi and Saraby (1958) completed the first stratigraphic description of the Cretaceous Colorado Group in the Clark Fork Valley. Performing much of their work near Drummond, they concluded that shale and sandstone of the Blackleaf Formation were deposited in a deep marine setting, based on the presence of glauconite. They also interpreted conglomerate beds of the Dunkleberg Formation (named by Gwinn and Mutch, 1965) as ancient river deposits, based on lenticular cobbles and pebbles. Gwinn and Mutch studied the stratigraphy of the Clark Fork Valley between 1958 and 1965. They are responsible for many of the descriptions of the Colorado Group within the Clark

Fork River Valley. Gwinn (1960) concluded that the facies they observed were indicative of lagoonal and barrier bar sequences. In 1998, Waddell completed studies on Cretaceous strata near Garrison, Montana. Specifically, she studied the upper half of the Carten Creek, and the overlying Golden Spike Formation. She inferred that the upper half of the Carten Creek was a meandering fluvial deposit, while the overlying Golden Spike was a sequence of proximal volcanic and nonvolcanic gravity flow deposits.

Purpose

Numerous geoscientists have contributed to descriptions and interpretations of Cretaceous deposits in the Clark Fork Valley (McLaughlin and Johnson, 1955; McGill, 1958; Kaufman, 1963; Gwinn and Mutch, 1965; Waddell, 1998). However to the east of Garrison there exists a large undescribed section of the basin. The section is bordered by Garrison in the west and Avon in the east, and parallels US Highway 12 along the Little Blackfoot River.

This study was completed to further understand the depositional controls on the thick accumulation of Cretaceous strata in the Clark Fork Valley. Since this valley is bordered to the north by the Lewis and Clark Line, a primary goal was to develop stratigraphic tests for the theory of clockwise fault block rotation of the Belt Basin along the Lewis and Clark line (Symons and Timmons, 1988; Sears, 1988). According to the theory, the fault block rotated around a vertical axis near Helena, MT and physically separated the Clark Fork Valley from the rest of the foreland to the east. Evidence of a partitioned foreland would further constrain the date of this rotation. Also, this study was conducted to extend the interpretations of Waddell (1998), with respect to depositional environment and source area of the upper Cretaceous strata in the Clark Fork Valley.

Methods

Field Studies

Fieldwork for this study was conducted between May 1998 and May 2000. It consisted of the measurement of section and sample collection. Two transects were measured along McDonald Creek, and the Beck Homstead/Clear Creek, which parallels Powell County Road 186. Stratal thickness measurements were made using a 60-meter measuring tape. A minimum of two strike and dip measurements were made along each tape as well as the trend and plunge of each tape in order to calculate the true stratigraphic thickness. Detailed measured sections were surveyed along these transects as well as some along adjacent road-cuts, which were then projected into the larger transects. The Carten Creek Formation is only partially represented in the measured sections due to limited outcrop quality and lack of access (i.e. denied access by landowner). Sample collection was conducted along all measured sections. In addition, minor sampling (grab samples) was completed in reconnaissance areas and stratigraphic position of samples was then projected into nearby measured transects.

Paleocurrent Studies

Paleocurrent indicator measurements were made on symmetrical ripple crests, slip faces of ripple cross-stratification, and trough limb axes of trough cross-stratification. All measurements were restored to horizontal and plotted on rose diagrams using GEOrient (v. 7.2). Further, the paleocurrent orientation of the trough limb axes were calculated using the "Biplanar Method" of trough axes averaging developed by DeCelles et al. (1983).

Provenance Analysis

Provenance analysis entailed sandstone point counting, as well as clast counts of the conglomerates. Sandstone point counts were based on the Gazzi (1966) and Dickinson (1970) Method. Further developed by Ingersoll (1984), this method recognizes crystals larger than 0.0625mm in lithic grains as individual monocrystalline grains. Five hundred grain counts were performed on each slide. One half of each slide was stained for calcite and potassium feldspar with alarazin red and sodium cobaltinitrate, respectively. The counts were completed using a Leitz Wetzlar polarizing microscope. The following grain types were identified and tabulated: mono and polycrystalline quartz, chert, plagioclase feldspar, potassium feldspar, biotite, muscovite, chlorite, lithic sedimentary grains, extrabasinal carbonate lithics, lithic volcanic, lithic metamorphic, unidentified lithics, unidentified nonlithics, and dense minerals. Cement, matrix and pore space also was tabulated. Specific criteria used to identify lithics are as follows: 1) Lithic volcanic grains were identified on the basis of plagioclase laths, or by the presence of interlocking polymineralic crystal grain boundaries within the grains; 2) Sedimentary grains were identified by distinguishable grain boundaries of included clasts or their support by siltstone/mudstone matrix; 3) Extrabasinal carbonate lithics were identified by eliminating diagenetic origin, i.e. cement.

These data were normalized as Qt-F-L (percentages of total quartz (including chert), total feldspar (plagioclase and potassium feldspar), and total lithic grains (lithic volcanic + lithic sedimentary + lithic metamorphic), Qm-F-Lt (percentages of monocrystalline quartz, total feldspar, and total lithic grains), Qp-Lvm-Lsm (percentages of polycrystalline quartz, including chert, lithic volcanics, and lithic sedimentary grains), and Qm-P-K (percentages of monocrystalline quartz, plagioclase and potassium feldspar). These normalized values were then plotted on four bar graphs (Figures 26-29).

Clast counts were conducted by identifying between 120-200 various sized clasts in each conglomerate sample. Large pieces of conglomerate were collected at each sample site and transported to the sedimentology lab at the University of Montana. These conglomerates were then broken apart, and the clasts counted. Results are graphically displayed in Figures 30 and 31.

Stratigraphy

Composed mostly of shale and sandstone, the Colorado Group within the Garrison Depression consists of the Blackleaf, Coberly, Jens, and Carten Creek Formations (Figure 3). Based on lithology the section appears to be the result of two transgressive/regressive cycles, which I interpret as stratigraphic sequences. The Colorado Group overlies lacustrine limestone of the Kootenai Formation, and is in turn overlain by an angular unconformity and the Golden Spike Formation of the Montana Group.

The McDonald Creek transect (Figure 4) is approximately 75 meters thicker than the Beck Homestead/Clear Creek transect (Figure 5). This difference is most likely an underestimation due to structural thickening and poor outcrop quality in the Upper Blackleaf and Coberly Formations along the Beck Homestead/Clear Creek transect.

Discussion of stratigraphy will proceed upsection from the Blackleaf Formation. Descriptions will refer to the detailed stratigraphic columns as well as Appendices I and II, which contain the full record of the McDonald Creek and Beck Homestead/Clear Creek measured transects, respectively.

Blackleaf Formation

The Blackleaf Formation is the basal member of the Colorado Group and in the Garrison Depression consists of the Flood, Taft Hill, and Dunkleberg Members (Gwinn, 1960). The type section of the Blackleaf, located near the Sweetgrass Arch in north central Montana (Cobban et. al., 1976) is divided into four members and is lithologically variable in the upper two members. In the type section, bentonitic strata characterize the Dunkleberg equivalent Vaughn member. In the Garrison Depression, the Dunkleberg is siliceous, volcanic, and non-bentonitic. The uppermost member of the Blackleaf Formation is the Bootlegger Member, which not present within the Garrison Depression. The Bootlegger Member has been interpreted as an offshore sand ridge (Meckel, 1999).

In the field area the Blackleaf Formation was measured along both the McDonald Creek and the Beck Homestead/Clear Creek transects. Detailed sections of the Flood and Dunkleberg Members (Figures 6 and 12) were measured at outcrops along US Highway 12 between mile markers 8 and 9 (SEC 35 T.10N R.9W) and 7and 8 (SEC I T.9N R.9W), respectively. A detailed section of the Taft Hill (Figure 9) was measured along an irrigation canal one-quarter mile east of Timothy Beck's Homestead (SEC 1 T.9N R.9W), both of which are located off Powell County Road 186. All sections were then projected into the adjacent Beck Homestead/Clear Creek transect.

Flood Member

Based on the index fossil *Inoceramus Comancheanus*, the Flood Member is dated as late Albian (Gwinn, 1960 and Cobban et al, 1976). The detailed section (Figure 6), measured along US Highway 12, provides the best outcrop exposure and is 68 meters thinner than the Blackleaf section in McDonald Creek to the west. The eastward thinning Flood Member has been separated into a lower and upper facies (Gwinn 1960), both of which were identified in each transect (Appendix I and II; see below). The

Kootenai/Blackleaf contact was placed at the top of the highest bed of mollusc-bearing limestone of the Kootenai Formation.

The lowermost 75 meters of the detailed section, and 0-40 meter interval in Appendix II, represent the lower facies. Poor exposures within the McDonald Creek transect limited documentation, but local outcrops, persistent float, and Gwinn's (1965) observations in the central Garrison Depression support correlation of the lower facies across the study area. Lithologically this facies is composed of interbedded mollusc coquina, siltstone, and sandstone.

Local coquina horizons (Figure 7) are present in the lowermost 25 meters. These coquinas create distinguished black horizons in the host siltstone and sandstone. These horizons increase in thickness upsection and culminate in two large coquina beds. Overlying quartzite beds are well sorted, gray to green, and contain symmetrical ripples (Figure 8) and upper plane bed lamination. The quartzites fine upward and are bioturbated, particularly in exposures in Shearing Plant Gulch (SEC35 T.10N R.9W). It is this lower unit that marks the beginning of the first transgression of the Cretaceous Sea (Gwinn, 1960).

The upper facies begins around the 75-meter mark of the detailed section (Figure 6), and within the 100-200 meter sections of Appendix I and II. This upper facies crops out in both the McDonald Creek and Beck Homestead/Clear Creek transects. Composed mainly of parallel laminated black shale, the upper facies forms a prominent topographic swale in the study area and provides a good marker unit within the section. Also, detrital biotite is quite common in one outcrop up Warm Springs Creek to the north of the field area. Overall, the upper facies of the Flood Member coarsens upwards to include fine-grained sandstone beds, which display hummocky cross stratification. This shoaling pattern continues into the regressive Taft Hill Member that overlies the Flood.

Taft Hill Member

The Taft Hill Member of the Blackleaf Formation is also reported to be Late Albian based on stratigraphic position between the Albian Flood and Cenomanian Dunkleberg (Cobban et. al., 1976). In its type section, the Taft Hill Member is characterized by glauconitic sandstones and bentonitic silty shale (Cobban et. al., 1976). The Taft Hill is well exposed along both transects and is 73 meters thinner in the eastern Beck Homestead/Clear Creek transect. Based on lithologic observations, I have divided the Taft Hill member into three facies; a lower interbedded shale and sandstone unit, a set of cross-bedded sandstones in the middle, and an upper series of interbedded sandstones and siltstones. The Flood/Taft Hill contact is placed at the first continuous outcrop of chert litharernitic (i.e. "salt and pepper") sandstone. The basal Taft Hill is represented by the lowermost 35 meters of the detailed section (Figure 9) (200-225 meter intervals of the appendices). This lowermost facies consists of shale and siltstone interbeds that continue the coarsening upward sequence observed in the upper Flood Member. This interbedded facies contains bioturbated gray shale and well-sorted, fine grained, brown sandstone. These sandstones exhibit low angle cross stratification, symmetrical ripples, and upper plane beds.

The middle facies of the Taft Hill Member is represented by the 47-65 meter interval of the detailed section. It is also documented in the 300-370 meter interval in

McDonald Creek (Appendix I), and is contained within the 250–300 meter section of Beck Homestead/Clear Creek (Appendix II). Beds of coarse and medium grained, moderately well sorted sandstone characterize this middle facies. Upper plane beds (Figure 10), trough cross beds (Figure 11), climbing ripples, and mudchips from underlying siltstones were also observed in this middle facies. An 8-meter thick fining upward sequence caps this middle facies and leads into the upper interbedded facies.

The Upper Taft Hill Member is represented by the upper 25 meters of the detailed section, the 270–330 meter, and the 400-450 meter intervals of the Beck Homestead/Clear Creek and McDonald Creek transects, respectively. Dominated by mostly fine and medium grained, gray/green siliciclastics, this middle facies is characterized by multiple fining upward sequences of siltstone and sandstone. Stratigraphic structures include worm burrows, wood fragments, root casts, and mudchips, while upper plane bedding and trough cross bedding characterize sandstones. This upper facies of the Taft Hill is unconformably overlain by the Dunkleberg Member of the Blackleaf Formation.

Dunkleberg Member

The Dunkleberg Member of the Blackleaf Formation is the most lithologically diverse unit of the formation, and is the only member with a type section in the Garrison Depression and not the Sweetgrass Arch (Gwinn, 1960). The correlative member within the Sweetgrass Arch is the Vaughn Member, which consists of bentonite and nonmarine siltstone and sandstone. Within the Garrison depression, the Dunkleberg has been dated through K-Ar methods as Cenomanian (Cobban in Wallace, 1990).

The best exposure of the Dunkleberg is along the US Highway 12 roadcut, where the detailed section was measured. Overall the Dunkleberg appears to be about 60 meters thicker in the Beck Homestead/Clear Creek section than in the McDonald Creek section, opposite the thickness trend observed in the two lower members of the Blackleaf Formation. This thickening is likely caused by structural repetition of section well exposed in Shearing Plant Gulch (SEC35 T.10N R.9W), where the lower Flood quartzite is mapped (Sears et. al, 1999) as Taft Hill.

The Dunkleberg member in the eastern Garrison Depression has been divided into three facies: a basal conglomerate, a middle tuffaceous sandstone, and an upper porcellanite and chert unit. The chert and porcellanite are due to diagenesis of bentonite and likely represent volcanic tuffs. The Taft Hill/Dunkleberg contact is placed at the base of the first cobble conglomerate.

Although not represented in the detailed section the basal conglomeratic facies was measured at the 480-550 meter interval and the 325-350 meter interval of appendices I and II, respectively. The conglomerate facies was observed in both transects, but variation in clast size and number of conglomerate beds inhibited correlation of individual beds. The clasts range in size from 0.5-0.7 centimeters (Figure 13) in diameter and appear to be derived from Paleozoic rocks.

The middle facies of the Dunkleberg was measured in the first 20 meters of the detailed section (Figure 12), the 550-700 (mostly covered), and the 550-720 meter interval of Appendix I and II, respectively. Trough crossbedded, tuffaceous and non-tuffaceous sandstones comprise fining upward sequences that characterize this unit. Mudchips mantling bedding planes were observed in some sandstones. Further, lapilli were identified within some cherts, consistent with Gwinn's (1965) observations in the central and western Garrison Depression.

These tuffaceous sandstones give way to the upper facies, which is comprised of fine-grained siliciclastics, and is represented by the upper 15 meters of the detailed section. Although this facies does not crop out well in either transect, Gwinn (1965) reported a similar upper facies of the Dunkleberg in the western Garrison Depression. Sedimentary structures consist mainly of some trough crossbeds within fine grained sandstones as well as climbing ripples in the black chert and green porcellanite beds (Figure 14). Wood fragments were observed locally in the upper facies.

Environment of Deposition

The Blackleaf Formation and its three members record the first transgressive/regressive cycle of the Cretaceous Interior Seaway in the Garrison Depression. In the study area, this strata is interpreted to represent a marginal marine setting.

Beginning with the Flood Member, the lower facies is suggestive of a transgressive lag and tidal bar sequence, based on the existence of the valve fragment coquinas, bedforms, and overall stratigraphic position. The multiple coquina lags (Figure 7) occur at the base of the section and record an episodic transgression. Above the lag horizons, the low angle cross stratification, and upper plane bedded quartzites, are consistent with bar sand and washover deposits, respectively. The overlying symmetrically rippled, bioturbated quartzites (Figure 8) suggest further back barrier deposition. Finally, supporting all these interpretations is the overall stratigraphic position. This lower bioclastic/quartzose sequence overlies the lacustrine limestones of the Kootenai, and is in turn overlain by the upper flood facies of black shale, clearly a transgressive sequence. These patterns of barrier and back barrier deposits are similar to those reported in the Upper Cretaceous St. Mary River Formation of southern Alberta (Young and Reinson, 1975) and also mimic the transgressive sequence model proposed by Hubbard and Barwis (1976).

The upper flood facies is interpreted to represent moderate depth oceanic to shelfal conditions. This interpretation is based on the parallel bedded fissile black shale, that in turn coarsens upward to include sandstone beds with HCS (Figure 6), interpreted as shelfal storm deposits. The Flood Member is important in that the stratigraphy records the initial transgression, maximum flooding surface, and beginning of the first regression of the Cretaceous Interior Sea within the Garrison Depression.

The Taft Hill represents continued regression, and was most likely deposited in a shallow marine to marginal marine setting. The basal interbedded facies of the Taft Hill represents a shallow marine environment. This basal facies is a continuation of the shoaling shelfal sequence begun in the upper Flood Member, which continues into the medial Taft Hill. This medial facies of the Taft Hill Member is indicative of an upper shoreface, based on bedding architecture and paleocurrents indicators. These trough cross and upper plane bedded sandstones yield south/south-west paleocurrent indicators (Figure 9) that are inferred to reflect longshore drift. The upper facies, containing numerous upward fining sequences, is inferred to represent continued regression to a tidal-inlet/marsh environment. This is supported by the existence of bioturbation, root casts, and wood fragments along with thin plane and trough crossbedded sandstones (Figures 10 and 11). This succession is quite similar to Walker and Plint's (1992) model of a regressive, gradational shoreface succession. It is here in the eastern Garrison Depression that the Taft Hill Member marks the transition from an open marine to backshore environment.

The regressive pattern continues into the Dunkleberg member where an erosive lower facies of lenticular conglomerates is suggestive of fluvial channels. Three conglomerates crop out in McDonald Creek whereas only two conglomerates were documented in Meade Creek. This interpretation of fluvial origin is concurrent with Gwinn's (1965) conclusions in the central and western Garrison Depression.

The medial facies of tuffaceous sandstones suggests deposition in a deltaic environment. This is based on the existence of large packaged (approximately 7 meters) upward fining sequences and the presence of wood fragments in some porcellanite beds (Figure 12). This change from fluvial to deltaic environments marks the beginning of the second transgressive systems tract. The upper facies of the Dunkleberg continues this trend and is dominated by fine-grained siliciclastics, which suggest deposition within a prodelta/bay environment. It is here that an abundance of chert, and porcellanite (Figure 14) were documented. The Dunvegan Formation in Alberta records a similar transgressive deltaic succession (Bhattacharya and Walker, 1991).

The Blackleaf formation records the first transgressive/regressive cycle of the Cretaceous Sea and the beginning of the second transgression. The basal and upper Flood Member mark the first transgression, while the initial regression is represented by the shelfal to fluvial environments of the Taft Hill and lower Dunkleberg Members. It is within the Dunkleberg that the second transgressive cycle begins as marked by the transition from fluvial to deltaic environments.

Coberly Formation

The Coberly Formation, like the Dunkleberg, has its type section in the Garrison Depression (Gwinn, 1960). The Coberly was biostratigraphically dated as Cenomanian through middle Turonian (Cobban in Wallace, 1990), based on the presence of the index fossils *Crassostrea soleniscus* in the lower Coberly and *Rhynchostreon suborbiculatum* in the upper Coberly. The Coberly has been biostratigraphically correlated with the medial Marias River Shale to the east (Cobban et al, 1976 and Wallace et. al., 1990). Lithology does differ slightly, but is most likely due to the effects of foreland deepening to the east.

This formation was measured along both the McDonald Creek and the Beck Homestead/Clear Creek transects. The best exposure is observed along a cliff face that borders Clear Creek in the Beck Homestead/Clear Creek transect (Figure 15). The Coberly, like the underlying Dunkleberg Member, appears to thicken to the east by approximately 95 meters. This apparent thickening is attributed to intra-formational folding that was not exposed.

The Coberly in the eastern Garrison Depression has been divided into a lower sandstone/mudstone facies, a medial coquina, and an upper plane and crossbedded sandstone facies. This is concurrent to Gwinn's (1965) Coberly interpretation in the western and central Garrison Depression. The Dunkleberg/Coberly contact was placed above the last outcrop of chert/porcellanite, which differs from the geologic map by Sears et. al, (1999), where the contact was placed at the base of the first coquina bed.

The lower sand/siltstone facies first recognized near Drummond by Gwinn (1965) fails to outcrop well in either measured transect. Limited exposures are represented in the 750-860 and 790-830 meter intervals of Appendices I and II, respectively. These silt/sandstones are organized into upward fining sequences, reminiscent of the upper Dunkleberg fine-grained siliciclastic facies. In this grouping the sandstones are cross and upper plane-bedded and tend to be gray/brown, well-sorted, and fine to medium grained. The brown siltstones do not crop out well, but were reported to contain abundant bioturbation near Drummond (Gwinn, 1965).

Upper and lower coquina beds distinguish the middle Coberly Formation. Both are quite extensive and are useful marker units. The first 15 meters of the detailed section (Figure 15) represent the upper portion of this medial facies. Documentation of the whole facies is contained in the 850-1225 meter interval of both appendices. Between these valve fragment coquinas, bioturbated siltstone and sandstone is topped by massive medium-grained sandstones, which contain large mudchips (Figure 16). This unit is partially represented in the 3-7.5 meter interval of the detailed section (Figurer 15), and is both cross and plane bedded (Figure 17). The sequence fines upward to include wood fragments in siltstone beds, and then is topped by the upper valve fragment coquina.

Above this upper coquina bed lies the uppermost plane and crossbedded sandstone facies. The upper 45 meters of the detailed section (1210-1350 meters of Beck Homestead/Clear Creek) represent this unit. This upper facies was not recognizable in the McDonald Creek transect due to poor outcrop. Consisting of lenticular beds of sandstone and siltstone, this upper facies displays upper plane bed lamination, and trough cross bedding. Forming numerous fining upward sequences, these siltstones and sandstones continue to fine into the overlying shale of the Jens Formation.

Environment of Deposition

The Coberly Formation represents part of the second transgression recorded by the Colorado Group within the Garrison Depression. The lower and middle Coberly consist of two cyclic stratigraphic successions, stacked one atop the other. The upper Coberly differs slightly but is still part of the overall transgressive sequence. For the lower and medial Coberly I resubmit Gwinn's (1965) interpretations of deposition in "brackish lagoons or bays and in flanking barrier bar complexes."

The basal siltstone/sandstone facies outcrops very poorly in the field area. It appears to continue the depositional trend seen in the upper facies of the Dunkleberg. Upward fining packages, several meters thick, of sandstone and siltstone are interpreted as resulting from the mixed zone of tidal and fluvial effects expected in a prodelta/bay environment. This type of stratigraphic succession is also seen in the lower Bearpaw-Horseshoe Canyon of Southern Alberta, which is also interpreted as a delta front sequence (Rahmani, 1989).

The coquina beds, siltstones, and sandstones of the medial facies are interpreted as channel lags, lagoonal muds, and deltaic sands, respectively. This sequence is evidence of the cyclic and episodic nature in which the Coberly was deposited. As mentioned, these valve fragment coquinas, interpreted as channel lags, are very similar to the "death assemblages" (Miall, 1984) I observed in the Flood Member of the Blackleaf Formation. Above the lower coquina bed, 150 meters (850-1000M interval Appendix II) of fine grained, bioturbated siliciclastics dominate the stratigraphy, suggesting a rise in base level that deposited these thick silts in a bay/estuarine environment.

Overlying these siltstones, medium/coarse grained, cross-bedded sandstones contain abundant amalgamation surfaces mantled by large mud clasts (Figure 16). These erosive crossbedded sandstones (Figure 17) give way to more massive planar-bedded sands (1070-1085 interval of Appendix II). These crossbedded sandstones yield east/southeast paleocurrent indicators (Figure 25) that suggest an influx of sediment from the west. This succession of the lower and medial facies is overlain by a second package comprising the same succession. This stacking pattern of thick siltstones topped by erosive, plane, and cross bedded sandstones is very similar to the model of a highly dissected coastal plain regression proposed by Reinson (1992), and that of a forced regression (Figure 18) put forth by Walker and Plint (1992).

The upper package of the Coberly records the continuation of the second trangression recorded by the Colorado Group. Consisting of lenticular siltstones and plane bedded sandstones this facies is interpreted to mark a marine incursion based on bedforms and stacking patterns. Lenses of sandstones enclosed in siltstone suggest tidal channel deposition. Above these lenticular sand and siltstones thick, plane bedded, fine/medium grained sandstones are suggestive of a shoreface environment. Finally, overlying siltstones fine upwards and are, in turn, overlain by fissile gray marine shale of the Jens Formation. This stacking pattern is suggestive of a transgressive sequence and culminates with marine shale of the Jens Formation.

Jens Formation

The type section of the Jens Formation is located just north of Interstate 90, exit 162 along Hoover Creek (Gwinn, 1965). The Jens Formation has been dated as Turonian through middle Coniacian by the identification of *Inoceramus frechi* (Merewether in Wallace, 1990). The Jens has been biostratigraphically correlated with the upper Marias River Shale and Telegraph Creek Formation to the east (Cobban et.al, 1976 and Wallace et. al., 1990). All formations are dominated by shale and fine-grained sandstones/siltstones (Cobban in Wallace, 1990).

I measured the Jens along both transects. The detailed section presented in Figure 19 was measured along the best exposure of the Jens, located at a roadcut along Powell County Road 186 (Beck Homestead/Clear Creek transect). Because of poor exposure and structural inconsistency due to an invading sill complex, I measured the Jens thickness along McDonald Creek using GPS coordinates.

The Jens Formation thins to the east by 200 meters between the two measured transects. This value may in part reflect uncertainty in the different measuring technique I employed at each transect, explained above. I placed the contact with the underlying Coberly Formation at the base of the lowermost outcrop of gray shale. The shale of the Jens, like the Flood Member of the Blackleaf, creates easily recognizable swales in the field area.

Based on stratigraphic observations the Jens was divided into a lower parallel bedded shale facies, middle upward coarsening silt and sandstone facies, and an upper trough cross bedded sandstone facies. Varicolored volcanic beds reported near Drummond (Gwinn 1965) are absent in the eastern Garrison Depression.

Parallel bedded shale makes up the lower facies of the Jens Formation. The first 35 meters of the detailed section (Figure 19) and the 1350-1450 meter interval of the Beck Homestead/Clear Creek transect (Appendix II) represent these gray shales. The Jens is not represented in the McDonald Creek transect (Appendix I), due to the poor outcrop quality. Although Gwinn recognized bioturbation in the lower Jens to the west, none was observed in the field area. This lower facies coarsens upward over 20 meters to siltstone, which in turn grades upward into the middle siltstone and sandstone facies.

Represented by the top 50 meters of detailed section (Figure 19) and the 1450-1550 meter interval of Appendix II, the middle facies of the Jens consists of a coarsening upward sequence of interbedded gray shale, and brown siltstone and sandstone. Siltstone is mostly parallel bedded like the underlying shale, but some does display symmetric rippling. Many siltstone beds also exhibit soft sediment deformation caused by the loading of overlying sandstone beds. These thin, well-sorted sandstones first occur near the 90-meter mark of the detailed section (Figure 19). Some of these sandstone beds contain hummocky cross stratification (Figure 20), which was also observed up Meade Creek. This shoaling pattern continues as sandstone in the middle Jens becomes more prevalent in the upper facies.

The uppermost facies of the Jens Formation is characterized by large scale trough cross beds. This facies is best exposed on the eastside of the Meade Creek canyon (SEC 9 T.9N R.9W). The lower facies of the Jens were identified in Meade Creek Canyon, and this upper facies was observed directly above the middle unit with HCS. This outcrop consists of roughly 20 meters of cliff forming, fine grained, well sorted, gray sandstone with the trough cross bed sets, 0.5-1 meter in relief (Figure 21). This upper facies of the Jens continues the upward shoaling sequence into the medium and coarse-grained sandstones of the Carten Creek Formation.

Environment of Deposition

The Jens Formation records the end of the second transgressive event and the beginning of the last regression of the Cretaceous Sea from the Garrison Depression. Based on the stratigraphic succession, bedforms, and paleocurrent indicator directions (Figure 25), the Jens was most likely deposited in moderate depth oceanic to coastal shelf conditions.

The basal facies of the Jens is dominated by parallel bedded gray shale, which overlies the upper sandstone facies of the Coberly. These fissile shales imply deposition below wave base in a moderate depth oceanic environment. Above the thick package of shale, the thin sandstone lenses are most likely a result of intermittent bottom agitation. This transition to an environment within wave base also marks the beginning of the final regression.

The middle interbedded siltstone and sandstone facies of the Jens continues the shoaling pattern started in the lower facies. The transition to shelfal conditions is supported by the increase in grain size, the occurrence of HCS in sandstones (Figure

20), and soft sediment deformation in beds of siltstone overlain by sandstone. All this stratigraphic evidence supports a shoaling sequence that is within wave base.

The upper trough cross-bedded facies of the Jens is interpreted to represent continued regression through an upper shoreface environment, based on bedding architecture and paleocurrent indicator measurements (Figure 25). Trough axes yield south/south-west paleocurrent indications that are inferred to suggest longshore drift (Figure 25). The Jens closely mimics the succession seen in the Flood and Taft Hill Members of the Blackleaf Formation. This succession is inferred to represent a shoaling shelfal environment that begins with shale deposited below wave base and grades upward to hummocky cross-stratified, shelf sandstone. These sandstones in turn grade upward to near-shore cross-bedded sandstone with paleocurrent indicators that suggest longshore drift.

Carten Creek Formation

Gwinn (1960) originally defined the Carter Creek Formation in the uppermost portion of the Colorado Group. This type locality was near Carten Creek, and hence recent publications have changed the nomenclature to more accurately reflect the type sections locale (Ruppel et al.; 1981, Wallace et al., 1990; Wadell, 1998). Biostratigraphically, the lower Carten Creek has been dated as middle Coniacian through Santonian, based on the identification of *Cardium cf. C. pauperculum, Volviceramus involutus*, *Pleuriocardia*, *Cymbophora arenaria*, *Tellina(?)*, *Corbula*, *Scaphites*, and *Placenticeras benningi* (Gwinn, 1965; Cobban in Wallace, 1990). The upper Carten Creek is dated as early Campanian on the basis of correlation between the overlying Golden Spike Formation and the Elkhorn Mountain Volcanics (Wallace, 1990). The Carten Creek Formation has been biostratigraphically correlated with the upper Telegraph Creek Formation and the Virgelle Sandstone (Cobban in Wallace, 1990).

In this study I measured only the lower portion of the Carten Creek Formation along the Beck Homestead/Clear Creek transect. The Carten Creek Formation failed to crop out in McDonald Creek. The best exposures of the Carten Creek in the study area are along Powell County Road 186 (Clear Creek), and two roadcuts along US Highway 12, mile markers 1(SEC 24 T.9N R.10W) and 5 (SEC 15 T.9N R.9W). I obtained a composite thickness of the whole Carten Creek Formation by analysis of the geologic map, using trigonometry to correct for the bedding dip. I calculated the total thickness to be 432 meters. Gwinn (1965) measured 1830 meters of Carten Creek in the central Garrison Depression. The considerable difference in Carten Creek thickness between the western and eastern portion of the Clark Fork Valley is a result of a beveling angular unconformity (Gwinn, 1965).

The Jens/Carten Creek contact was placed at the base of the first massive sandstone overlying the siltstone and sandstone facies of the Upper Jens Formation. Based on the limited exposure, the lower Carten Creek Formation has been divided into a basal cross-stratified interbedded sandstone/siltstone facies and a middle trough cross and point bar sandstone facies. Waddell (1998) documented and divided the upper Carten Creek into five lithofacies, and these observations and discussion will not be repeated here.

The lower Carten Creek is represented by the 45 meter detailed section (Figure 22). The basal interbedded facies consists of multiple upward fining and upward coarsening sequences of siltstone and sandstone. Sedimentary structures include bioturbation and ball and pillow soft sediment deformation in siltstone, caused by the sandstone loading. Bedding is parallel in places, but is mostly obscured by bioturbation. Sandstone beds are mostly fine grained and display lenticular and cross stratification. Some of the upper interbedded sandstone beds also include mudchips that appear to be derived from the underlying siltstones.

The middle facies of the Carten Creek formation is partially represented in the 25-45 meter interval of the detailed section. Consisting mostly of medium-grained sandstone, the middle Carten Creek is characterized by planar lamination, low angle cross-stratification, and trough cross bedding. Mudchips, likely derived from the lower facies siltstone, were also observed. Not pictured in the detailed section but observed along US Highway 12, mile marker 5 (SEC 15 T.9N R.9W), are medium grained sandstones organized into large point bar sets (Figure 23). The Carten Creek continues to coarsen upward into the upper pebbly facies described by Waddell (1998).

Environment of Deposition

The Carten Creek Formation is the uppermost unit of the Colorado Group, and marks the final regression of the Cretaceous Interior Sea from the Garrison Depression. Based on stacking pattern, and bedforms the lower Carten Creek is interpreted to represent a meandering river deposit.

The basal interbedded facies display rhythmic alternation of sandstone and siltstone. I interpret these as overbank deposits (Figure 23). The erosive nature of the sandstone beds combined with the abundant soft sediment deformation suggests rapid deposition during flooding events. Rapid vertical accretion in a meandering system is also documented by Walker and Cant (1979) in the Lower Devonian Battery Point Formation near Gaspe, Quebec. Also the siltstones display heavy bioturbation that supports the interpretation of deposition in quieter, post-flood episodes with minimal current activity. Although roots casts were not observed, the multiple upward fining sequences suggest deposition in a meandering stream system.

I also infer the upper facies to reflect meandering fluvial deposition, though mainly in the form of channel and point bar deposition. These upper plane bedded, erosive sandstones, containing abundant mud intraclasts, are also heavily cross-stratified. The most convincing evidence of fluvial deposition are lateral accretion sets found in the US Highway 12 outcrop mentioned above (Waddell, 1998). Further, the trough crossbedded sandstone units yield paleocurrent indicators (Figure 25) suggesting transport to the southeast, consistent with the conclusions of Waddell (1998).

Sequence Stratigraphy

Van Wagoner (1985) defined a stratigraphic sequence as, "a relatively conformable succession of genetically related parasequence sets bounded by surfaces (called sequence boundaries) of erosion or their correlative conformities." By this definition I interpret the two transgressive/regressive cycles recorded by the Cretaceous Colorado Group of the Garrison Depression as two stratigraphic sequences. Figures 24 and 25 show stratigraphic columns from each measured transect and a Cretaceous Sea Level Curve (Haq et. al., 1988). This curve was aligned with the stratigraphic column using age constraints, described previously. This section will proceed through each stratigraphic sequence, and discuss stratigraphic succession and sea level curve agreement.

The first sequence includes the Flood, Taft Hill, and Dunkleberg Members of the Blackleaf Formation. The basal Flood Member contains multiple coquina beds that thicken upward, and are interpreted as episodic transgressive lag deposits. Above these lag deposits is the fissile black shale of the upper Flood Member that marks the highstand and maximun-flooding surface of the first sequence. This first transgression has been termed the T_{00} (Figure 33) by Gwinn (1965) and represents the transgression of the "Mowry" Sea from the north (Reeside, 1957; Wulf, 1962; DeCelles, 1986). The lowstand and first regression is recorded in the thick sandstones and silstones of the Taft Hill and Dunkleberg Members of the Blackleaf Formation. Paleocurrent indicators of the middle Taft Hill suggest southerly longshore drift (Figure 24 and 25) and proximity to a paleo-shoreline. This southerly directed longshore drift is consistent with Slingerlands findings along the west shoreline of the Western Interior Seaway. Gwinn (1965) has termed this regression as the R_0 (Figure 34). It is this Albian transgressive/regressive cycle that contains the first record of the Cretaceous Interior Seaway in the Garrison Depression.

The sea level curve matches moderately well with the inferred record of sea level suggested by the Blackleaf Formation in the study area. The large fall is concurrent with the early Cenomanian strata of the Taft Hill and Dunkleberg Members that I interpret as representing shoreface and deltaic deposition. It is in the Dunkleberg between the basal conglomerate and medial tuffaceous sandstones that I infer a conformable sequence boundary. Between these two facies, deltaic strata, suggesting the beginning of the second transgressive sequence top fluvial sediments.

The second sequence begins with the middle facies of the Dunkleberg Member and ends with the Carten Creek Formation. Gwinn (1965) interpreted the T_0 transgressive/regressive event to occur between the Dunkleberg and Coberly, but I diDepressionree with this conclusion based on lack of sedimentological evidence. The lower Coberly continues the deepening trend started in the Upper Dunkleberg. This inferred transgression is most likely due to basinal subsidence, because evidence of a second marine incursion is not observed until the coquina beds within the middle Coberly Formation, which I infer to be channel lag deposits. Further, the cyclic stacking pattern observed in the Coberly supports an episodic transgression that corresponds with the T_1 (Figure 35) transgression of Weimer (1960). The highstand strata of the Jens shale then overlie the coquina beds. This marine shale records the maximum flooding surface of this second sequence. The upper facies of the Jens exhibits the influence of longshore currents that mark the beginning of the R_1 (Figure 36) regression as also defined by Weimer (1960). The regression culminates in the massive fluvial sandstones of the Carten Creek Formation.

The sea level curve of the second stratigraphic sequence fits moderately well with the observed character of strata. The Turonian highstand begins in the Coberly and continues through the Jens shale, while the Conacian/Santonian lowstand corresponds with the coarse clastic strata of the Carten Creek Formation. The upper sequence boundary is the angular unconformity between the massive debris flows of the Golden Spike Formation (Waddell, 1998) and the underlying uppermost Carten Creek Formation.

Provenance

An important component of this sedimentary basin analysis was a compositional analysis of suitable sandstone samples and conglomerate clasts. The methods of sandstone point counting and cobble clast counts were outlined in the introduction. Sandstone and conglomerate samples were collected at fixed intervals along transects. In addition, grab samples were also collected and then projected into adjacent transects according to stratigraphic position.

Sandstone Point Counts

A total of 52 sandstones were prepared in thin section. Due to heavy calcite replacement only 18 were point counted. The resulting compositions were then plotted in four bar graphs (Figures 26-29). These four diagrams plot the types of quartz, lithic grains, and feldspars as explained in the methods section.

The Taft Hill sandstones are quartzo-lithic with a great deal of diagenetic calcite alteration. The least altered samples, 9MDCBTC and 9TBHBT1, are from the middle crossbedded facies of the Taft Hill Member of the Blackleaf Formation. These sandstones are characterized by over 80 percent chert, whereas sedimentary lithics (shale, siltstone) consist of only 17 percent (Table 1). The remaining 3 percent consists of unidentified grains.

The quartzo-lithic composition continues in the lower facies of the Dunkleberg Member. Two samples from the McDonald Creek transect (9MDCBD1 and 9MDCBD3) show a marked increase in lithic volcanic grains, as do samples 9US12KBD2 and 9US12KBD4 from the middle tuffaceous sandstone facies of the Dunkleberg. High in lithic grains, these samples are the first to display dominance of feldspar over quartz. In each sample, plagioclase feldspar accounts for over 75 percent of counted grains.

Nine sandstones of the middle coquina facies within the Coberly Formation were point counted. These sandstones are characterized by quartzo-lithic compositions that trend to quartzo-feldspathic compositionally upsection. Lithic populations in the lower samples (9MDCBD4, 0MDCKC2, 9TBHC1, and Coberly 4b) are equally split between sedimentary and volcanic lithic fragments. The five samples from the upper middle facies of the Coberly (9CCC1, 9CCC2, 9CCC4, 8MCC2, and 8MCC3) average 38 percent plagioclase feldspar.

This quartzo-feldspathic trend continues into the lower facies of the Carten Creek Formation. Three samples from the lower cross-bedded facies (0CCKCC1, 0CCKCC2, and 0CCKCC3) show extremely similar compositions (Figure 26 and 27). The remaining sample was taken from the middle point bar facies that c rops out along US Highway 12, mile marker 5 (SEC 15 T.9N R.9W). This sandstone (Sample 9 Carten Creek) trends back to a quartzo-lithic composition, concurrent with the provenanve analysis of the Upper Carten Creek performed by Waddell (1998).

Interpretation

The sandstones from the Colorado Group of the eastern Garrison Depression fluctuate between quartzo-lithic and quartzo-feldspathic compositions. I interpret these trends to reflect Cretaceous volcanism and sandstone derivation from uplifted Paleozoic strata, both occurring west of the field area.

Sandstones of the Taft Hill Member of the Blackleaf Formation begin this trend with their high lithic chert content, most likely derived from the Permian Phosphoria

Formation. Although active volcanism is first suggested by abundant detrital biotite in the shale of the Flood Member, the Dunkleberg sandstones suggest renewed volcanism. This renewed volcanism is reflected by the increases in feldspars and volcanic lithics of the tuffaceous sandstones. The return to quartzo-lithic composition in the lower middle Coberly is peculiar, but most likely represents a period of volcanic quiescence. The quartzo-feldspathic characteristic of the upper middle Coberly and Carten Creek suggests a lull in volcanism and possibly the beginning of the dissection of a volcanic arc to the west. The high percentages of feldspar in the Coberly and Carten Creek sandstones support this. Also volcanic strata is absent from the upper three formations and doesn't reappear until the Campanian Golden Spike Formation (Waddell, 1998).

Conglomerate Clast Counts

A total of five clast counts were completed. Three conglomerate samples were collected in the McDonald Creek transect (Figure 30) and two samples were collected in the Beck Homestead/Clear Creek transect (Figure 31).

The McDonald Creek conglomerate samples are dominated by quartzite low in the section and chert clasts higher in the section. The basal conglomerate (sample 0MDCKBDC1) of McDonald Creek contains 72% quartzite, 25% chert, 3% argillite, and 3% carbonate clasts. These percentages represent a total of 189 cobble counts. This composition is in contrast to the second conglomerate (sample 0MDCKBDC2) where chert is dominant at 46%, quartzite makes up only 23%, and argillite makes up 29%. Clasts of unidentified composition comprise the final 2%, and no carbonate clasts were observed (n=163). The uppermost conglomerate of McDonald Creek (sample

0MDCKBDC3) consists of 46% chert, 29% argillite/porcellanite, 23% quartzite, and 2% unidentified clasts (n=161). I infer the abundant porcellanite clasts to reflect cannibalization of Dunkleberg strata.

In the Beck Homestead/Clear Creek transect only two conglomerates were found. The basal conglomerate of the Beck Homestead/Clear Creek transect (sample 0TBHKBDC1) is composed of 60% quartzite, 37% chert, 2% argillite, and 1 unidentifiable (n=163). Although this basal unit has the smallest clast size of all conglomerates, the compositional data mimic the basal unit of McDonald Creek (sample 0MDCKBDC1). The second conglomerate of the Beck Homestead/Clear Creek transect (sample 0TBHKBDC2) consists of 58% chert, 35% quartzite, and 7% argillite (n=199). No porcellanitic clasts were observed, unlike the uppermost conglomerate of McDonald Creek.

Interpretation

Even though correlation of these conglomerate beds between the two transects was not possible the compositional data are very similar at various stratigraphic levels in each section. Both show a predominance of quartzite low in the section, which is replaced by chert, and to a lesser extent argillite higher in the section. I interpret this trend to reflect the unroofing of early Cretaceous and Paleozoic strata. This unroofing sequence begins in the Cretaceous Kootenai Formation, and continues through the Mississippian limestones of the Madison Formation.

The lowest stratigraphic Dunkleberg conglomerate consists mostly of quartzite, but has a great deal of chert, some argillite, and carbonate nodules. Gwinn (1965) suggested the quartzites were derived from the Belt Supergroup, but I diDepressionree.

Most quartzite clasts are clean and white, which suggests derivation from the Pennslyvanian Quadrant Formation. Belt quartzites are quartzo-feldspathic, and display hematitic staining around the feldspar grains (D. Winston, 2000, personal commun.). Red sandstone clasts were observed from each section, but the reddish color is a nonhomogenous stain that is drastically different from the characteristics of the Belt quartzites. These red sandstone clasts may have been derived from the red beds of the Cretaceous Kootenai or Jurassic Morrison Formation. The chert is most likely signifies erosion of the Mississippian Limestones. Finally caliche nodules are scarce and, like the stained quartzites, could be eroded from the red beds of the Morrison, or Kootenai Formations.

The pervasiveness of chert in the upper conglomerates is most likely the result of the beginning of the erosion of the Madison Limestone (Winston, 2000, personal commun.). Quadrant quartzite is still pervasive, but argillite and most importantly porcellanite suggest cannibalization of the Dunkleberg.

In conclusion, the compositions of the conglomerate clasts from the Blackleaf Formation suggest the unroofing of Paleozoic strata. The lower Dunkleberg Member of the Blackleaf Formation contains abundant Pennsylvanian Quadrant Quartzite. Chert then replaces quartzite upsection as the dominant compositional clast, suggesting erosion of the Mississippian Madison limestone. This type of unroofing sequence is common in compressional orogenies and is often preserved in the foreland basin sedimentation (DeCelles and Giles, 1996).

Depositional Controls and Implications

Sedimentary Strata of the Colorado Group in the Garrison Depression are the thickest Cretaceous deposits in Montana (Gwinn, 1965). Hence, it is necessary to discuss the controls on accommodation space during late Cretaceous time. As discussed, the Colorado Group of the Garrison Depression records two transgressive events, but overall thickness trends and accumulation rates, suggests both eustatic and tectonic effects created a quickly subsiding basin complex.

First, the Cretaceous and Paleozoic provenance of Colorado Group Strata suggest folding and thrusting to the west. Lower Cretaceous thrusting along the Moyie Fault has been documented by the dating of the White Creek batholith in southeastern British Columbia (Archibald et al, 1983, Archibald et al, 1984). Rb-Sr dated as 115 Ma (Wanless et. al., 1968), the White Creek batholith cuts the Moyie Fault, which is included within the western edge of Lewis and Clark Shear Zone. Further, abundant volcanic lithics and eastward directed paleocurrent indicators in the Blackleaf and Coberly Formations strongly suggest volcanism to the west. The active tectonics and volcanism likely produced the clastic influx represented by lower Colorado Group Strata. Thrusting combined with a clastic influx caused crustal loading, producing a rapid episode of subsidence in the Montana foreland basin.

Second, the pre Carten Creek Colorado Group thins by approximately 150 meters from the central Garrison Depression to the study area in the eastern Garrison Depression. I believe this is a gross underestimation due to structural thickening observed within the Beck Homestead/Clear Creek transect. Good structural control does exists along the northern end of the McDonald Creek transect. It is here that the Blackleaf Formation and its three inherent members exhibit a loss of over 300 meters from their equivalents in the central Garrison Depression, approximately 50 kilometers to the west (Figure 32). Accumulation rates reflect this thinning. In the central Garrison Depression the Blackleaf Formation has a rate of 17.2cm/1000 years, and in the eastern Garrison Depression this rate decreases to 12.5cm/1000years. This trend mimics foreland basin geometry where the highest rate of subsidence is proximal to the orogenic belt (Beaumont, 1980).

Presently, the Garrison Depression is isolated from the rest of the foreland complex to the east by the Purcell Anticlinorium, which was emplaced as part of the 30 km thick Lewis-Eldorado-Hoadley thrust plate (Sears et.al., 2000). Contrary to Sears' original hypothesis of Campanian emplacement (1988), trachyandesite sills near Garrison, Montana yield new 40Ar/30Ar dates, reported by Sears, et al. (2000). These new ages suggests that the Lewis-Eldorado-Hoadley thrust plate was emplaced between 74 and 59 Ma, well after the Colorado Group Strata was deposited.

In addition, Wallace et. al. (1990) proposed that the Garrison Depression was partitioned from the northern foreland by uplift along the Lewis and Clark Line. Wallace et. al. (1990) cites the inconsistent lithologic succession between the deep-water, Colorado equivalent strata, near Wolf Creek, Montana to the north, and the marginal marine Coloradan Sediments near Drummond to the south. I disagree with this partitioning mechanism presented by Wallace and then resubmitted by Waddell (1998), based on a lack of sedimentological evidence. The transition from near strandline to open marine deposits north of the Lewis and Clark Line is inconclusive. This effect could easily be a relict of foreland deepening, due to the documented thrusting along the Moyie Fault to the west (Archibald et. al., 1983 and Archibald et. al., 1984).

I interpret the unique thickness of the Colorado Group of the Garrison Depression to be the result of deposition in the wedge top position (Figure 33) of the foreland basin complex (DeCelles, 1996). The wedge top depozone is proximal to the orogenic belt. It characteristically thins toward the rest of the orogenic wedge (in this case to the east), contains compositionally immature sediment, shelf sediments, and in some situations may contain unconformities (DeCelles, 1996).

The Colorado Group of the Garrison Depression thins rapidly toward the rest of the orogenic wedge to the east. The loss of 300 meters to the east within the Blackleaf Formation alone suggests an eastern basin margin. In addition, the sediments show relative immaturity, supported by the cannibalization of the Dunkleberg within its own conglomerates. Also all Colorado Group members do contain sediments deposited in shelfal environments. Finally, the beveling unconformity atop the Carten Creek is further evidence that the Garrison Depression was deposited in the wedge top position of the foreland complex (Lawton et al., 1993; DeCelles, 1996).

In conclusion, it was a combination of eustatic and tectonic controls that influenced the deposition of the Colorado Group in the Garrison Depression. Active tectonism to the west created a clastic influx and crustal loading, producing a rapidly subsiding basin within the Garrison Depression. Differences in accumulation rates across the Garrison Depression and drastic eastward thinning suggest an eastern basin margin. Finally, the Colorado Group within the Garrison Depression was deposited in the wedge top position of the foreland basin complex (DeCelles, 1996).

Conclusions

This thesis presents a detailed stratigraphic and sedimentologic study of Colorado Group strata within the eastern Garrison Depression in west central Montana. The purpose was to document Colorado Group stratigraphy and analyze the controls responsible for depositing the thickest accumulation of Cretaceous Strata in Montana.

The conclusions that can be made from the this study are as follows:

I. Sedimentologic Interpretations

  A. Blackleaf Formation

    1. Flood Member: The Flood is characterized by the first Cretaceous marine incursion into the Garrison Depression, marked by a coquina lag, barrier bar deposits, fissile black shale, and a shoaling upward sequence which includes storm deposits.
    2. Taft Hill Member: This member signifies the first regression of the Cretaceous Sea and records a shoaling sequence of shelfal, shoreface, and tidal inlet/marsh environments.
    3. Dunkleberg Member: The Dunkleberg records an episode of depositional deepening marked by erosive fluvial deposition, deltaic, and prodelta/bay environments, and volcanism to the west.

  B. Coberly Formation

    1. The Coberly Formation records an episodic transgression of the Cretaceous Sea and is marked by a prodelta, two cyclic sequences of

coquina lag, interdistributary bay mud and deltaic sand, and an uppermost intertidal deposit.

C. Jens Formation

1. The Jens signifies the second Cretaceous marine incursion into the Garrison Depression, with gray fissile shale, a shoaling shelf sequence with storm deposits, and a near shore zone affected by long shore drift currents.

D. Carten Creek Formation

1. The Carten Creek documents continued regression and is characterized by erosive sandstone and overbank deposits which are indicative of deposition in a meandering river environment.

II. Sequence Stratigraphy

1. The Colorado Group of the eastern Garrison Depression is composed of two stratigraphic sequences that contain the T00, RO, T1, R1 sea level rises/falls of Gwinn (1965), and Weimer (1960).

III. Provenance

1. Sandstone compositions trend from quartzo-lithic to quartzo-feldspathic. This trend suggests provenance from thrusted Paleozoic strata to the west and perhaps the dissection of a relict volcanic arc.
2. Clast counts of the Dunkleberg conglomerates display an unroofing trend beginning in the Cretaceous Kootenai and continuing through the Pennsylvanian Madison Formation.

IV. Stratigraphic Tests For Sears (1988) Clockwise Rotation Theory

1. Although evidence of an eastern basin margin was found in the study area, new data (Sears et al., 2000) suggests the Purcell Anticlinorium was emplaced after mid Campanian time.

V. Analysis of Depositional Controls

1. A combination of eustatic and tectonic effects controlled the deposition of the Cretaceous Colorado Group.
    - a. The provenance data and documentation of thrusting along the Moyie Fault support the interpretation of active tectonism and subsequent crustal loading to the west.
    - b. Higher accumulation rates in the western Garrison Depression suggest a rapidly subsiding basin complex.
2. Deposition of the Colorado Group took place within the wedge top depozone of the foreland complex (Figures 34-37).
    - a. An eastern basin margin is suggested by the loss of over 300 meters within the Blackleaf Formation from west to east in the Garrison Depression.
    - b. Relative immaturity of the sediments is documented by cannibalization in the Blackleaf Formation.
    - c. The angular unconformity at the Carten Creek/ Golden Spike contact further supports deposition of the Cretaceous Colorado Group of the Garrison Depression in the wedge top depozone of the Montana foreland complex.

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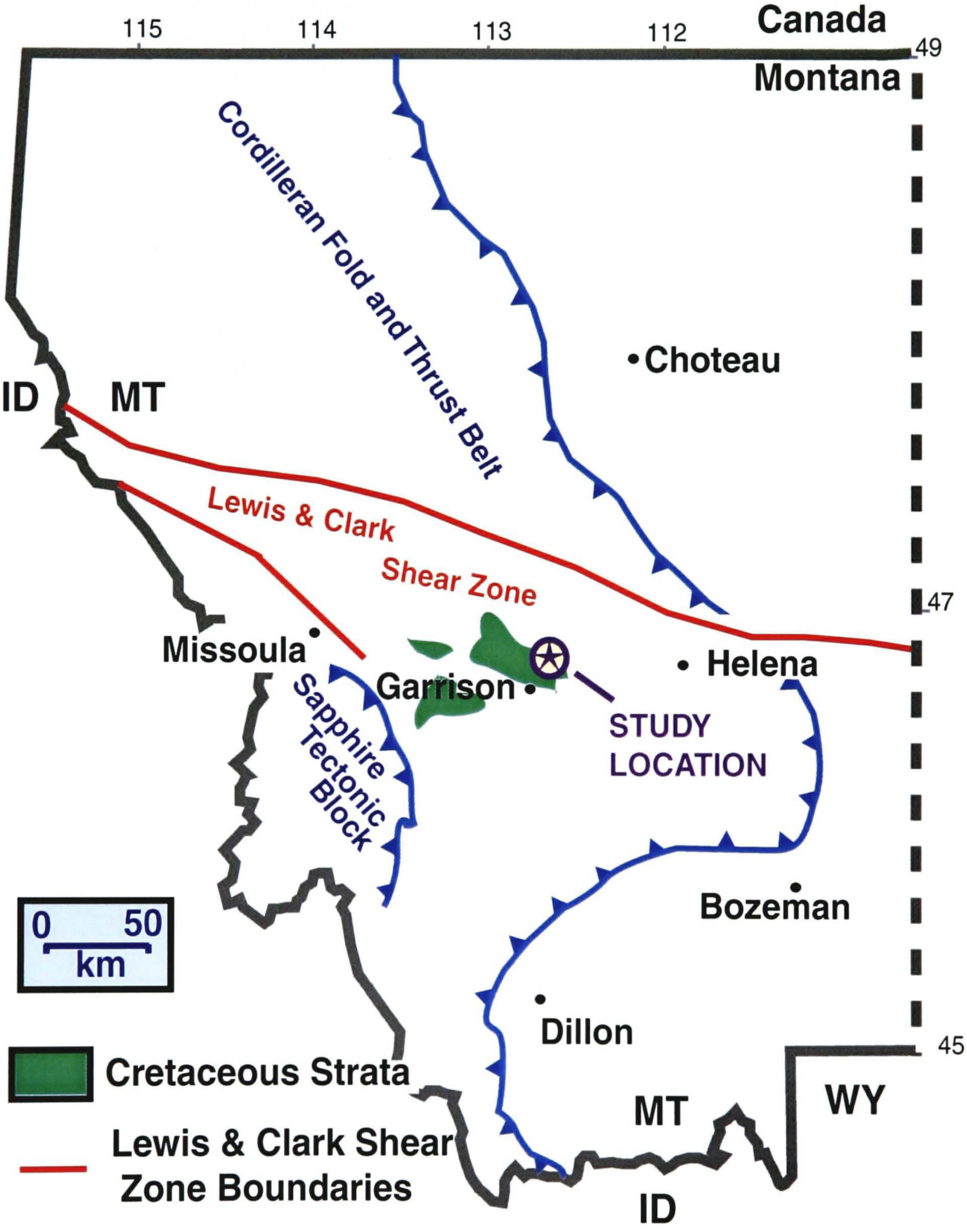
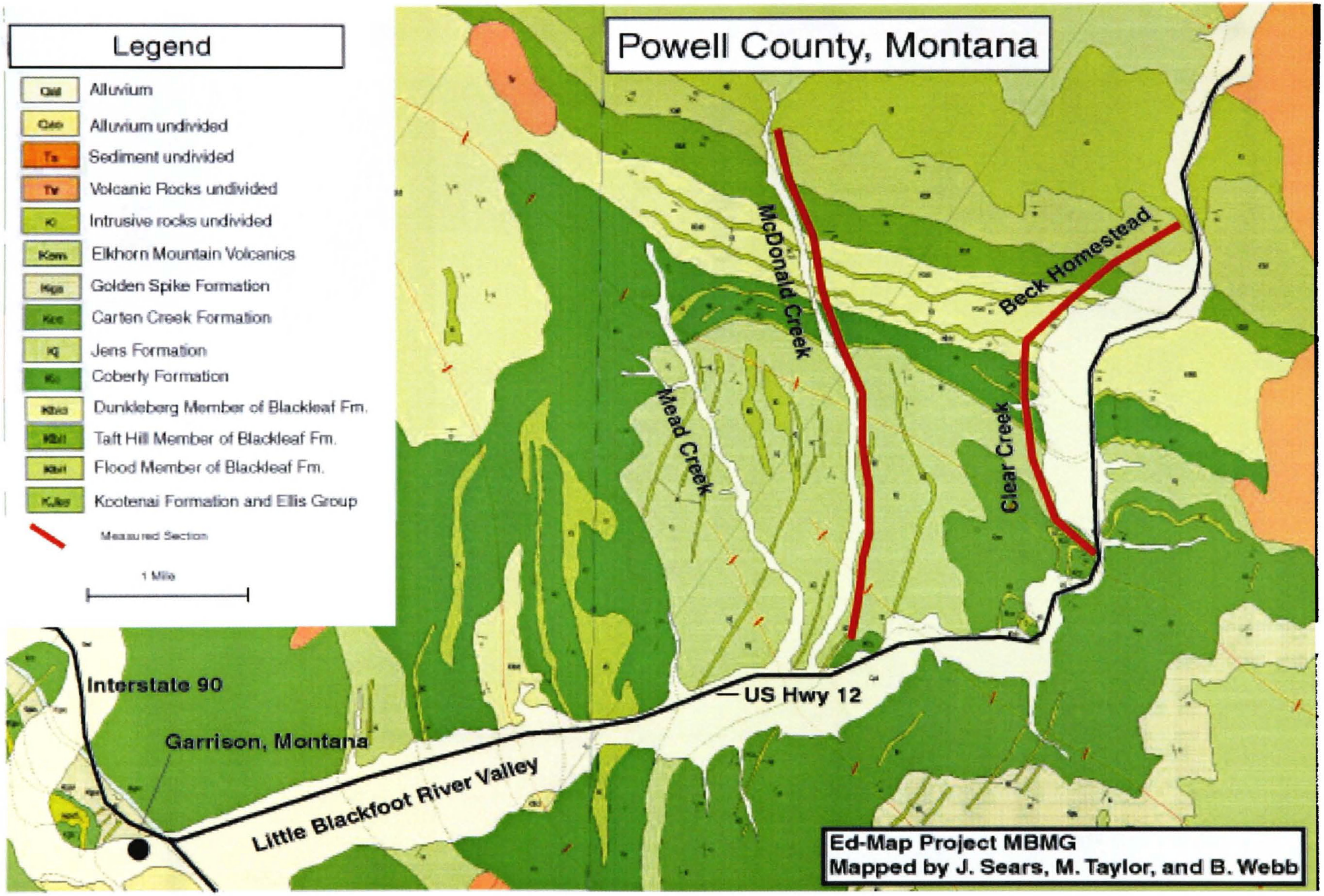


Figure 1. Regional geologic structure map and location of study area

Figure 2. Geologic map of the field area, location of measured transects


Legend
Alluvium
Alluvium undivided
Sediment undivided
Volcanic Rocks undivided
Intrusive rocks undivided
Elkhorn Mountain Volcanics
Golden Spike Formation
Carten Creek Formation
Jens Formation
Coberly Formation
Dunkleberg Member of Blackleaf Fm.
Taft Hill Member of Blackleaf Fm.
Flood Member of Blackleaf Fm.
Kootenai Formation and Ellis Group
Measured Section
1 Mile
Powell County, Montana
McDonald Creek
Beck Homestead
Mead Creek
Clear Creek
Interstate 90
US Hwy 12
Garrison, Montana
Little Blackfoot River Valley
Ed-Map Project MBMG
Mapped by J. Sears, M. Taylor, and B. Webb

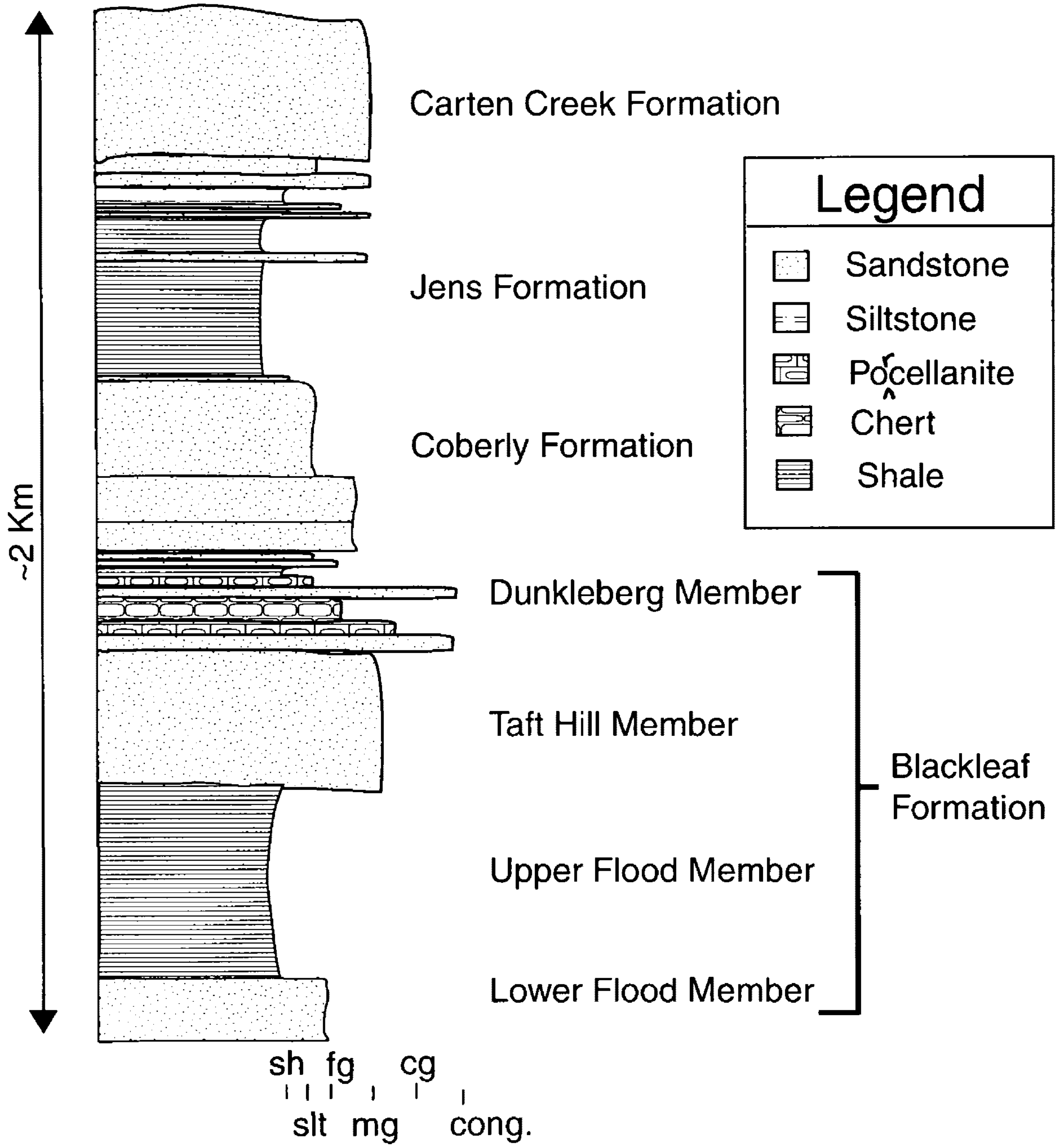


Figure 3. Idealized stratigraphic column of the Cretaceous Colorado Group within the study area

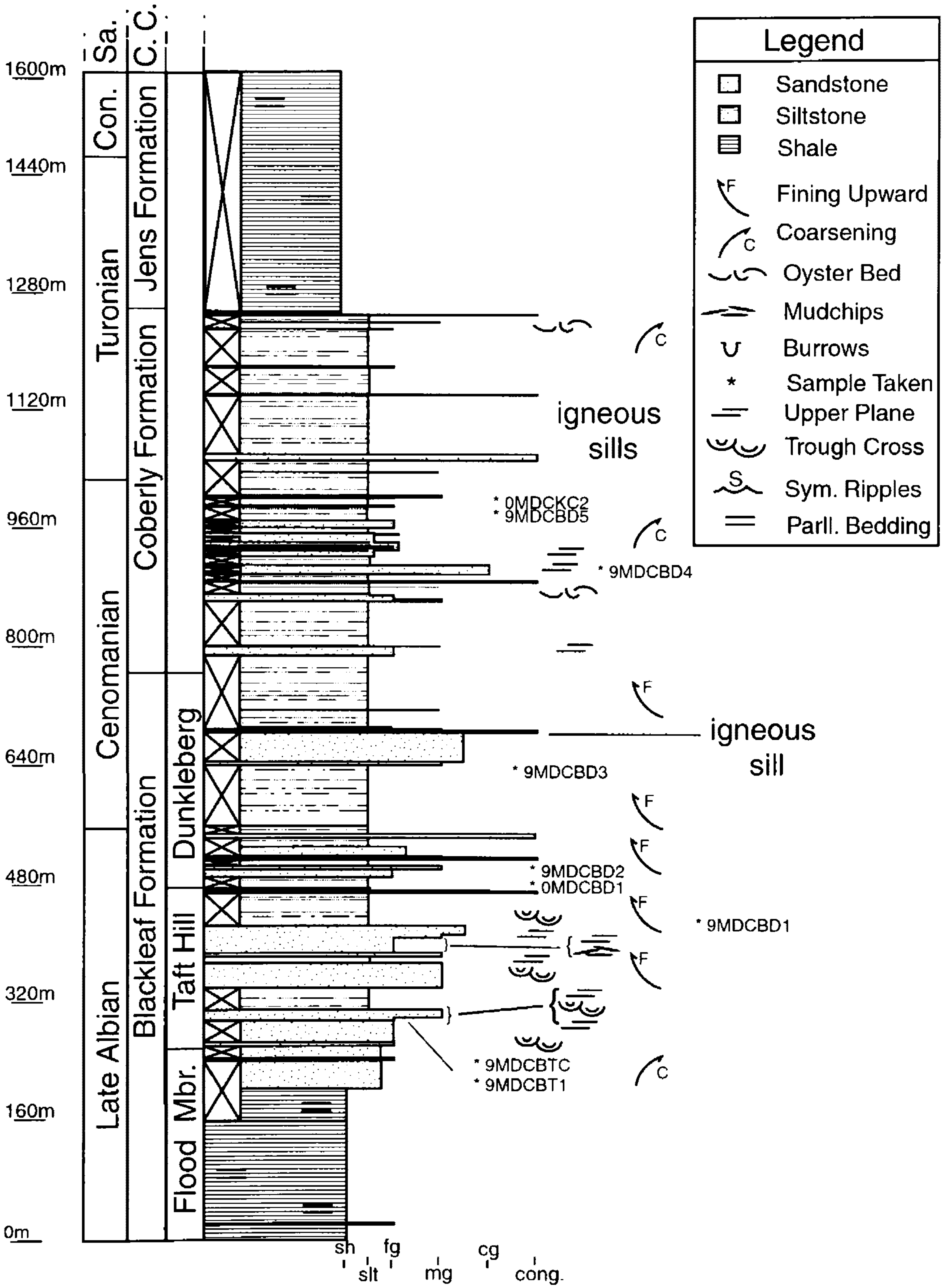


Figure 4. McDonald Creek measured transect

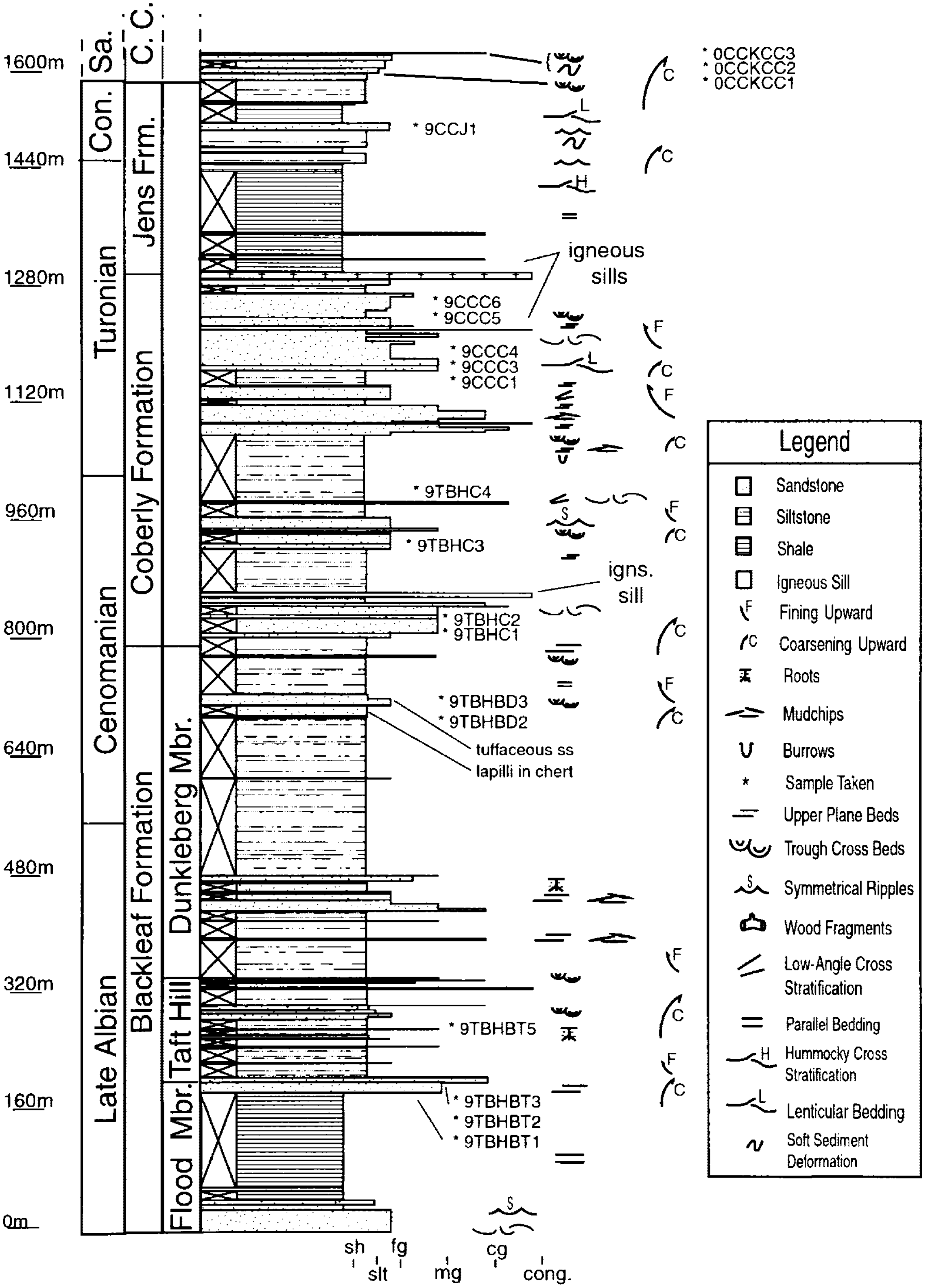


Figure 5. Beck Homestead/Clear Creek measured transect

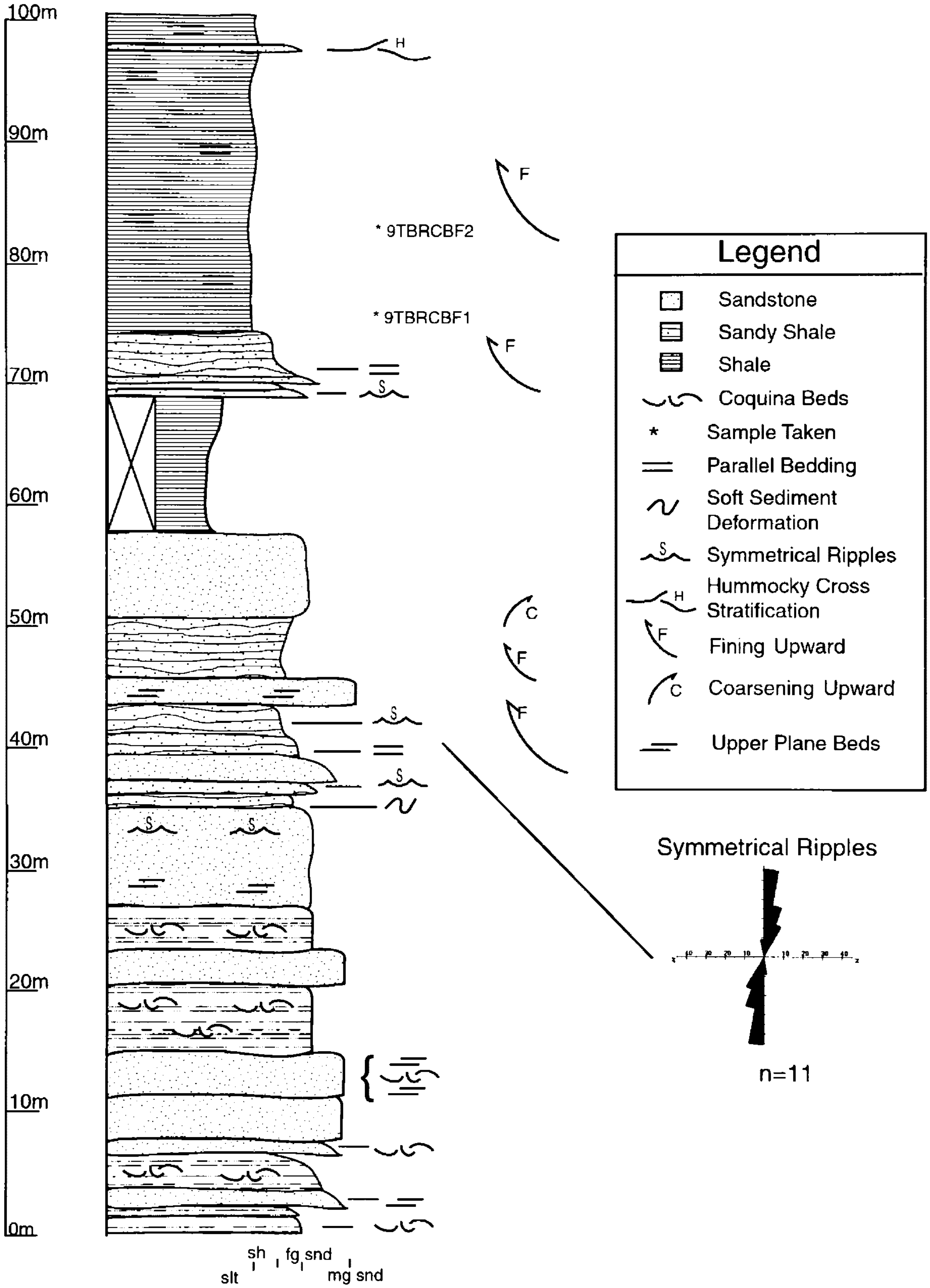
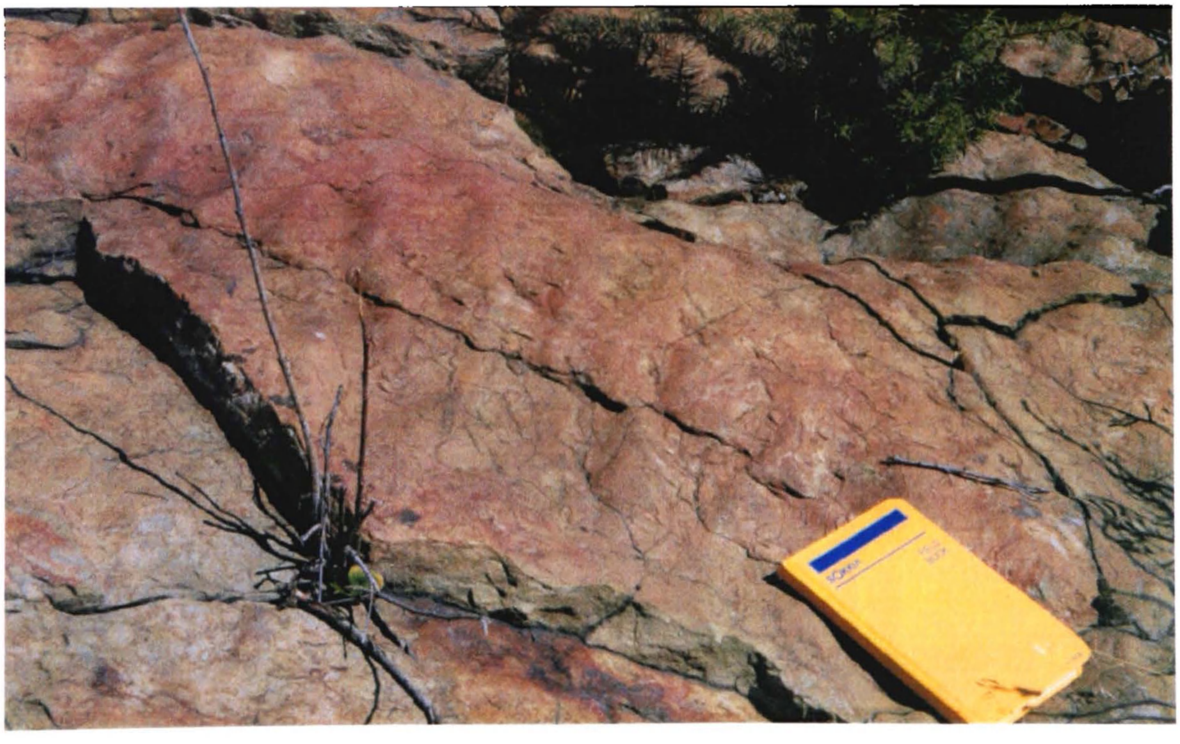


Figure 6. Flood Member of the Blackleaf Formation, detailed section; US Higway 12 outcrop

Figure 7: Photograph of coquina bed in the lower Flood Member, lens cap for scale; meter 25 of the detailed lower Flood Member section (Beck Homestead/Clear Creek Transect, Figure 6)

Figure 8: Photograph of symmetric ripples in the lower Flood Member showing bioturbated crests, fieldbook for scale; meter 43 of the detailed lower Flood Member section (Beck Homestead/Clear Creek Transect, Figure 6)



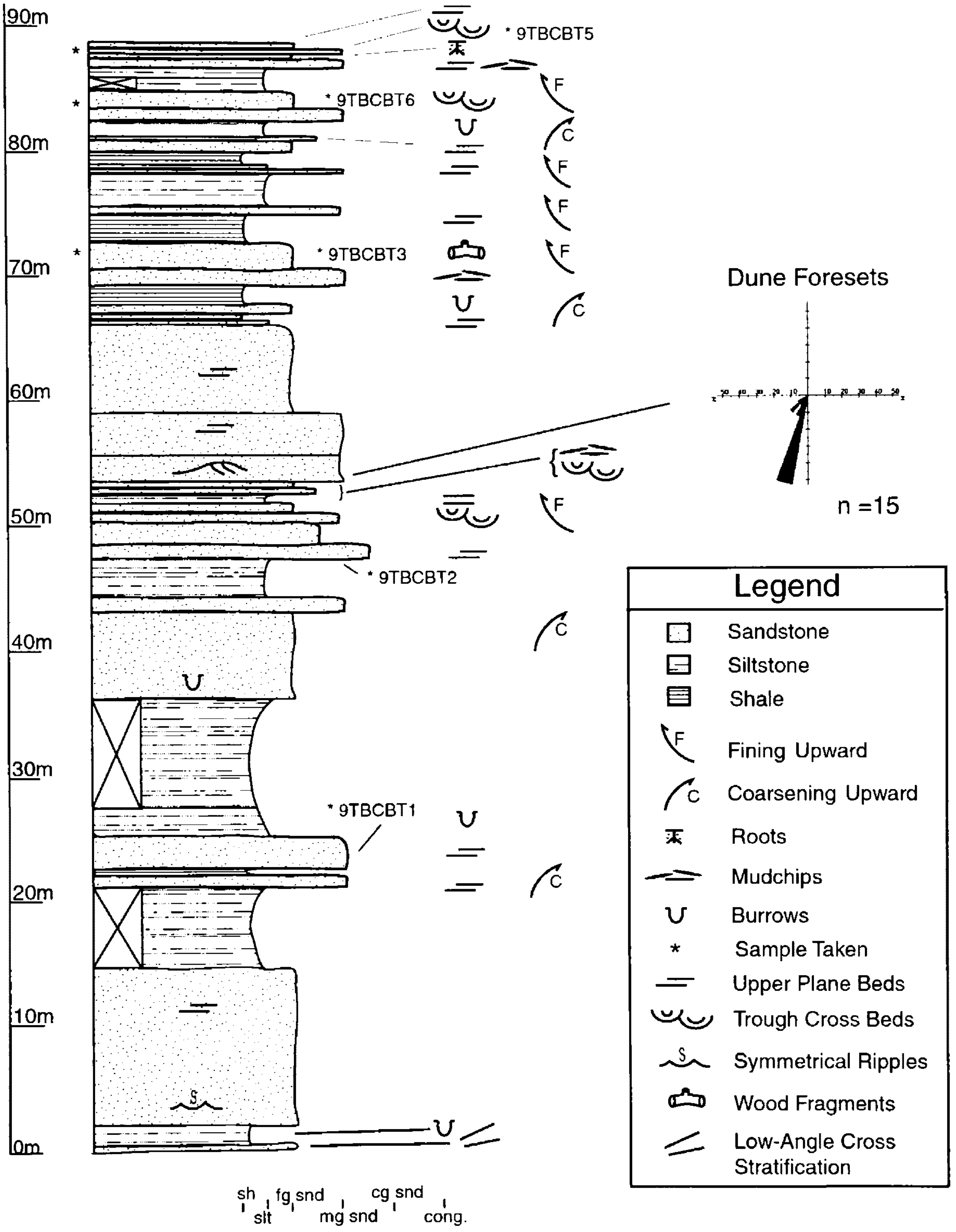


Figure 9. Taft Hill Member of the Blackleaf Formation, detailed section; Beck Canal outcrop

Figure 10: Photograph of upper plane bedded sandstones in the Taft Hill, hammer for scale; meter 301 of the McDonald Creek Transect (Appendix 1)

Figure 11: Photograph of trough crossbeds in the Taft Hill, fieldbook and compass for scale; meter 306 of the McDonald Creek Transect (Appendix 1)

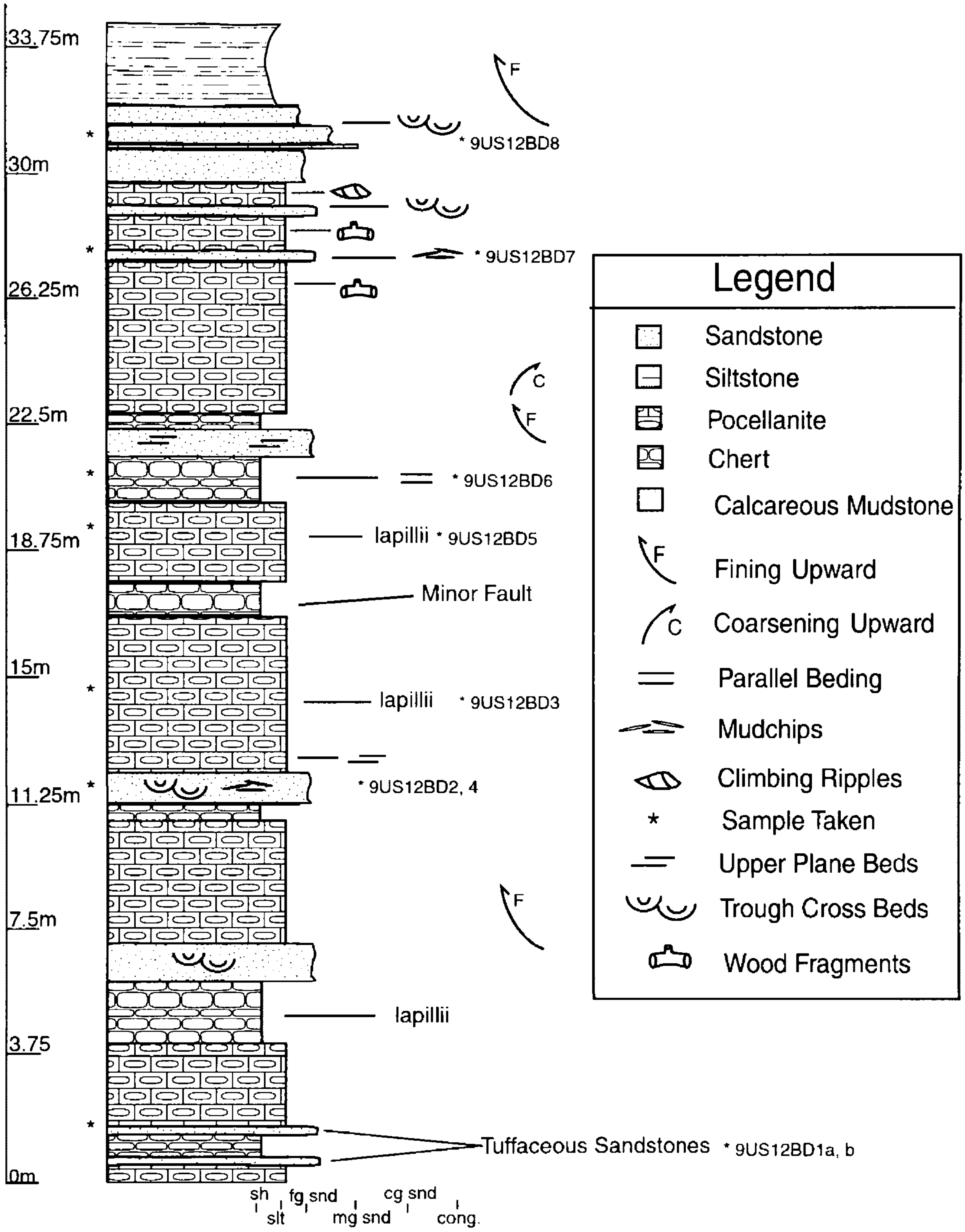


Figure 12. Dunkleberg Member of the Blackleaf Formation, detailed section; US Highway 12 outcrop

Figure 13: Photograph of conglomerate bed in the Dunkleberg, lens cap for scale; meter 467 of McDonald Creek Transect (Appendix I)

Figure 14: Photograph of bedded porcellanite and chert in the Dunkleberg, lens cap for scale; meter 22 of detailed Dunkleberg Member section (Beck Homestead/Clear Creek Transect, Figure 12)


Nikon


Nikon

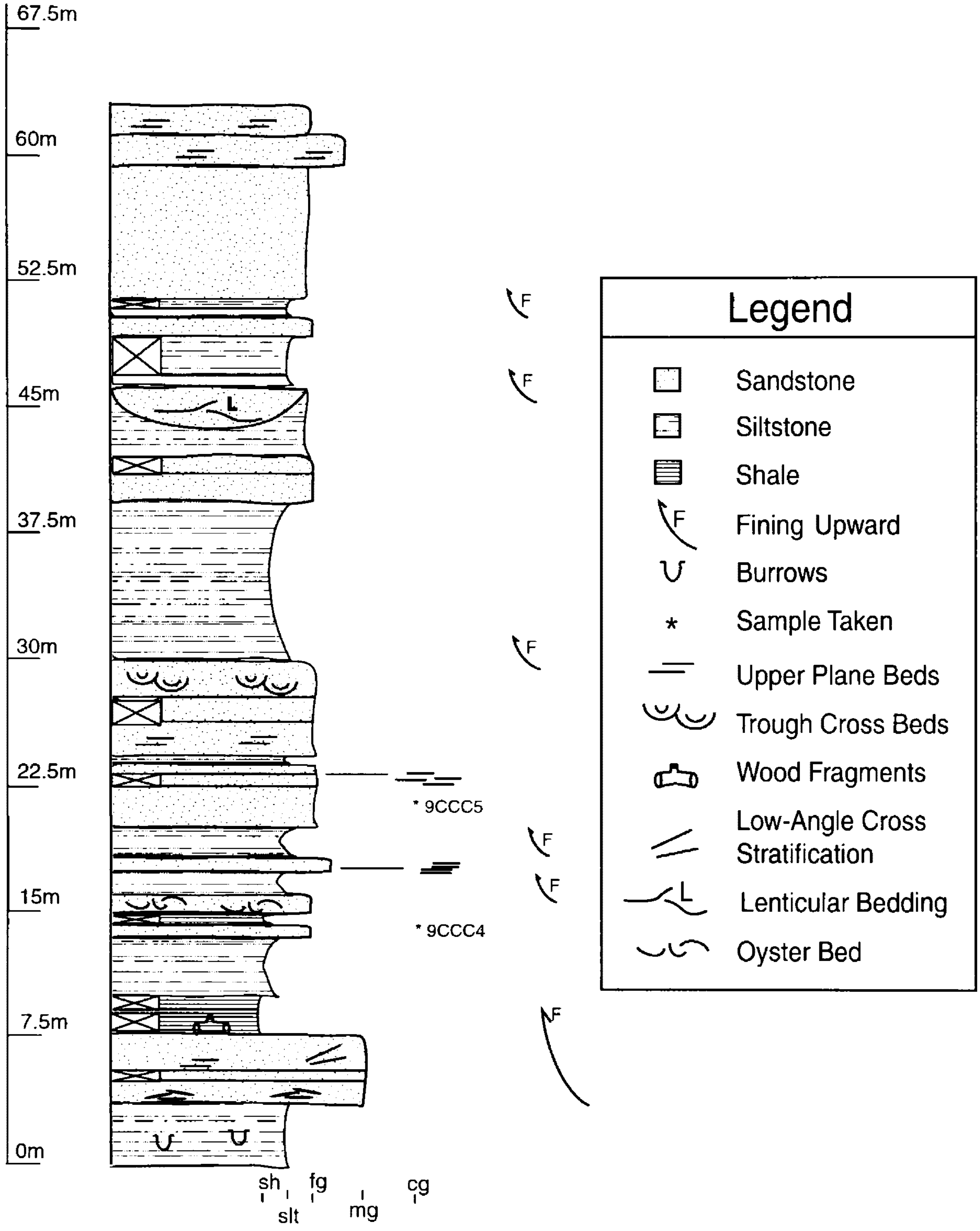


Figure 15. Coberly Formation, detailed section; Clear Creek outcrop

Figure 16: Photograph of sandstone with mudchips in the Coberly, lens cap for scale; meter 1080 of Beck Homestead/Clear Creek Transect (Appendix II)

Figure 17: Photograph of crossbedded sandstones in the Coberly, hand lense for scale; meter 1200 of Beck Homestead/Clear Creek Transect (Figure 25)

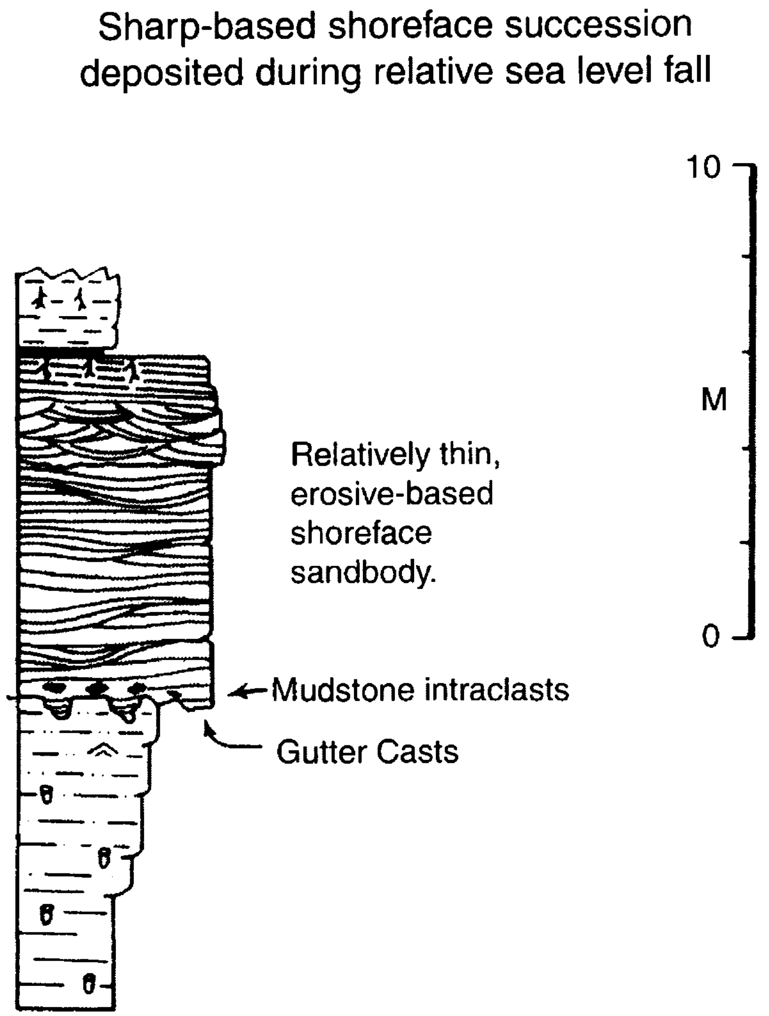


Figure 18. Schematic diagram of a forced regressive sequence. This stratigraphic succession closely mimcs that succession found in the medial Coberly Formation (1070-1085M interval Appendix II). Modified from Walker and Plint (1992).

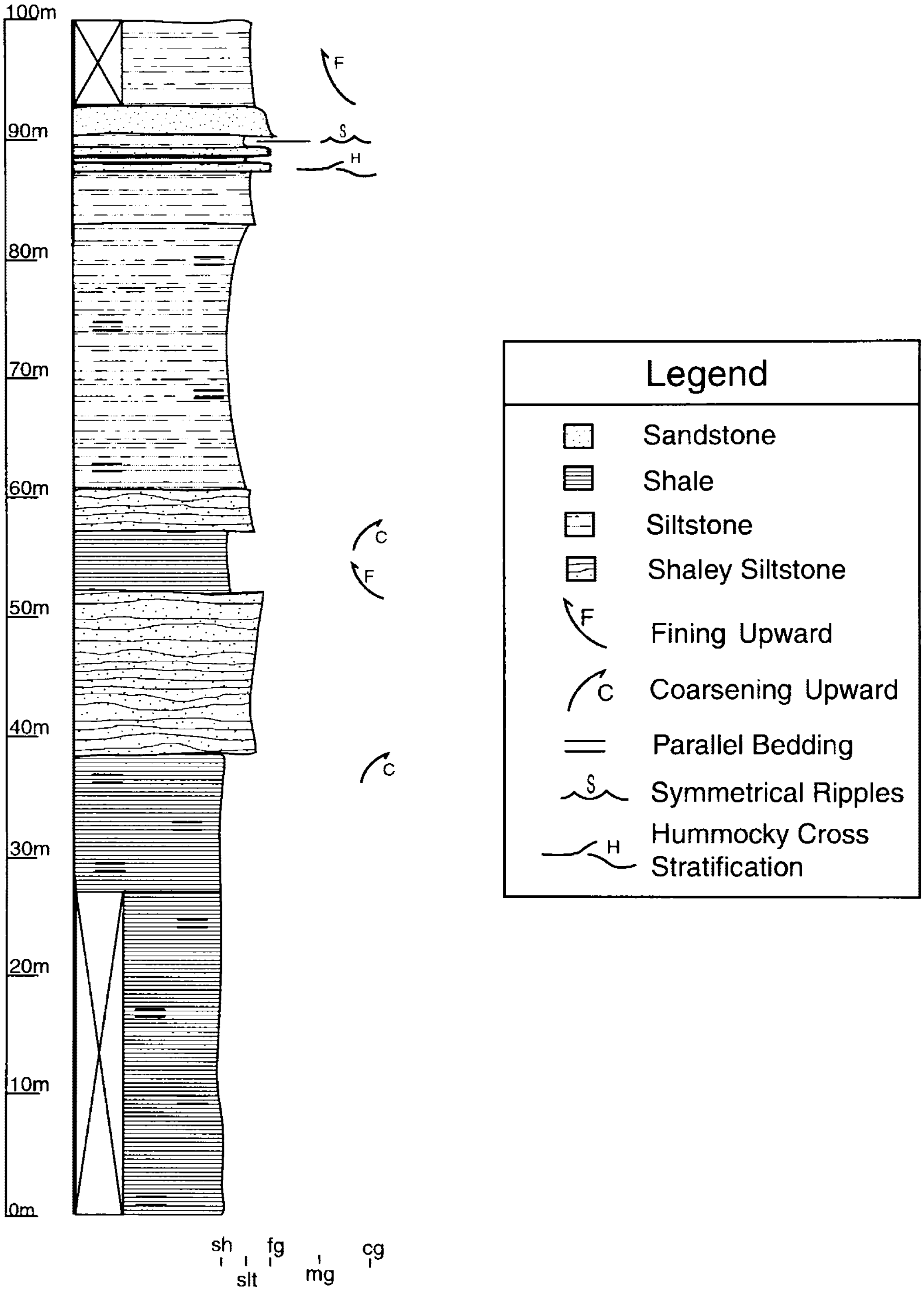


Figure 19. Jens Formation, detailed section; Clear Creek outcrop

Figure 20: Photograph of hummocky cross stratification in the Jens, orange tape wheel for scale; Meade Creek outcrop (SEC 9 T.9N R.9W) projected into the Beck Homestead/Clear Creek Transect ~ meter 1520

Figure 21: Photograph of trough crossbeds(outlined) in the Jens, lens cap for scale; Meade Creek outcrop (SEC 9 T.9N R.9W) projected into the Beck Homestead/Clear Creek Transect ~ meter 1570

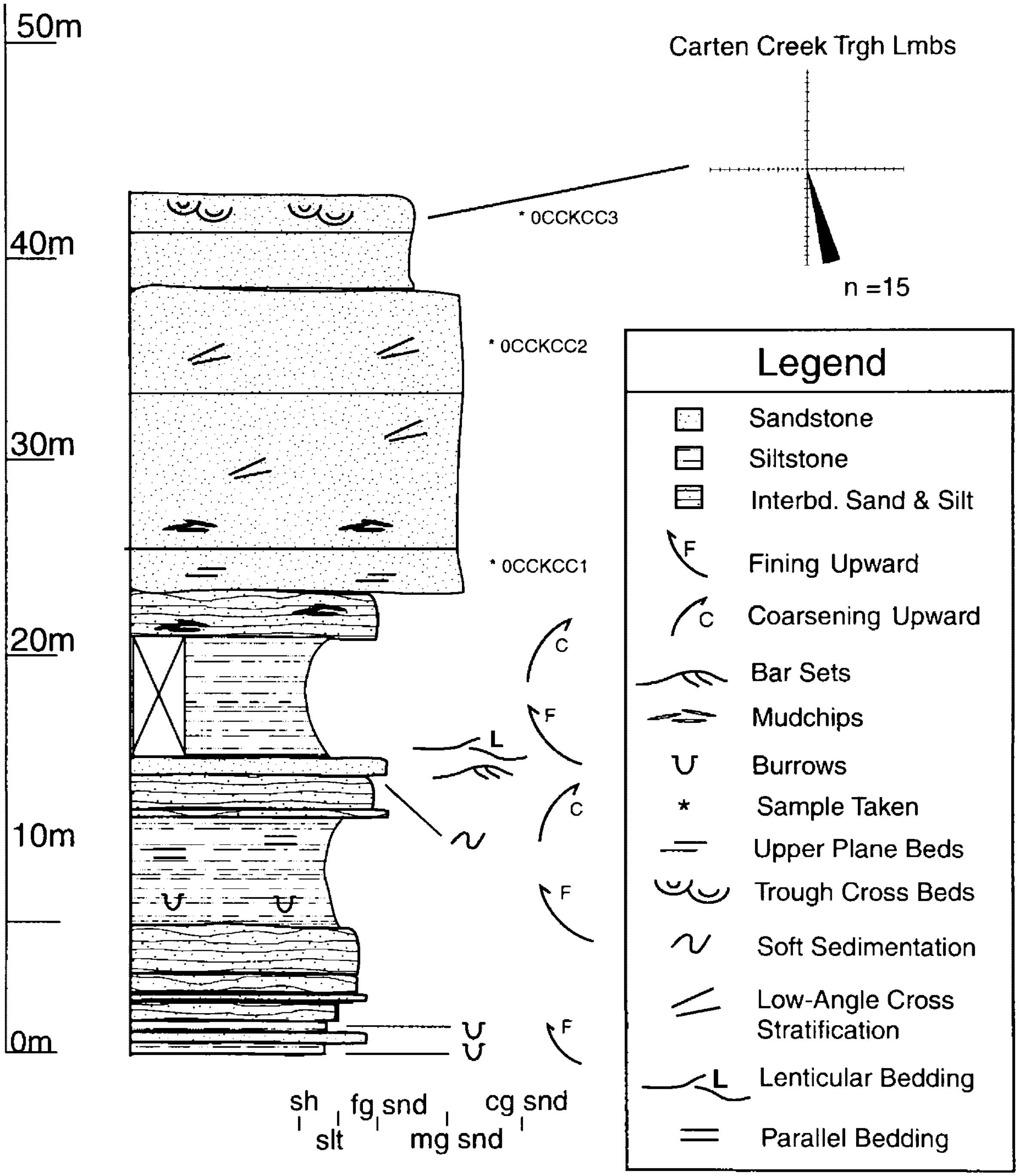


Figure 22. Carten Creek Formation detailed section; Clear Creek outcrop

Figure 23: Photograph of overbank deposits (center), point bar sets (outlined upper left) in the Carten Creek; field book for scale

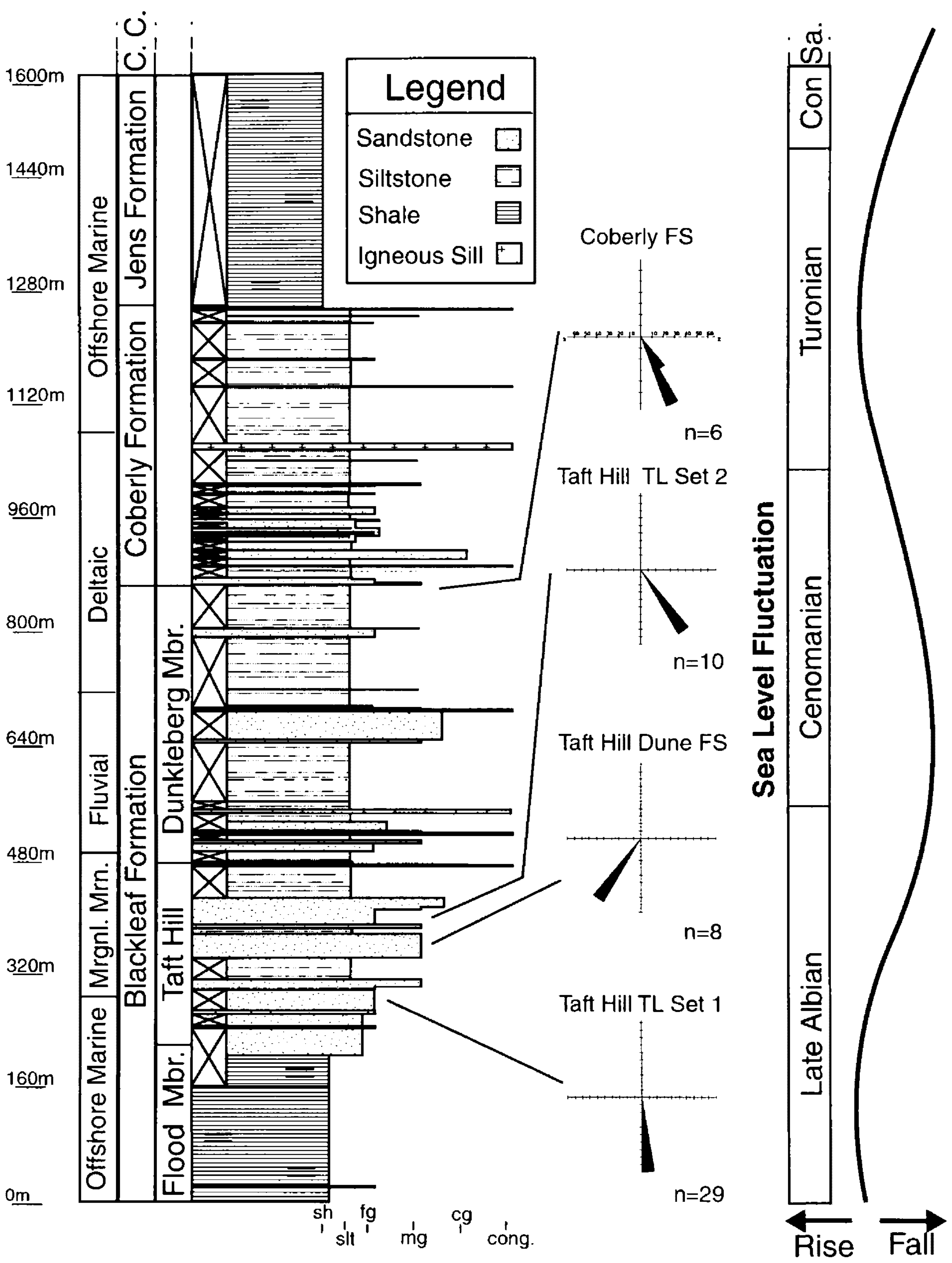


Figure 24. McDonald Creek measured section with interpreted paleocurrents of long shore drift; sea level curve based on Haq (1988) curve matched by age

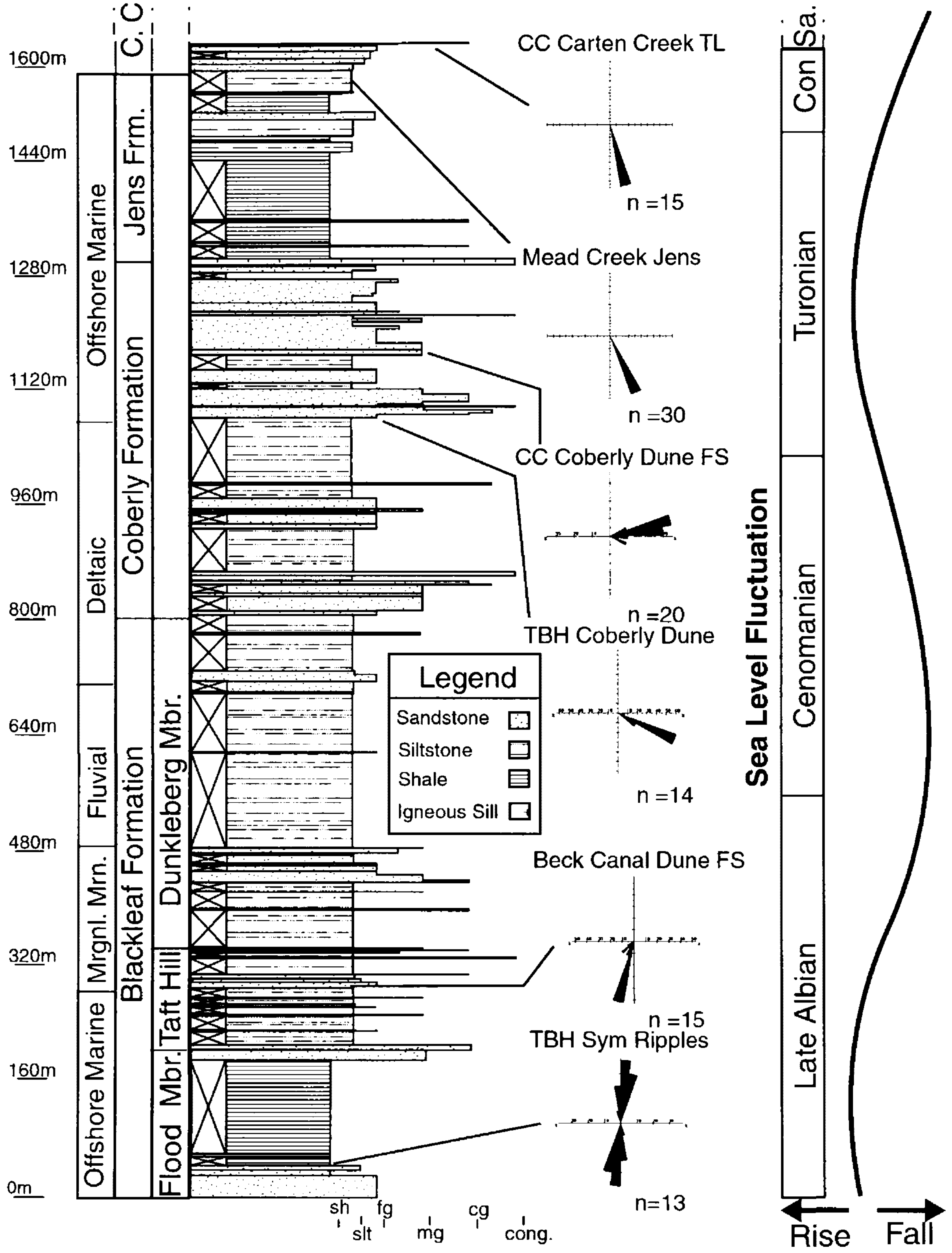


Figure 25. Beck Homesteadmeasured section with interpreted paleocurrents of long shore drift; sea level curve based on Haq (1988) curve matched by age

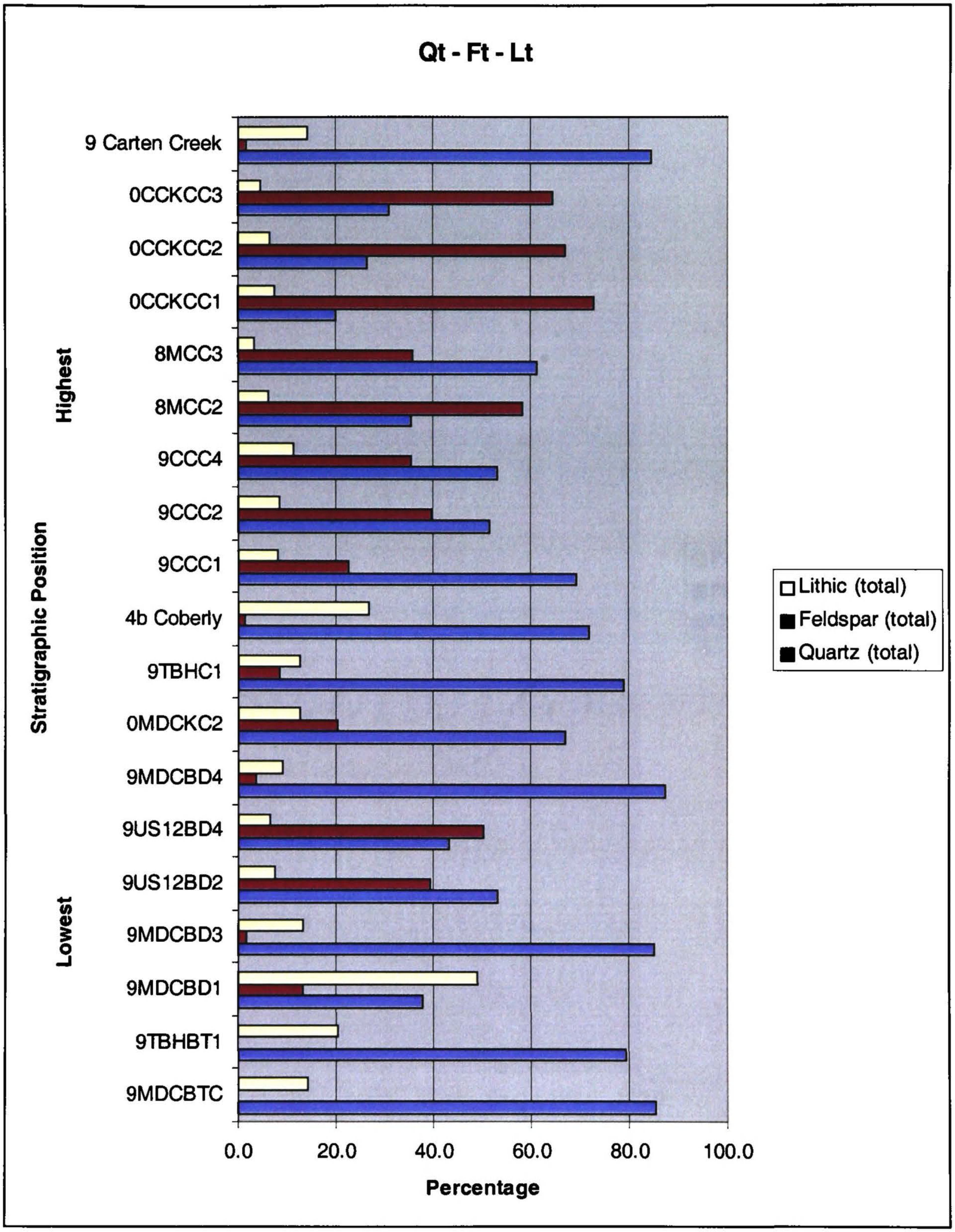


Figure 26. Total quartz, total feldspar, and total lithic composition percentages of sandstones from the Colorado Group strata of the eastern Clark Fork Sag

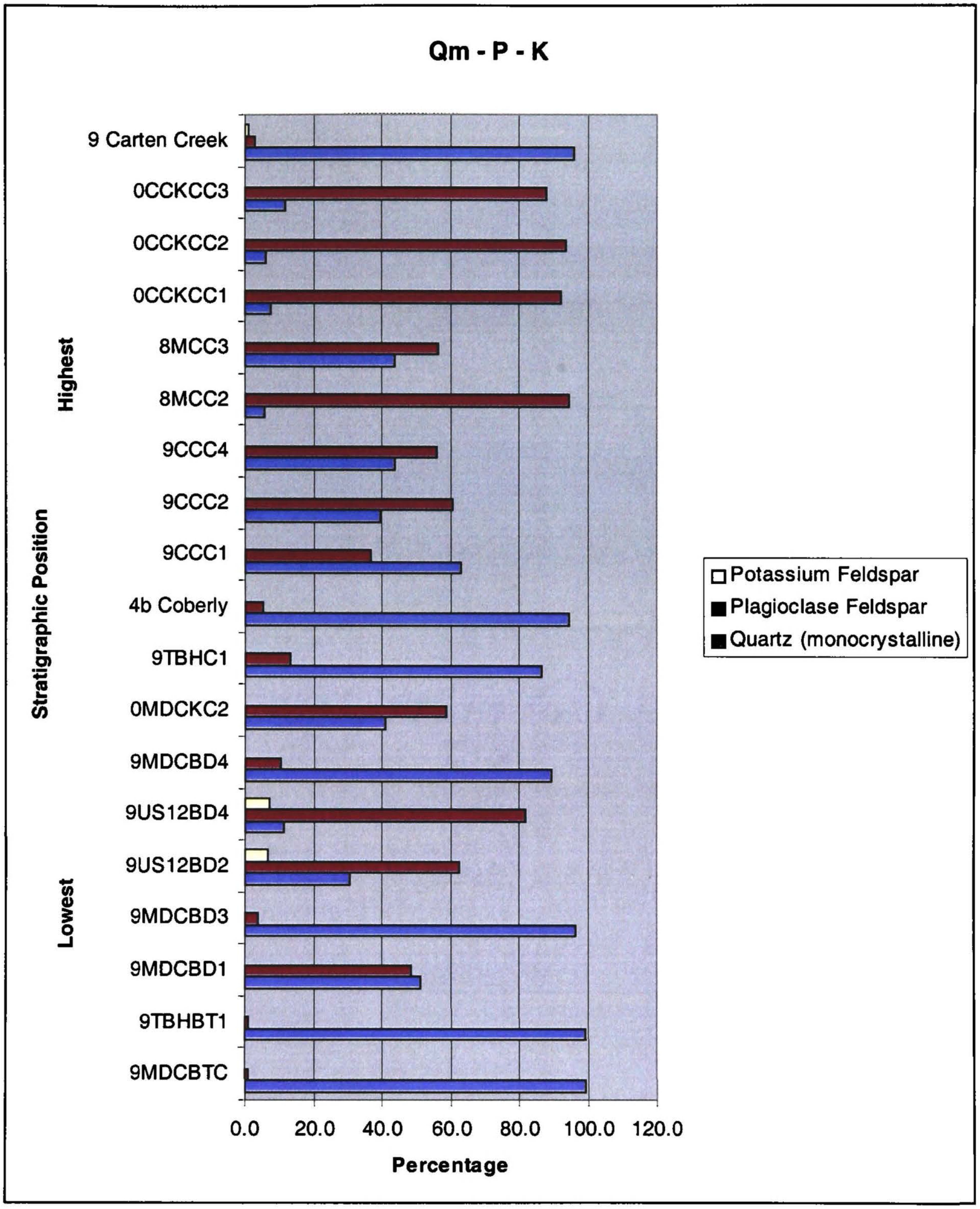


Figure 27. Monocrystalline quartz, plagioclase feldspar, and potassium feldspar composition percentages of sandstones from the Colorado Group strata of the eastern Clark Fork Sag

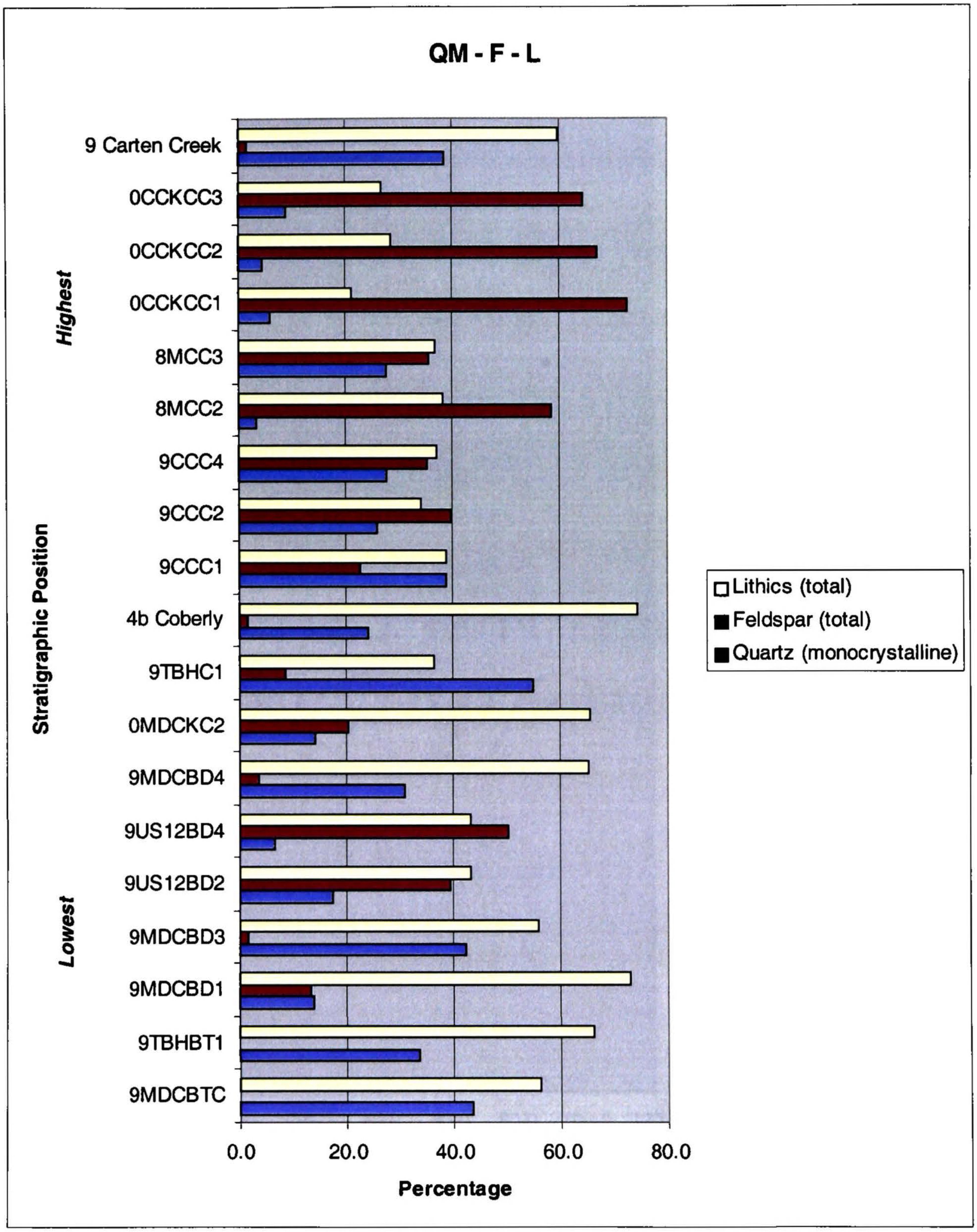


Figure 28. Monocrystalline quartz, total feldspar, and total lithic composition percentages of sandstones from the Colorado Group strata of the eastern Clark Fork Sag

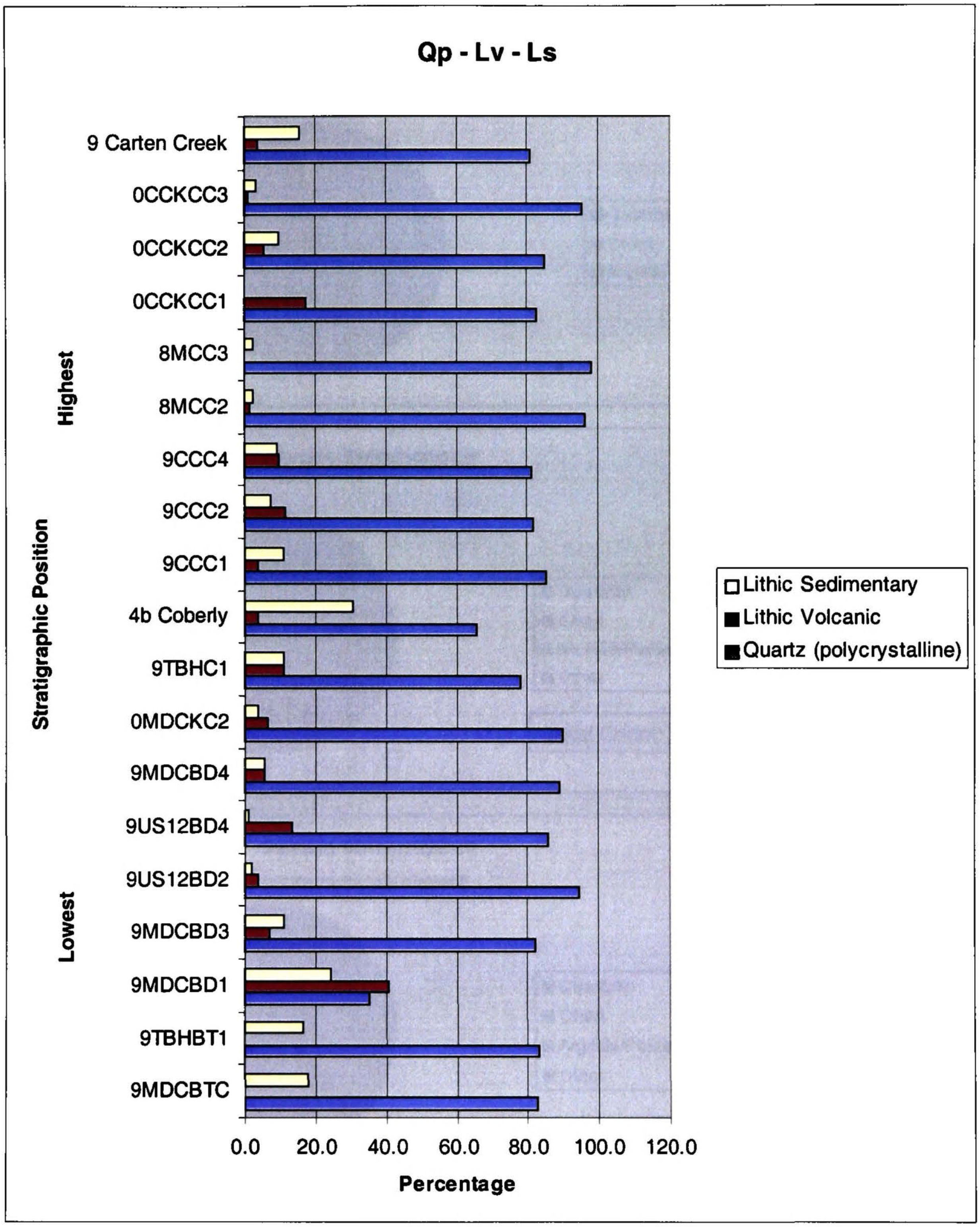


Figure 29. Polycrystalline quartz, lithic volcanic, and lithic sedimentary composition percentages of sandstones from the Colorado Group strata of the eastern Clark Fork Sag

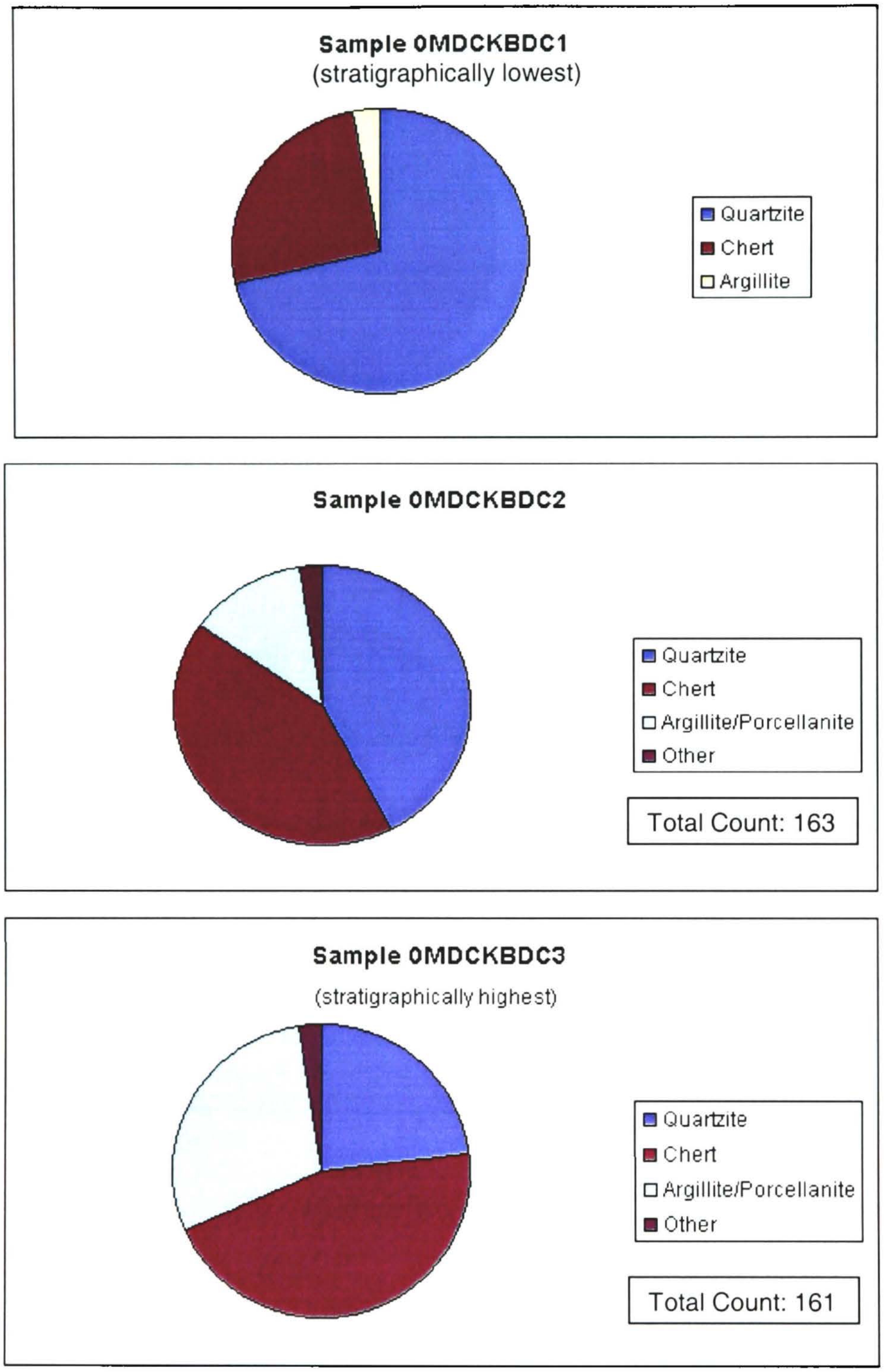


Figure 30. McDonald Creek conglomeratic clast count results. Conglomerate samples collected from Dunkleberg Member of the Blackleaf Formation.

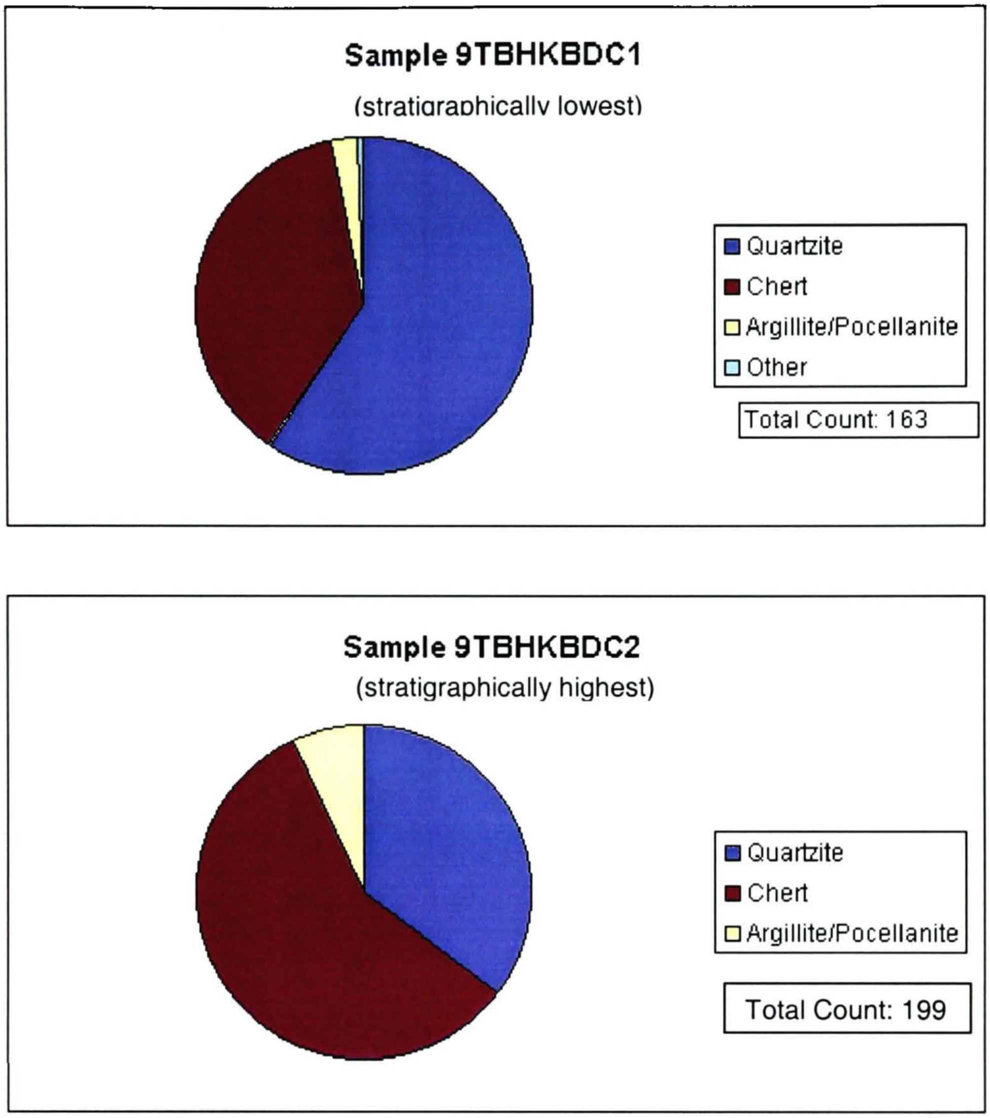


Figure 31. Beck Homestead/ Clear Creek conlomeratic clast count results. Conglomerate samples collected from the Dunkleberg member of the Blackleaf Formation.

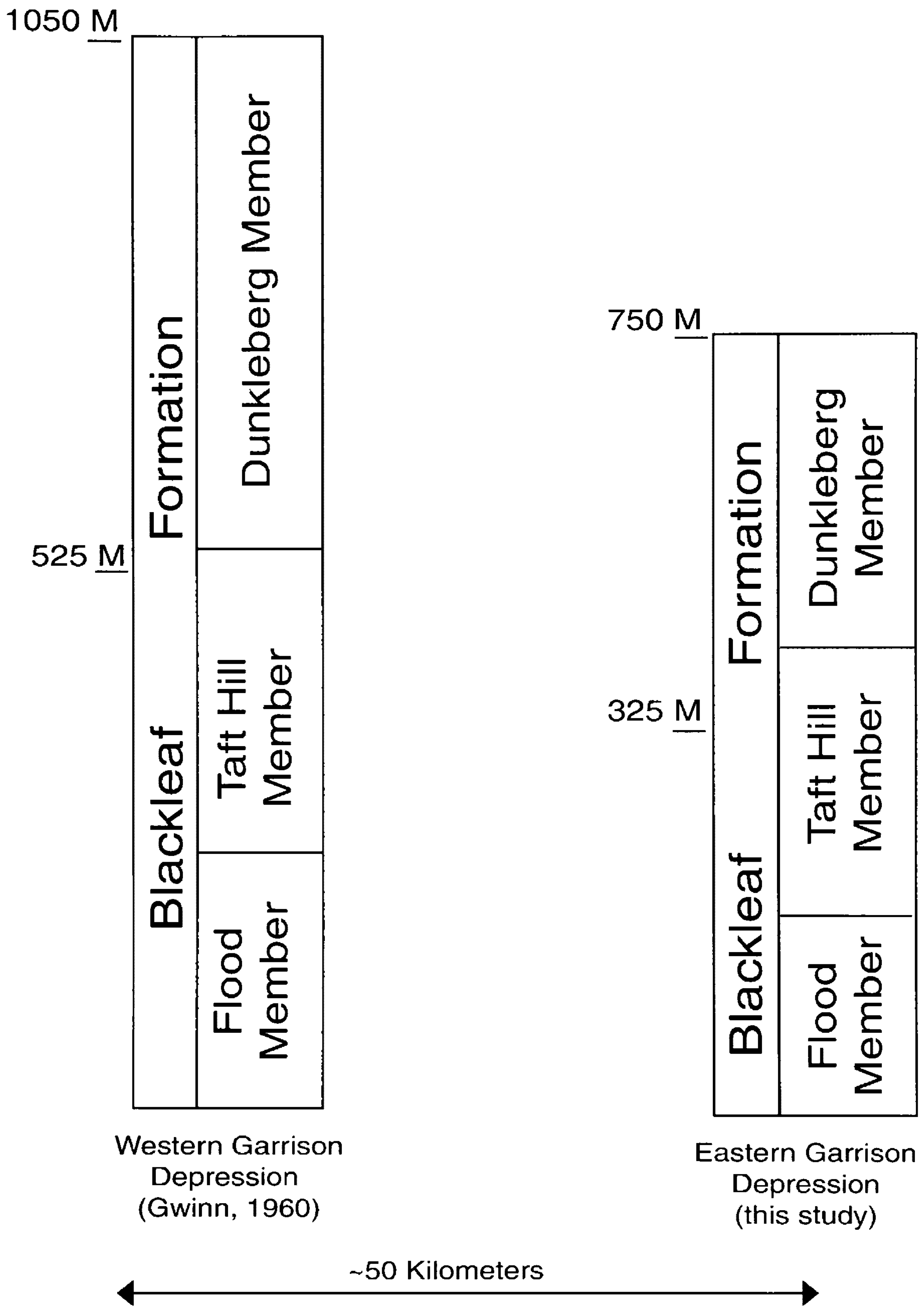


Figure 32. Eastern thinning of the Blackleaf Foramation within the Garrison Depression

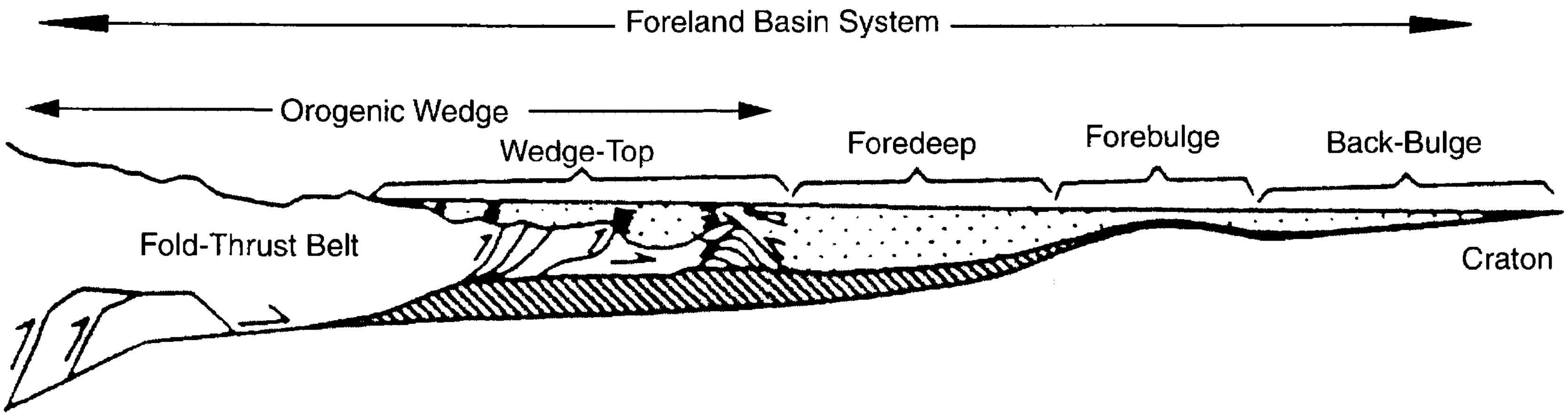


Figure 33. Schematic cross-section of a foreland basin system. Foreland strata is represented by coarse stipple, and the parallel ruled are indicates pre-existing miogeoclinal strata. Modified from DeCelles and Giles (1996).

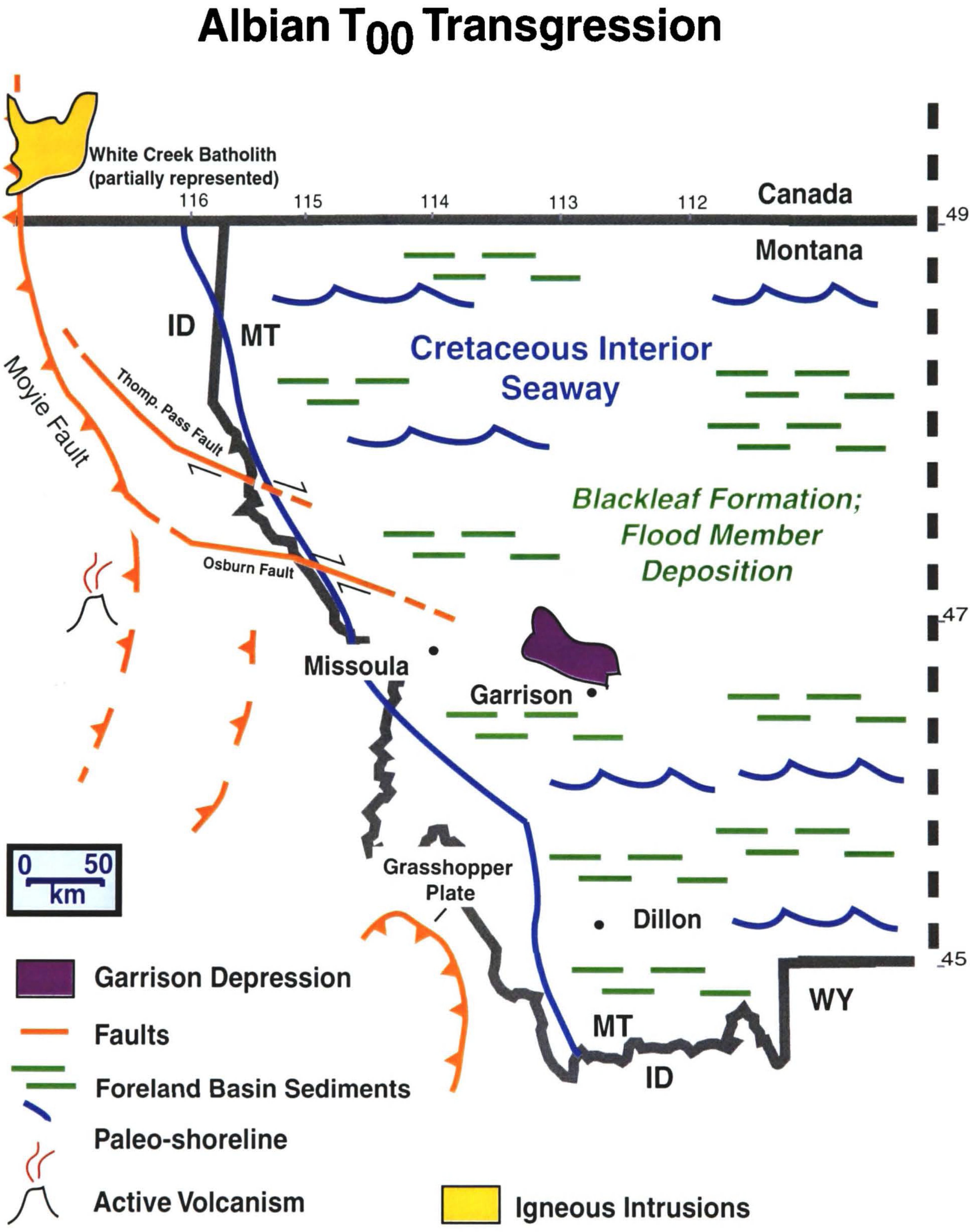

Albian T_{00} Transgression

Figure 34. Early Cretaceous thrusting along the Moyie Fault; detrital biotite points to active volcanism in the west; deposition of Flood Member of the Blackleaf Formation during the T_{00} transgression from the north

Albian-Cenomanian R_0 Regression

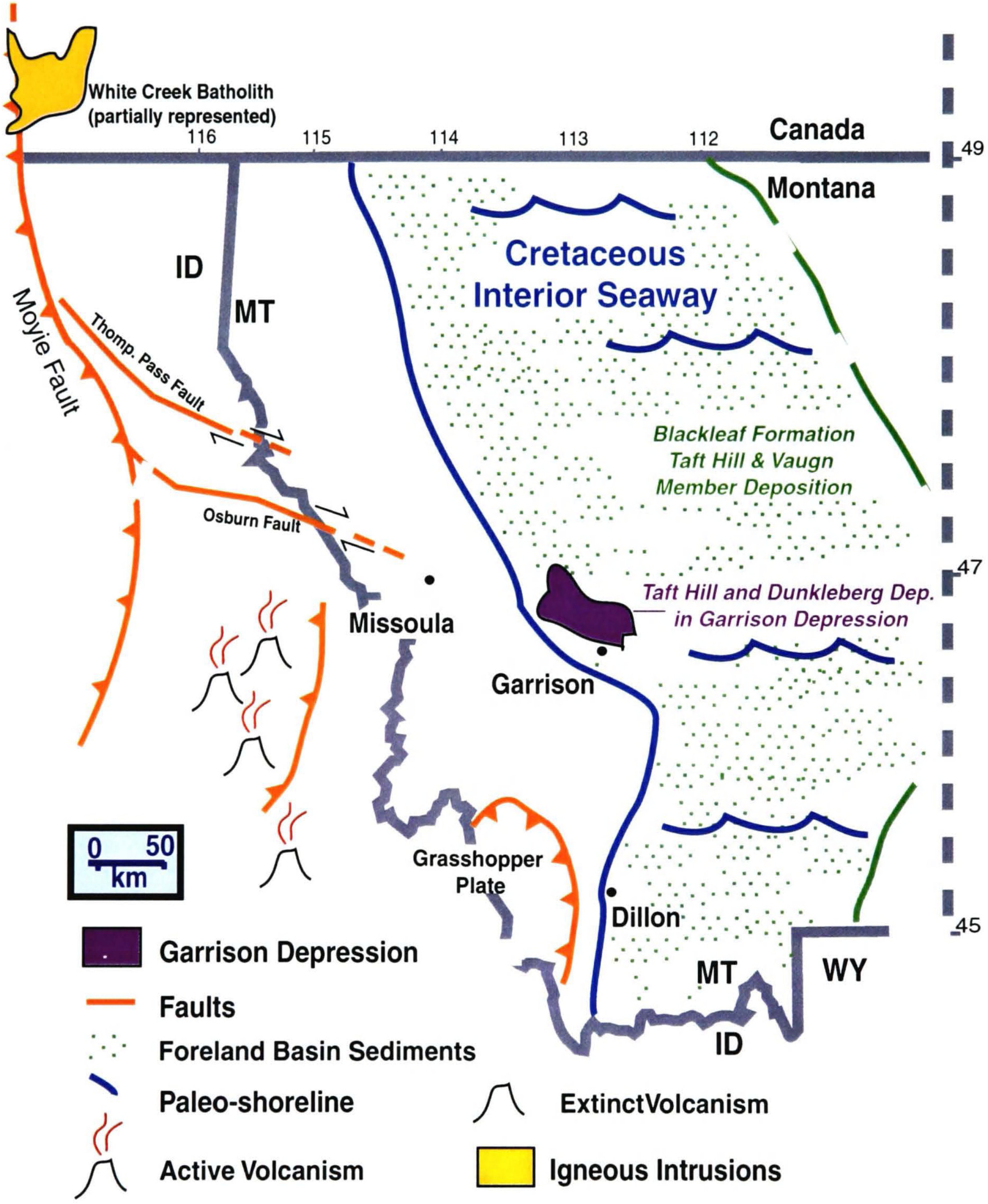


Figure 35. Increased thrusting and volcanism to the west; early Cretaceous thrusting to the south associated with the Grasshopper Plate; deposition of Taft Hill and lower Dunkleberg Members of the Blackleaf Formation during the R_0 regression

Cenomanian-Turonian Episodic T_1 Transgression

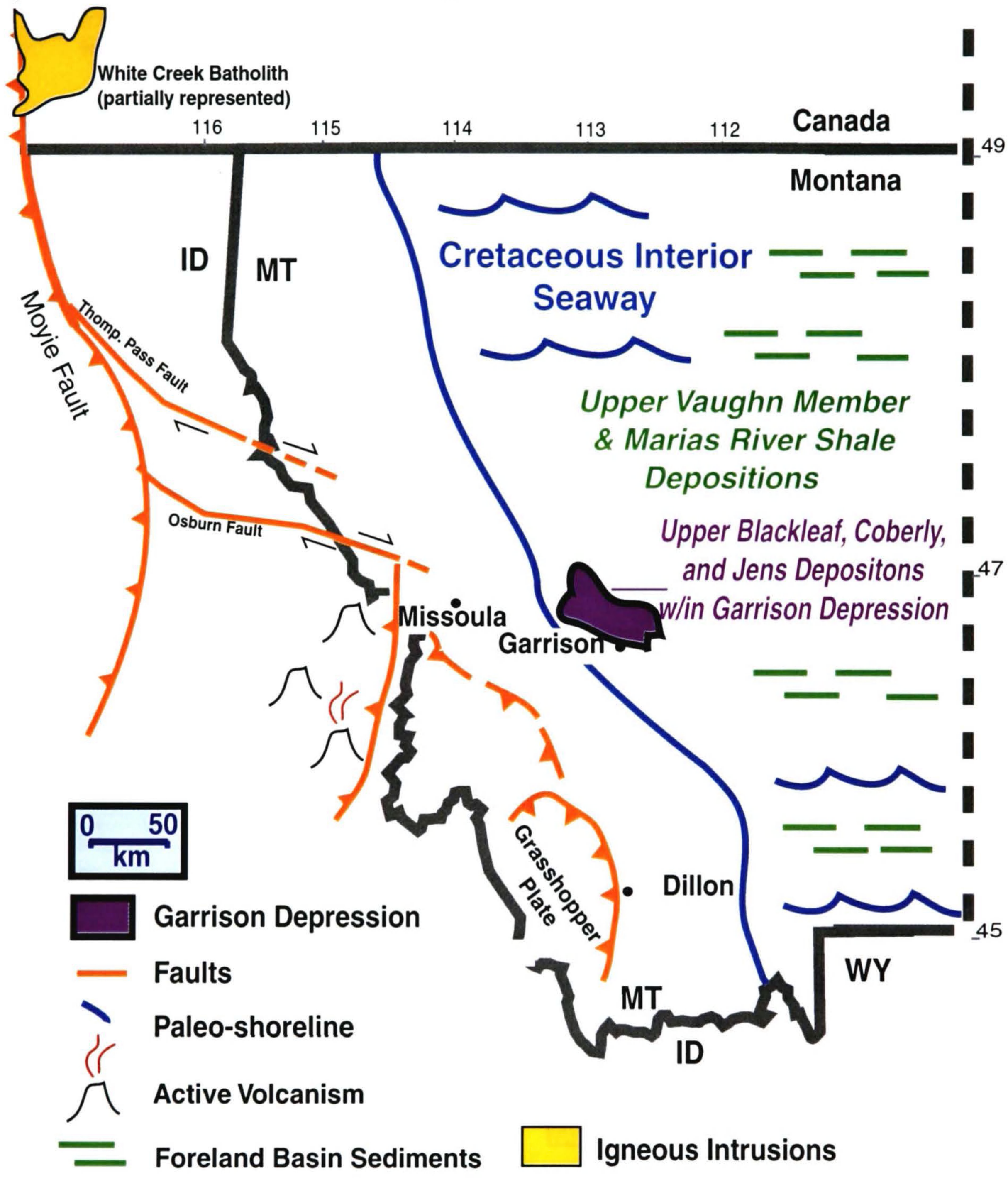


Figure 36. Upper Blackleaf, Coberly and Jens Formations are deposited in the Garrison Depression within a rapidly subsiding wedge top complex; Correlative upper Marias River Shale and Virgelle Sandstone depositions throughout the rest of the Montana Foreland

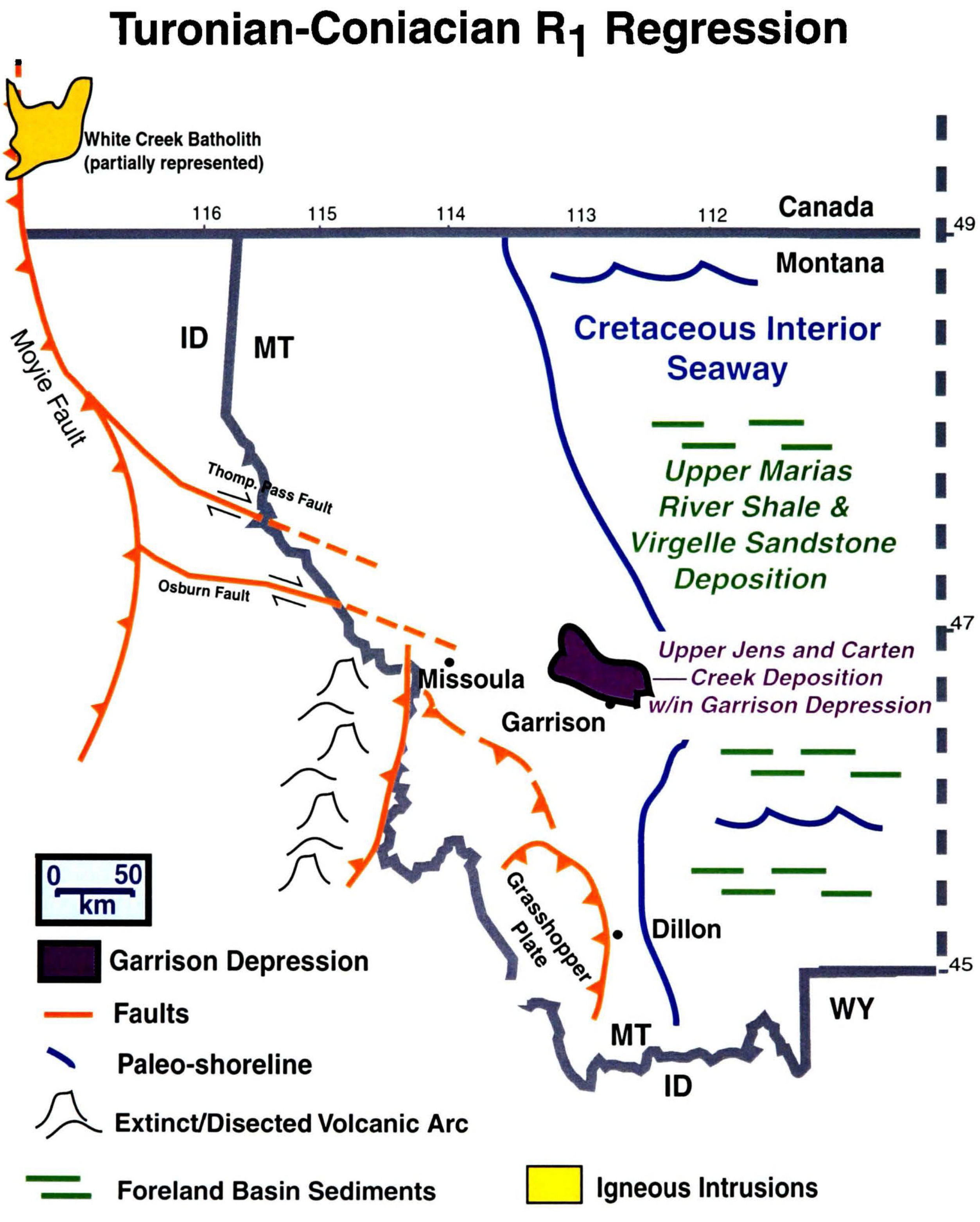

Turonian-Coniacian R_1 Regression

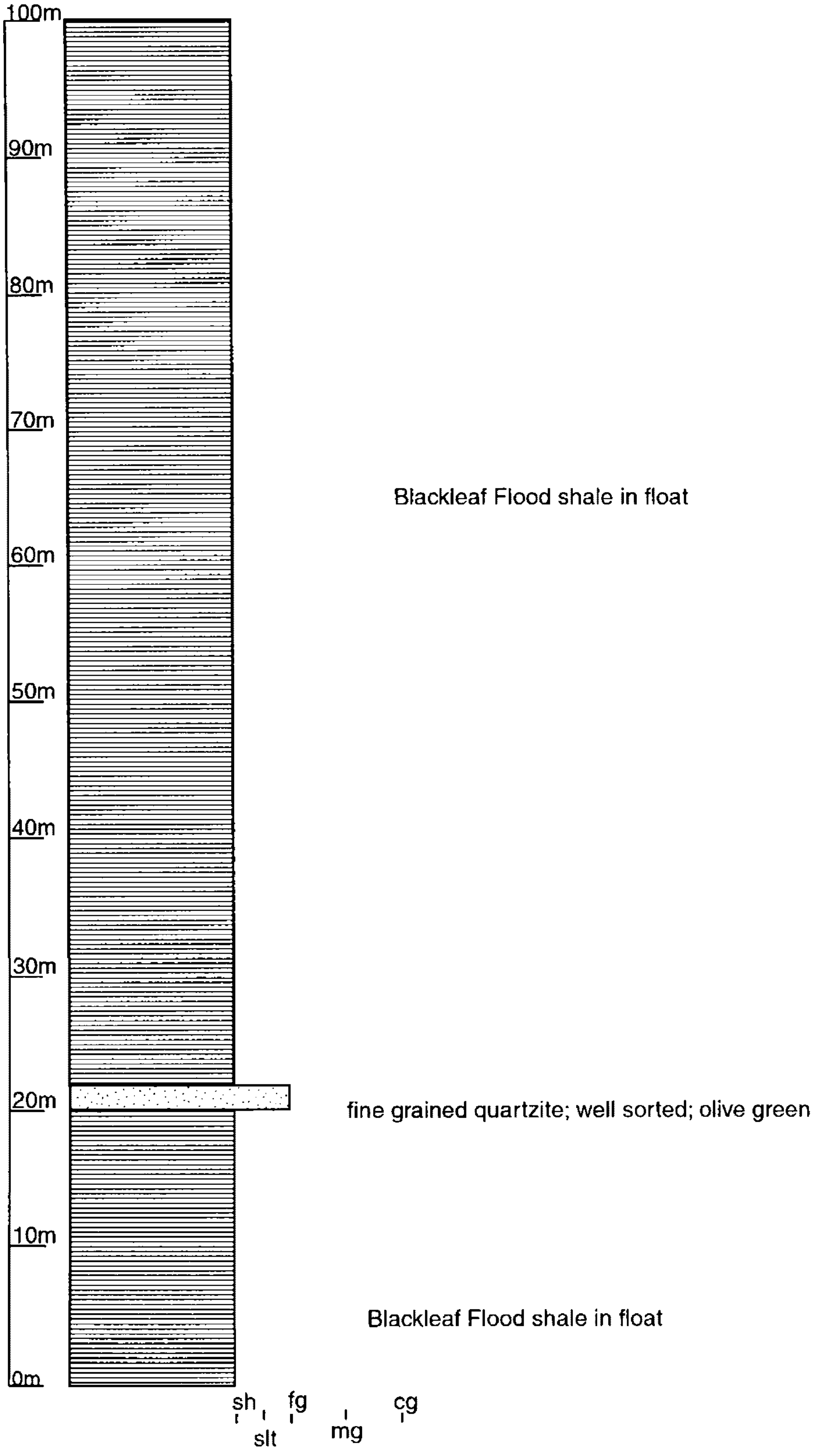
Figure 37. Deposition of the Upper Jens and Carten Creek resulted in the filling of the Garrison Depression; both the Carten Creek Forrmation and the Virgelle Sandstone are correlative and were deposited simultaneously; within the Garrison Depression the Carten Creek was deposited in a delatic/meandering fluvial environment

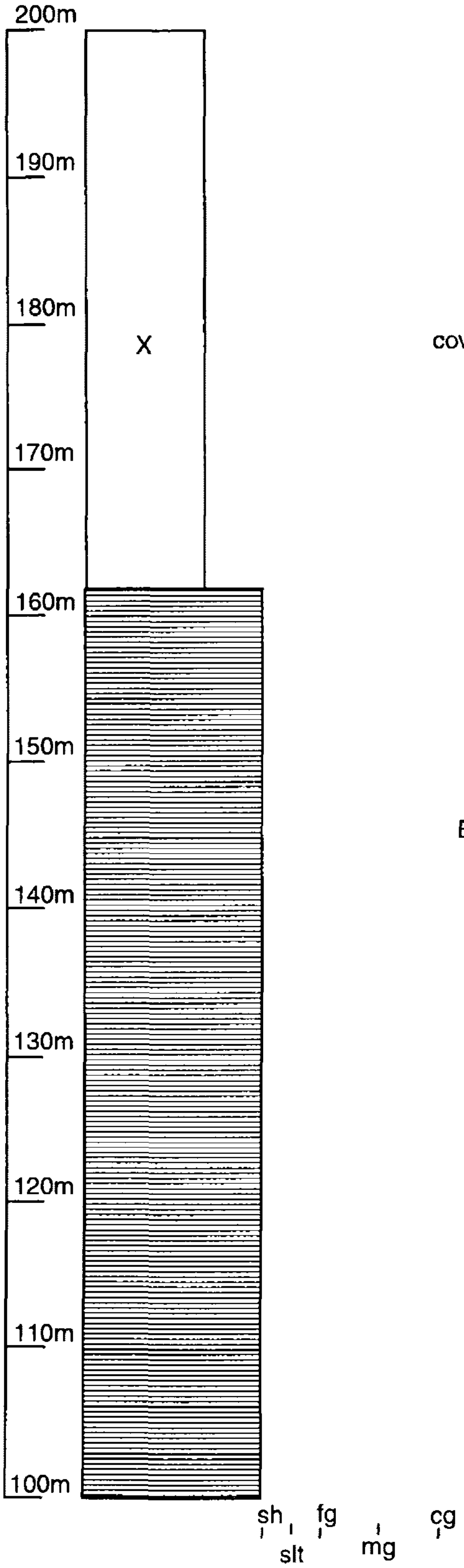
Appendix I

McDonald Creek Measured Transect

Key for Appendices I and II

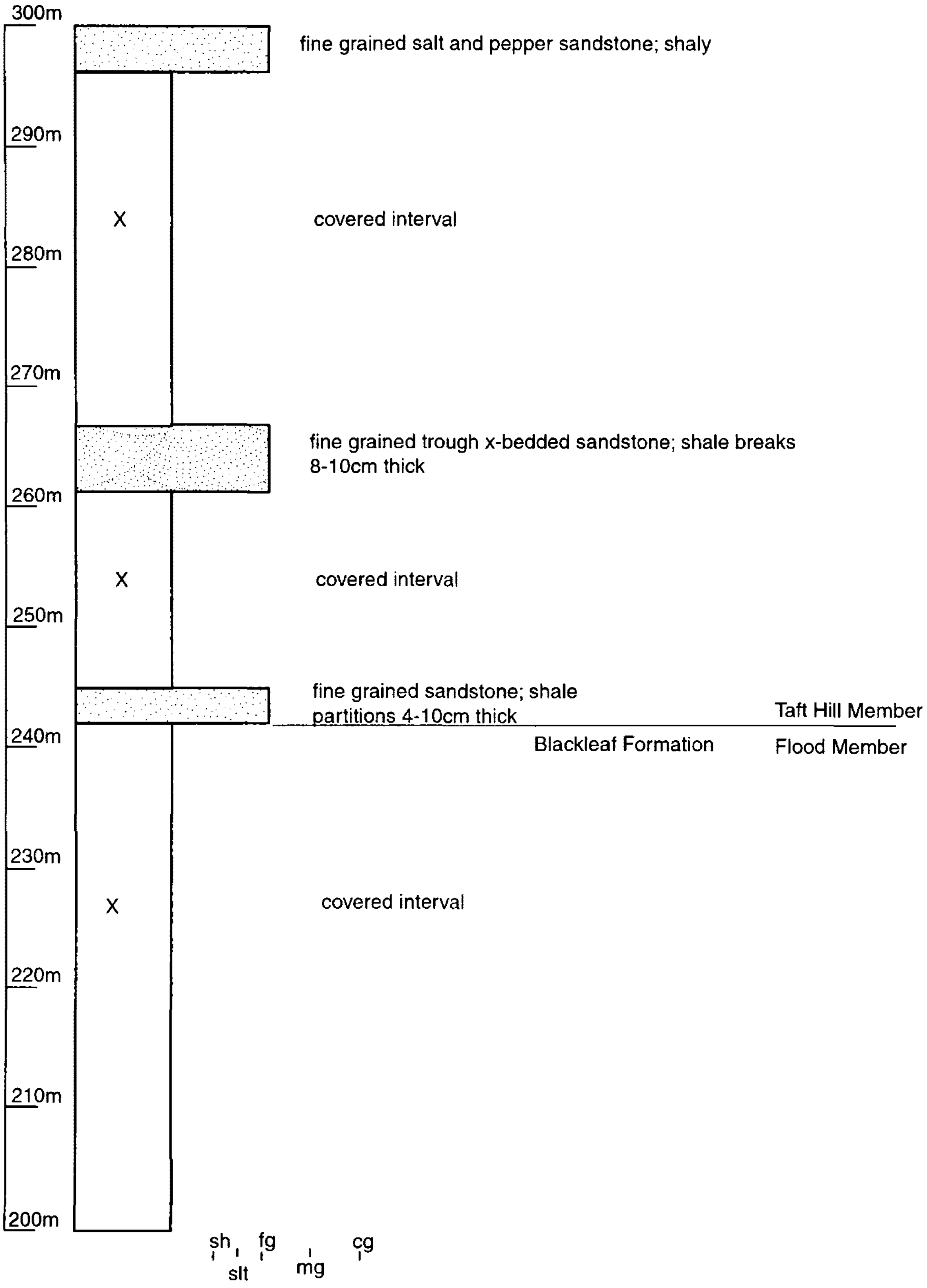
▒	Coarse Grained Sand
░	Fine Grained Sand
☰	Siltstone
▤	Shale
▦	Chert
▥	Porcellanite
+	Igneaous Sill

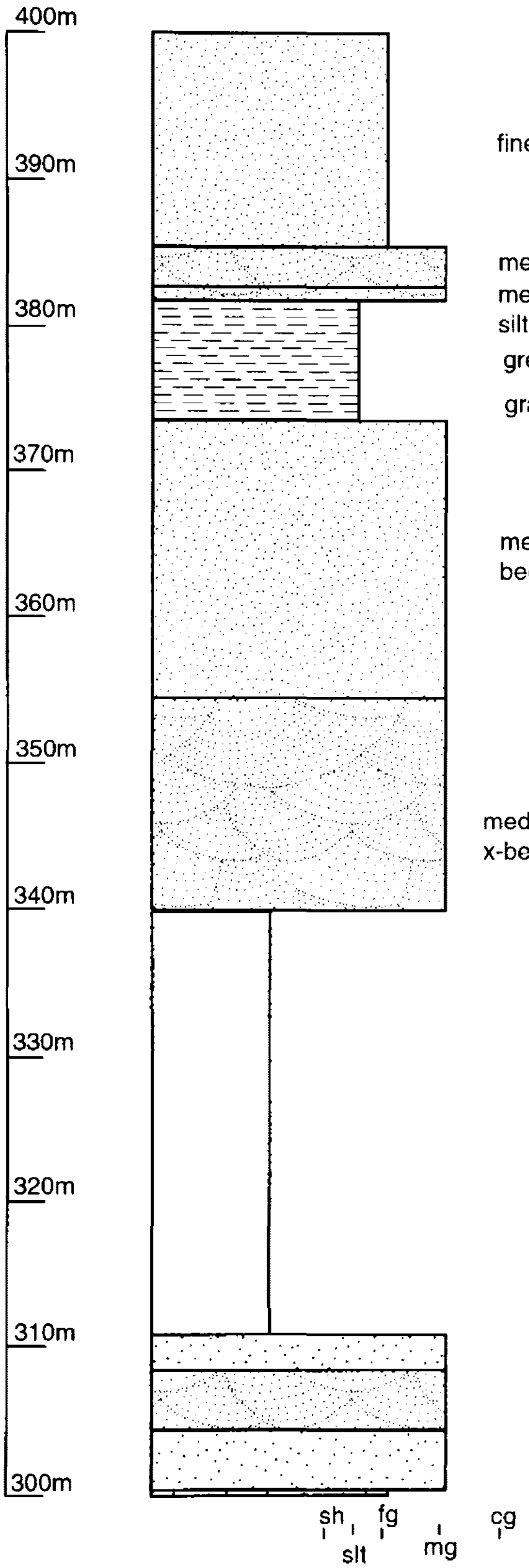

100m
90m
80m
70m
60m
50m
40m
30m
20m
10m
0m
Blackleaf Flood shale in float
fine grained quartzite; well sorted; olive green
Blackleaf Flood shale in float
sh
slt
fg
mg
cg



covered interval

Blackleaf Flood shale in float


300m
290m
280m
270m
260m
250m
240m
230m
220m
210m
200m
fine grained salt and pepper sandstone; shaly
X
covered interval
fine grained trough x-bedded sandstone; shale breaks 8-10cm thick
X
covered interval
fine grained sandstone; shale partitions 4-10cm thick
Taft Hill Member
Blackleaf Formation
Flood Member
X
covered interval
sh
slt
fg
mg
cg



fine grained salt and pepper sandstone; plane bedded

medium grained salt and pepper sandstone; x-bedded

medium grained salt and pepper sandstone; x-bedded; green siltstone clasts

green siltstone

grades to green argillite

medium grained salt and pepper sandstone; plane bedded

medium grained salt and pepper sandstone; alternating x-beds(2-5cm) and plane beds(3-5cm) in thickness

covered interval

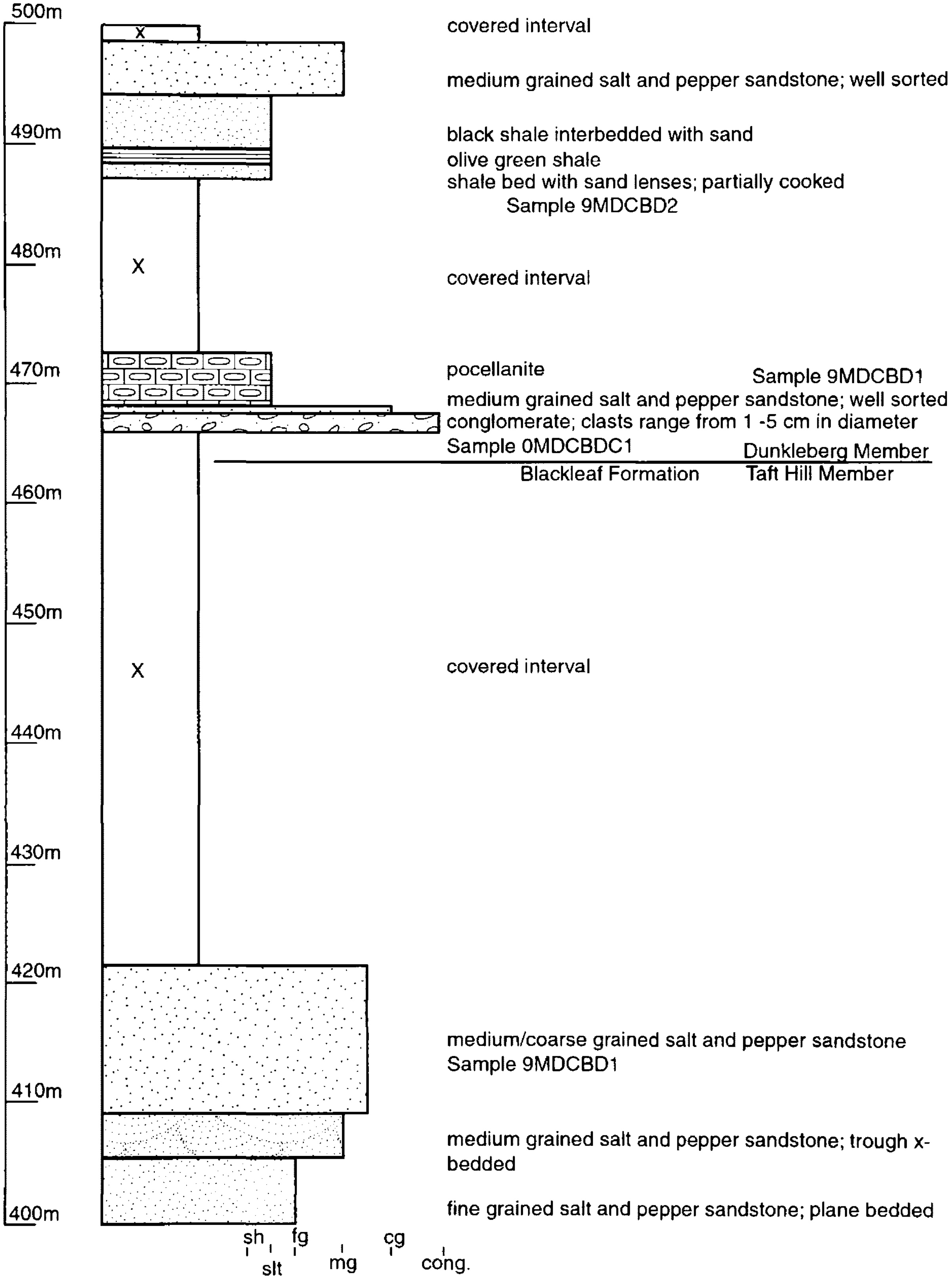
medium grained salt and pepper sandstone; plane bedded

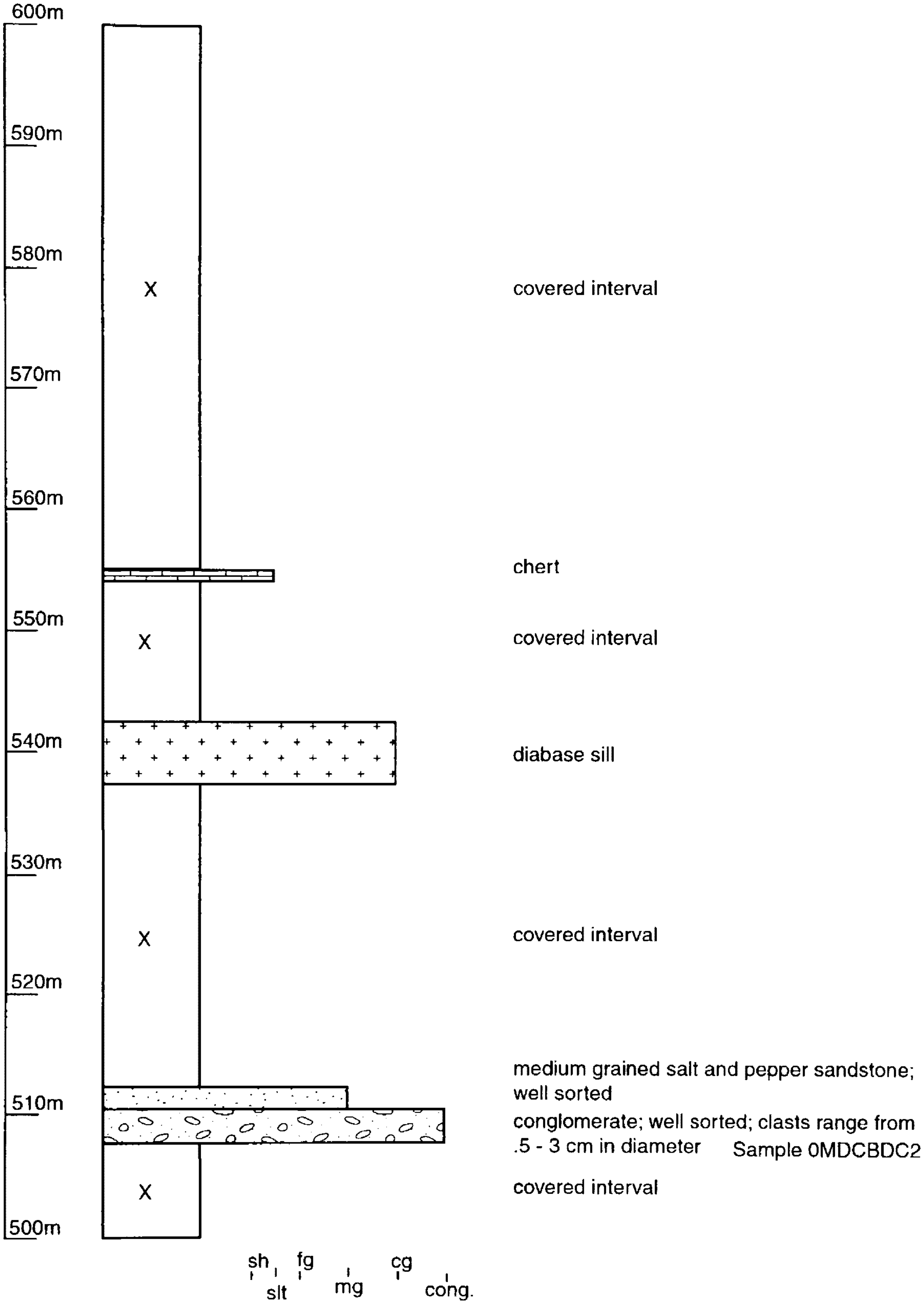
medium grained salt and pepper sandstone; trough x-bedded; trough packages ~10cm thick

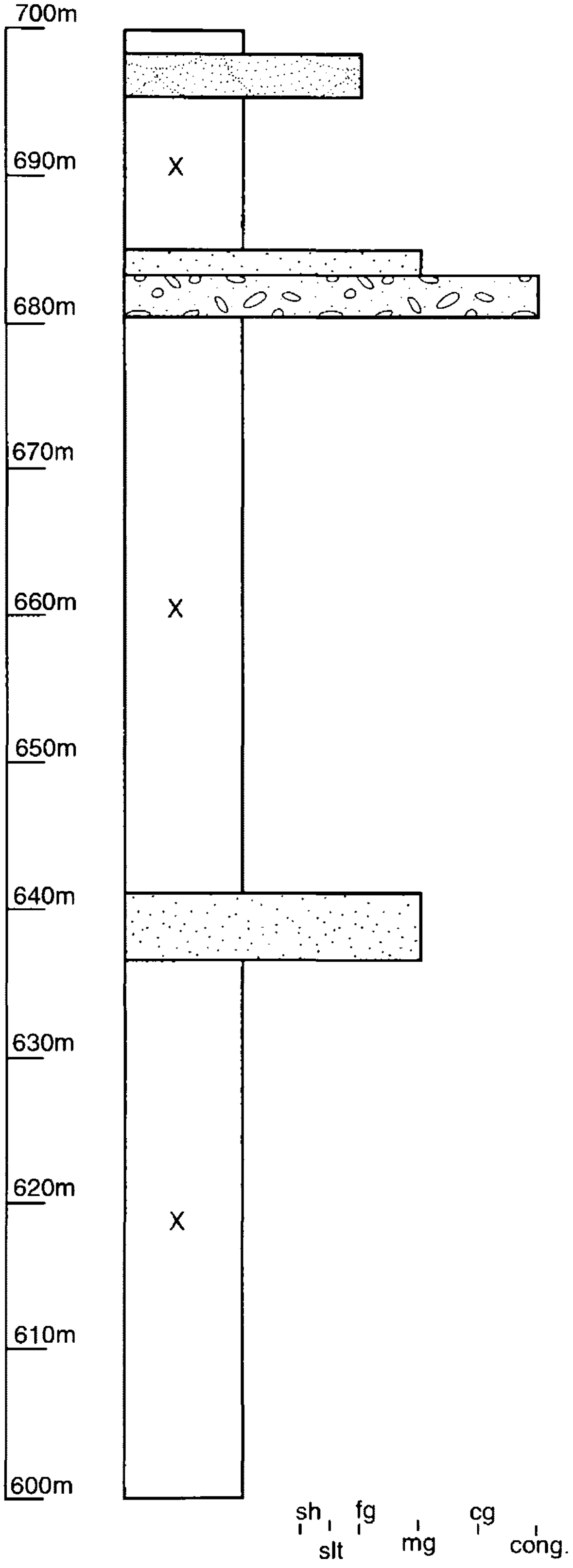
Sample 9MDCBTC1

medium grained salt and pepper sandstone; plane bedded

fine grained salt and pepper sandstone; shaly


500m
490m
480m
470m
460m
450m
440m
430m
420m
410m
400m
X
X
X
covered interval
medium grained salt and pepper sandstone; well sorted
black shale interbedded with sand
olive green shale
shale bed with sand lenses; partially cooked
Sample 9MDCBD2
covered interval
pocellanite
Sample 9MDCBD1
medium grained salt and pepper sandstone; well sorted
conglomerate; clasts range from 1 -5 cm in diameter
Sample 0MDCBDC1
Dunkleberg Member
Blackleaf Formation
Taft Hill Member
covered interval
medium/coarse grained salt and pepper sandstone
Sample 9MDCBD1
medium grained salt and pepper sandstone; trough x-bedded
fine grained salt and pepper sandstone; plane bedded
sh
fg
cg
slt
mg
cong.


600m
590m
580m
570m
560m
550m
540m
530m
520m
510m
500m
X
covered interval
chert
X
covered interval
diabase sill
X
covered interval
medium grained salt and pepper sandstone; well sorted
conglomerate; well sorted; clasts range from .5 - 3 cm in diameter
Sample 0MDCBDC2
X
covered interval
sh
slt
fg
mg
cg
cong.



fine grained sandstone; tabular x-beds Paleocurrents

covered interval

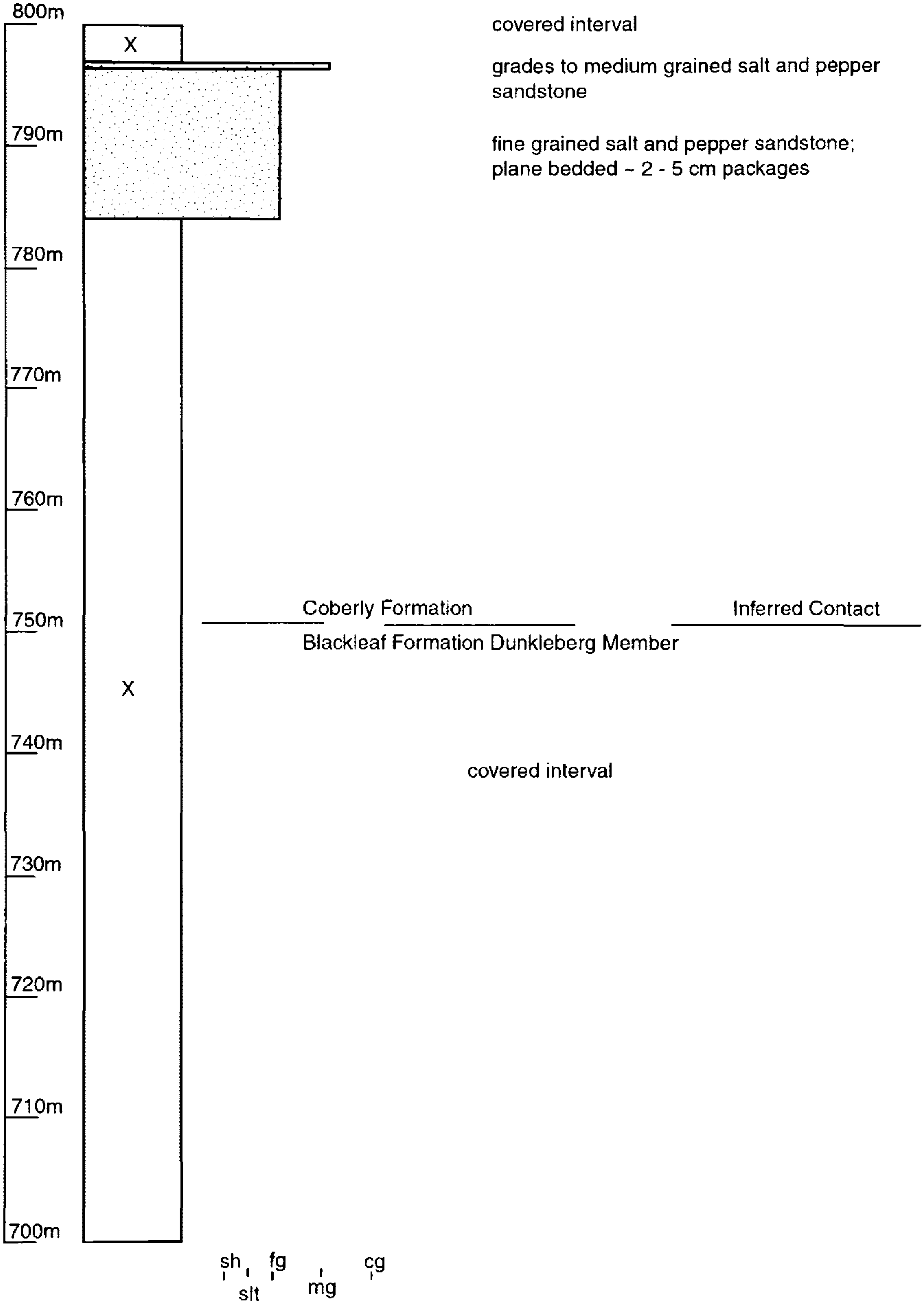
fine to medium grained salt and pepper sandstone; plane bedded

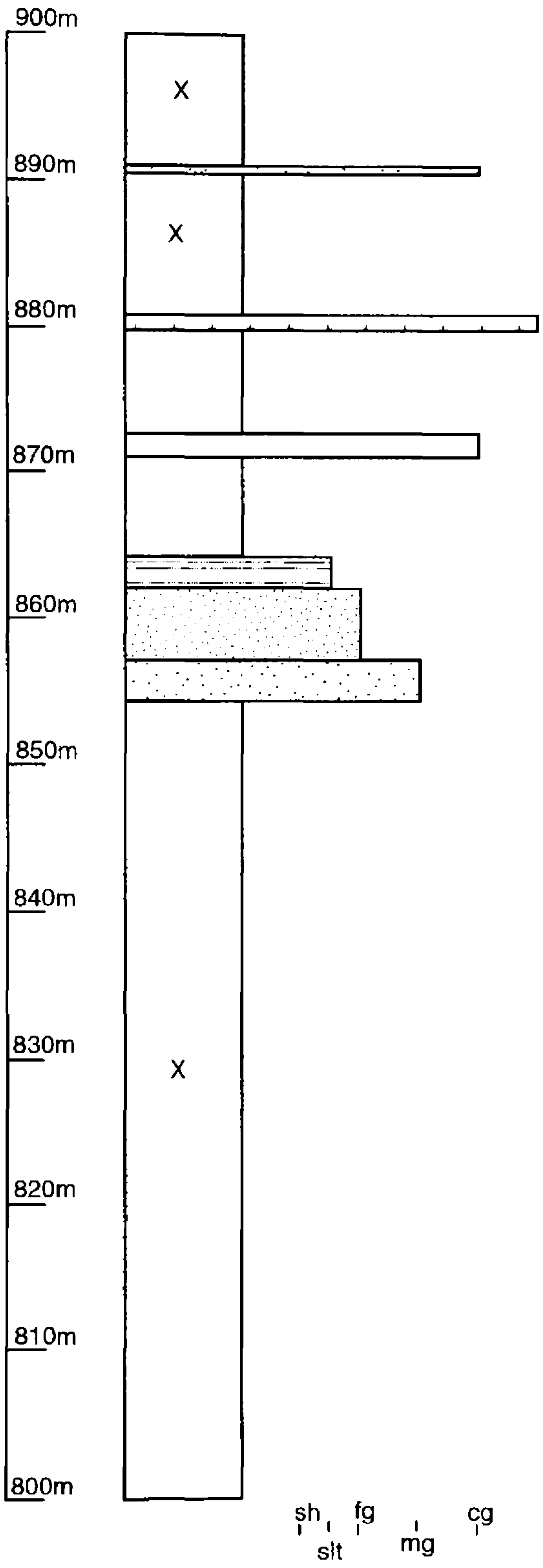
conglomerate; fair/well sorted; 1 - 7 cm in diameter Sample 0MDCBDC3

covered interval

medium grained salt and pepper sandstone; well sorted Sample 9MDCBD3

covered interval


800m
790m
780m
770m
760m
750m
740m
730m
720m
710m
700m
X
X
covered interval
grades to medium grained salt and pepper sandstone
fine grained salt and pepper sandstone; plane bedded ~ 2 - 5 cm packages
Coberly Formation
Inferred Contact
Blackleaf Formation Dunkleberg Member
covered interval
sh
slt
fg
mg
cg



covered interval

coarse grained salt and pepper sandstone; plane bedded Sample 9MDCBD4

covered interval

diabase sill

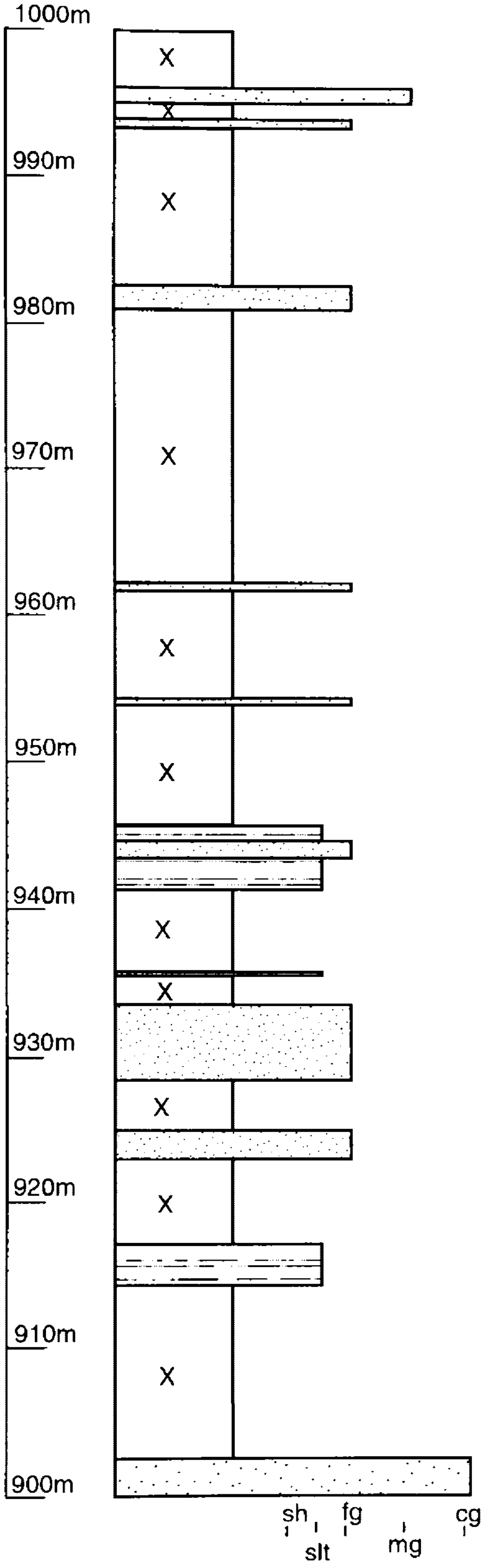
Inferred Oyster Bed in Lower Coberly; Float

grades to brown siltstone

grades to fine grained salt and pepper sandstone; beds ~ 4 mm thick

medium grained salt and pepper sandstone; beds ~ 1 - 7 cm thick

covered interval



covered interval
medium grained salt and pepper sandstone
covered interval
fine grained sandstone;
Sample 9MDCBD5
covered interval

fine grained sandstone/quartzite; black

covered interval

fine grained sandstone; grey

covered interval

fine grained sandstone; green

covered interval

grades back to black siltstone
grades to fine grain salt and pepper sandstone
black siltstone

covered interval
black siltstone
covered interval

fine grained sandstone; well sorted; plane bedded

covered interval

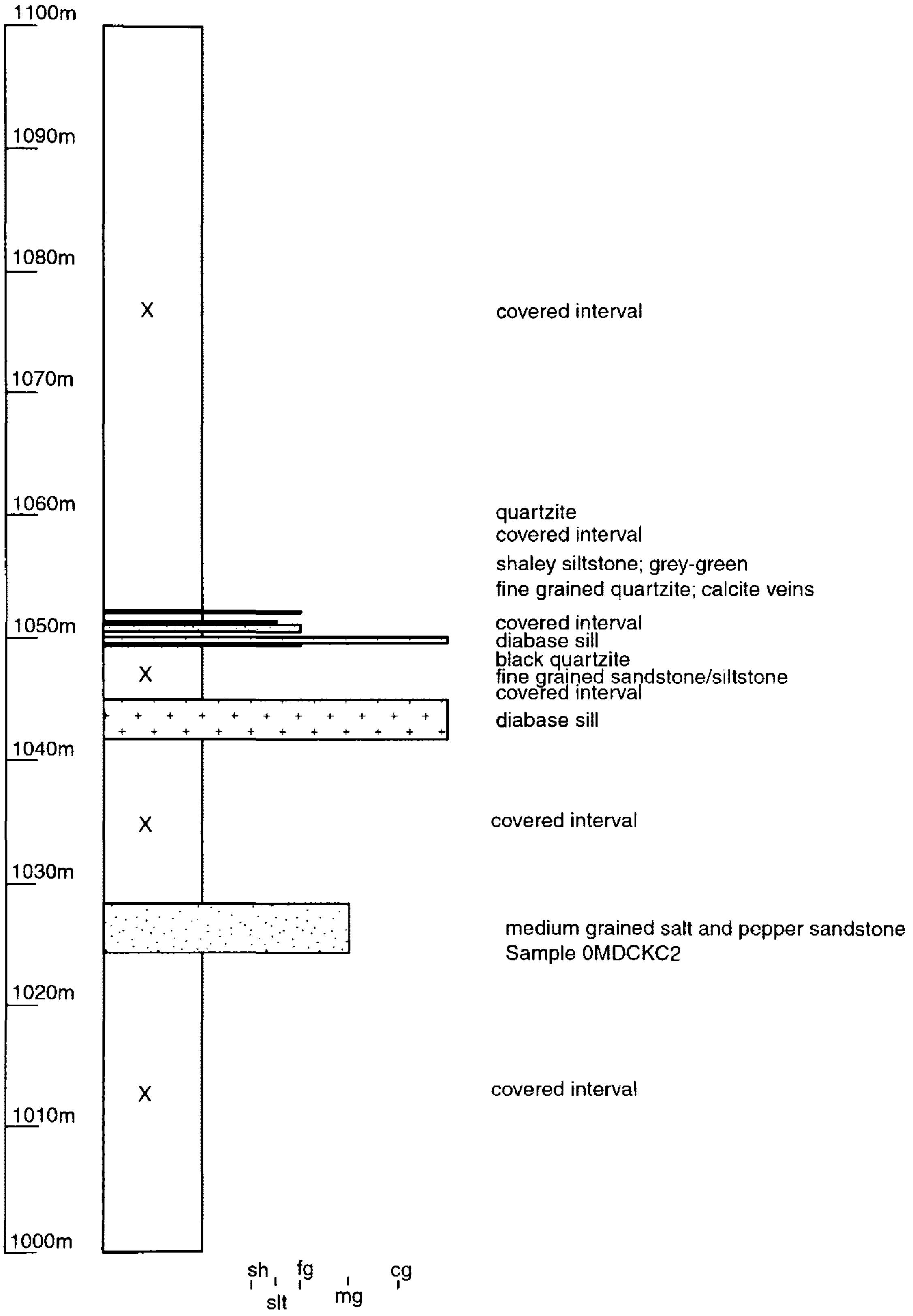
fine grained sandstone/quartzite

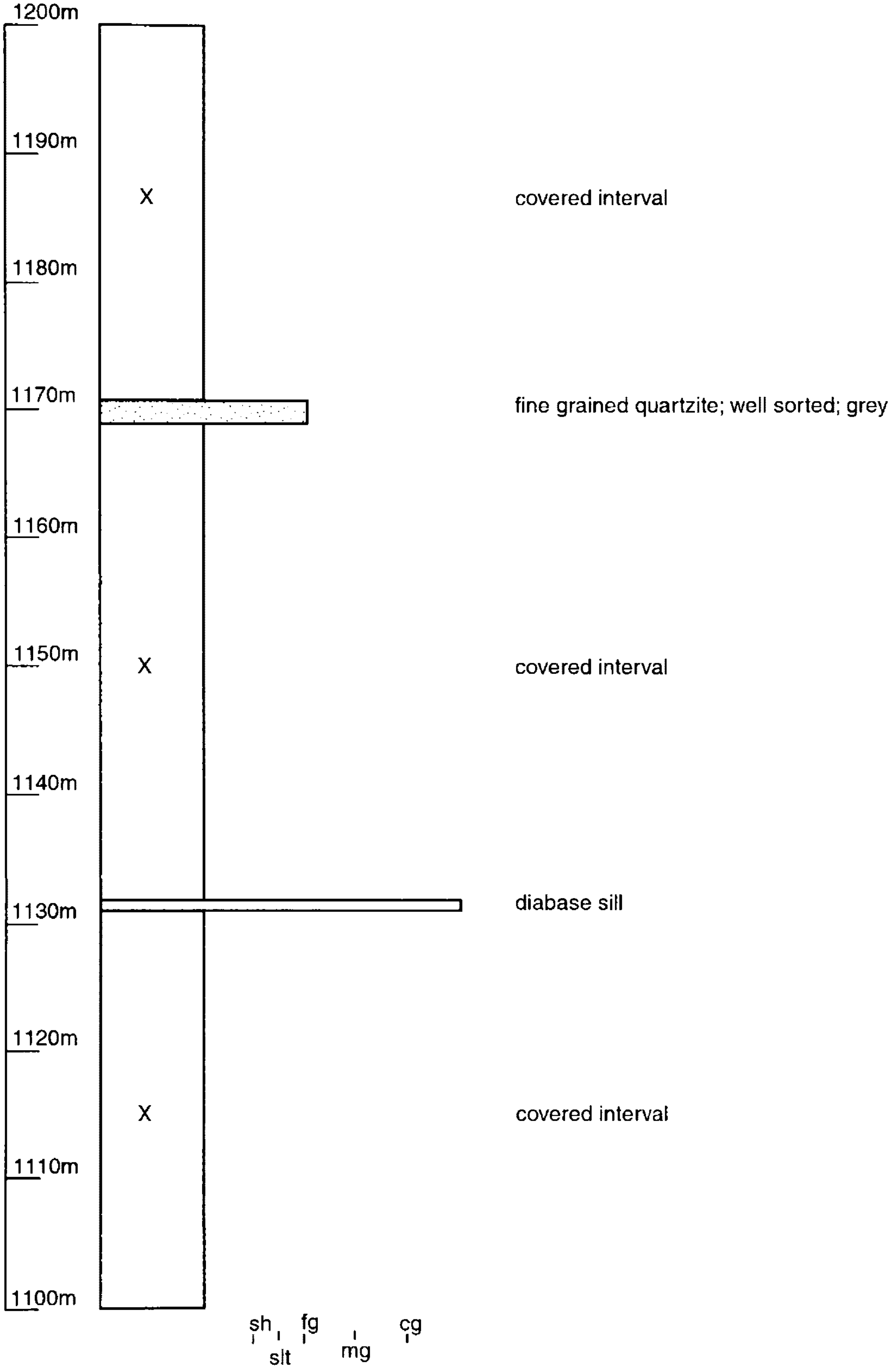
covered interval

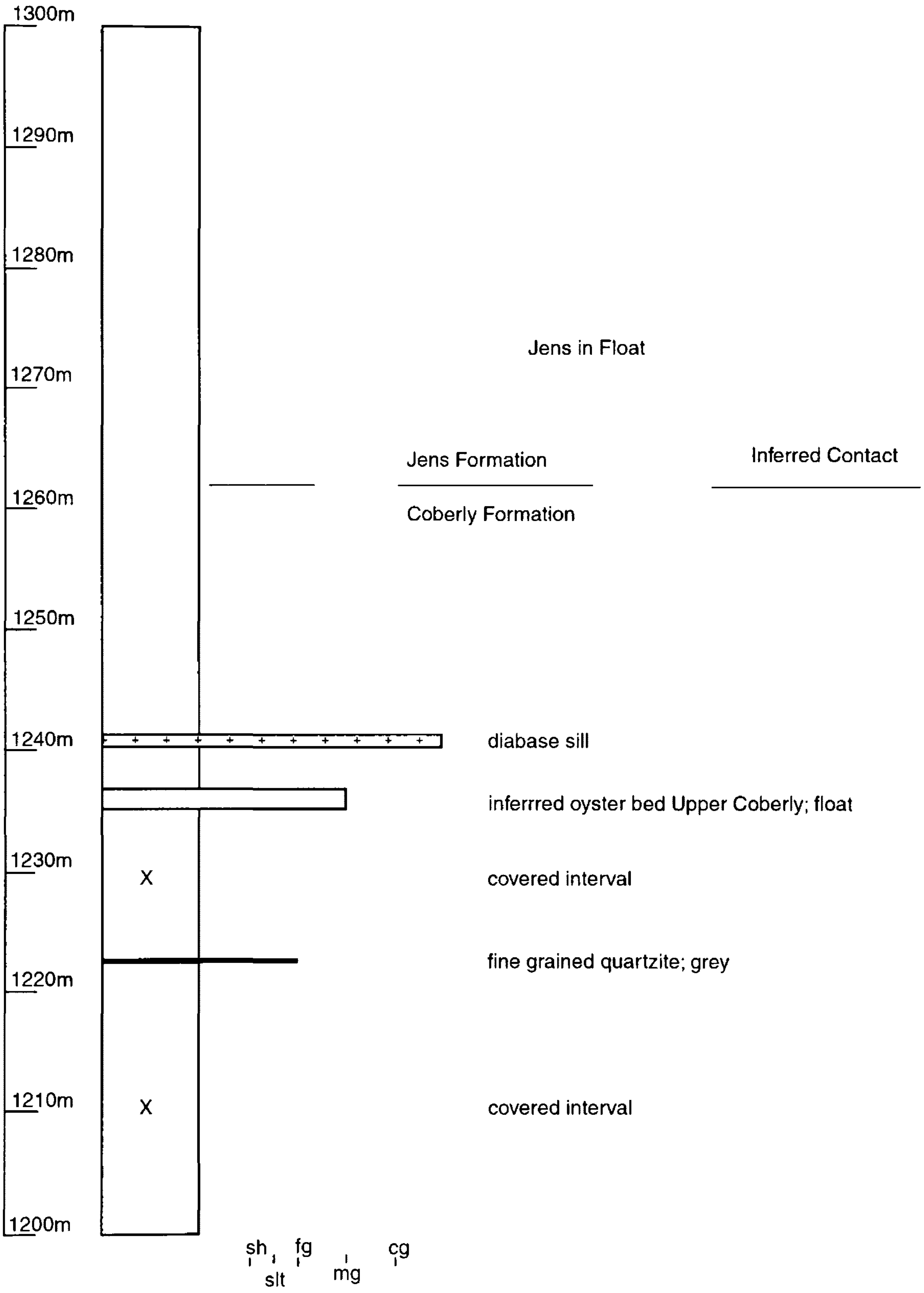
green siltstone

covered interval

coarse grained salt and pepper sandstone; plane bedded

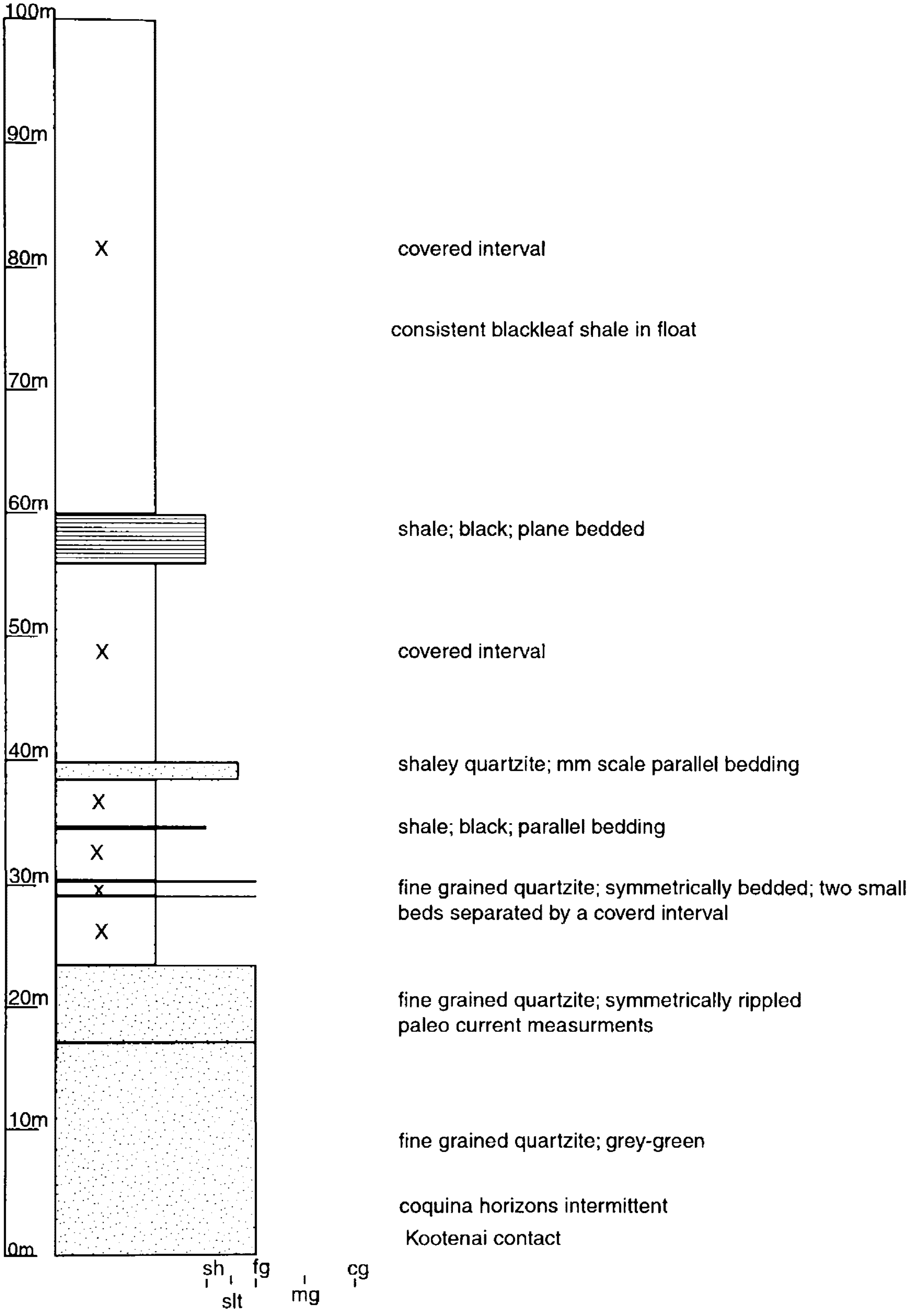

1100m
1090m
1080m
X
covered interval
1070m
1060m
quartzite
covered interval
shaley siltstone; grey-green
fine grained quartzite; calcite veins
1050m
covered interval
diabase sill
black quartzite
X
fine grained sandstone/siltstone
covered interval
diabase sill
1040m
X
covered interval
1030m
medium grained salt and pepper sandstone
Sample 0MDCKC2
1020m
X
covered interval
1010m
1000m
sh
fg
cg
slt
mg

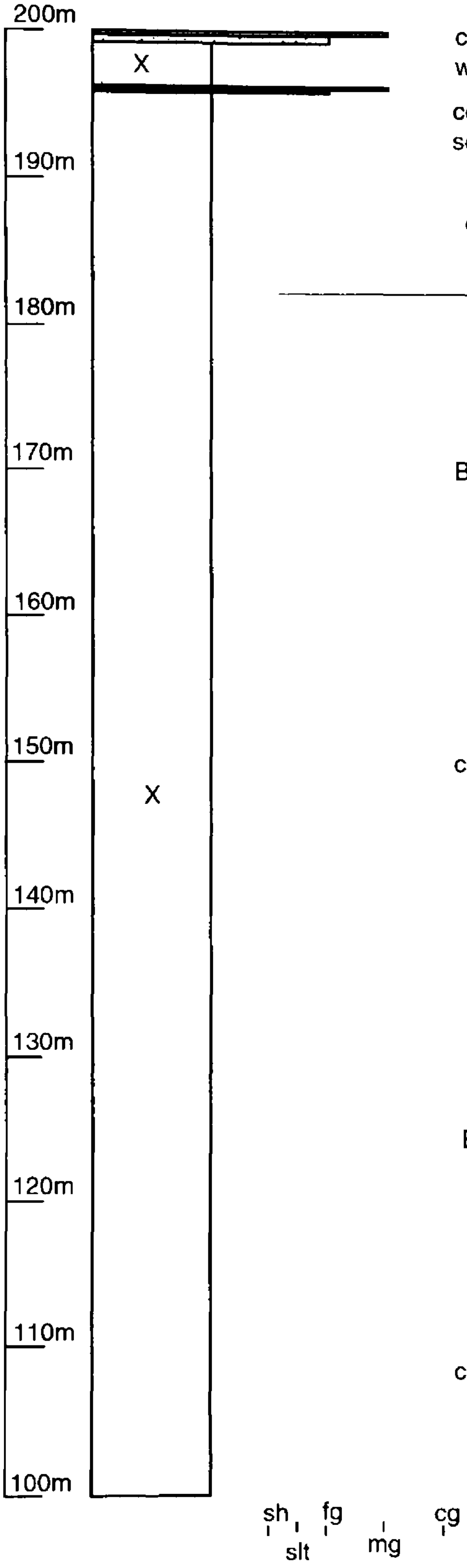

1200m
1190m
1180m
1170m
1160m
1150m
1140m
1130m
1120m
1110m
1100m
X
covered interval
fine grained quartzite; well sorted; grey
X
covered interval
diabase sill
X
covered interval
sh
slt
fg
mg
cg


1300m
1290m
1280m
1270m
1260m
1250m
1240m
1230m
1220m
1210m
1200m
Jens in Float
Jens Formation
Inferred Contact
Coberly Formation
diabase sill
inferrred oyster bed Upper Coberly; float
X
covered interval
fine grained quartzite; grey
X
covered interval
sh
fg
cg
slt
mg

Appendix II

Beck Homestead/Clear Creek Measured Transect


100m
90m
80m
70m
60m
50m
40m
30m
20m
10m
0m
X
covered interval
consistent blackleaf shale in float
shale; black; plane bedded
X
covered interval
shaley quartzite; mm scale parallel bedding
X
shale; black; parallel bedding
X
fine grained quartzite; symmetrically bedded; two small beds separated by a coverd interval
x
X
fine grained quartzite; symmetrically rippled paleo current measurments
fine grained quartzite; grey-green
coquina horizons intermittent
Kootenai contact
sh
slt
fg
mg
cg



coarsening upward sequence of salt and pepper sandstone; well sorted; fine - medium grained; plane bedded

coarsening upward sequence of salt and pepper sandstone; well sorted; fine - medium grained

consistent salt and pepper sandstone in float @ 183.51M

Blackleaf Formation Taft Hill Member

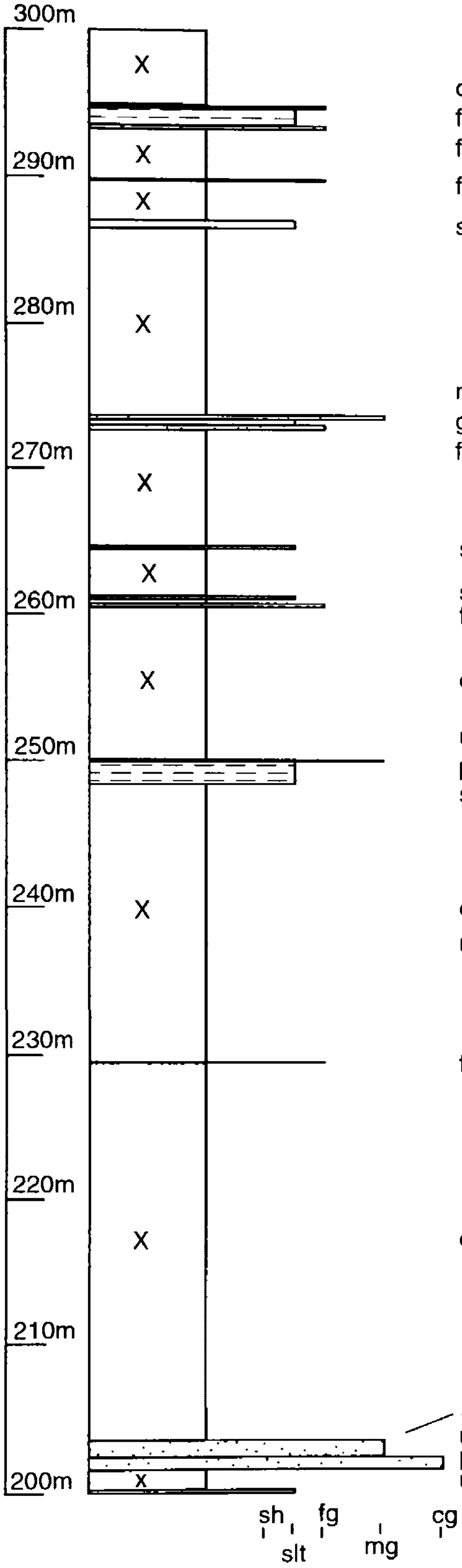
Flood Member

Blackleaf Flood shale in float

covered interval

Blackleaf Flood shale in float

consistent Blackleaf shale in float with some quartzite



coarsens to fine grained sandstone
fines to siltstone; green
fine grained sandstone
fine grained sandstone; brown
siltstone; grey

medium grained salt and pepper sandstone Sample 9TBHBT5
grades to siltstone
fine grained salt and pepper sandstone; well sorted

siltstone

siltstone; risoturbation
fine grained salt and pepper sandstone; well sorted

covered interval

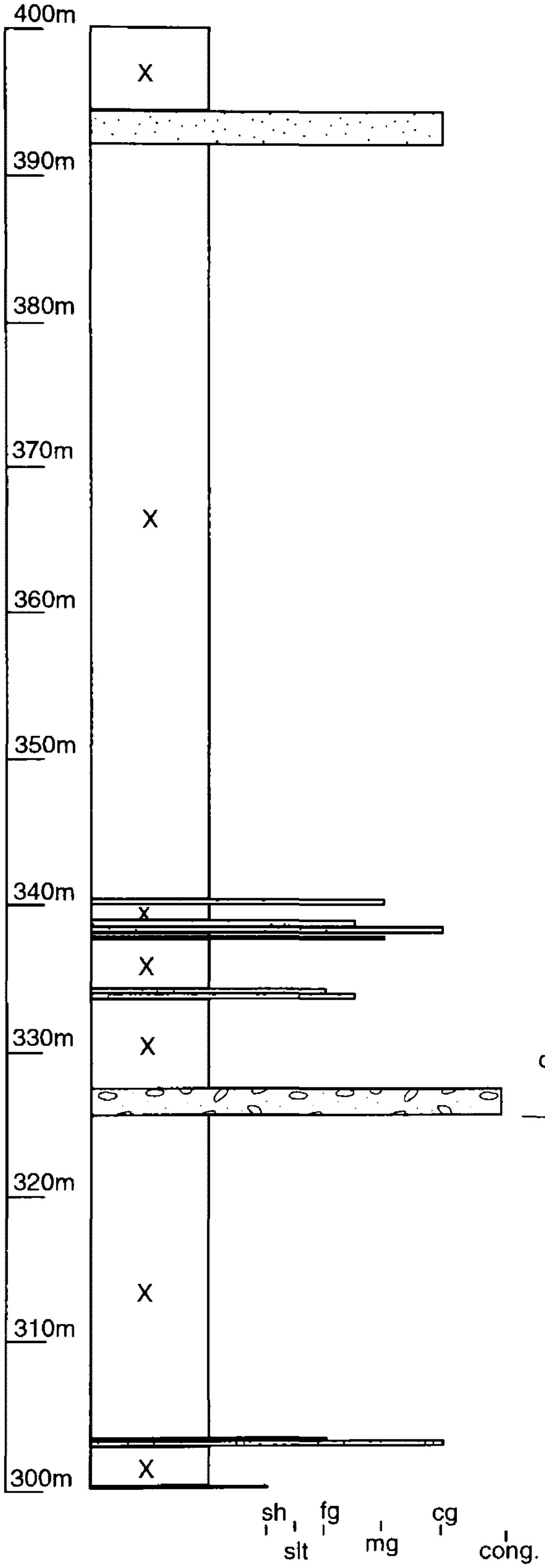
upward coarsening to f/m grained salt and pepper sandstone;
plane bedded
siltstone; risoturbation

covered interval
risoturbated siltstone in float

fine grained salt and pepper sandstone

covered interval

Sample 9TBHBT3
upward fining medium grained sandstone; moderately sorted
pebbly sandstone; poorly sorted Sample 9TBHBT2
upward fining siltstone; argillite; plane bedded Sample 9TBHBT1



coarse grained salt and pepper sandstone; mudchips; plane bedded; sorting increases vertically

medium grained salt and pepper sandstone; x-bedded; well sorted

fining upward sequence; coarse-fine grained salt and pepper sandstone; well sorted

medium grained salt and pepper sandstone; x-bedded

fining upward sequence; fine grained salt and pepper sandstone

Sample 9TBHBDC1

conglomerate; clasts range from .5 - 2cm in diameter

Dunkleberg Member

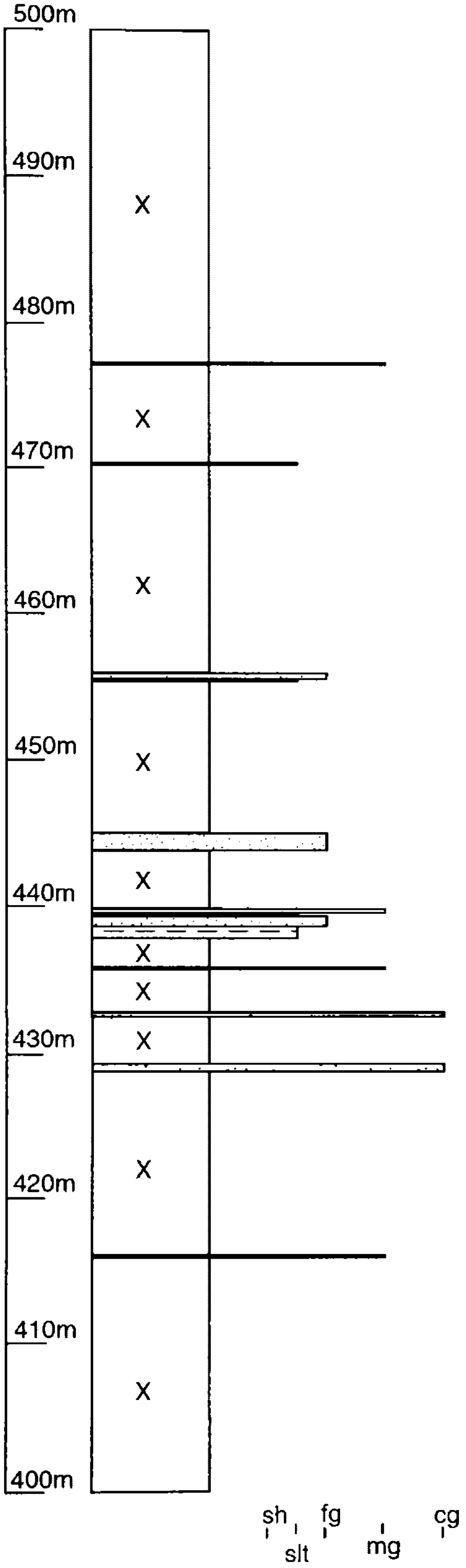
Blackleaf Formation

Taft Hill Member

fine grained salt and pepper sandstone; plane bedded; unconformable

coarse grained salt and pepper sandstone; x- bedded

green shale; synorogenic calcite veins and concretions



medium grained salt and pepper sandstone; plane bedded; well sorted

siltstone; green

upward coarsening sequence; green siltstone - fine grained salt and pepper sandstone; well sorted

fine grained sandstone; risoturbation

medium grained salt and pepper sandstone; mudchips of underlying grey siltstone

upward fining sequence; fine grained salt and pepper sandstone - siltstone; ss is plane bedded

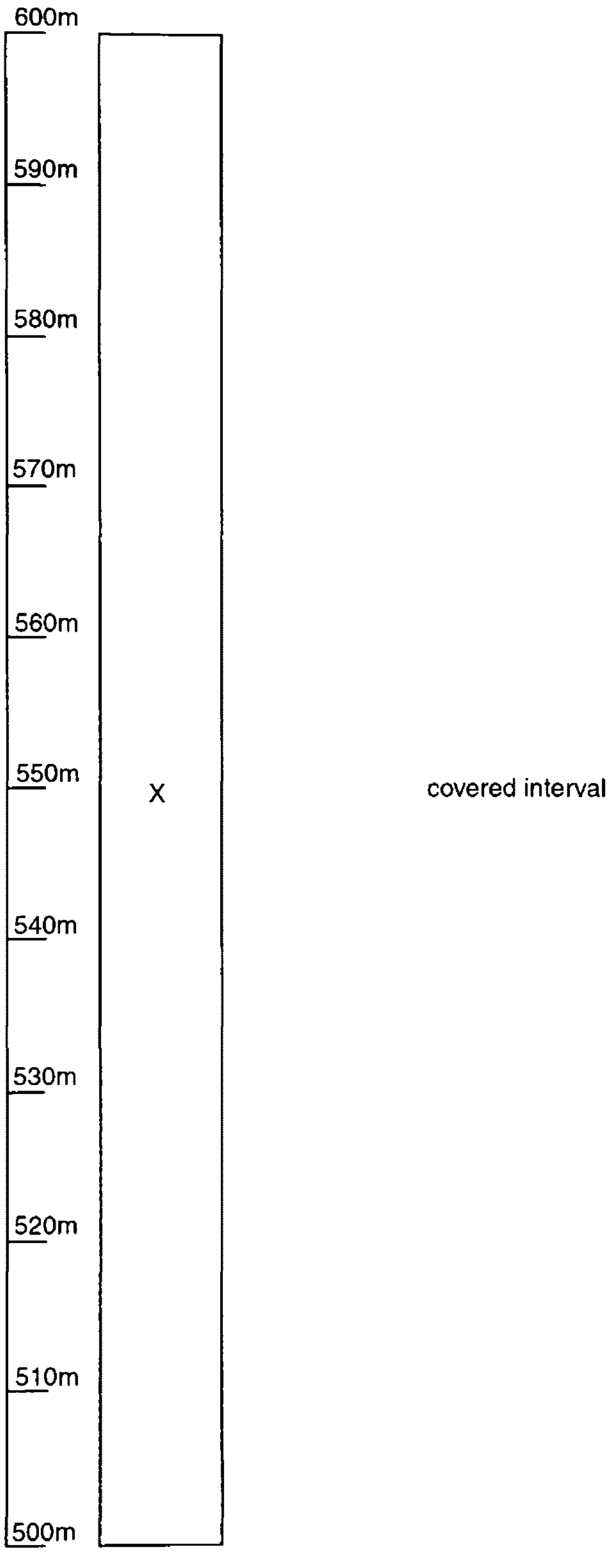
siltstone; grey;

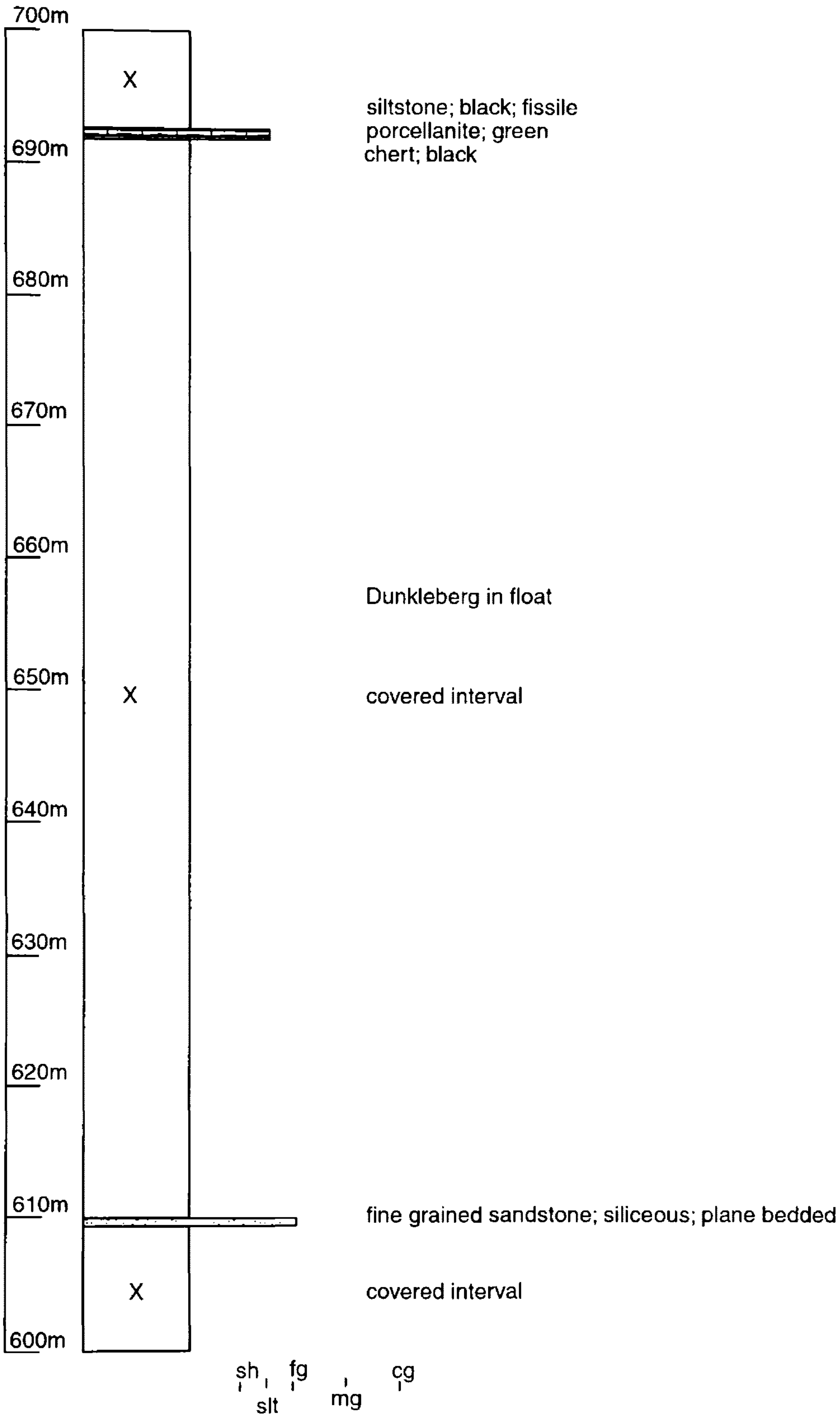
medium grained salt and pepper sandstone; well sorted

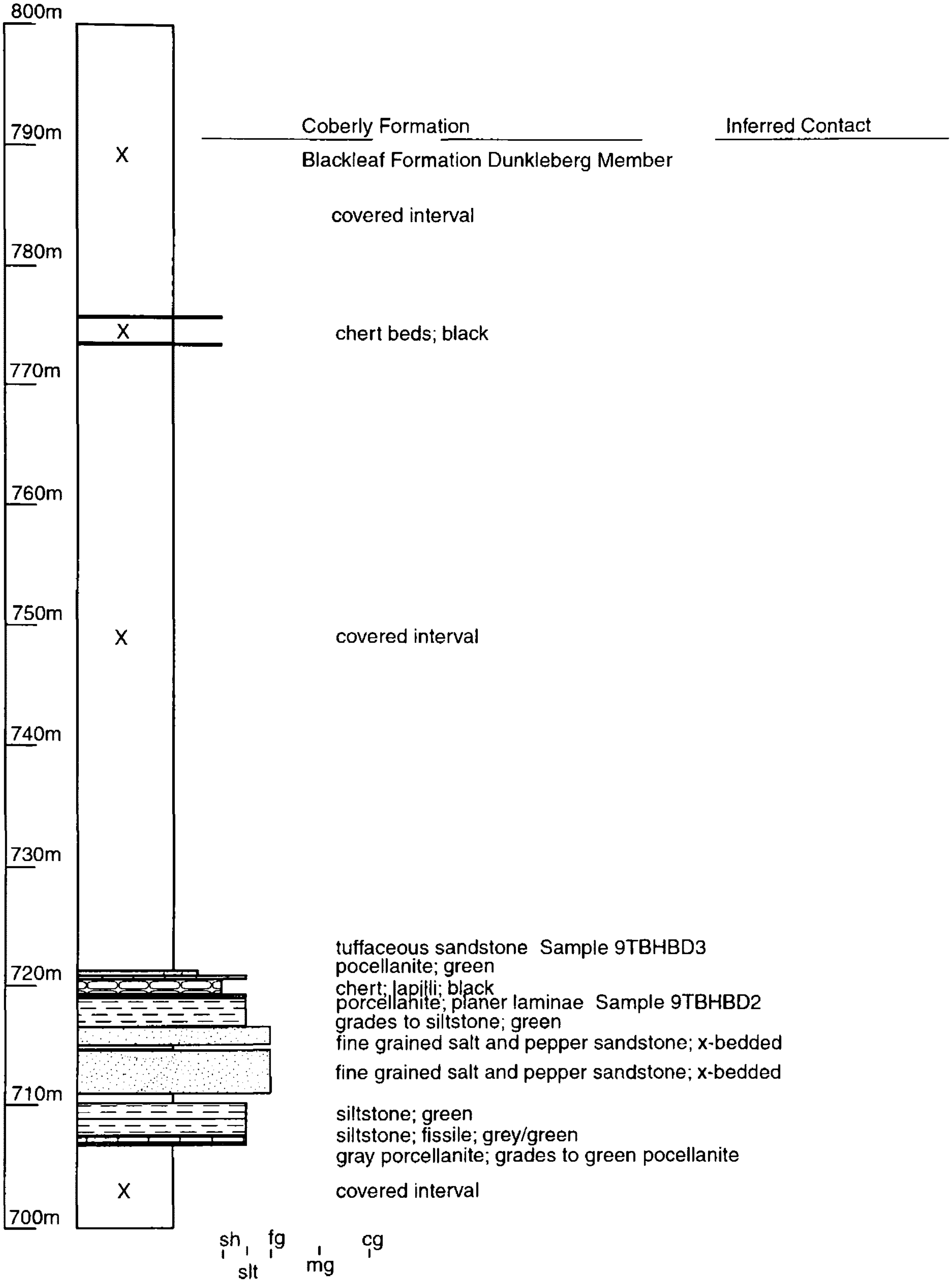
coarse grained salt and pepper sandstone; well sorted

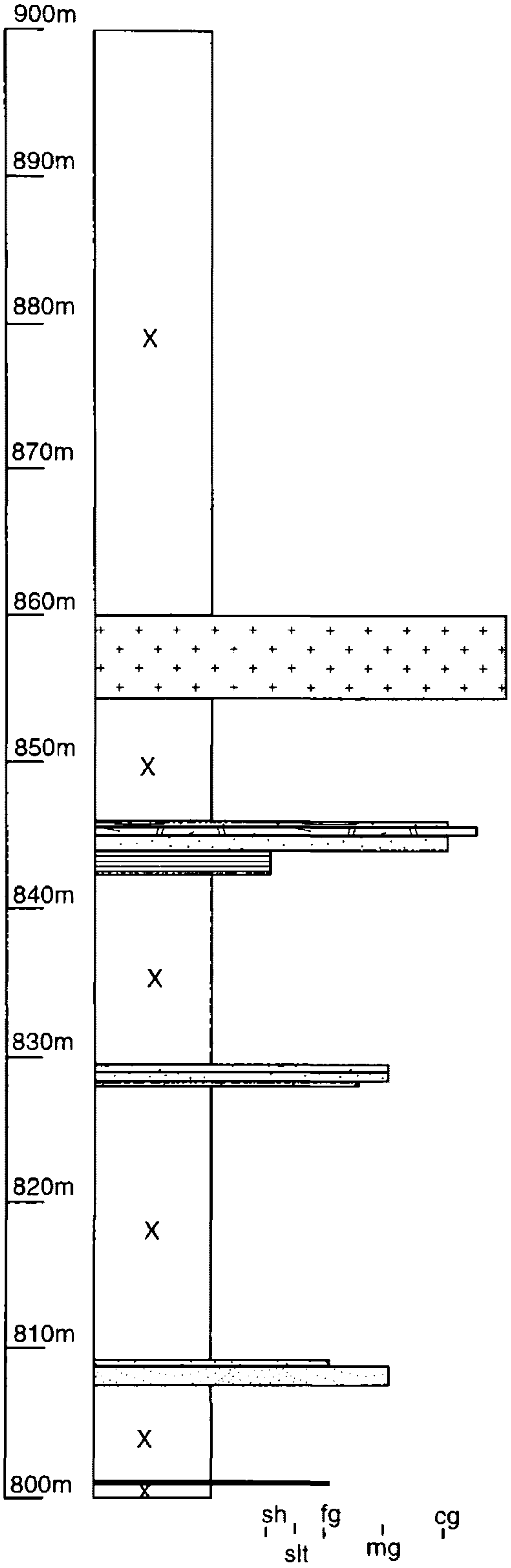
coarse grained salt and pepper sandstone; well sorted

medium grained salt and pepper sandstone; well sorted


600m
590m
580m
570m
560m
550m
X
covered interval
540m
530m
520m
510m
500m


700m
X
siltstone; black; fissile
porcellanite; green
chert; black
690m
680m
670m
660m
Dunkleberg in float
650m
X
covered interval
640m
630m
620m
610m
fine grained sandstone; siliceous; plane bedded
X
covered interval
600m
sh
slt
fg
mg
cg


800m
790m
780m
770m
760m
750m
740m
730m
720m
710m
700m
X
Coberly Formation
Inferred Contact
Blackleaf Formation Dunkleberg Member
covered interval
X
chert beds; black
X
covered interval
tuffaceous sandstone Sample 9TBHBD3
pocellanite; green
chert; lapilli; black
porcellanite; planer laminae Sample 9TBHBD2
grades to siltstone; green
fine grained salt and pepper sandstone; x-bedded
fine grained salt and pepper sandstone; x-bedded
siltstone; green
siltstone; fissile; grey/green
gray porcellanite; grades to green pocellanite
X
covered interval
sh
slt
fg
mg
cg



covered interval

diabase sill

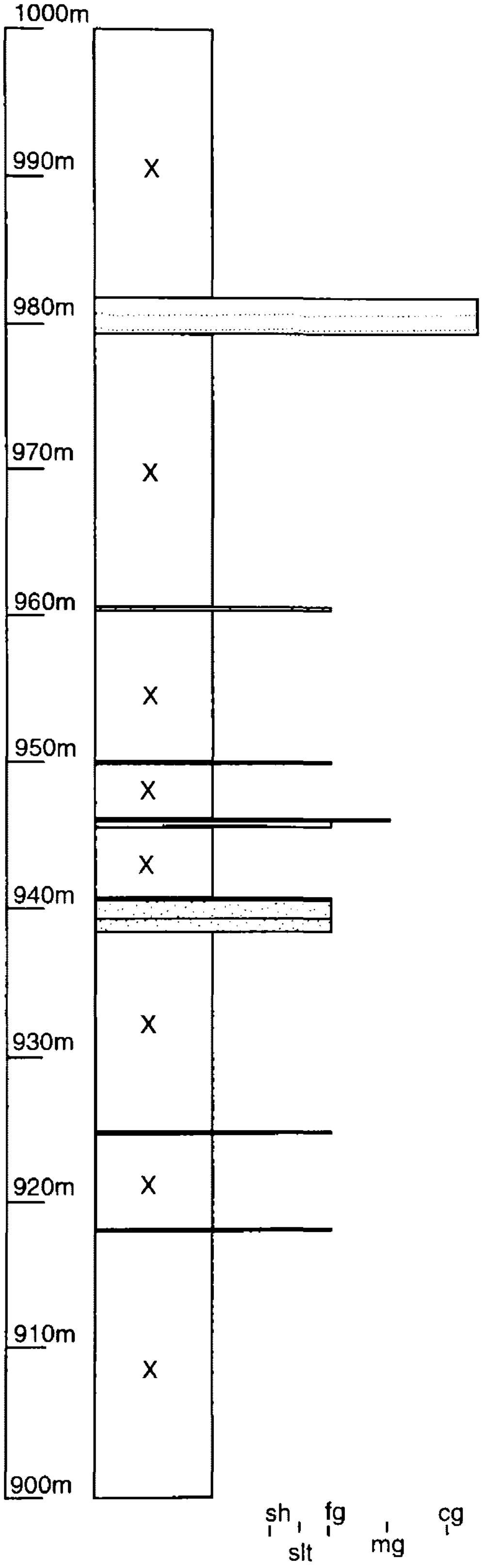
fine grained salt and pepper sandstone; symmetrically rippled Sample 9TBHC2
oyster bed Sample 9TBHC1
oyster beds 1-3cm thick; intermittent with calcareous shale
shale; black; fissile

covered interval

medium grained sandstone; plane bedded; siltstone intervals intermittent
coarsening upward sequence; medium grained salt and pepper sandstone

covered interval

fine grained salt and pepper sandstone; plane bedded; grey
medium grained salt and pepper sandstone; well sorted; x-bedded
covered interval
fine grained sandstone; siliceous



covered interval

medium grained salt and pepper sandstone; alternating planer and low angle cross-stratification; intermittent coquina fragments Sample 9TBHC4

covered interval

fine grained sandstone; symmetrically rippled; mud-drapes

covered interval

fine grained sandstone; x-bedded

grades to medium grained sandstone; well sorted
grades to fg sandstone; fissile
fine grained sandstone; muddy

grades back to thinly bedded fg sandstone
grades to thicker bedded fg sandstone; white specks..feldspar or bentonite? Sample 9TBHC3
fine grained sandstone; thin plane beds

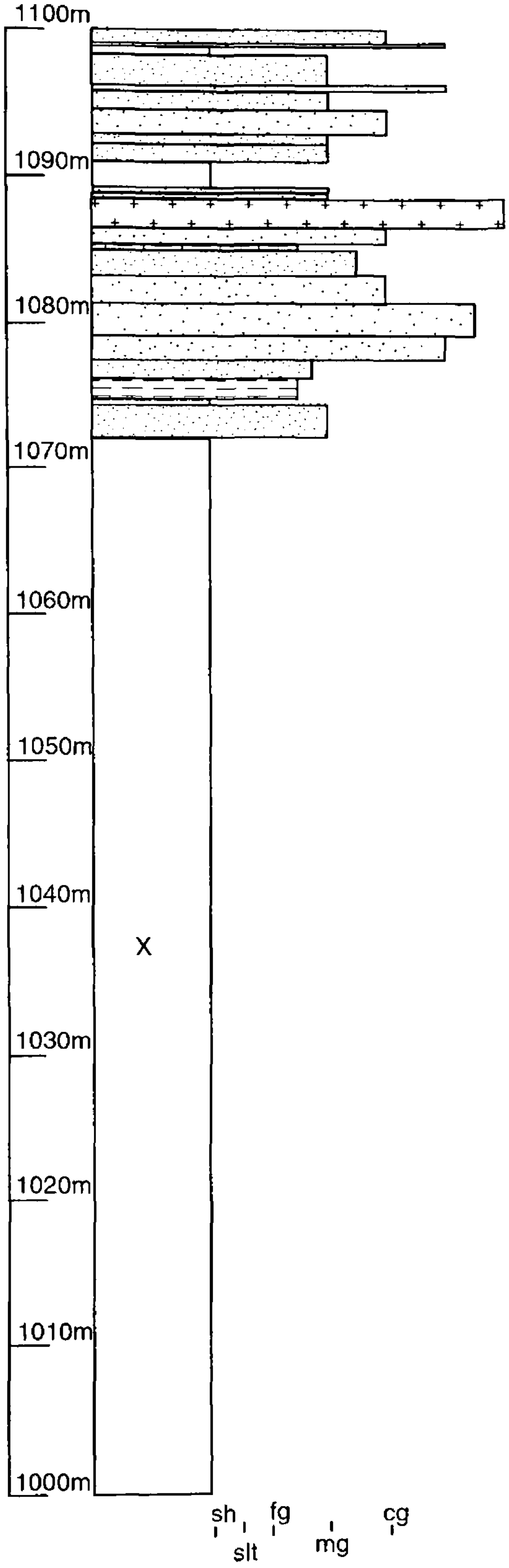
covered interval

fine grained salt and pepper sandstone; low angle x-stratified

covered interval

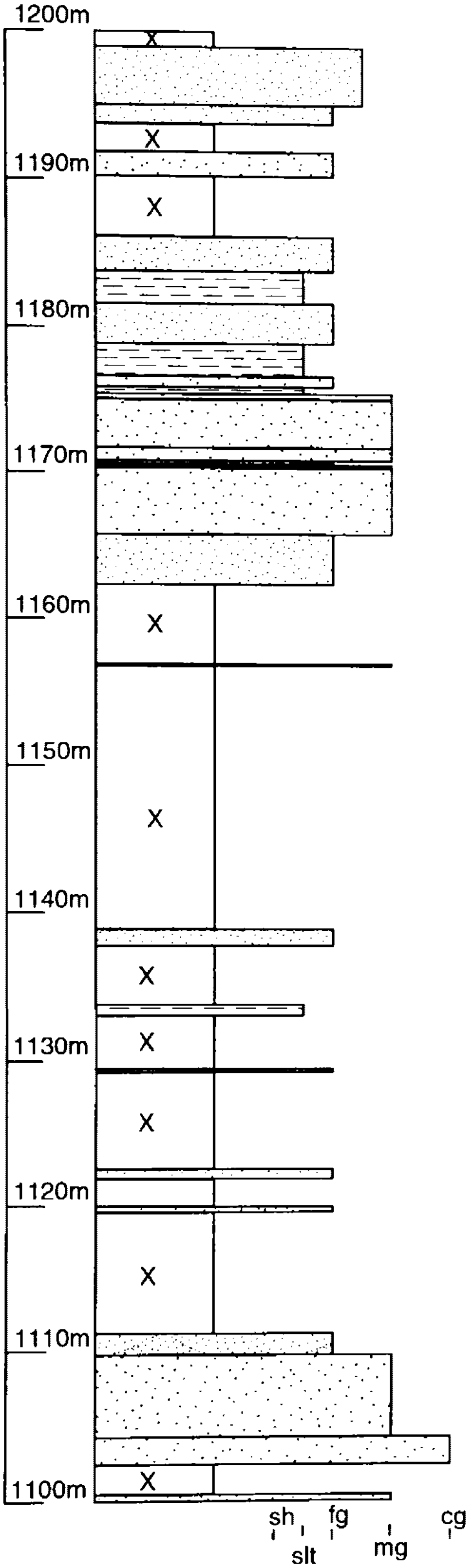
fine grained salt and pepper sandstone; well sorted; plane bedded

covered interval



cg S&P sandstone grades to mg S&P sandstone
fine grained S&P sandstone; pln bds; mud chips
amalgamated surface; cg S&P sandstone; pln bded; pr srt
grades to fine grained S&P sandstone; well sorted
medium grained salt and pepper sandstone; plane bedded
fine grained sandstone; moderately sorted
massive bedded quartzite
quartzite; chilled margin overlain by fg sandstone
diabase sill
medium grained sandstone; mud chips
porcellanite; x-bedded
grades to m/f grained sandstone; plane bedded
grades to mdm. grn. sandstone; mud chips decreasing; x-bedded
almalgamated srfc.; crs. grn. sandstone; mud chips; x-bedded
grades to coarse grained s&p sandstone; plane bedded
fine grained sandstone; thin planar bedding
siltstone; bioturbated
fine grained salt and pepper sandstone; olive green

covered interval



m/f grained S&P ss; plane bedded

fg S&P ss; plane bedded

fg S&P ss; well sorted; 3mm ms breaks intermittent

interfingered siltstone with fg ss; low
angle x-stratification
grades to siltstone; black
fg ss; brown
grades to siltstone; bioturbated
siltstone interfingered with fg ss; low angle x-stratification
siltstone
mg ss; thin plane beds
mg S&P ss; massive plane beds
two channel sequences stacked on top of one another;
mg ss; thin plane beds giving way to x-beds; lenticular

mg ss; massive plane beds; well sorted
fg quartzite; grey

mg S&P ss; plane bedded; arenacious
Sample 9CC1

fg ss plane bedded

siltstone

fg quartzite

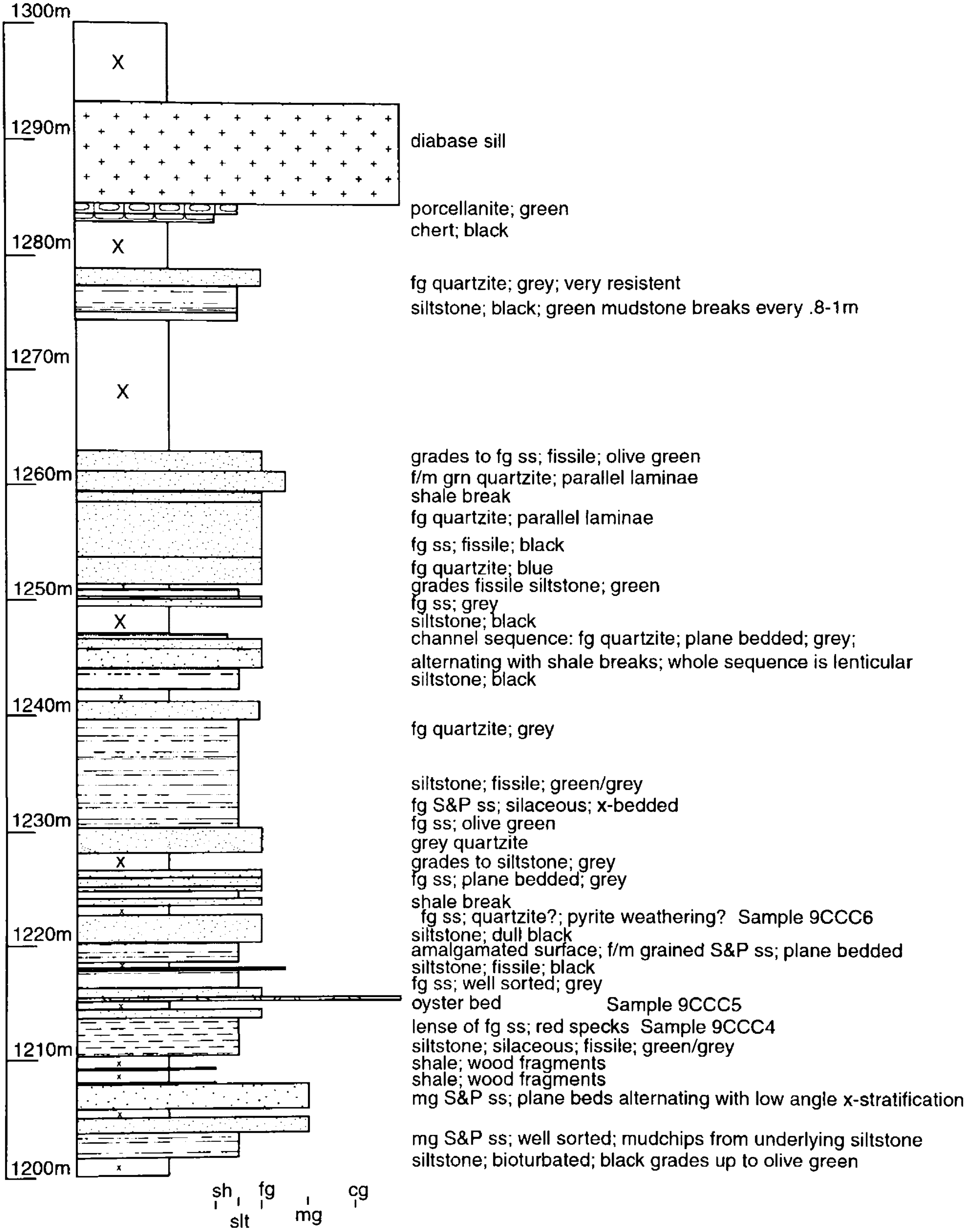
fg quartzite

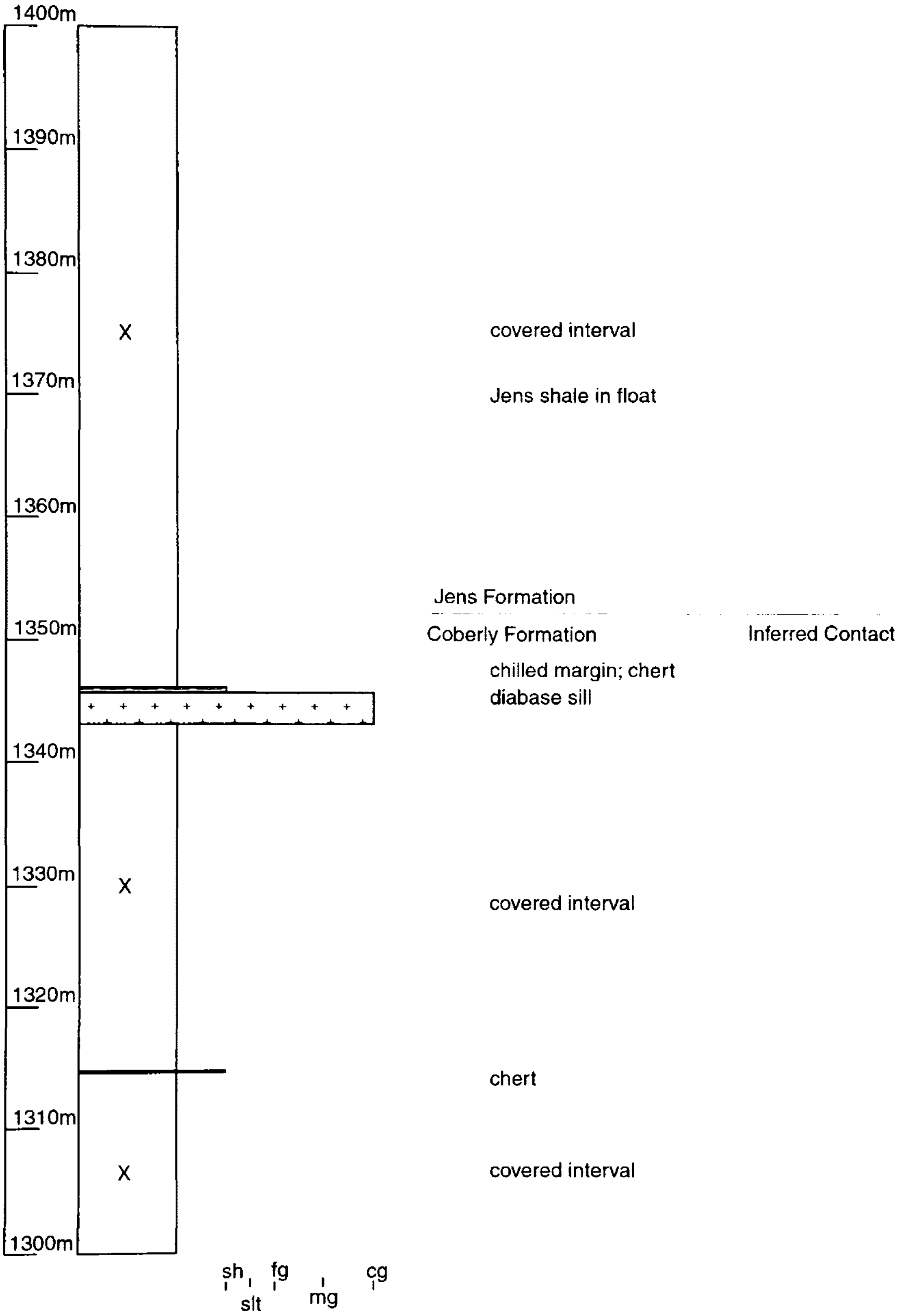
siltstone; olive green

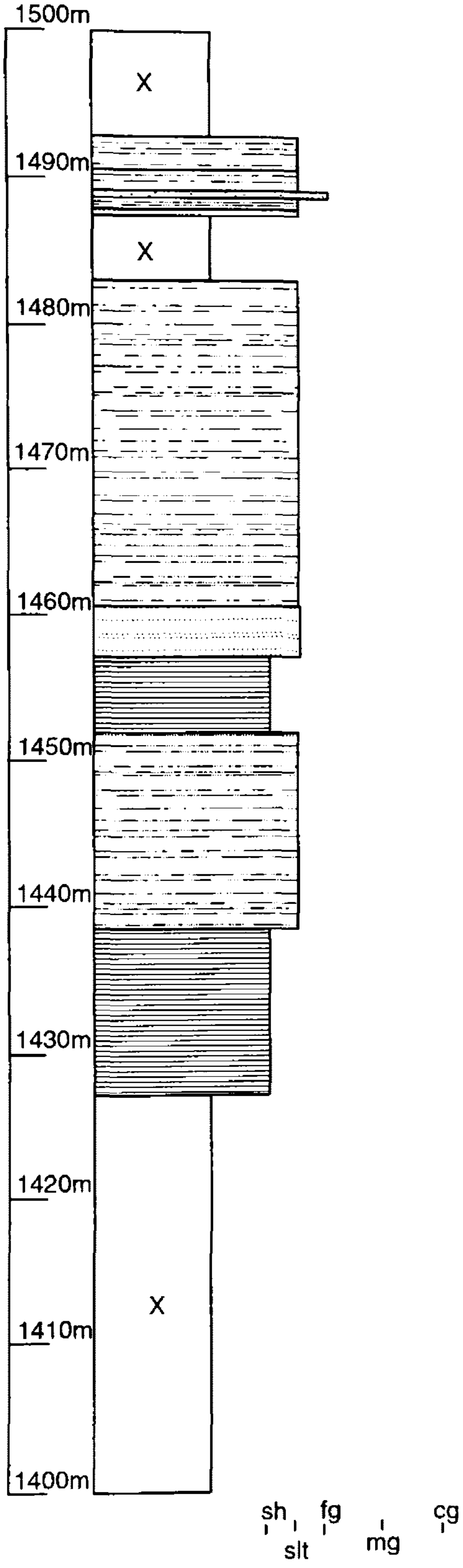
grades to fg S&P ss;low angle x-stratification

grades to mg S&P ss; plane bedded

cg S&P ss
mg S&P ss


1300m
X
1290m
diabase sill
porcellanite; green
chert; black
1280m
X
fg quartzite; grey; very resistent
siltstone; black; green mudstone breaks every .8-1m
1270m
X
grades to fg ss; fissile; olive green
1260m
f/m grn quartzite; parallel laminae
shale break
fg quartzite; parallel laminae
fg ss; fissile; black
fg quartzite; blue
1250m
grades fissile siltstone; green
fg ss; grey
X
siltstone; black
channel sequence: fg quartzite; plane bedded; grey;
alternating with shale breaks; whole sequence is lenticular
siltstone; black
1240m
x
fg quartzite; grey
siltstone; fissile; green/grey
fg S&P ss; silaceous; x-bedded
1230m
fg ss; olive green
grey quartzite
X
grades to siltstone; grey
fg ss; plane bedded; grey
shale break
x
fg ss; quartzite?; pyrite weathering? Sample 9CCC6
1220m
siltstone; dull black
amalgamated surface; f/m grained S&P ss; plane bedded
x
siltstone; fissile; black
fg ss; well sorted; grey
oyster bed
Sample 9CCC5
x
lense of fg ss; red specks Sample 9CCC4
siltstone; silaceous; fissile; green/grey
1210m
x
shale; wood fragments
x
shale; wood fragments
mg S&P ss; plane beds alternating with low angle x-stratification
x
mg S&P ss; well sorted; mudchips from underlying siltstone
siltstone; bioturbated; black grades up to olive green
1200m
x
sh
slt
fg
mg
cg


1400m
1390m
1380m
X
covered interval
1370m
Jens shale in float
1360m
Jens Formation
1350m
Coberly Formation
Inferred Contact
chilled margin; chert
diabase sill
1340m
1330m
X
covered interval
1320m
chert
1310m
X
covered interval
1300m
sh
slt
fg
mg
cg



covered interval

interbedded siltstone and shale
siltstone; symmetrically rippled; grey
fg ss; well sorted
siltstone shale lenses in siltstone; slts 10-40cm, shl 5-7cm
siltstone; HCS lamda~30cm, amp~6cm
covered interval

siltstone

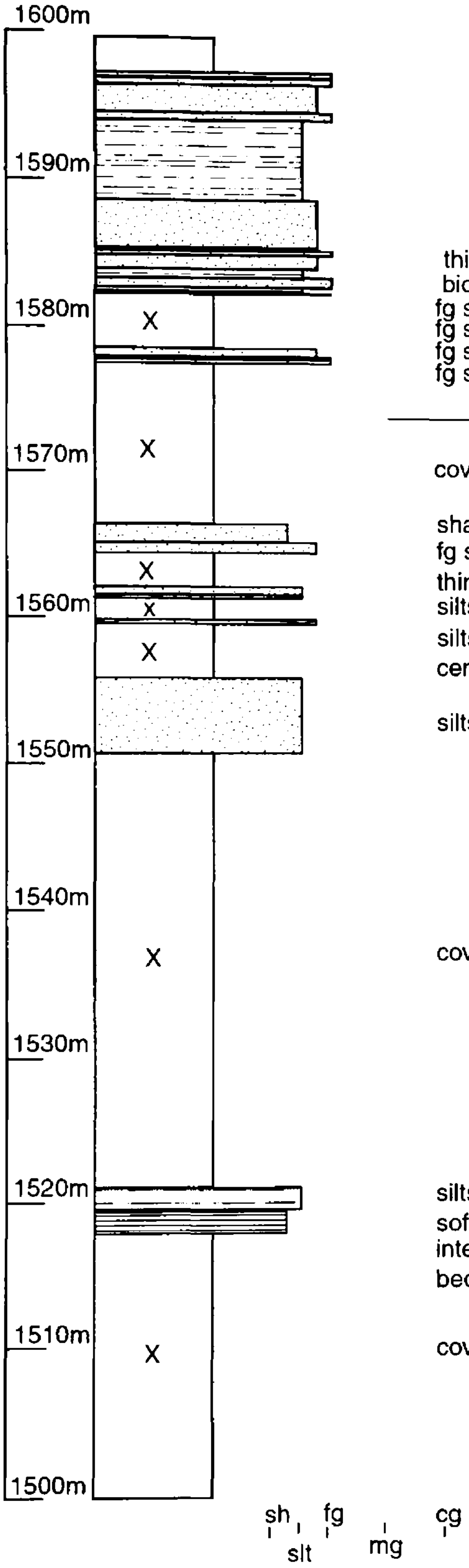
shale mixed with siltstone

shale; grey; fissile

shale interbedded with fg ss beds ~ .02-.1m thick

shale; grey; fissile

covered interval



thinly bedded fine grained ss
bioturbated siltstone
fg ss; black
fg ss (lenticular); interbedded with siltstone/shale
fg ss; plane bedded
fg ss; interbedded with lenticular shale

Carten Creek Formation

Jens Formation

Inferred Contact

covered interval

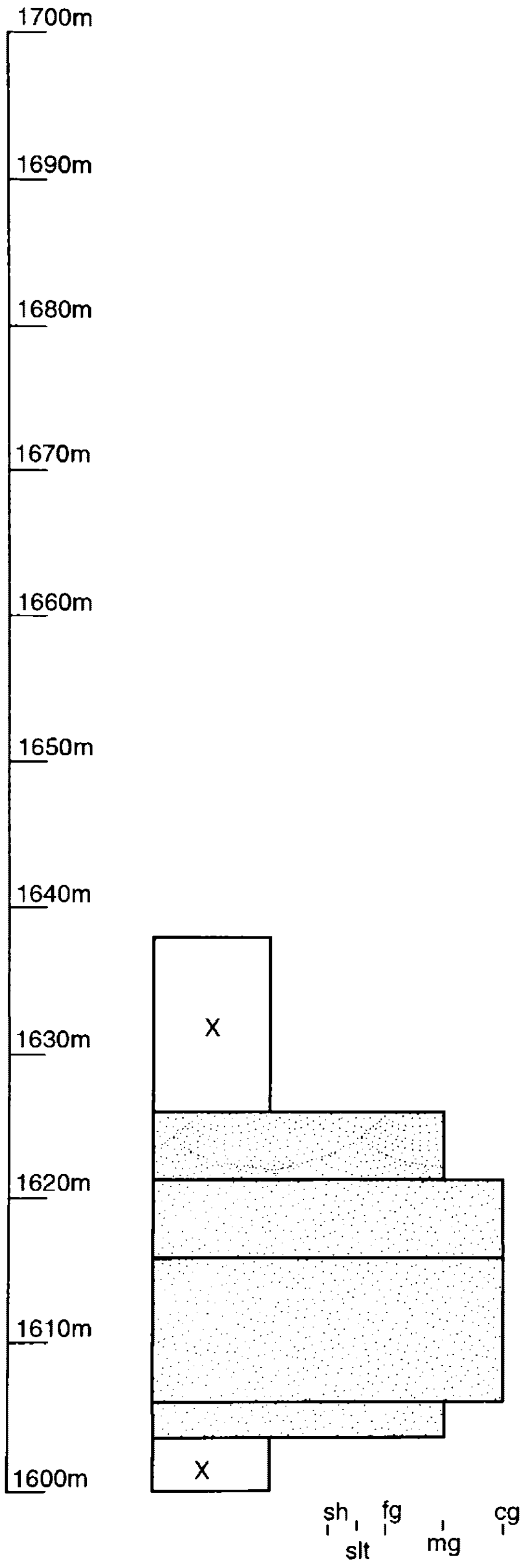
shale and siltstone interbedded
fg ss; black
thinly bedded (mm scale) siltstone; alternating sym. rippled bds
siltstone; lenticular
siltstone; shell frags; SSD caused by interbedded fg ss; well cemented
Sample 9CCJ1

siltstone; symmetrically rippled; shale interbedded

covered interval

siltstone; well cemented; HCS
soft sediment deformation; ball and pillow structures
interbedded siltstone and shale; siltstone is parallel bedded; shale is symmetrically riplled

covered interval



trough cross bedded medium grained sandstone
Sample 0CCKCC3

low angle cross stratified coarse grained sandstone

mudchips in sandstone Sampe 0CCKCC2
channelized

Appendix III

Sandstone Point Count Raw Data

Sample#	Frmtn	Q m	Q p	Cht.	K	P	Lv	Lslt	xb CO3	unid L	bt	ms	heav.	Cmt	Matr.	cmt+ma	Por	Unid T	CHK
9MDCBTC	KBT	135	6	125	0	1	0	26	2	16	0	1	0	187	0	187	1	0	500
9TBHBT1	KBT	123	1	167	0	1	1	33	0	41	0	5	1	125	2	127	0	0	500
9MDCBD3	KBD	211	5	208	0	8	18	29	0	18	0	0	0	0	0	0	0	3	500
9MDCBD1	KBD	69	0	118	0	65	136	76	6	25	0	0	0	5	0	5	0	0	500
9US12BD2	KBD	85	6	169	18	174	7	2	1	26	0	1	5	0	0	0	0	6	500
9US12BD4	KBD	31	0	178	19	223	27	2	0	2	1	3	0	10	0	10	0	4	500
9MDCBD4	KC	153	8	271	0	18	17	17	0	10	2	0	0	4	0	4	0	0	500
4b Coberly	KC	103	3	200	0	6	11	46	43	9	0	0	0	59	1	60	11	0	500
9CCC4	KC	134	2	122	0	171	15	12	2	26	3	0	2	11	0	11	0	0	500
9TBHC1	KC	262	2	112	0	40	16	12	4	28	0	0	0	20	4	24	0	0	500
9CCC2	KC	125	5	119	0	192	17	10	1	13	4	0	0	12	0	12	0	2	500
9CCC1	KC	183	3	142	0	107	6	19	0	13	1	0	0	25	0	25	0	1	500
8MCC3	KC	115	0	139	0	148	0	3	0	10	3	0	0	82	0	82	0	0	500
8MCC2	KC	14	3	130	0	243	2	3	0	21	10	11	1	62	0	62	0	0	500
0MDCKC2	KC	60	4	220	0	86	16	9	0	29	3	4	3	61	0	61	0	5	500
0CCKCC1	KCC	22	2	50	0	270	11	0	0	16	8	9	0	110	0	110	0	2	500
0CCKCC2	KCC	18	8	82	0	274	6	10	0	10	10	4	0	77	0	77	0	1	500
0CCKCC3	KCC	34	4	82	0	251	1	3	0	14	2	13	1	95	0	95	0	0	500
9 Carten Creek	KCC	180	9	204	1	6	10	23	19	14	0	0	0	24	9	33	0	0	500

* All other samples listed in Appendices I and II are in the Geological Museum Collection at the University of Montana, Missoula