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The Proterozoic Greyson-Spokane transition sequence: A stratigraphic and gravity study west-central Montana

Susan L. Bloomfield
The University of Montana

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THE PROTEROZOIC GREYSON-SPOKANE TRANSITION SEQUENCE:
A STRATIGRAPHIC AND GRAVITY STUDY,
WEST-CENTRAL MONTANA

by

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B.S., University of Delaware, 1980

Presented in partial fulfillment of the requirements for the degree of

Master of Science

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1983

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The Proterozoic Greyson-Spokane Transition Sequence: A Stratigraphic and Gravity Study, West-Central Montana

Four stratigraphic sections through the Greyson-Spokane transition sequence were measured at Trout Creek and Beaver Creek, east of the Eldorado thrust and at Wolf Creek and the Spokane Hills, west of the thrust. The transition sequence consists of four sediment types: 1) wavy couplet, 2) fine sand, 3) microlaminated couplet, and 4) coarse sand sediment types.

The four sediment types combine into three lithofacies: A, B, and C. Lithofacies A consists of the microlaminated couplet interbedded with the fine sand sediment type and represents a subtidal environment. Lithofacies B consists of the wavy couplet sediment type interbedded with fine sand beds and planar cross-bedded coarse sand beds. This lithofacies indicates an intertidal environment. Lithofacies C contains upper intertidal deposits represented by the horizontally-laminated coarse sand sediment type.

The repetitive succession of Lithofacies A, B, and C reveals an overall marine regression including four regressive-transgressive cycles. The four cycles define the transition sequence and correlate well across the four measured sections.

While the measure sections straddle the Eldorado thrust, they also straddle a proposed east-west trending Proterozoic fault zone (the Greenhorn line, Winston and others, 1982 ms.). The thickness of the transition sequence increases slightly south of the Greenhorn line possibly reflecting a higher subsidence rate. The data do not strongly suggest a fault zone. However, gravity data support evidence for changes in a tectonic style of thrusting around the Greenhorn line. Uplifted crystalline basement possibly acted as a buttress north of line causing thrusts to ramp steeply. South of the line, where no buttressing existed, the thrusts were able to ride at a low angle possibly into a down-dropped block.
Dedicated to Jan and Bill Bloomfield
for undying support and love.
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CHAPTER I
INTRODUCTION

During Middle Proterozoic time, sediments of the Belt Supergroup were deposited in a basin presently located in parts of Washington, Idaho, Montana, and southern Canada (Fig. 1). Don Winston and others (1982 ms.) proposed that the Belt basin was composed of several fault-bound blocks. The Proterozoic fault-zones between the blocks are referred to as lines (Fig. 2). They base their hypothesis on: 1) stratigraphic thickness changes across the fault zones, 2) response in Cretaceous to Paleocene thrusting, and 3) response in Eocene to Recent extension. This study tests part of Winston's hypothesis by focusing on one critical area: the intersection of the Greenhorn and Townsend lines (Fig. 3). A stratigraphic and sedimentological study of the Proterozoic Greyson-Spokane transition across the Greenhorn and Townsend lines was conducted to see if growth faults were reflected in the stratigraphic sequence or sedimentary environment. In addition, I compiled structural data and available maps and analyzed published gravity data to search for evidence of the proposed Proterozoic growth faults.

Previous Work

Several workers have mapped and described the Greyson and Spokane formations near Helena, Montana (Mertie and others, 1951; Nelson, 1963; Robinson and others, 1969; Weinberg, 1970; Bregman, 1971; Shaffer, 1971;
Figure 1. Map of Belt basin (after Harrison and others, 1974).
Figure 2. Map of proposed Proterozoic fault zones and crustal blocks in Montana (after Winston and others, 1982 MS).
Figure 3. Map showing location of measured sections (black triangles) and orientation of Greenhorn and Townsend lines.
Durham, 1972; Schmidt, 1972; Whipple, 1980; see Fig. 4). Davis and others (1963) also conducted a gravity and aeromagnetic study of the East Helena and Canyon Ferry quadrangles. Structural studies concerned with Mesozoic and Cenozoic tectonics and their effect on the Belt terrane have also been conducted in this area (Bregman, 1976; Reynolds, 1978; Woodward, 1981).

Present Study

I measured stratigraphic sections through the Greyson-Spokane transition sequence at Trout Creek, Beaver Creek, Wolf Creek, and the Spokane Hills (Fig. 5). Exact locations are given in Appendix A. All sections were measured by Brunton compass and Jacob's staff from the brown and grey, sandy shale of the upper Greyson into red sandy silt and argillite of the lower Spokane. Data from a total of 595 meters of measured section include a graphic and written log of each section compiled at a scale of 1 inch to 5 feet (Appendix B).

The gravity data used in this study came from United States Department of Defense files and United States Geological Survey Open-file reports (Appendix C). A two dimensional modelling program provided a basis for interpreting the data (Appendix D).

Structural Setting

The locations of the four measured sections spatially bracket the Eldorado thrust, the easternmost major north-northwestern-trending thrust of the overthrust belt (Mudge, 1970). The Wolf Creek and Spokane Hills sections lie to the east of the Eldorado thrust, and the Trout
Figure 4. Index to geologic maps used in compilation of geologic map of study area. Numbers are keyed to references as follows: 1, Bregman (1971); 2, Durham (1972); 3, Davis and others (1963); 4, Knopf (1963); 5, Lyons (1944); 6, Mertie and others (1951); 7, Robinson and others (1969); 8, Shaffer (1971); 9, Weinberg (1970).
Figure 5. Map showing locations of measured sections (black triangles) in relation to Eldorado thrust fault.
Creek and Beaver Creek sections lie to the west of the thrust (Fig. 5). Bregman (1971) calculated a minimum displacement of 16.9 kilometers for the Eldorado thrust based on stratigraphic thicknesses and the geometry of the thrust. Bregman (1976) also noted a change in the configuration of the thrust along the north edge of the Helena embayment. South of the Greenhorn line the Eldorado is a low-angle thrust, whereas north of the Greenhorn line the Eldorado has ramped steeply, possibly onto a Precambrian crystalline buttress (Bregman, 1976; Woodward, 1981; Winston, 1982 ms.). Reynolds (1978) recognized extensional strike slip faults and listric normal which curve westward as they approach the Greenhorn line from the south.
CHAPTER II

SEDIMENT TYPES: DESCRIPTION AND INTERPRETATION

Several lithologies occur in the Greyson-Spokane transition sequence. Although these lithologies reflect original sedimentation, diagenesis and metamorphic history, they are classified chiefly on the basis of original sedimentary characteristics because diagenesis and metamorphism are of secondary importance in constructing a paleoenvironmental model. Criteria such as composition, grain size, sorting, and primary sedimentary structures define the sediment types.

The Greyson-Spokane transition consists of four major sediment types. They are in order of decreasing abundance: 1) wavy couplets; 2) fine sand; 3) microlaminated couplets; and 4) coarse sand. Each sediment type is described individually and interpreted in terms of sedimentary processes and paleoenvironment.

Wavy Couplet Sediment Type

The wavy couplet sediment type consists of silty, very fine sand layers sharply overlain by mud layers (Fig. 6). Both sand and mud layers are continuous, forming wavy bedding as described by Reineck and Singh (1975). Sand layers 0.5 to 2.5 cm. thick show current and wave ripple cross-laminations. These layers thicken and thin with average wavelengths of 8 cm. and amplitudes of 2 cm. Most ripples are symmetrical and sharp-crested but some are flat-topped or reworked into
Figure 6. Wavy couplet sediment type.
interference patterns. Thin mud layers form drapes less than 1 cm. thick over the rippled sand layer beds. Together, a sand layer overlain by a mud layer constitutes a couplet which ranges from 0.5 to 3 cm. thick. Couplets cut by mudcracks commonly occur in this sediment type but in many parts of the section they are absent.

Interlamination of sand and clay forming wavy beds result from periods of traction-load transport and deposition from diurnal tidal currents alternating with periods of suspended-load deposition from standing water (Reineck and Singh, 1975). Because mud layers are preserved in wavy bedding, current velocities were probably low. Asymmetrical ripples in the sand layers result from tidal currents. During high water, symmetrical ripples formed by wave oscillation in shallow water and flat-topped ripples formed by receding water and subsequent exposure. Finally, clay settled from suspension in standing water onto these rippled beds. Shallow mudcracks indicate brief subaerial exposure. Mudchips were probably deposited by tidal currents in the sand layers (Fig. 7).

Many workers describe similar sedimentary packages from modern tidal environments (Reineck and Singh, 1975; Reineck, 1975; Sellwood, 1975) and others have interpreted similar Proterozoic sequences as intertidal deposits (Button and Vos, 1977; Bhattacharyya and others, 1980; Watchorn, 1980; Whipple, 1980).
Figure 7. Mudchips in the wavy couplet sediment type.
Fine Sand Sediment Type

The fine sand sediment type consists of very fine-grained, well-sorted, quartzose sand beds which average 3 to 8 cm. in thickness. Locally they range up to 40 cm. thick. Where fine sand beds are less than 5 cm. thick, internal stratification is dominated by asymmetrical ripple cross-laminations. As in the wavy couplet sediment type, they mostly appear sharp-crested, but are locally flat-topped and reworked. Beds thicker than 5 cm. are horizontally-laminated at the base, changing to ripple cross-laminated near the top (Fig. 8). Fine sand beds capped by mud drapes are interstratified with the wavy couplet sediment type.

Horizontally-laminated sand beds form in the plane-bed phase of the upper flow regime by traction-load current sedimentation (Simons and others, 1965). Flat laminations have also been produced in a flume by migrating oscillation ripples (McBride and others, 1975). Several workers have interpreted horizontally-laminated and ripple-topped sand layers as subtidal to intertidal deposits. Button and Vos (1977) and Klein (1970) proposed shallow subtidal sand bodies or bars as a possible explanation for these types of sand beds. Some authors postulate a more landward environment, such as shoreface deposits or reworked tidal sand shoals (Bhattacharyya and others, 1980; Watchorn, 1980). Ripple-topped sand beds may also be evidence for late-stage emergence run-off in an intertidal flat (Watchorn, 1980). Fine sand beds probably formed in environments that ranged from subtidal to high intertidal. They are common throughout the section regardless of evidence for subaerial exposure in the surrounding wavy couplet sediment type.
Figure 8. Fine sand bed horizontally-laminated at base, changing to current ripple cross-laminated near top.
The frequency and regularity of fine sand beds suggest that they represent fair weather processes. Whipple (1980) interprets fining-upward sequences that begin with similar fine sand beds as fluvial or sheetwash deposits in the Upper Middle Spokane. The fine sand beds of the Greyson-Spokane transition sequence probably represent fluvial or sheetwash deposits reworked by tides.

**Microlaminated Couplet Sediment Type**

The microlaminated couplet sediment type consists of millimeter-scale silt layers sharply overlain by mud layers of the same scale. Individual couplets are less than 5 mm. thick and are laterally continuous for several meters. Locally, silt layers pinch out or pass laterally into millimeter-scale foreset cross-laminations. Couple thickness ranges from less than 1 to 5 mm. and composition ranges from terrigenous through carbonaceous or calcareous. Thinner, carbonaceous couplets are commonly dislocated as tabular sheets and form centimeter-scale soft sediment folds. Locally, sets of couplets are truncated by scour and fill structures (Fig. 9). These carbonaceous couplets commonly occur interstratified with dolomitic couplets, which are normally thicker and contain "molar-tooth" (Fig. 10; see O'Connor, 1972, for description of molar-tooth). Stromatolites and stromatoforms are interstratified with molar-tooth structures.

Silt layers overlain by clay layers reflect alternating current velocities, possibly from tidal currents. Variations in currents and subsequent reworking caused the laminations (Thompson, 1975). The
Figure 9. Soft-sediment deformation in carbonaceous microlaminated couplets.
Figure 10. Molar-tooth structures in calcareous microlaminated couplets.
carbon-rich couplets incorporate organic material which may represent very thin cohesive mats that required slightly higher current velocities to remove (Grotzinger, 1981). Stronger, possibly storm currents induced the soft-sediment folds and scour and fill structures in the carbonaceous couplets. Stromatolites have been recognized as both intertidal and supratidal indicators (Reineck and Singh, 1975; Button and Vos, 1977) and as subtidal indicators as well (Gebelein, 1969; Bhattacharyya and others, 1980). Stromatolites within the microlaminated couplet sediment type are probably a good indicator for the subtidal environment because they lack any evidence for subaerial exposure.

**Coarse Sand Sediment Type**

A. Horizontally-laminated Coarse Sand Subtype

The horizontally-laminated coarse sand subtype consists of individual, horizontally-laminated sand beds up to 80 cm. thick (Fig. 11). Grains probably from the coarse sand environment are scattered in the fine sand sediment type and in the sand layers of the wavy couplet sediment type. These beds are interstratified with the wavy couplet sediment type.

Horizontally-laminated beds of the coarse sand sediment type record deposition from the upper flow regime like those of the fine sand sediment type. However, this sediment subtype is less abundant and includes a wider range of grain size and sorting than the fine sand sediment type. Larger grain size and individual bed size indicate
Figure 11. Horizontally-laminated coarse sand bed interbedded with the wavy couplet sediment type.
greater and more variable current velocities and perhaps a different source area, possibly reflecting transport by longshore currents (Winston, pers. comm.). Bhattacharyya and others (1980) interpreted poorly-sorted, horizontally-laminated sand beds as high intertidal storm deposits. Variations in bed size, grain size, and sorting plus association with subaerial sedimentary structures also support this hypothesis.

B. Planar Cross-bedded Coarse Sand Subtype

Planar cross-bedded sand beds form low angle tabular sets which range from 10 to 50 cm. thick (Fig. 12). Individual sets are continuous across several meters of outcrop but locally contain foreset laminations or are truncated by other low-angle cross-beds. This subtype is interbedded with the wavy couplet sediment type.

Low-angle planar cross-beds may represent upper flow regime processes in the marine foreshore. Slight deviations in beach slope between tidal cycles causes truncation of previously deposited layers and therefore produces low-angle cross-bedding that is typical of foreshore deposits (Clifton, 1969). Foresets within this subtype may represent micro-delta bar deposits formed by washover fans (Schwartz, 1982).
Figure 12. Low-angle planar cross-bedded coarse sand bed interbedded with the wavy couplet sediment type.
CHAPTER III
CORRELATION AND STRATIGRAPHIC SYNTHESIS

The last chapter discussed individual sediment types and proposed some depositional environments. The vertical succession of these sediment types in the Greyson-Spokane transition sequence defines three lithofacies labelled A, B, and C. This section 1) describes specific depositional environments for each of the lithofacies based on sediment type and stratigraphic juxtaposition, 2) correlates the measured sections, and 3) discusses conclusions based on the stratigraphy and sedimentation of the Greyson-Spokane transition sequence.

Lithofacies A

Lithofacies A consists primarily of the microlaminated couplet sediment type with occasional interstratified beds of the fine sand sediment type. Parallel lamination, absence of subaerial sedimentary structures, common dolomite, and stromatolites typify this lithofacies.

The structures within this lithofacies are characteristic of subtidal deposits. Carbonaceous microlaminated couplets probably formed by algal mats and stromatolites indicate deposition in the photic zone. Therefore, the subtidal environment of this part of the Helena embayment was probably shallow. The fine sand beds within this subfacies are generally thicker and less common than those interbedded with the wavy couplet sediment type. Subtidal fine sand beds were probably deposited and reworked by longshore currents (Whipple, 1980).
Lithofacies B

Lithofacies B consists primarily of interbedded wavy couplet and fine sand sediment types. The planar cross-bedded coarse sand subtype also occurs in this lithofacies. Mudcracks and mudchips commonly occur within the wavy couplets sediment type. Wavy bedding along with desiccation structures generally indicates an intertidal flat environment. Horizontally-laminated fine sand beds represent reworked, lower intertidal sand shoals. Planar cross-bedded coarse sand beds represent beach deposits also in a lower intertidal environment.

Lithofacies C

Lithofacies C consists of the horizontally-laminated coarse sand sediment subtype. This lithofacies occurs interstratified with the wavy couplet sediment type and is interpreted as an upper intertidal deposit. Whipple (1980) interpreted similar deposits in the Upper Spokane formation as beach berm deposits. Bhattacharyya and others (1980) interpreted horizontally-laminated coarse sand beds to be storm deposits which resulted from more intense wave action and turbulence.

Correlation

Each measured section has been subdivided into sequences of Lithofacies A, B and C. Correlation based on the succession of lithofacies reveals four marine regressive-transgressive cycles. Each cycle comprises an upward succession of Lithofacies ABCB (Fig. 13).
Figure 13. Schematic stratigraphic column showing four regressive-transgressive cycles.
The four cycles form the transition sequence and each cycle correlates well throughout all four measured sections (Fig. 14). Sections at Wolf Creek, Trout Creek, and Beaver Creek are approximately 100 meters thick while the Spokane Hills section is 220 meters thick.

Stratigraphic Synthesis

The Greyson-Spokane transition sequence represents a regressive sequence in a tide-dominated environment. However, it does not fit the "classic" tidal sequence because: 1) it lacks tidal channel deposits, and 2) lack of documented bimodal-bipolar current directions.

Several workers have interpreted Precambrian sequences (Klein, 1970a; Siedlecka, 1978) and Paleozoic sequences (Barnes and Klein, 1975; Walker and Harms, 1975) which lack evidence for tidal channels as tidal deposits. Several conditions might explain the absence of tidal channels. In a predominantly fine-grained system, a large volume of silt and clay that overwhelms sand may diminish development of beaches and shoals. Therefore, unrestricted tidal currents move over the flats in broad, uniform flow with little tendency to form channels. Lack of vegetation in the Proterozoic and the subsequent lack of a cohesive framework binding the surface of the tidal flat also enabled tidal currents to flow uniformly over the flat.

Sedimentary structures and bed configuration in the Greyson-Spokane transition sequence suggest an environment with low hydraulic energy. Extensive lateral continuity of individual beds suggest a broad, flat, featureless tidal flat and shelf. Nearshore wave intensity
Correlation of regressive transgressive cycles

Scale in meters

Figure 14. Correlation across four measured sections based on succession of lithofacies A, B, C, and D.
was probably generated by local winds rather than the wind fetch across the entire Belt sea. Because of the very large, shallow shelf, waves generated further out in deeper water "felt bottom" and lost energy as they travelled to shore. Additional evidence for low energy includes: 1) suspension-deposited silt and clay in the subtidal and intertidal zones rather than cross-bedded sands of more turbulent systems, and 2) preserved clay in wavy bedding rather than flaser bedding in the current-formed deposits.

Only apparent current directions were observed at the measured sections, therefore bimodal-bipolar current directions could not be documented. Although bimodal-bipolar current directions provide strong evidence for tidal currents, not all tidal deposits are bipolar. Time-velocity asymmetry produces unimodal crossbed directions in some tidal regimes (Klein, 1971; Watchorn, 1980). Therefore, even though tidal channels and bimodal-bipolar current directions are not documented in the Greyson-Spokane transition zone, a tidal flat interpretation is still possible.

Very fine sand, silt, and clay dominate the Greyson-Spokane transition zone. In the upper middle Spokane Formation, Whipple (1980) interprets horizontally-laminated subfeldspathic arenites as delta sheetwash and braided alluvial deposits surrounded by tidal flat deposits. The fluvial sediment input certainly affected sedimentation in the Spokane Formation. However, fine sand beds in the Greyson-Spokane transition sequence never occur in sets and never appear to be channel deposits. They probably represent totally reworked
sediments of a tidal environment whereas higher in the Spokane, they may represent primary fluvial deposits. The coarse sand size in the beach and storm deposits may indicate a different source with transport by longshore currents.
CHAPTER IV
GRAVITY ANALYSIS

The purpose of a gravity analysis of the study area was to look for more evidence for the proposed Proterozoic fault zones. Ideally, blocks of crystalline basement vertically offset near the fault zones would cause lateral changes in density and produce gentle, low frequency gravity trends. High frequency anomalies result from shallower sources. This study examines regional trends, anomalous residual features, and discusses interpretation of these features with respect to the proposed fault zones.

Gravity data were obtained from the U.S. Department of Defense. I hand-contoured Bouguer anomaly values at 5 milligal intervals over the study area and used a computer program to model a gravity profile over the area. Density contrasts are based on values published by Davis and others (1963) and Harrison and others (1980).

A generalized geologic map and Bouguer gravity map are shown in Figures 15 and 16. Major structural features include: 1) the Eldorado and related thrusts (York, Trout Creek, and Wolf Creek thrusts), 2) the exposed Paleozoic rocks north and east of the Scout Camp thrust, 3) the Helena and Townsend Valleys, and 4) the Boulder batholith and other Cretaceous intrusives.

The limited availability of gravity data beyond the study area made it difficult to discern a regional trend. Ballard (1980).
Figure 15. Generalized geologic map of the study area. See figure 4 for compilation index.
Figure 15.
Figure 16. Bouguer gravity map of the study area. Contours at 5 mgal. Cross-section in figure 17 from A to A'.
determined the regional trend near Helena to be a southwest-dipping plane which varies no more than 5 milligals through the study area. Therefore, regional gravity was ignored because of its negligible effect over the study area.

The higher frequency anomalies are well correlated with local geology. The Eldorado and related thrusts are reflected by a relatively high ridge which follows the thrust's north-northwesterly trend. Gravity lows with amplitudes of 20 to 25 milligals coincide with the Helena and Townsend Valleys and their low density fill (about 2.4 g/cm3). The Boulder batholith and satellite quartz monzonite intrusives also show up as gravity lows because of their negative density contrast with Belt rocks. Belt rocks generally coincide with higher gravity readings than the Paleozoic rocks so that the gravity low situated just south and west of the Scout Camp thrust and east of the Eldorado thrust requires further explanation.

Figure 17 shows the observed gravity and calculated anomalies from A to A' on Figure 16, a subsurface structure map and assumed density contrasts. In the cross-section, the gravity low over the Helena Valley is best modelled using a -0.4 g/cm3 density contrast with surrounding Belt rocks. Using this model, basin fill approximates 2000 meters thick, in good agreement with values of 1800 meters obtained by Davis and others (1963). The gravity high to the east of Helena Valley may be explained by Belt rocks ramped over Belt rocks. Belt rocks also crop out immediately east of the York and associated thrusts, although the gravity is anomalously low. Further to the
GRAVITY PROFILE
ACROSS A – A'

Figure 17. Observed and calculated gravity anomalies from A to A' with model and densities used given below.
east, Paleozoic rocks are exposed along the Scout Camp thrust, and generally cover the northeastern corner of the study area. The anomalous gravity low over the Belt rocks south of the Scout Camp thrust may best be explained by Belt rocks thrust over Paleozoic rocks. A gravity model which places a lower density slab beneath Belt rocks in between the Eldorado and Scout Camp thrusts adequately accounts for the observed gravity low. As shown in Figure 17, the low density slab is flat-lying and near the surface.

The high frequency gravity data of this study are well explained by near surface geology, such as basin fill, intrusive stocks, and major thrust faults. Crystalline basement can not be delineated because the maximum anomaly expected over the uplifted basement block would be 10 to 12 milligals (using +0.1 g/cm³ density contrast at 2400 meters depth). Near surface structures produce anomalies with amplitudes of 20 to 25 milligals which might mask lower amplitude anomalies. However, it is reasonable to discuss the possible control of near surface structures by deeper structures. Several workers note changes in tectonic style around the area marked by the intersection of Winston's (1982 ms.) Greenhorn and Townsend lines.

Major thrusts within the Helena embayment steepen and curve westward as they approach the Greenhorn line (Reynolds, 1978) and pass into left-lateral strike slip faults north of the line (Birkholtz, 1967; Bregman, 1976; Woodward, 1981; Fig. 18). The Eldorado thrust also shifts westward north of the Greenhorn line. Bregman (1971, 1976) noticed that the thrust changed from high-angle imbricate slices north
of the Helena embayment to a single, low-angle slab near the Greenhorn line. He concluded that the imbricate thrusts north of the line resulted from buttressing by the crystalline basement. South of the line, where no similar buttressing exists, the thrust was able to ride at a low angle into the Helena embayment (Fig. 18). The most significant finding of this gravity study supports the hypothesis of low-angle, single sheet thrusting in the Helena embayment. Presumably, Belt rocks moved over nearly flat-lying Paleozoic rocks as a single sheet without the buttressing effect from a crystalline basement block.

The gravity part of this study did not prompt any new conclusions about crustal or near surface structure. Also in part, because of limited data outside the study area, there are no indications of "deep" basement offsets in the data. However, they do suggest a change in the tectonic style of the eastern thrust belt near Helena, which might represent a change in deeper crustal configuration.
Figure 18. Map showing change in orientation of the Eldorado thrust near the Greenhorn line of Winston and others (1982 MS).
CHAPTER V

CONCLUSIONS

The stratigraphy and sedimentary structures of the Greyson-Spokane transition sequence reflect sedimentation in the intertidal to subtidal zone of a shallow, flat shelf. Rocks in the transition sequence record an overall marine regression including four regressive-transgressive cycles. The four cycles define the transition sequence and are well correlated across the four measured sections. The occurrence of both horizontally-laminated fine sand beds and horizontally-laminated coarse sand beds suggests two source areas. Sheetwash and fluvial deposits which occur in the Upper Middle Spokane Formation (Whipple, 1980) probably represent the source for the abundant fine sand fraction. Variation in sediment input from this source may explain changes in the proportion of fine sand to silt and clay size material throughout the Greyson-Spokane transition sequence. Coarse sand, possibly reflecting a different source, may have been brought in by longshore currents.

Gravity data in the area encompassing the measured sections generally reflect near surface geology and structure. An anomalous gravity low over Belt rocks on the upper plate of the Scout Camp thrust may be modelled by placing a thin slab of Belt rocks over a nearly horizontal block of lower density, Paleozoic rocks. These results suggest that the Scout Camp thrust is a low-angle, single
sheet thrust, and agree with Bregman's (1971, 1976) conclusions about the Eldorado thrust to the west.

Evidence for Proterozoic fault zones from the data in this thesis is similar to data used by Winston and others (1982 ms.). Their primary evidence consists of stratigraphic thickness changes and differential thrusting response across their proposed lines. North of the Greenhorn line and east of the Townsend line, the Greyson-Spokane transition sequence is approximately 100 meters thick. South of the Greenhorn line, in the Helena embayment, the sequence is 220 meters thick. Since the measured sections are located on two different thrust plates, only sections on the same plate may be correlated with known distance between them. Some reconstruction is necessary to compare sections across the Eldorado thrust. Several estimates of shortening from the Idaho-Wyoming and Canadian thrust belts fall very close to 50 percent (Royce and others, 1975). The Trout Creek (120 meters) and Spokane Hills (240 meters) sections lie on opposite sides of the Eldorado thrust approximately 10 kilometers apart. Using the 50 percent shortening value, the minimum distance between two sections which straddle the Greenhorn line increases to 20 kilometers. This displacement value agrees fairly well with Bregman's (1971) estimate of 16.9 kilometers. A slight thickness change south of the Greenhorn line may suggest a higher rate of subsidence however, evidence for faulting seems weak.

An additional conclusion drawn from this study is the suggestion for a mappable contact between the Greyson and Spokane Formation.
Previous workers used the first appearance of red color in the rocks for the contact (Mertie and others, 1951; Durham, 1972). The lowest red beds vary in stratigraphic level from section to section in the transition sequence. A change in primary sedimentary features rather than secondary diagenetic features would be more clearly definable and consistent. For this reason, I propose that the contact be drawn at the top of the last calcareous microlaminated couplet sequence. This would reduce the confusion caused by the irregular diagenetic red and green coloration of the rocks in the Greyson-Spokane transition sequence.
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Appendix A

Exact locations of measured sections
WOLF CREEK SECTION

Located in Section 15, T.14 N., R.4 W.

(2.8 miles south on I-15 from Wolf Creek, Montana)
BEAVER CREEK SECTION

Located in Section 11, T.12 N., R.2 W.
(1.3 miles east from Nelson, Montana)
TROUT CREEK SECTION

Located in Section 9, T.11 N., R.2 W.
SPOKANE HILLS SECTION

Located in Section 12, T. 10 N., R.2 W.

(on Curly McMaster's property)
Appendix B

Measured Sections
50 B
Green horn-laminated silt-gypt and ripple laminated sands with many silt-agglutinate concretions. Horns sands up to 5 cm, X-beded at top. Sands more dominant at top of unit.

45 C
Below 45' 5" coarse horn-lam sandstone 1.5-2.5% well sorted, sub-well rounded almost exclusively quartz 60% Pink, green

40 B
Sand below C is calcareous, contains horn-squashed clumps very tiny, need hand lens to see

35 D
Very fine sandy or calcareous silty limestone with small 1 cm MT (53)

30 C
Coarse lam seashore lag overlain by slightly calcareous, blind lime concretions. Some look like RAPLAM, with similar slight cement, no mp-ups. Up-section, some interconnected very fine MT sands (1-3 cm), beds are irregular, with pinch and swell.

25 B
Contrares, horizontally laminated, grain siltite agglutinate complete with some small (2 cm) soft-bedded, ed set structures. Complete above. Concretes become larger, up section (1-5 cm). Interbedded with horns laminated and ripple * laminated Quick, very fine grained and quartz. Sands > 1 cm are horn, guiding to ripple, 5 cm are just applied. Many sands have coarse lag on seashore base. Sands near A contain some tapers of sub-rounded quartz 1.5-2.5% with MT 10%.

20 C
Fiddler, with small MT units (another at 12'). Coarse sand with seashore base at 20' is 18 cm WJP, slightly calcareous, mod. sorted, sub-rounded 10-25% quartz grains with 17% fiddler, horns, laminated. The very bedding is complete.

15 B

10 A
Very calcareous layer (separates black RAPLAM from green siltite)

WOLF CREEK SECTION 430A.
<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>91'</td>
<td>Interbedded 1&quot; horst-ripple laminated sand with many green silt-mudstone cements. Becomes predominantly green at 91'</td>
</tr>
<tr>
<td>85</td>
<td>Interbedded horst-ripple laminated green sands (fairly regularly spaced - 3-8&quot;) 2-4&quot; thick and fine grained, well red and green cements. Sand - grey-green, silt - red, ripples, good mudcracks</td>
</tr>
<tr>
<td>75</td>
<td>Fault</td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>Interbedded X-interbedded 1-3 cm sands and very green silt-mudstones, couplets. Mottled red clay at 55' and 9 cm thick. Fine-grained green quartzite</td>
</tr>
<tr>
<td>55</td>
<td>Interbedded green arenaceous strata, few short couplets, 1 cm thick. Interbedded sandstone and siltstone. Pore spaces are open to close.</td>
</tr>
<tr>
<td>50</td>
<td>Calcite breccia cement up to 53'2&quot;.</td>
</tr>
</tbody>
</table>
**Wolf Creek - P. 3**

At 149', 30mm coarse 1.0-2.0 d well sorted, sub-rounded quartzite (WT)

At 144', 125mm coarse 2.0-7.5 s well sorted, sub-rounded quartzite (porear)

Slightly calcareous (WT)

Interbedded ripple-laminated green fine quartzite with gum, sandy silty-aggregate
crystals. Bedding slightly wavy, bands. Further apart, occasional mud cracks
Upper section more sand, larger crystals 1.0m, more rippleeds, wavy bedding

Black sand at 144', range very fine-grained sands 2-7mm domes. Grain
upward to green aggleite (WT)

**Repeated Section**

Black, hazy and wavy bedded MT (random hazy, mostly horizontal oriented) sand-
stone, very fine-grained, very calcareous (WT)

Very hazy laminated quartz and black very fine sands 2mm, with a black aggleite
1-2mm pebbles, becoming more calcareous, upper section (WT)

Same but very scarce wackestone, less calcareous, SRT

**Wolf Creek Section 100-150'**
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>At 195', course 2.0-3.0% poorly sorted, sub-rounded, feldspathic sand, lamind. 4.5% grades into wavy green coalecs. sands (13) slightly calcareous.</td>
</tr>
<tr>
<td>195</td>
<td>Intermixed ripple lamination. Sands 1-2&quot; near base, very chloritic, increasing to 3-4&quot;, with grey, very green coalecs. Occasional rip-ups, completes are black 190-195'.</td>
</tr>
<tr>
<td>185</td>
<td>Coarse 1.5-2.0% carbonaceous, yellow, one-sixth quartzite, dominantly quartz, feldspar, pink, shelly, beds 4.6 cm (pink 6 and 7) contains white 192. END OF REPEATED SECTION</td>
</tr>
<tr>
<td>170</td>
<td>At 168', black, stratified sand with some MT. 9&quot; followed by fine black coalecs.</td>
</tr>
<tr>
<td>165</td>
<td>Black, feldspar, phyllitic, argillic, wettens orange, lots of soft and deformation blacking on 3 mm scale. microcracks slightly calcareous. (132)</td>
</tr>
<tr>
<td>155</td>
<td>Interstraddled ricer sands and very siltaceous coalecs.</td>
</tr>
</tbody>
</table>

**Plot**

![Plot](image)

**Note**

- 30 ft of repeated section.
- **WEIRD STRUCTURE AROUND 150'**
- **REPEATED SECTION DUE TO THIS FAULT**
Wolf Creek - P.5

200

Coupled with trees, several dikes run through → at 245', dikes, covered by trees.

Same except back to quartz, sand units becoming sparse, green silt-micaite complex are not as rippled, lots of ripples, lots of chertite from sicken along fault 6020.

Metamorphosed rock near dikes (O50) (date 1127?)

Met in a pinkish and black quartzite.

Same as below except some sandy beds are reddish-brown.

friable, Quartz, less sand, more ripples becoming more deep moron up section.

At 200' and 204", 10 cm very fine 3.0-3.25 mm horizontal laminated quartz, while quartzite white fine into interbedded fine sand with some green sill-micaite complex 2.5 mm, sands, 3-8 cm, lots of recrystallization. Then sand, no ripple interbedded, thicker ones are brown-lamin to ripples at top. Some modern ones (O21).
At 260', 37 on course 120-260, poor mud, show, strata inclined 90°

At 275 - 275 1/2', 3-8' Nora ripple sands with slivers in an angle of gneis argillite, to 280' are sandy, many silicilite 6-8 mm complete sands are 1-2'

11 m water lath sandstone (375), black, very fine quartzite, brown, sift

Lingwal ripple-lam sands and many complete, ripples, mudcracks

Relatively heavy, slightly bluish, subangular quartz 1-2 mm, coated by feldspar, well-rounded encase and not all shown, giving very good contact.

Same?? Too high to be seen by me anyway
WOLK CREEK SECTION - 2.7

- 1st unit: red, grey, compact, more evenly sandier (coarser), lots of rip-ups, sequence sometimes gray to brown, slightly clay.

- 2nd unit: red, sandy, slightly grey, 1-2mm sands are quartz, 1" ripple sands are green.

- 3rd unit: massive, fine-grained red, altered from red, cemented from red, quartz.

- From 320-340', very fine-grained, green, silty, angular, less well cemented. Here and there occasional ripples in sand layers, very few calcite. 3mm clay. Lots of aug. clay.

- At 266' 3", upper part grey, 1-2mm red, mud chips, green, small sands rear.

- At 335' 7", source shales, green, sandy, coarse (likely chlorite(?))

- At 266' 2" coal, muriatic, clay, carbonized coal.

- Near coal, slight olive green, 3mm angular.

- Scattering green, rippled, 1mm. Sands with red mud chips, mudcracks, forming up to red argillite.

- Same as above, but sand is all green.

- At 241', very fine-grained, greener, calcareous marine fragments at 397' 2", arenaceous, very fine-grained, 5mm sand, some 2-5mm pebbles (like Trust but on road?).

- Sandstone (from previous page).
Wolf Creek Section - P. B.     

Green, sandy slightly sandy, 15 feet agglomerates

At 393' 8" sepiolite, very stratified argillaceous sandstone

Sand, except at 393', coarse and thinner, more continuous, still
many sand ripples. 5 millimeters, 2 millimeters. 3 millimeters - 364'

Getting more sandy - 3" air conv., some more, non-repeated. 6 times, 1 time,
non-repeated cycle. 3" dense argonite sand. 364'

Red, new

Green sandy, sandy silt, argillite and 1-2" sands, except 6 millimeters - 3" mud
shells,贝壳

At 370', 20 cm, very fine mg., well sorted, gray-white quartzite, grades 1-2 cm.

some parts adding. 360'

At 366', becomes constantly gray, still gray, slightly sandy, sandy 639.
mercury, perfectly translucent.

At 366', 20 cm, dense to 10 s, very poorly sorted well rounded, brown, sand, sand
of medium crystals. 5 millimeters, argillite, sand, sandest ph. medium, long, of red argillite. 639

Sand, a little more even (see 1), growing to have a reticulated appearance
(in levels - jittery)
BEAVER CREEK SECTION - K 1

45

COVERED

C

Interbedded thin 5mm-2cm, slightly wavy black sandy silt-argillite complets, with 2-10cm sandy (dolomitic) beds

35

At 26', 12cm massive, very fine-grained, gray quartzite, slightly calcareous (B2)

25

At 26', 10cm coarse, 1-3mm horiz lam, black silt-argillite, poor exposure, covered by scattered soil

15

Thinly laminated 2cm complets, large 5-6cm nodule, gaps,stromataforma SSD, (C2) + 24cm

10

Interbedded 5-15mm sandy, black, dolomitic argillite (very rare clasts) with 3-7cm comressible silts (E2) calcarous, stratified A-15, nodule, teeth, eggs, and insect (generally) increasing in carbonate content.
BEAVER CREEK SECTION - P.2

Wavy, 1-2cm quartz silt, agglomerates grade into very flat, horizontally
bedded, agglomerates becoming increasingly sandy and dolomite

At 28'6", 48cm, very flinty limestone with large molar tooth conch, 30cm, grades into thin-bedded 5mm, quartz sand complete Bc

Covered

22 cm of gray silt, interstratified 2-12 cm coarse, poorly sorted sand

At 50', 80 cm red, coarse 1.5-3.5 cm, poorly sorted, subrounded, 41% feldspar
quartz, slightly calcareous m/calcite in fractures, fines upw ard (some source) border, laminated

Interbedded quartz, less calcareous, sandy, siltite, agglomerate complete bedding
1mm-3mm, wavy, with 10-40cm wavy, fine-grained sands

Covered
BEAVER CREEK SECTION - P. 3.

COVERED

Interbedded many green silt-sandstones, complete to 1cm with some 5-10cm sandy rippled beds, some coarse sandstones

1. SILL

38 cm

Interbedded slightly many green silt-sandstones with small 2-5mm pebbles and small sands, complete 2cm - 3cm with fine-grained green quartzite containing less and less stringers of coarse, poorly sorted, surounded clasts, interference ripple marks

Interbedded many green, silt-sandstones, complete to 1cm with some 5-10cm sandy rippled beds, some coarse sandstones

2. Holslam, calcareous, 10-25p, angular-rounded green quartzite, poorly sorted E5 B 25

Finely laminated, hols, fine dolomite sands, with some limnetic layers 2cm with MT cavities

3. SILL

Interbedded sandy micaceous, over, Many silt-sandstones complete with

2 sandy limestone, irregular bedding, selfared deformation E5 3rd

Fine has lots of MT, limits. Each interval is 20cm
**BEAVER CREEK SECTION - P. 4**

- *Wavy, thin-beded, blackish-gray silt-augillite compts., clay stringers, ripple marks*
  
- **B.**
  - Fine, blackish-gray quartzite
  - Fine black silt-augillite 1-2 mm compts., clay stringers, slightly wavy
  - Very calcareous, black siltite with large mudrubs (B13)
  - Black, very fine silt-augilite quartzite, with coarse 250-100 siltites, micaceous (B1)
  - Fine, green, micaceous, rippled quartzite

- **FAULT A**
  - Very fine grey quartzite interbedded with black siltite 70 cm, very calcareous, base and upper x-laminated

- **185**
  - 44.1 cm thin black, micaceous, bivalve-rich augillite

- **B**
  - Interbedded sandy, wavy, green 1-2 mm siltite-augillite compts. and 5-12 cm fine, hor. lam., green sand. Sands have cementing bases, grade into compts.

- **COVERED**

- **SILL**
  - 75 cm
BEAVER CREEK SECTION - P.G

COV.

A
5-20 cm lens, planar and 2-3 cm triangles. Interbedded. 85% of quartzite, black and gray color, calcarcous, interbedded with black argillite (25%)

Thin 5 cm, Mt., chert-like form limestone
detrital BIVALVE

COV.

A
Unit below graptolitic, calcareous, Mt., crinoid, pinch, swell, roll-over, salt-graded, large rip-up (intralastic), slumping and scoured marks

1.5 mtr., very fine grt. horiz. laminated black quartzite with some small, broad ripples (calcarcous) (5%)

Unit below fines upward to wavy, sandy, mud-cracked surface and is further overlain by 2-3 cm thick, dimly rippled into black, sandy, slightly wavy argillite

C
Poorly sorted graptolitic, fine, 1 cm, (in 30% ) grey to maroon, flat, very slightly calcareous (due to secondary calcite veins) black, (25%) horiz. laminated (contains calcarcous ripples)

Same grading into more horizontal, 5 cm graded, finer black calcite
BEAVER CREEK SECTION - P.7

B
Interbedded very fine grained argillite comblets with bedding with sandy layers, pinch and swell, ripple marks, X: bedding

COVERED

C
15 cm. + veins (0.5 cm.) partly coated; extra-rounded, glassy, quartzite, calcareous (slightly like Breccia quartzite) (2)

Sm. - Zon.0 m. grum argillite comblets, clay rip-ups, slightly wavy bedding, some red argillites

COVERED
BEAVER CREEK SECTION - P. 8 (LAST PAGE)

Interbedded 2-5 cm horiz but mainly ripple sands. Fining upward to agglutite, complete 7-12 cm basal agglutites - red, sandy black. Weathered, greenish, lots of mud streaks.
<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>COVERED</td>
</tr>
<tr>
<td>40</td>
<td>Unlaminated, 24cm basalt. 30-40 cm pinkish (slightly feldsparic quartzite)</td>
</tr>
<tr>
<td>30</td>
<td>COVERED</td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Similar to 9-5', brown, fine-grained, small pebbles, black, occasional soft-sediment deformation</td>
</tr>
<tr>
<td>5</td>
<td>At 5', molar tooth (very horned ribbons), MT ripples, bedding, S and MT and rip-up in some layers. Interbedded with 1cm silty layers.</td>
</tr>
<tr>
<td>0</td>
<td>Buff-colored resistant silt, thin-bedded, 2-5mm horn, laminated very fine-grained. MT, quartzite, silty, thin, continuous, sometimes slightly vesicular. Dolomite.</td>
</tr>
</tbody>
</table>
Trout Creek Section - P.T.

A

Poor exposure, 5mm bedded, dark grey, fine-sandy silt, agilitic
complits, float sand.

Covered
TROUT CREEK SECTION - P.3

B
very fine-grained, small, low silty clay, complete 2-5mm, load structures, bedding continues away

COVERED

fine-grained, reddish-brown, silty silt (II)

Beneath slightly wavy, larger scale bedding

RAPIDLY, mostly very continuous bedding, some odd, soft, streamlined deformation occurs in one, some and all others flat. (II) very sandy

A

Same as below

Same as below
### Trout Creek Section - P.6

#### Sill

- Interbedded lutite and argillite, 3mm. thick, very fine grained sandstone, and then bedded low to medium grade slate and limestone, 4.5m. (15 feet) thick, 2 to 3m. thick. Many large horizontal ribbons, some with visible deformation. Shallow, i.e., 0.5 to 2.5m. The upper 3m. thick shows thin, laminated calcite, nearly 3m. thick, later 0.5m. thick.

#### Sill

- Garnet, sillimanite complete 1-2mm. scale, interbedded with slates and lenses of very fine-grained quartzite, very poorly sorted, large sub-rounded grains; quartz-feldspar, many lithic fragments, complete and fine sand size. X-bedded (T-9), undercuts the section in argillite. At 225' horizon, laminae, coarse sand with very coarse grains 1-2cm. thick, 15 to 20m. wide, covering base, fins and upward to 280'.

#### Sill

- Very fine, argillite, complete, tough, X-bedded, 2 cm. thick, 10m. up. Finer up and 2 cm. thick, mudstone, grading later to sill (horiz. lam.)
Trout Creek Section - P.9

Time-bedded - 1 cm sandy wavy, red silt, angular, complete

Interbedded 2-5 cm very fine sand with dominantly red sandy silt, angular, complete, mudclasts

400

425

450

475

500

525

550

Coarse (10-12%), sand, >25% gravel, rounded, rounded, massive, but possibly blocky, compacted.
SPokane Hils Section - P-1 (Curly's section)

- Very thin, micro-completed, bone, gravel, sandy, Silt-sandstone
- Slightly wavy, many times due to slumping, very continuous
- Almost like raplan except for absence of familiar.
- Soft beds, def., lam, not black, not.

32 ft (9.7 m) very fine, thin, massive brown sandstone
- Ripple X-bedding in some places
- Thin-bedded, thin, brown, sandy, dolomitic silt-sandstone complete
- Very continuous bedding, some areas slightly wavy
- Massive, slightly calcarine, medium-fine sandstone

(Some rigid olivum on west side of 13 gallon)
SPEARNE HGS SECTION - 72

A

very slightly wavy, sometimes horizontal, sandy green silt-agglutinate complete.
1-2mm sample 10

B

1-2mm bedded, slightly wavy, sandy green silt-agglutinate with 1-2cm sands
COVERED

C

2-3cm very wavy, red-brown carbonate, large soft-sed deformation

D

grades into massive, very fine-grained greenish buff sands interbedded with muddied stringers and nodular beds

E

Same with increased soft sediment deformation, up section looks more like RAPAM not with the bed forms
SPOKANE HILLS SECTION - P. 3

SAND, BRENNING DOMINANT, 2-4 CM SAGS WITH COMPLETES GO FROM Silt
DOMINANT, BACK TO SAND DOMINANT

LOOS SAND, JUST SMALL NODULES, SCANNING BASES ON 2-1 CM COMPLETS

INTERBEDDED, 2-5 CM, RAPEL SANDS, 2-5 CM WITH MANY GUM Silt-argillite

COMPLETS 1 CM

8 FT (2,400 CM) DRILLERS LIMESTONE, CELTIC TOOTH, LARGE WEST STRUCTURES WITH

\* OF 4 FT

RARE GUM Silt-argillite Complete

COVERED

VERY, VERY SAGGY Silt-argillite Complete, MANY

SAND, NODULES, SAGS AND FILL

COVERED

SAND AS BELOW, SLIGHTLY MORE SANDY
Similar to below, but fairly regular fine grain sands 3–7 cm flinty
upward into very heavy, rippled, well-sorted, ripple, and argillite

Same as below, but grain, many muskeg, possible salt casts?
mudrocks, lots of scours, ripple marks (C16) micaceous

COVERED

dominantly grain rippled laminated fine sands, with inter-silt-lithite
coarse sand 2–4 mm and stringers of clay, after 375", same
but becoming maroon colored (5YR) and wood chips present (C15)

COVERED
Spokane Hills Section - P7

Covered with green sandy silt-slaglite float.

Interbedded fine grain sands with silt-slaglite. Complete, small rip-ups are red, larger rip-ups are green. Gradual color change over lift.

Covered

Similar, but more sandy. Only a few rip-ups, very consistent in change in color to green.
SPokane Hills Section - P.B.

A. Thin bedded 1-3mm iron, grey, silt-siltstone, sandstone, conglomerate.

S2cm very fine, very coherent quartzite, massive.

Covered with green float (same as below).
SPOKANE HILLS SECTION - P.9

COVERED

3A. very prominent ridge forming quartzite (looks like Flathead)
C. 3.5-3.9 B, well sorted, rounded, quartzite, massive, very white 019

COVERED

thick bedded 2-3 mm., horiz. continuous green sandy silt, argillite, tuffites

COVERED

could be very dirty sandstone, more likely a Sill 018

COVERED

same as above
SPEAKANE Hills Section - P.10

Some, but few, ripple marks. Very dominant occurring in
5mm beds REd near 500

Thin, very fine silt-sand, interbedded with grey fine sands
with much planar and trough bedding, all directions. Layers of
rippled material are surrounded by continuous sets that curve around
ripples

460

B

470

480

490

500

510

465

Plum bedded 1-3mm very grey silt-sand interbeds

465

Intercalated fine horizontal or massive quartzite with thin 2-3mm
layers with lenses silt-sand interbeds, sands 10-12 cm
SPOKANE HILLS SECTION - P. E. L.

530

Horizontal - slightly wavy green silt-agglutinate complete 2-3mm

535

10cm sandy silt-agglutinate laminated

540

thin, horizontal laminated sands with some ripple X-lamination containing much intraclast material interbedded with green silt-agglutinate complete with some rip-up, some material up to 10-20° of poorly sorted, sub-rounded, clastic mostly quartz.

545

550

Same with 65cm sand layers
89

SPokane Hills Section - P. 12

B. interbedded horizontal and horizontal sands with sub-agglomerate concretions, red and green sands 2-10 cm, red near top.

Covered

Blocky outcrop, same calcite green, stromatolites, little coarse stringers

becomes calcareous, 'chalky'

Horizontal sand dominant

Same as below, getting very sandy
B

Thin-bedded, colloconous gray silt-sandstone, coarse 0.1 cm
Same auttops covered but appears continuous.

C

75 cm coarse, poorly sorted (20-30%) rounded, well-rounded
slightly foliated quartzite, fine- to medium (GS)

Same as above
Spokane Hills Section - P.15

B: Interbedded, horizontal 15-20 cm gray sands with some low angle X-beds, scattered shingles, thin rip-ups with gray silt.  Silicious streaks.

Covered

Measure,stromatolitic limestone

A: Very thin, non-coal, horizontally bedded graywacke, 30% quartzite, slightly calcareous

Covered

B: Horizontal for some time, maybe (x-braced) red sand with [salt?].  Complete 2-3 mm.
Appendix C

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Note: The table continues with similar entries.
| 47.7465 | -111.357 | 231.4 | 952275.72 | 143.6 | -135.1 |
| 47.5442 | -111.357 | 14134 | 952452.17 | 14.2 | -134.5 |
| 47.9255 | -111.422 | 150.7 | 952425.92 | 24.3 | -121.0 |
| 47.9054 | -111.344 | 150.9 | 95351.1 | 39.6 | -124.3 |
| 47.9563 | -111.391 | 248.9 | 953511.12 | 17.2 | -150.5 |
| 47.9565 | -111.423 | 248.4 | 95258.47 | 17.3 | -151.4 |
| 47.9147 | -111.475 | 1218.5 | 95736.1 | 5.1 | -122.6 |
| 47.9143 | -111.556 | 1185.9 | 95935.15 | 9.5 | -127.9 |
| 47.9145 | -111.347 | 1214.2 | 95233.32 | 14.4 | -123.6 |
| 47.9463 | -111.265 | 121.6 | 95523.99 | 14.9 | -124.6 |
| 47.9467 | -111.250 | 275.3 | 95251.9 | 95.7 | -152.5 |
| 47.9462 | -111.252 | 1027.0 | 959449.26 | 32.2 | -157.5 |
| 47.9462 | -111.252 | 1512.6 | 95531.42 | 64.0 | -147.2 |
| 47.9532 | -111.412 | 2443.6 | 95225.97 | 15.0 | -150.3 |
| 47.9535 | -111.149 | 152.4 | 95535.49 | 15.0 | -150.3 |
| 47.9577 | -111.816 | 1734.1 | 95336.03 | 35.3 | -153.9 |
| 47.9333 | -111.912 | 1771.0 | 95334.02 | 49.6 | -153.7 |
| 47.9692 | -111.692 | 2350.1 | 95724.68 | 113.9 | -159.3 |
| 47.9713 | -111.618 | 1484.9 | 95546.82 | 1.94 | -151.3 |
| 47.9728 | -111.343 | 1227.0 | 95526.66 | 1.49 | -130.6 |
| 47.9747 | -111.312 | 1521.0 | 95536.1 | 14.05 | -131.3 |
| 47.9792 | -111.357 | 2774.1 | 95174.79 | 121.2 | -140.5 |
| 47.9793 | -111.3 | 1217.4 | 95528.56 | 14.3 | -137.0 |
| 47.9510 | -111.313 | 1428.4 | 95654.76 | 14.6 | -129.0 |
| 47.9527 | -111.550 | 1239.9 | 95534.73 | 13.5 | -116.5 |
| 47.9657 | -111.567 | 1211.1 | 95531.62 | 14.5 | -126.9 |
| 47.9667 | -111.843 | 1221.3 | 95536.29 | 14.6 | -131.3 |
| 47.9667 | -111.322 | 1224.3 | 95527.12 | 14.7 | -122.6 |
| 47.9667 | -111.457 | 1237.0 | 95522.28 | 13.6 | -124.1 |
| 47.9657 | -111.343 | 1231.7 | 95521.17 | 13.5 | -124.2 |
| 47.9672 | -111.350 | 1223.2 | 95523.54 | 13.3 | -126.4 |
| 47.9667 | -111.469 | 1253.1 | 95514.75 | 13.7 | -127.3 |
| 47.9467 | -111.347 | 1251.4 | 95514.10 | 14.2 | -127.5 |
| 47.9667 | -111.333 | 1284.5 | 95521.44 | 14.05 | -129.1 |
| 47.9667 | -111.427 | 1271.1 | 95557.73 | 21.4 | -137.7 |
| 47.9867 | -111.493 | 1283.6 | 95555.36 | 11.19 | -131.9 |
| 47.9867 | -111.494 | 1276.0 | 95553.46 | 11.92 | -132.3 |
| 47.9867 | -111.483 | 1292.7 | 95549.69 | 18.16 | -134.4 |
| 47.9775 | -111.483 | 1292.5 | 95549.27 | 18.20 | -134.3 |
| 47.9882 | -111.912 | 1335.1 | 95267.18 | 150.10 | -157.5 |
| 47.9467 | -111.475 | 1366.4 | 95449.78 | 7.06 | -134.1 |
| 47.9946 | -111.539 | 1423.5 | 95946.52 | 9.6 | -137.0 |
| 47.9442 | -111.453 | 1327.4 | 95745.16 | 9.3 | -137.2 |
| 47.9942 | -111.348 | 1339.6 | 94849.42 | 10.22 | -141.5 |
| 47.9942 | -111.537 | 1366.9 | 94746.42 | 7.25 | -144.8 |
| 47.9442 | -111.566 | 1378.3 | 94747.42 | 9.96 | -147.4 |
| 47.9443 | -111.566 | 1374.9 | 94747.13 | 0.97 | -147.4 |
Appendix D

Two-dimensional gravity modeling program
DIMENSION X(I),Z(I),X(N+1),Z(N+1),GSUM(I),XA(I),ZA(I)
DIMENSION POLY(I)

PI=3.1415927
OPEN(UNIT=1,DEVICE="DSK",ACCESS="SEQUENT",FILE="GRAV.DAT")

791 FORMAT(2)/
792 FORMAT(3)/
793 FORMAT(4)/
794 FORMAT(5)/
795 FORMAT(6)/
796 FORMAT(7)/
797 FORMAT(8)/
798 FORMAT(9)/
799 FORMAT(10)/

C...NOW LOOP THROUGH COMPUTATIONS FOR NPOL TIMES
DO 650 NCO=1,NPOL

650 CONTINUE

C...ZERO THE GRAVITY ARRAY
DO 600 K=1,KKK
D(K)=0
600 CONTINUE

C...READ IN DATA (M) IN CLOCKWISE FASHION ONE
1,2 PAIR PER LINE

104
GO TO 499

THE FOLLOWING LOGIC TESTS FOR SPECIAL CASES
49 IF (A) 71, 51, 72
51 IF (C) 54, 50, 52
52 IF (B) 53, 53, 53
53 IF (C-E) 119, 130, 112
71 IF (F) 72, 81, 72
72 THETA1 = ATAN (C/A)
THETA2 = ATAN (D/B)
73 IF (THETA1 = THETA2) 73, 50, 73
74 IF (C-U) 74, 140, 74
81 IF (C-D) 52, 13, 52
82 IF (C-B) 123, 50, 126

COMPUTATION FOR CASE ONE
110 CALL APCHEC (A, B, C, PHI)
CALL ATERM (A, B, C, PHI, AA)
CALL A1CHEC (A, B, C, T1)
ALPHA = 1 - PHI / 2
TPHI = ((D-C) / (B-A))
THETA = TPHI * ALOG (COS (T1) * (TAN (T1) - PHI))
GO TO 499

COMPUTATION FOR CASE TWO
120 CALL APCHEC (A, B, C, PHI)
CALL ATERM (A, B, C, PHI, AA)
CALL A1CHEC (A, C, T1)
ALPHA = 1 - PHI / 2
TPHI = ((D-C) / (B-A))
THETA = TPHI * ALOG (COS (T1) * (TAN (T1) - PHI))
GO TO 499

COMPUTATION FOR CASE THREE
130 IF (A) 131, 132, 134
131 IF (D) 134, 133, 134
132 T1 = PHI / 2
CALL A1CHEC (B, D, T2)
GO TO 135
133 T2 = PHI / 2
CALL A1CHEC (A, C, T1)
GO TO 139
134 CALL A1CHEC (A, C, T1)
CALL A1CHEC (A, C, T1)
135 GZ = C * (T2 - T1)
PHI = -
GO TO 499

COMPUTATION FOR CASE FOUR
140 CALL A1CHEC (A, C, T1)
CALL A1CHEC (A, C, T1)
GZ = A * ALOG (ABS (COS (T1)) / (COS (T2)))
PHI = -
GO TO 499

COMPUTATION FOR THE GENERAL CASE
150 CALL APCHEC (A, B, C, PHI)
CALL ATERM (A, B, C, PHI, AA)
CALL A1CHEC (A, C, T1)
CALL A1CHEC (A, C, T1)
ALPHA = 1 - T2
TPHI = ((D-C) / (B-A))
T1 = COS (T1) * (TAN (T1) - PHI)
T2 = COS (T2) * (TAN (T2) - PHI)
T = 1 / t
GZ = TPHI * ALOG (T)
GZ = A * (ALPHA * PHI)
GO TO 499

CONTINUE
AN=4+1
DO 10 I=1,4
X(I)=X(I)+CD
10 CONTINUE
DO 11 N=N'+1
40 CONTINUE
C FOR HORIZONTAL DISTANCE OUTPUT IN METERS, DROP THIS DO LOOP
DO 12 K=1,XXK
AX(K)=AX(K)/11000
12 CONTINUE
DO 965 K=1,XXK
AX(K)=AX(K)/U0C.
965 CONTINUE
966 IF(NPOL.GT.1)GO TO 677
967 FORMAT(" COMBINED GRAVITY EFFECT OF //"13,//" POLYGONS//")
968 TYPE 9'S
969 FORMAT(2X,(I9.9),G9.4/*POLY(K)*/)
970 WRITE(10,968) XX(K),POLY(K)
971 WRITE(10,969) XX(K),POLY(K)
972 CONTINUE
STOP
END
SUBROUTINE ATERM (AX,8X,CX,DX,P2,AA)
AA=RX+(DX*((3X-i.X)/(CX-O X)))
AA=0.1*SIN(P2)' »C0S(P2)
RETURN
END
SUBROUTINE A1CZC (XA,XC,T1)
PI=3.1415927
IF (XC/XA) 5,6,5
5 T1=ATAN(XC/XA)
GO TO 11
4 T1=ATAN(XC/XA)
11 CONTINUE
RETURN
END
SUBROUTINE A2CHEK (X3,XD,T2)
PI=3.1415927
IF (XD/XB) 5,6,5
5 T2=ATAN(XD/XB)+PI
GO TO 11
4 T2=ATAN(XD/XB)
11 CONTINUE
RETURN
END
SUBROUTINE APCHEC (XA,XB,XC,XD,PHI)
PI=3.1415927
IF ((Xu-XC)/(XB-XA>) 7,8,8
7 PHI=ATAN((X3-XC)/(XB-XA))+PI
GO TO 11
6 PHI=ATAN(((X3-XC)/(XB-XA))
11 CONTINUE
RETURN
END