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Stratigraphy and sedimentation of the Proterozoic Burke and Revett Formations Flathead Reservation western Montana

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STRATIGRAPHY AND SEDIMENTATION OF THE PROTEROZOIC BURKE AND REVETT FORMATIONS, FLATHEAD RESERVATION, WESTERN MONTANA

by

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ABSTRACT

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Stratigraphy and Sedimentation of the Proterozoic Burke and Revett Formations, Flathead Reservation, Western Montana

Director: Don Winston

Two informal members of the Burke Formation and three informal members of the Revett Formation can be correlated from their type areas in the Coeur d'Alene district to the southern end of the Flathead Reservation. These members combine to form a well-defined coarsening and shallowing-upward sequence which is interpreted as the product of a large tide-dominated delta.

The lower member of the Burke Formation, which consists of subaqueous, subwave base siltite, overlies subaqueous, subwave base argillite of the Prichard Formation. These rock types represent prodelta silt and mud, respectively.

The upper member of the Burke Formation contains moderately- to well-sorted quartzite with subordinate amounts of prodelta siltite and tidal flat coupleted argillite, thin-bedded quartzite, and siltite. The quartzite of the upper Burke records deposition of distributary mouth bar sands.

Coupleted argillite, thin-bedded quartzite, and siltite which overlie quartzite of the upper Burke record deposition on subaqueous and subaerial tidal flats which fringed the Burke/Revett deltaic lobe. These rock types occur widely throughout the Burke and Revett Formations on the Flathead Reservation.

The quartzite-rich lower and upper members of the Revett Formation record pulses of sand which prograded out into the Belt basin during periods when deposition exceeded subsidence. From west to east, these quartzite units record fluvial deposition, passing to intertidal deposition, passing to distributary mouth bar deposits.

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INTRODUCTION

GENERAL STATEMENT

The Revett Formation of the Ravalli Group, which crops out widely in the central and western portion of the Middle Proterozoic Belt terrane, is best known because it hosts the stratabound ore deposits of the western Montana copper sulfide belt as well as many of the sulfide deposits of the enigmatic Coeur d'Alene district (Harrison, 1972, 1974; Bennett and Venkatakrishnan, 1982; Hobbs et al., 1965; Figure 1). The underlying Burke Formation of the Ravalli Group also hosts zinc-lead deposits within the Coeur d'Alene district (Fryklund, 1964; Bennett and Venkatakrishnan, 1982).

Previous detailed stratigraphic and sedimentologic studies of the Revett have concentrated on the western facies of the formation (Figure 2). Hrabar (1971, 1973), working mainly in the St. Regis Formation of the Ravalli Group, concluded that the Ravalli Group represents a large turbidite complex. Bowden (1977a, 1977b) concluded that the quartzite of the Revett Formation was deposited by a large braided river and that the finer-grained units within the Revett represent overbank deposits. White and others (1977), and White and Winston (1977, 1982), on the basis of their work in the Coeur d'Alene district, concluded that the Revett consists of informal lower, middle and upper members, representing braided stream and fan delta

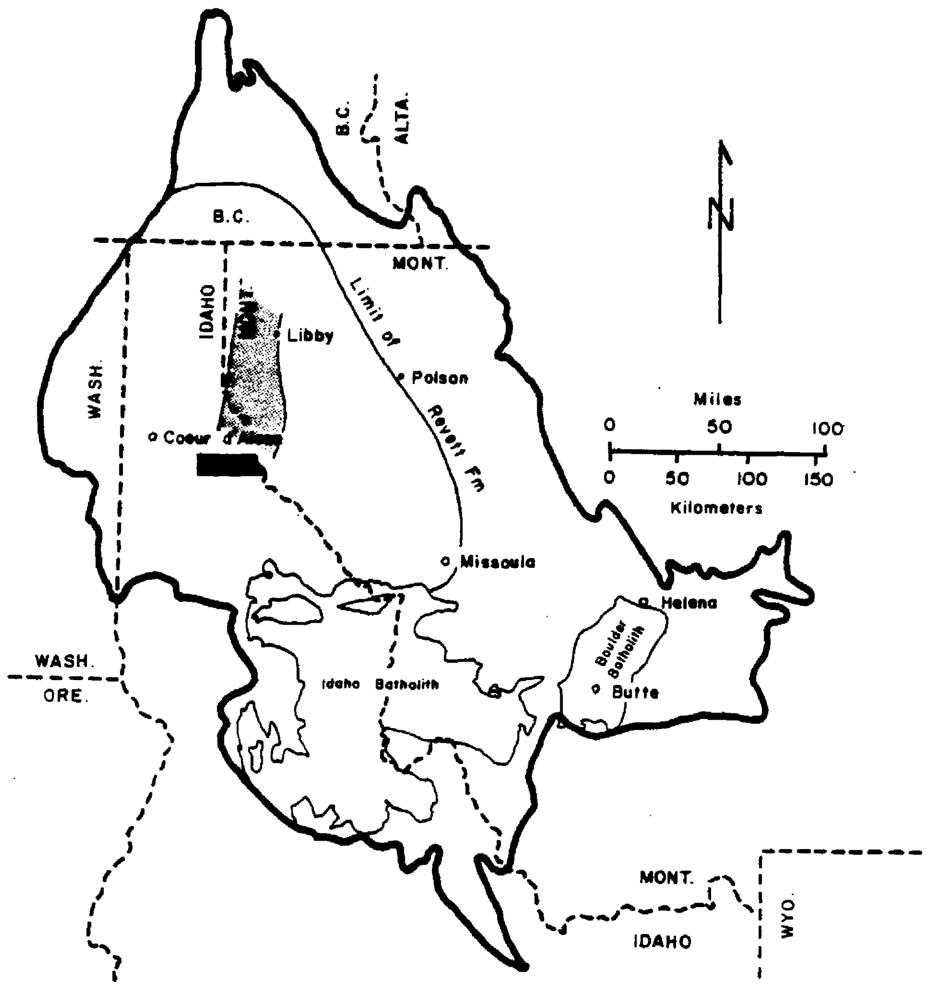


Figure 1. Map showing location of Belt terrane, western Montana copper sulfide belt (lightly stipled), Coeur d'Alene mining district (black), and limit of Revett Formation. Modified from Harrison (1972, 1974) and Hobbs et al. (1965).

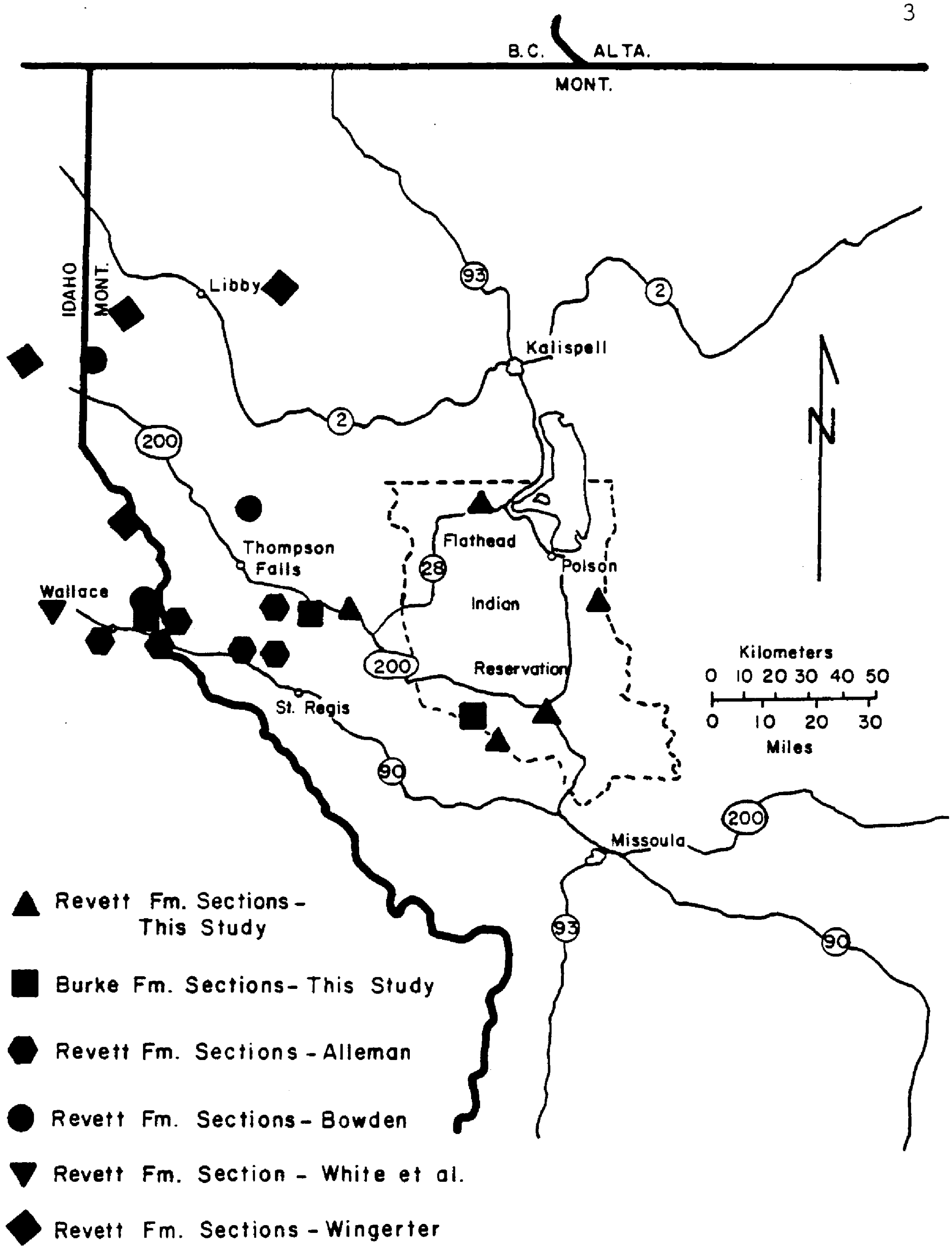


Figure 2. Map showing location of previous detailed stratigraphic work in the Revett Formation, and location of stratigraphic sections examined during this study. Compiled from Bowden (1977a), Alleman (1983), White and Winston (1982), and Wingerter (1982).

deposits. Wingerter (1982) concluded that the Revett Formation represents a barrier island complex. Alleman (1983) developed a sheet flood model for the Revett Formation to explain the abundant tabular, laterally persistent quartzite beds of the Revett which commonly lack basal scour. The stratigraphy and sedimentation of the Burke Formation has not been previously studied in detail.

This study examines the stratigraphy and sedimentation of the Revett Formation as exposed on the Flathead Reservation, and the stratigraphy and sedimentation of the Burke Formation from the Coeur d'Alene district to the southern end of the Flathead Reservation (Figure 2). The purpose of this study is threefold: 1) to establish a stratigraphic framework for the less studied eastern facies of the Revett; 2) to establish a stratigraphic framework for the Burke Formation; and 3) to propose an integrated model for deposition of the Burke and Revett Formations.

GEOLOGIC SETTING

Metasediments of the Middle Proterozoic Belt Supergroup crop out over much of eastern Washington, northern Idaho, and northwestern Montana (Figure 1). The Belt Supergroup contains four major stratigraphic subdivisions: the lower Belt, the Ravalli Group, the middle Belt carbonate interval, and the Missoula Group (Harrison, 1972; Figure 3). The Burke and Revett Formations lie within the Ravalli Group (Figure 3).

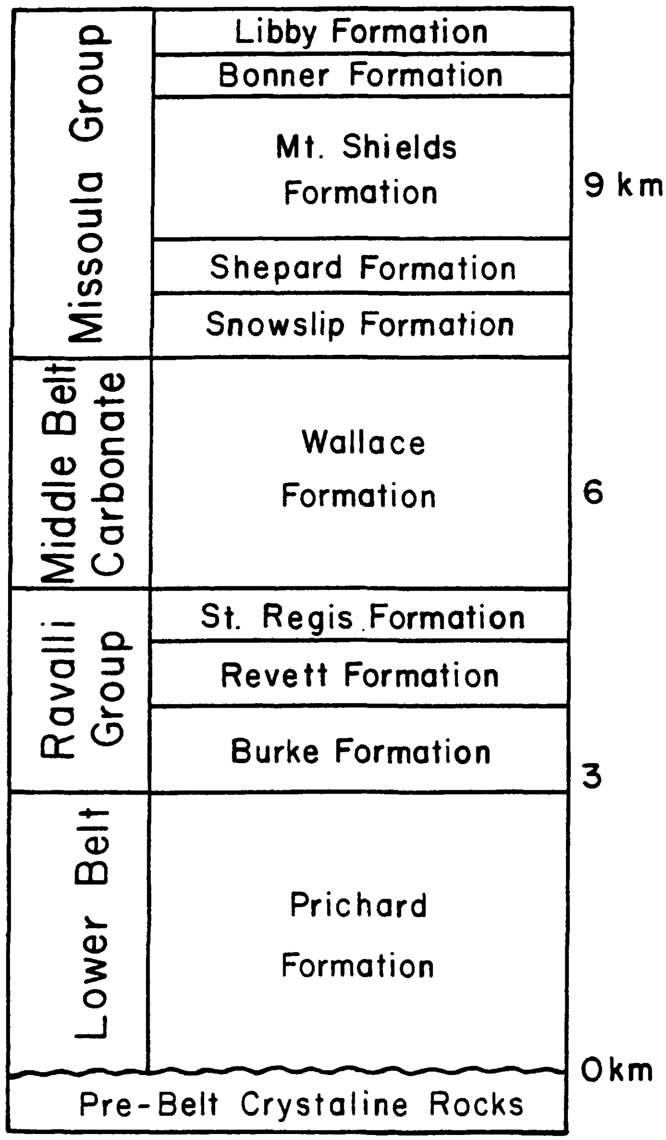


Figure 3. Stratigraphic subdivisions of the Belt supergroup in the central and western portion of the Belt terrane.

The Belt terrane has a long, complex history of deformation:

1) Proterozoic block faulting and compression affected the Belt basin (Harrison et al., 1974a; McMechan and Price, 1982; Winston, 1982). Winston (1982) proposed that major syndepositional growth faults cut the Belt basin during the Middle Proterozoic (Figure 4). One of Winston's (1982) proposed growth faults which may cross the Flathead Reservation is the Jocko Line: a proposed down-to-the south growth fault.

2) Paleozoic faulting cut much of the Belt terrane (Harrison et al., 1974a).

3) During the Cretaceous and Paleocene, major thrusts cut this terrane, transporting Belt rocks eastward (Harrison et al., 1980; Figure 5). Therefore, the rocks on the Flathead Reservation are allochthonous. Although these thrusts complicate or mask many facies changes, by working within thrust sheets, one can identify significant facies changes within the Belt terrane.

4) Eocene to Recent extension created major block faults (Harrison et al., 1980).

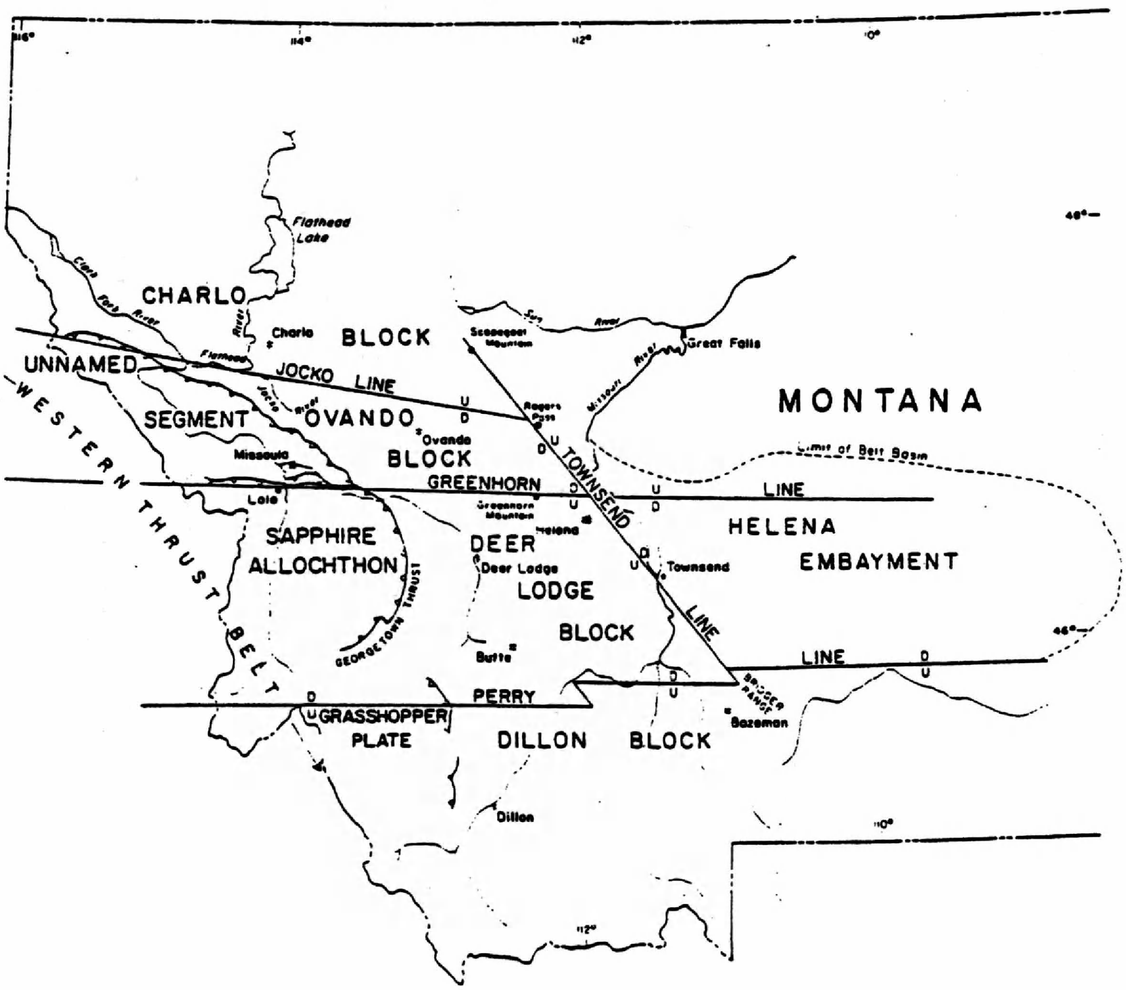


Figure 4. Map of proposed Proterozoic fault zones and crustal blocks. From Winston (manuscript).

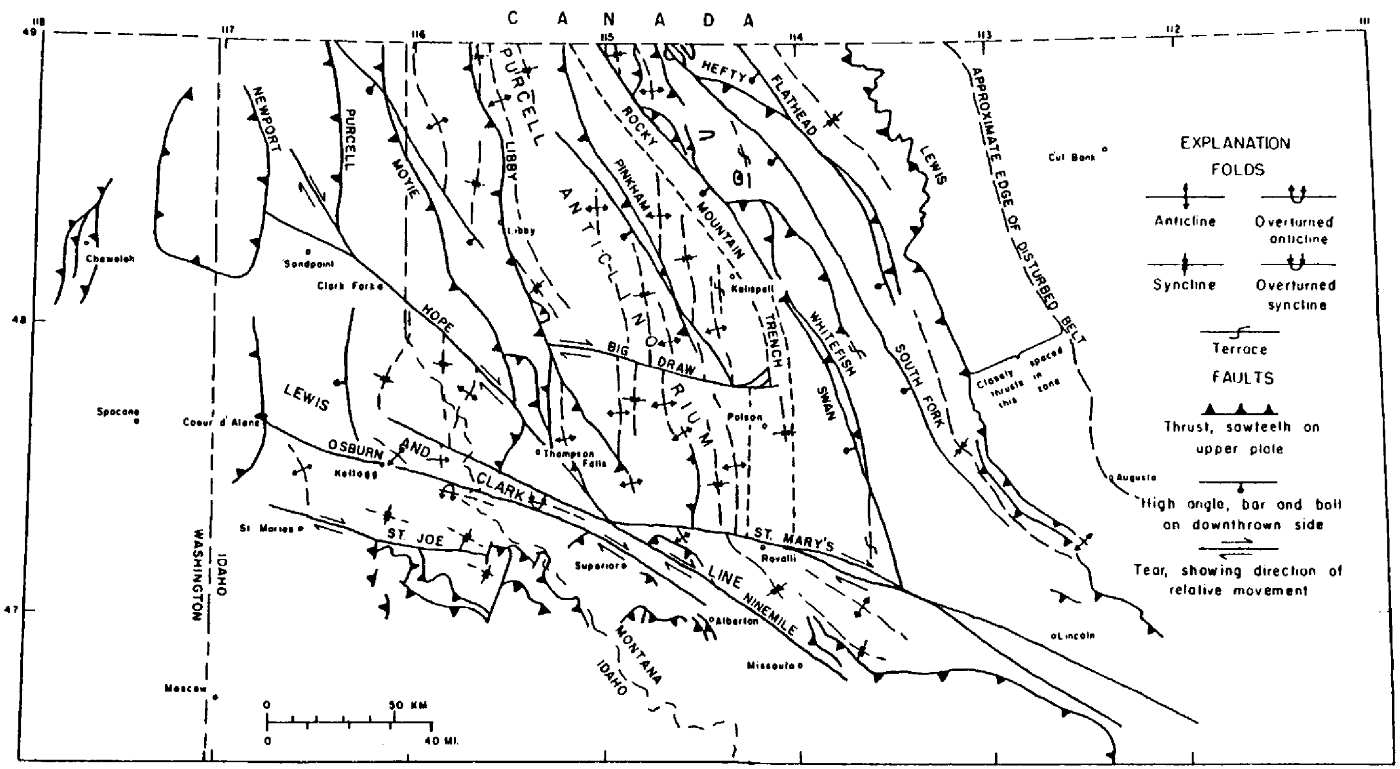


Figure 5. Generalized structure map of part of the Belt terrane. Redrawn from Harrison et al. (1980).

The Revett stratigraphic sections examined during this study (Figure 6) are not separated by major thrusts; I therefore consider these sections to represent a parautochthonous unit. In contrast, because the Burke stratigraphic sections are separated by several major thrusts, lateral changes in lithology may result from either tectonic telescoping or facies changes. Nonetheless, these sections establish a general stratigraphic framework for the southern facies of the Burke Formation.

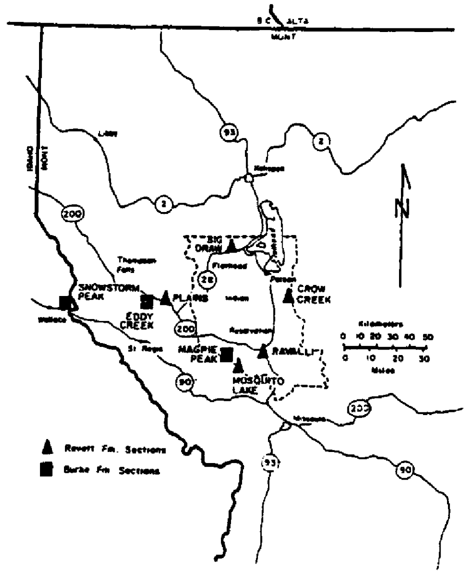


Figure 6 A. Location of stratigraphic sections examined during this study.

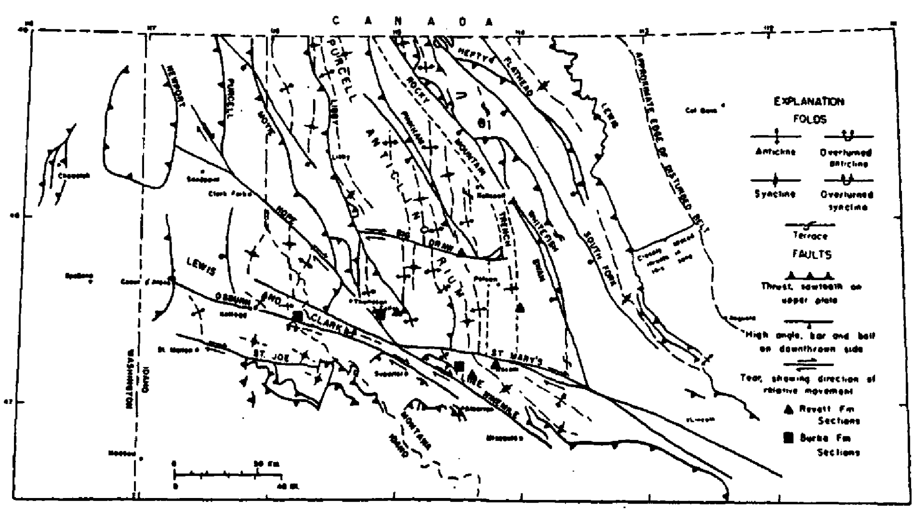


Figure 6 B. Location of stratigraphic sections measured during this study, and major tectonic elements within the study area. Modified from Harrison et al. (1980).

ROCK TYPES

GENERAL STATEMENT

Describing Belt rocks is a complex problem because their most obvious features are best described using the nomenclature of sedimentary petrology, but burial metamorphism to the greenschist facies has transformed these sediments into metamorphic rocks (Maxwell and Hower, 1967). Consequently, former workers have given Belt rocks metamorphic names: quartzite, siltite and argillite. A rigorous adherence to metamorphic nomenclature can produce confusing, cumbersome descriptions (e.g.: the argillaceous units consist of couplets; each couplet composed of a quartzite or siltite layer overlain by an argillite layer). Because metamorphic names are entrenched in Belt literature, I use names proposed by other workers (Harrison and Campbell, 1963; Winston, 1977, 1978), but instead of describing only metamorphic rocks, I describe their sedimentary constituents separately from subsequent diagenetic and metamorphic changes.

In this section I describe the pre-metamorphic sedimentary constituents of the five metamorphic rock types which comprise the Burke and Revett Formations: cross-stratified quartzite, tabular to lenticular quartzite, siltite, coupleted purple argillite, and coupleted green argillite. I also interpret general environments of deposition for each rock type (Table 1).

ROCK TYPE	GRAIN SIZE AND SORTING	STRATA THICKNESS	SEDIMENTARY STRUCTURES	INTERPRETATION
Cross-stratified quartzite	fine to medium sand; well to very well	Sets = 0.3 to 1.5 m	large-scale cross strata, local ripples, bimodal bipolar or nearly unimodal	Tidal channels where bimodal bipolar, fluvial or shelf sand where more nearly unimodal
Thick-bedded tabular to lenticular quartzite	fine (to medium) sand; well to very well	15 cm to 2 m	commonly flat-laminated, locally ripple cross-laminated, silty or micaceous basal and/or top layer common	lower and upper flow regime flow in many possible environments
Thin-bedded tabular to lenticular quartzite	very fine to fine sand; moderately to well	3 to 15 cm	discontinuous layers, small-scale scours, current ripple cross-laminated, local opposing current ripples	sandy tidal flat, small tidal channels
Siltite	silt to fine sand to mud; moderately (to well)	0.5 to 15 cm	massive, graded, and/or flat-laminated, rare lenticular bedding	rapid suspended load deposition from sediment - laden water
Coupleted purple argillite	silt to sand to mud; moderately	0.5 to 4 cm	fining upward sedimentary couplets with local lenticular and flaser bedding, mud cracks, rare scours	tidal flat, marsh, overbank, or alluvial/deltaic plain
Coupleted green argillite	silt to sand to mud; moderately	less than 1 cm	fining upward undulose sedimentary couplets with local lenticular and flaser bedding, synaeresis cracks, fluid escape structures	subtidal deposit or lacustrine deposit
Laminated argillite	silt and mud; moderately	0.05 to 1 cm	thin laminations, graded strata	suspended load deposition in subaqueous, sub-wave base environment

Table 1. Rock type summary table.

CROSS-STRATIFIED QUARTZITE

DESCRIPTION - ROCK TYPE

This rock type is white, tan, gray, green, or purple cross-stratified quartzite.

DESCRIPTION - SEDIMENTS

Cross-stratified quartzite formed from sediments that consisted of well- to very well-sorted cross-stratified fine to medium sand. Cross-strata most commonly occur as tabular sets of planar cross-strata with angular to tangential bases (terminology of McKee and Weir, 1953; Figure 7). Locally, lenticular sets of trough cross-strata occur. Epsilon cross-strata (terminology of Allen, 1963) are rare. Sets are 0.3 to 1.8 meters thick, but most are 0.5 to 1.0 meters thick.

Sets of cross-strata locally exhibit scoured bases. The basal portions of cross-strata are commonly micaceous. Many cross-strata sets are overlain by flat-laminated sand which is in turn overlain by ripple cross-laminated sand capped by a desiccation-cracked mud drape.

Locally, entire bedforms - backsets as well as foresets - are preserved. These exposures indicate that these bedforms were 0.7 to 1.2 meters high. Wavelength can not be determined from the exposures I have examined.

At the southern end of the Flathead Reservation, paleocurrent measurements from tabular sets of planar cross-strata reflect nearly unimodal, unidirectional sediment transport

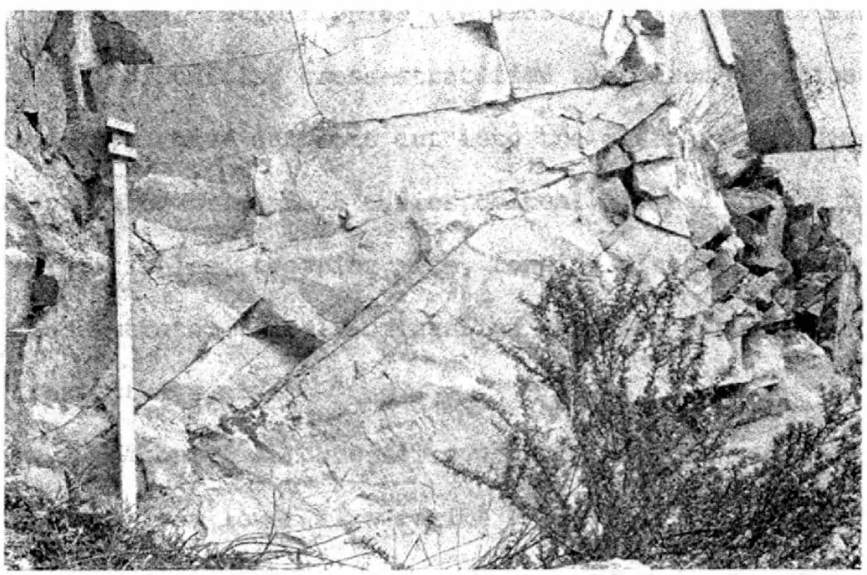


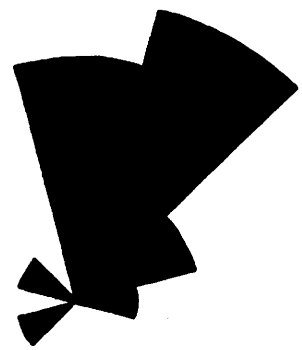
Figure 7. Photograph of tabular set of planar cross-strata. Jacob's staff is 1.5 meters long.

to the north (Figure 8). In contrast, at Plains paleocurrent measurements from tabular sets of planar cross-strata reflect distinctly bimodal bipolar paleocurrents (Figure 8). Bimodal bipolar paleocurrents are not unique to the Plains section; Bowden (1977a) and Hrabar (1971) also measured cross-strata which locally reflect bimodal bipolar paleocurrents (Figure 9).

INTERPRETATION - SEDIMENTS

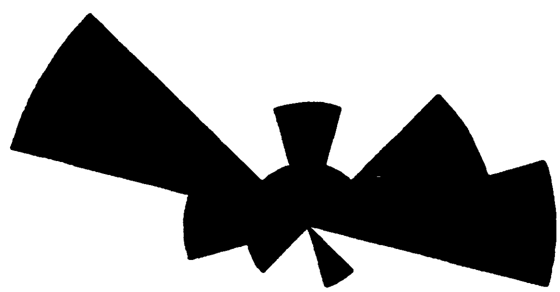
Currents moving in the lower flow regime formed migrating two-dimensional large ripples and, less commonly, three-dimensional large ripples (terminology of Costello and Southard, 1981), depositing cross-stratified sand from traction load. Locally, these currents cut into the underlying sediments, forming scours. Back eddies commonly formed at the base of these large ripples, trapping mica, forming micaceous bases for many cross-strata. Rarely, migrating channels deposited epsilon cross-strata.

Commonly, as deposition progressed, the water shallowed, passing from lower flow regime to upper flow regime flow, depositing flat-laminated sand over cross-stratified sand. Subsequent decrease in velocity caused currents to pass into lower flow regime flow, depositing ripple cross-laminated sand over flat-laminated sand. As the currents slowed and stopped, a thin mud layer settled out of suspension. Occasionally, this mud layer was subaerially exposed long enough to dry out, allowing it to become desiccation-cracked.



MOSQUITO LAKE

N=14



PLAINS

N=20

Figure 8. Paleocurrent roses from the Revett Formation at the Plains and Mosquito Lake sections.

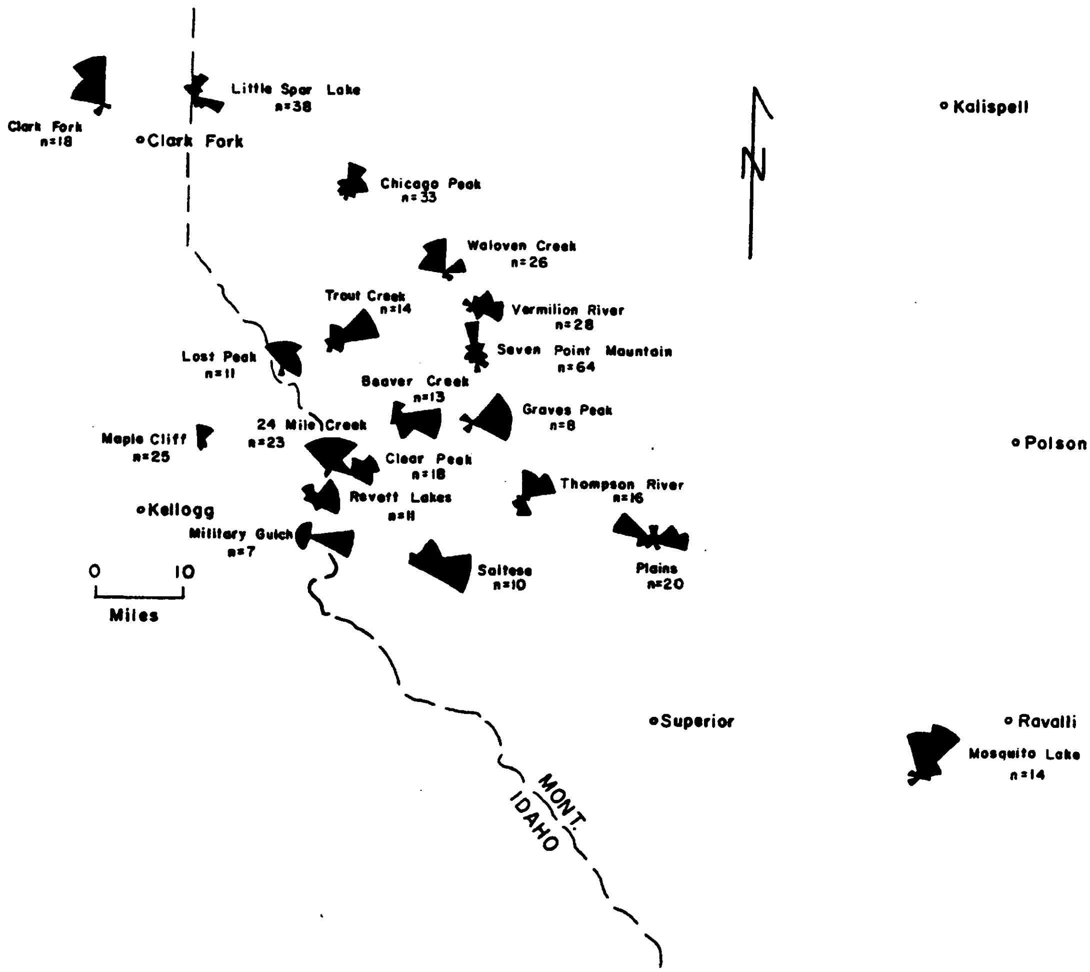


Figure 9. Paleocurrent roses from the Revett Formation. Compiled from Bowden (1977a) and Hrabar (1971).

The presence of unimodal paleocurrents and well-defined fining-upward sequences indicates that fluvial deposition dominated locally (Miall, 1977). Elsewhere, cross-stratified sediments were deposited from bimodal bipolar currents, indicating tidal currents (Selley, 1976, 1978; Potter and Pettijohn, 1977).

Currents which flow fast enough to deposit cross-stratified sand are capable of transporting medium to coarse sand and pebbles (Harms et al., 1982). However, the cross-stratified quartzite units of the Burke and Revett contain only fine to medium sand. The absence of coarse grains in cross-stratified sandstones could reflect either the absence of coarse material in the source terrain, or prolonged sediment transport which abraded all clasts into fine grain size. Petrographic studies indicate that the Revett and Ravalli Group rocks were derived from a terrain which contained both igneous and metamorphic rocks (Herndon, 1983; Hayes, 1983; Latuszynski, 1962), and therefore I conclude that Burke and Revett sediments underwent extremely long transport.

TABULAR TO LENTICULAR QUARTZITE

DESCRIPTION - ROCK TYPE

This rock type is white, tan, gray, green, or purple flat-laminated and ripple cross-laminated quartzite.

DESCRIPTION - SEDIMENTS

Tabular to lenticular quartzite sediments consist of moderately- to very well-sorted, flat-laminated and ripple cross-laminated medium to very fine sand and silt. Beds range from 5 cm to 2 meters thick, but most commonly are 25 cm to 1 m thick. Because the sedimentary structures in tabular to lenticular quartzite beds greater than about 15 cm thick differ from sedimentary structures in thin, tabular to lenticular quartzite strata less than 15 cm thick, thick-bedded and thin-bedded tabular to lenticular quartzite are described separately below.

Thick-Bedded Tabular to Lenticular Quartzite - Description

Tabular to lenticular quartzite beds commonly occur as wide, sheet-like beds, with width-to-height ratios much greater than 50:1 (Figure 10). Locally, they occur as more lenticular beds, with width-to-height ratios less than 20:1 or 30:1. These beds are locally separated by discrete siltite strata, and rarely pass laterally into thinner siltite strata. Some bases are scoured and overlain by mud chip lags. Within single beds, flat-laminated sand locally passes upward into ripple cross-laminated sand. Some beds contain 1 to 3 cm thick silty or micaceous basal layers, and many contain 1 to 3 cm thick upper silty layers

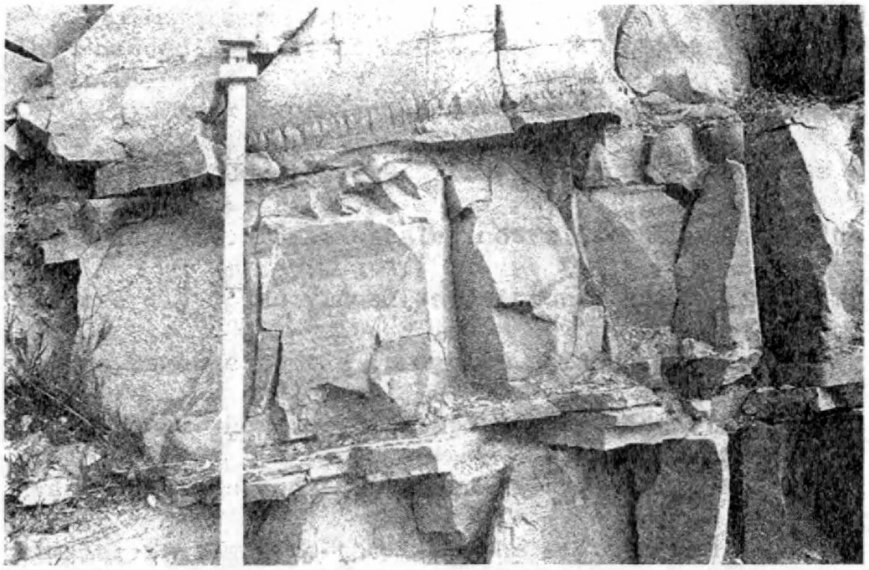


Figure 10. Photograph of thick-bedded tabular to lenticular quartzite. Jacob's staff marked in feet.

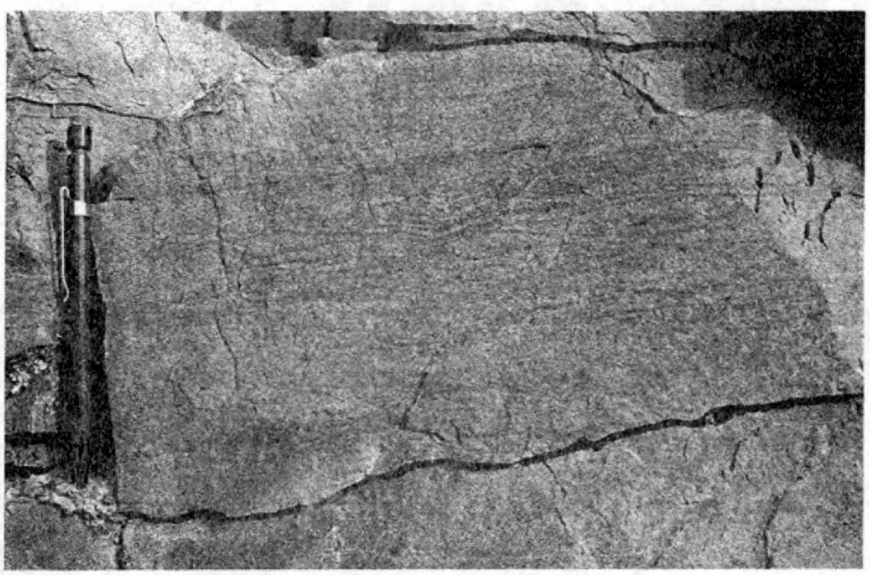


Figure 11. Photograph of thin-bedded tabular to lenticular quartzite.

near their tops, overlain by clay caps.

Thin-Bedded Tabular to Lenticular Quartzite - Description

This rock type is characterized by ripple-cross lamination and discontinuous layers. Irregular, discontinuous wisps of clay occur locally. Small-scale scours are abundant in this rock type (Figure 11). Individual depositional units are difficult to define because of the irregular, discontinuous configuration of the strata. However, it appears that individual depositional events in this rock type have left layers 1 to 10 cm thick, similar in scale to those in the siltite and argillite rock types. Locally, ripple cross-laminae indicate opposing paleocurrent directions in different layers. Rarely, current ripple cross-laminae which are directed one way are scoured and overlain directly by current ripple cross-laminae directed the opposite way.

INTERPRETATION - SEDIMENTS

Thick-Bedded Tabular to Lenticular Quartzite - Interpretation

Currents moving in the upper and lower flow regimes deposited sand from traction load, producing flat-laminated and ripple cross-laminated sand, respectively. Locally, current velocity slowly decreased during the waning stages of depositional events causing currents to pass from upper to lower flow regime flow, thereby depositing ripple cross-laminated sand over flat-laminated sand. Commonly, however, currents slowed and shallowed rapidly during the waning stages of depositional events, and therefore lower flow regime flow was bypassed (Turnbridge, 1981). After currents ceased, silt and mud settled out of suspension, capping individual strata.

Thin-Bedded Tabular to Lenticular Quartzite - Interpretation

The abundance of small-scale scours and the evidence of current reversals clearly separate this rock type from thicker-bedded quartzite units. Traction load deposition of sand alternated with suspended load deposition of thin clay drapes. Subsequent currents reworked these sediments, often removing the clay drapes and commonly scouring the sand layers. These currents probably flowed back and forth, as indicated by reversed directions of current ripple cross-laminae. This sequence may be explained by diurnal tides moving back and forth over a high-energy, sandy tidal flat. Similar deposits have been described on recent tidal flats (Reineck, 1975; Klein, 1971, 1977; Terwindt, 1975), and on ancient tidal flats (Ovenshine, 1975; A.M. Thompson, 1975). Alternatively, these sediments may represent deposition in small tidal channels, such as those described near the Colorado River delta by Meckel (1975).

SILTITE

DESCRIPTION - ROCK TYPE

This rock type is tan to gray to green siltite.

DESCRIPTION - SEDIMENTS

Siltite sediments consist of moderately- to well- sorted silt with subordinate fine sand and clay forming uniform tabular beds 0.5 cm to 10 cm thick. Most siltite is flat-laminated, some is massive. Rare lenticular bedding occurs where isolated current ripples of fine sand form lenses within massive siltite (Figure 12). Paper-thin clay caps commonly define individual beds and laminae.

INTERPRETATION - SEDIMENTS

Siltite sediments represent rapid suspended load deposition of silt, sand and mud from sediment-laden water. Periodic quiet intervals allowed paper-thin clay laminae to settle out of suspension. Locally, traction load deposition of fine sand by currents in the lower flow regime alternated with suspended load deposition of silt and mud from sediment-laden water. As discussed below, I believe the siltite of the lower Burke represents the suspension- and traction-load deposits of a prodelta slope.

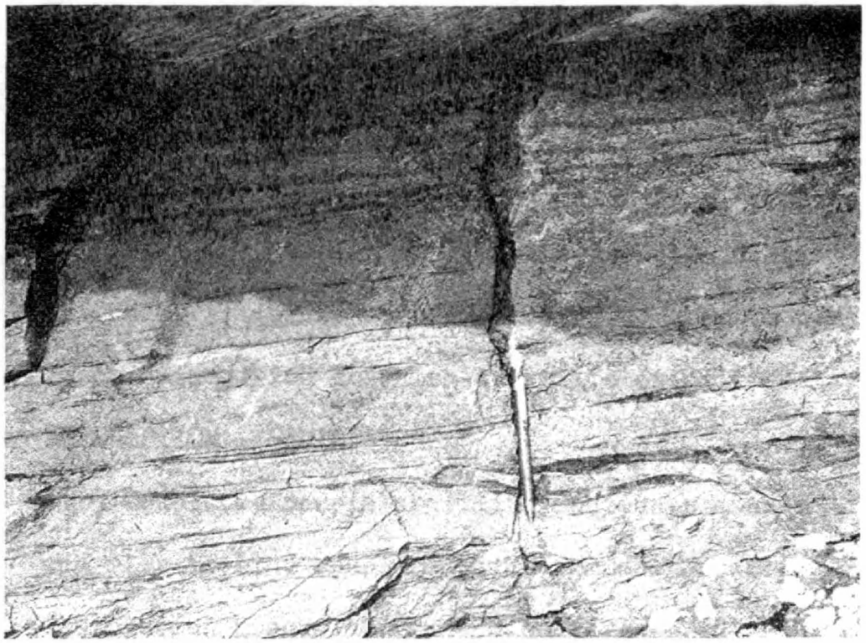


Figure 12. Photograph of lenticular bedding in siltite.

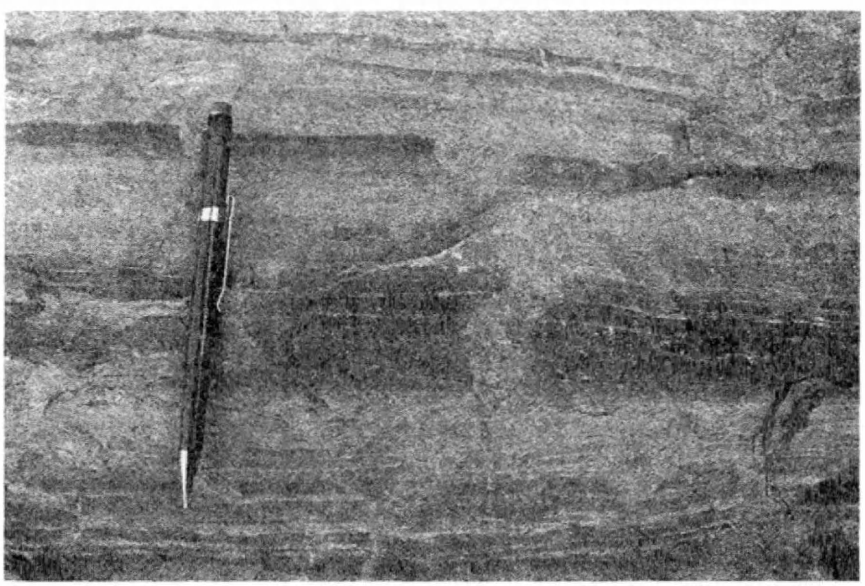


Figure 13. Photograph of coupleted purple argillite.

COUPLETED PURPLE ARGILLITE

DESCRIPTION - ROCK TYPE

This rock type ranges from argillite to argillitic siltite; its color varies widely from purple to gray to purple argillite layers mixed with greenish quartzite or siltite layers.

DESCRIPTION - SEDIMENTS

Coupleted purple argillite sediments consist of fine sand and silt-to-clay couplets which commonly contain abundant desiccation cracks and mud chips (Figure 13). Purple argillite couplets are 0.5 to 4 cm thick. A layer of moderately-sorted very fine sand and silt forms the lower two-thirds to three-quarters of each couplet; clay forms the upper portion. In some couplets, the fine sand and silt pass gradationally upward to clay; in other couplets, clay layers abruptly overlie layers of fine sand and silt. Contacts between couplets are planar.

Coupleted purple argillite sediments locally contain lenticular and flaser bedding (terminology of Reineck and Wunderlich, 1968). These sediments contain rare scours up to 10 cm deep, and rarely contain fluid escape structures. Individual couplets can be traced across outcrops several meters wide. Evaporite minerals such as gypsum and halite do not occur in this rock type.

INTERPRETATION - SEDIMENTS

Traction-load deposition of silt alternated with suspended-load deposition of clay, thereby forming silt-to-clay couplets. Commonly, subaerial exposure followed suspended load deposition, creating desiccation cracks. The next influx of water often lifted polygons of dried mud, and redeposited them as mud chips. This alternation of traction load deposition with suspended load deposition can be best explained by deposition on a muddy tidal flat, where diurnal tides created a rhythmic alternation of current-controlled deposition and deposition from standing water. Similar sediments have been described from modern intertidal and supratidal flats (Evans, 1975; Coleman and Wright, 1975; Oomkens, 1974; Klein, 1971, 1977; Larsonneur, 1975; Knight and Dalrymple, 1975; R.W. Thompson, 1975), and ancient intertidal flats (Ovenshine, 1975). Alternatively, these sediments may have been deposited in an overbank area, or alluvial/deltaic plain (Evans, 1975; Larsonneur, 1975; Glass and Wilkinson, 1980; Van Dijk et al., 1978). The absence of evaporite minerals and evaporite turbation in this rock type indicate that these sediments were not deposited in a sabkha or playa lake environment (R.W. Thompson, 1975; Handford, 1982).

COUPLETED GREEN ARGILLITE

DESCRIPTION - ROCK TYPE

This rock type is an apple-green argillite; the green color results from chlorite and phengite.

DESCRIPTION - SEDIMENTS

Coupleted green argillite sediments are composed of moderately-sorted, silt-to clay couplets which are commonly less than one centimeter thick (Figure 14). Undulose boundaries commonly separate individual couplets. A couplet consists of a layer of very fine sand or silt overlain gradationally or abruptly by a clay layer. Typically, silt layers are flat-laminated, but rarely they contain ripple cross-laminae. Clay layers are massive.

These sedimentary couplets locally consist of flaser, wavy and lenticular bedding (terminology of Reineck and Wunderlich, 1968), and commonly contain synaeresis cracks (c.f. Donovan and Foster, 1972; Picard, 1966; Plummer and Gostin, 1981; Reineck and Singh, 1980, p. 60), fluid escape structures, and pyrite. Desiccation cracks and scours rarely occur in this sediment type. Individual couplets are commonly continuous across outcrops several meters wide.

Figure 14. Photograph of coupleted green argillite.

Because coupleted green argillite rarely contains the same sedimentary structures as coupleted purple argillite, the environment of deposition for these sediments was rarely similar to that of coupleted purple argillite. The color difference in these rocks is apparently a post-sedimentary feature.

INTERPRETATION - SEDIMENTS

Suspended load deposition from slack water formed flat-laminated and massive silt and clay layers. Occasionally, weak currents moving in the lower flow regime laid down current ripple cross-laminated very fine sand as traction load deposits. Subsequent deposition from standing water deposited massive silt and clay layers, forming lenticular bedding.

Two features indicate that coupleted green argillite sediments remained under water: 1) the lack of subaerial sedimentary structures such as desiccation cracks and mud chips; 2) the relative abundance of subaqueous sedimentary structures such as synaeresis cracks (Picard and High, 1969; White, 1961; Burst, 1965; Jungst, 1934) and fluid escape structures. The presence of pyrite and the green color from chlorite reflect that these sediments were reduced, perhaps shortly after deposition. Undulose contacts separate couplets because influxes of fine sand and silt could easily settle into the underlying soft, oozy, wet mud, deforming it. Local oscillation ripples preserved in wavy bedding indicate that coupleted green argillite sediments occasionally formed in standing water above wave base.

Coupleted green argillite sediments resemble many modern subtidal deposits (de Raaf and Boersma, 1971; Reineck, 1975; R.W. Thompson, 1975; Terwindt, 1975). They also resemble some lacustrine deposits, such as those in the Eocene Green River Formation of Wyoming (Bradley, 1931, 1964; Hardie et al., 1978; Glass and Wilkinson, 1980; Van Dijk et al., 1978). However, because of their association with other lithologies which are best interpreted as tidalites, I believe that these are also tidal deposits.

LAMINATED ARGILLITE

DESCRIPTION - ROCK TYPE

This rock type consists of laminated black and white or dark green and white argillite which commonly contains pyrite or pyrrhotite.

DESCRIPTION - SEDIMENTS

Laminated argillite sediments consist of flat-laminated and graded mud and silt laminae 0.05 to 1 centimeter thick. Other sedimentary structures rarely occur in this rock type; desiccation cracks, mud chips, and oscillation ripples are conspicuously absent.

INTERPRETATION - SEDIMENTS

Suspended load deposition in a relatively sediment-starved, subaqueous, sub-wave base environment formed graded and flat-laminated mud and silt laminae. As discussed below, I believe this rock type may represent prodelta silt and mud.

STRATIGRAPHY

GENERAL STATEMENT

Figures 15 and 16 portray generalized stratigraphic sections of Burke and Revett sections measured during this study. Appendix A presents these stratigraphic sections at a scale of 1 inch equals 50 feet. Figure 17 shows the general stratigraphy of the Burke and Revett Formations in this study area.

BURKE FORMATION

As illustrated in figures 15 and 17, I subdivided the Burke Formation into informal lower and upper members. The lower member gradationally overlies the Prichard Formation and consists of siltite with minor argillite. The upper member contains quartzite with subordinate interbeds of siltite and argillite (Figures 15 and 17).

The contact of the lower Burke with the underlying Prichard Formation is gradational over 100 to 500 meters (Wells, 1974; Cressman, 1982). In this interval, Prichard-type laminated argillite is interbedded with Burke-type green to grayish-green, thickly-laminated to thinly-bedded magnetiferous siltite units with millimeter-scale argillite caps. I placed the formation

GENERALIZED STRATIGRAPHIC SECTIONS OF THE BURKE FORMATION

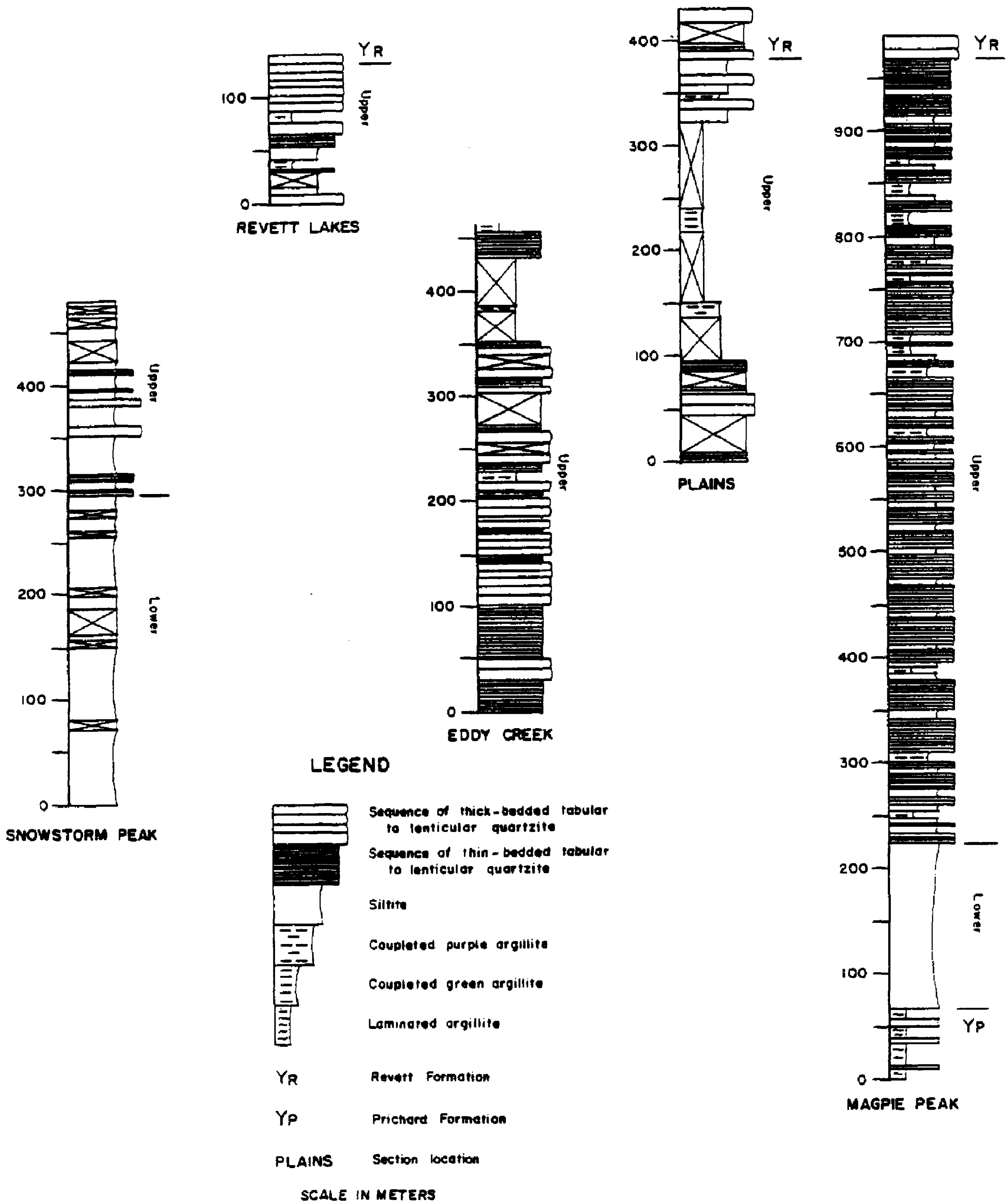


Figure 15. Generalized stratigraphic sections of the Burke Formation. Quartzite bed thickness not determined at Magpie Peak section because section based on float mapping.

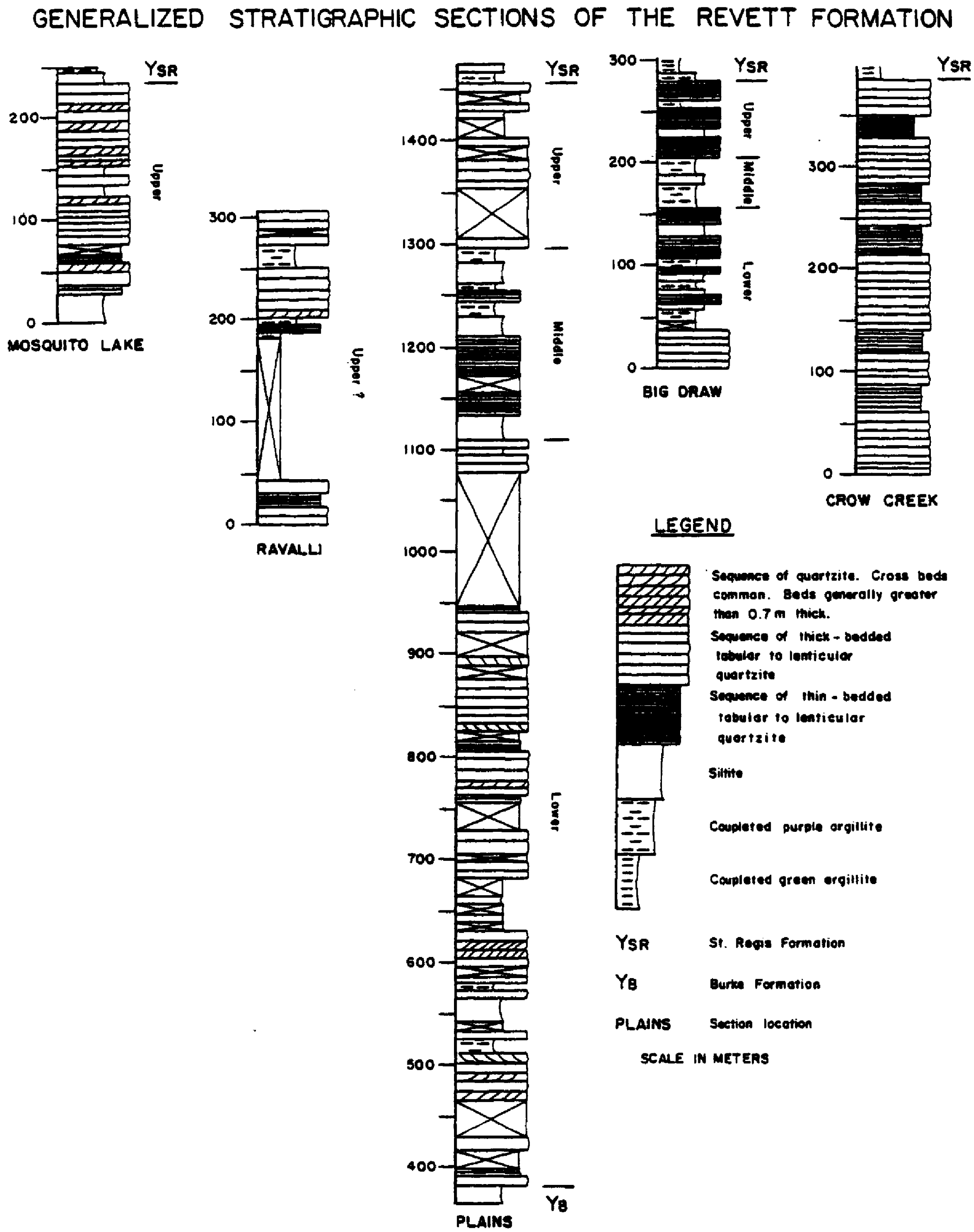


Figure 16. Generalized stratigraphic sections of the Revett Formation.

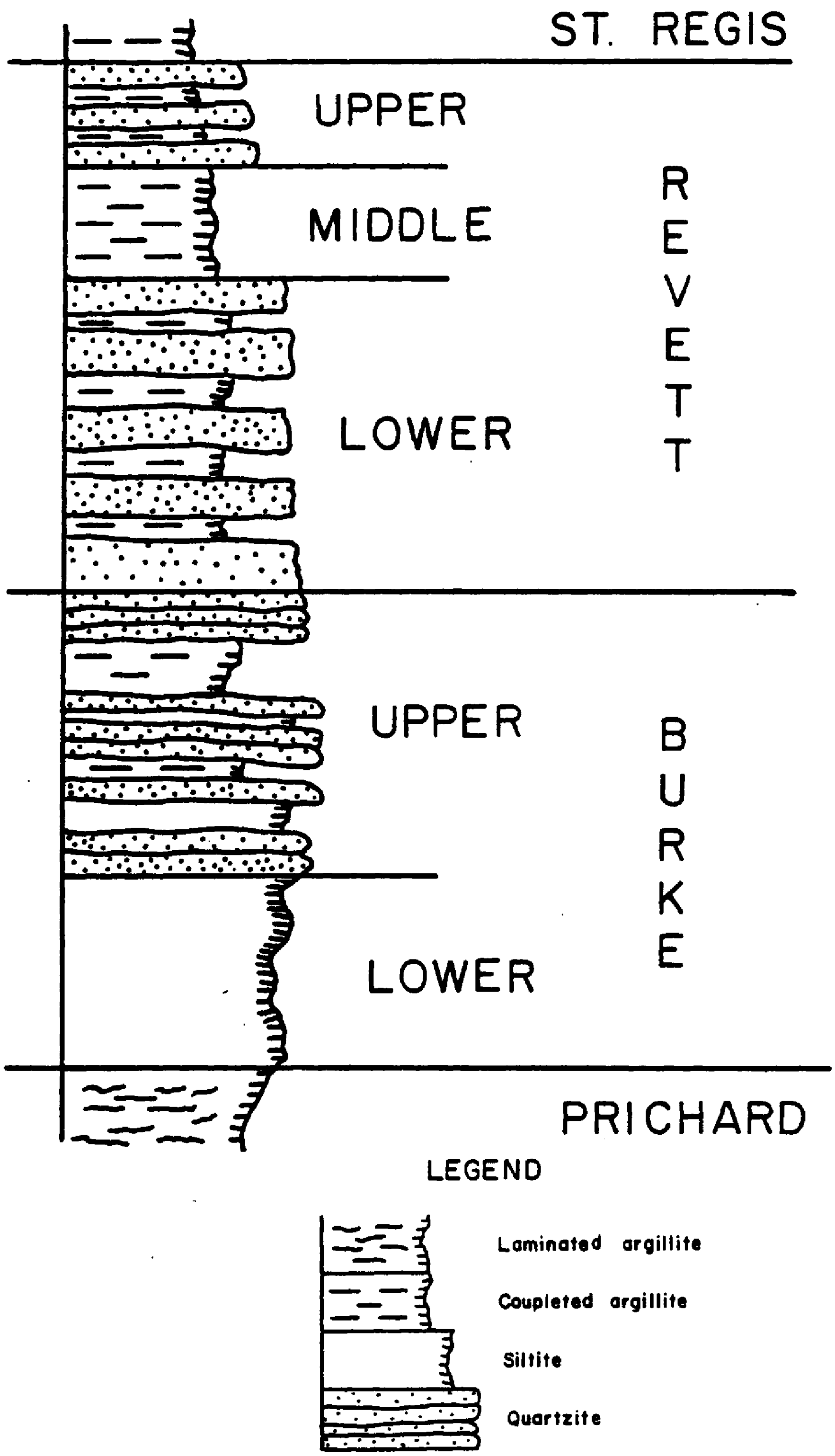


Figure 17. Generalized stratigraphic subdivisions of the Burke and Revett Formations.

contact within this transition zone at the top of the highest Prichard-type strata. This placement generally coincides with the contact as mapped by Harrison et al. (1974b), and Wells (1974), but is about 500 meters above where Cressman (1982) draws the contact based on the lowest occurrence of Burke-type siltite strata.

The upper Burke consists of three lithologic intervals. The lower interval is thick-bedded tabular to lenticular quartzite with minor siltite and rare coupleted argillite. The middle interval of the upper Burke consists of coupleted argillite with local siltite and tabular to lenticular quartzite. The upper interval of the upper Burke contains tabular to lenticular quartzite with subordinate intervals of siltite and coupleted argillite. This interval grades up to the Revett Formation. I placed the Burke/Revett contact where thinner-bedded, impure quartzite of the Burke passes up to thicker-bedded, better-sorted, more commonly cross-bedded quartzite characteristic of the Revett. In most places, this contact generally coincides with the contact mapped by Harrison et al. (1974b), though, as described below, my data indicate that this contact has not been placed at the same lithostratigraphic interval everywhere.

North of my study area, Mike Lis has developed a tripartite subdivision for the Burke in the Libby/Kalispell area. Appendix B describes and discusses this classification.

REVETT FORMATION

White and Winston (1977, 1982) and White et al. (1977) subdivided the Revett into three informal members: 1) a lower member of quartzite intervals alternating with intervals of siltite and argillite; 2) a middle member of siltite and argillite with minor quartzite; and 3) an upper member of quartzite intervals alternating with intervals of siltite and argillite (Figure 17). The lower member grades down to the quartzite, siltite, and argillite of the underlying Burke Formation; the upper member passes up to the argillite and siltite of the St. Regis Formation.

Generally, in areas west of this study, the Revett Formation consists of quartzite and siltite, with rare coupleted purple argillite (Hrabar, 1971; Bowden, 1977a; White and Winston, 1977, 1982; White et al., 1977; Alleman, 1983). Consequently, in the Coeur d'Alene district, White and Winston (1977, 1982) place the upper contact of the Revett with the St. Regis at the base of the lowest coupleted purple argillite with desiccation cracks and mud chips. Because coupleted purple argillite rarely occurs in the Revett in the Coeur d'Alene district, this criterion works well there. However, as illustrated in figure 15, coupleted purple argillite occurs locally within the Revett Formation on, and adjacent to, the Flathead Reservation. This is especially true to the north, where coupleted purple argillite interbeds form approximately one-quarter of the Revett. Because of this, I placed the upper contact of the Revett Formation on the Flathead Reservation at the top of the highest thick interval of thick-bedded quartzite. Quartzite does occur in the St. Regis Formation, but it is generally thin-bedded and does not form thick sequences. This contact commonly coincides with the contact mapped by Harrison et al. (1974b), and Wells (1974) though, as described below, my data indicate that this contact has not been placed at the same lithostratigraphic interval everywhere.

STRATIGRAPHIC CORRELATIONS

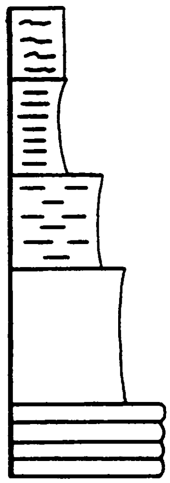
Lithologic sequences in composite sections of the Burke Formation from the Coeur d'Alene district, the Plains area, and Magpie Peak are similar (Figures 15 and 17). All have the informal basal siltite member overlain by the informal quartzite member which contains siltite and argillite units.

This lithologic sequence has been mapped differently in different locations. At the Plains section, Harrison et al. (1974b) have included the top 400 meters of this lithologic sequence within the Revett. At Magpie Peak, Wells (1974) mapped this sequence as lower Burke. These inconsistencies indicate that the Burke has locally been mismapped. Based on exposures in the type area, I believe that the Burke/Revett contact at the Snowstorm Peak, Revett Lakes, and Eddy Creek sections has been consistently and properly mapped. However, this contact apparently has been mismapped at the Plains and Magpie Peak sections.

Figure 19 compares the stratigraphic section I measured at Plains with stratigraphic sections at Eddy Creek and Thompson River. This figure indicates that at Plains, Harrison et al. (1974b) included part of the upper Burke in the Revett Formation, and also included the middle and upper members of the Revett in the St. Regis Formation.

Figure 20 compares a composite section of Wells' (1974) lower Burke, upper Burke, and Revett to composite sections of the Burke and Revett from the Coeur d'Alene district and Eddy Creek plus Thompson River. This comparison indicates that Wells (1974) included the lower and middle Revett within the upper Burke Formation, and mapped the upper member of the Revett as the entire Revett.

LEGEND



Laminated argillite

Coupleted green argillite

Coupleted purple argillite

Siltite; includes siltite and thin-bedded tabular to lenticular quartzite of this study and siltite-argillite of White and Winston

Quartzite

YSR	St. Regis Formation
YR	Revett Formation (undivided)
YRu	Upper member of the Revett Formation
YRm	Middle member of the Revett Formation
YRl	Lower member of the Revett Formation
YB	Burke Formation (undivided)
YBu	Upper member of the Burke Formation
YBl	Lower member of the Burke Formation
YP	Prichard Formation

Contacts recognized during this study

Stratigraphic changes implied by U.S.G.S. mapping

Scale in Meters

Figure 18. Key to figures 19 and 20.

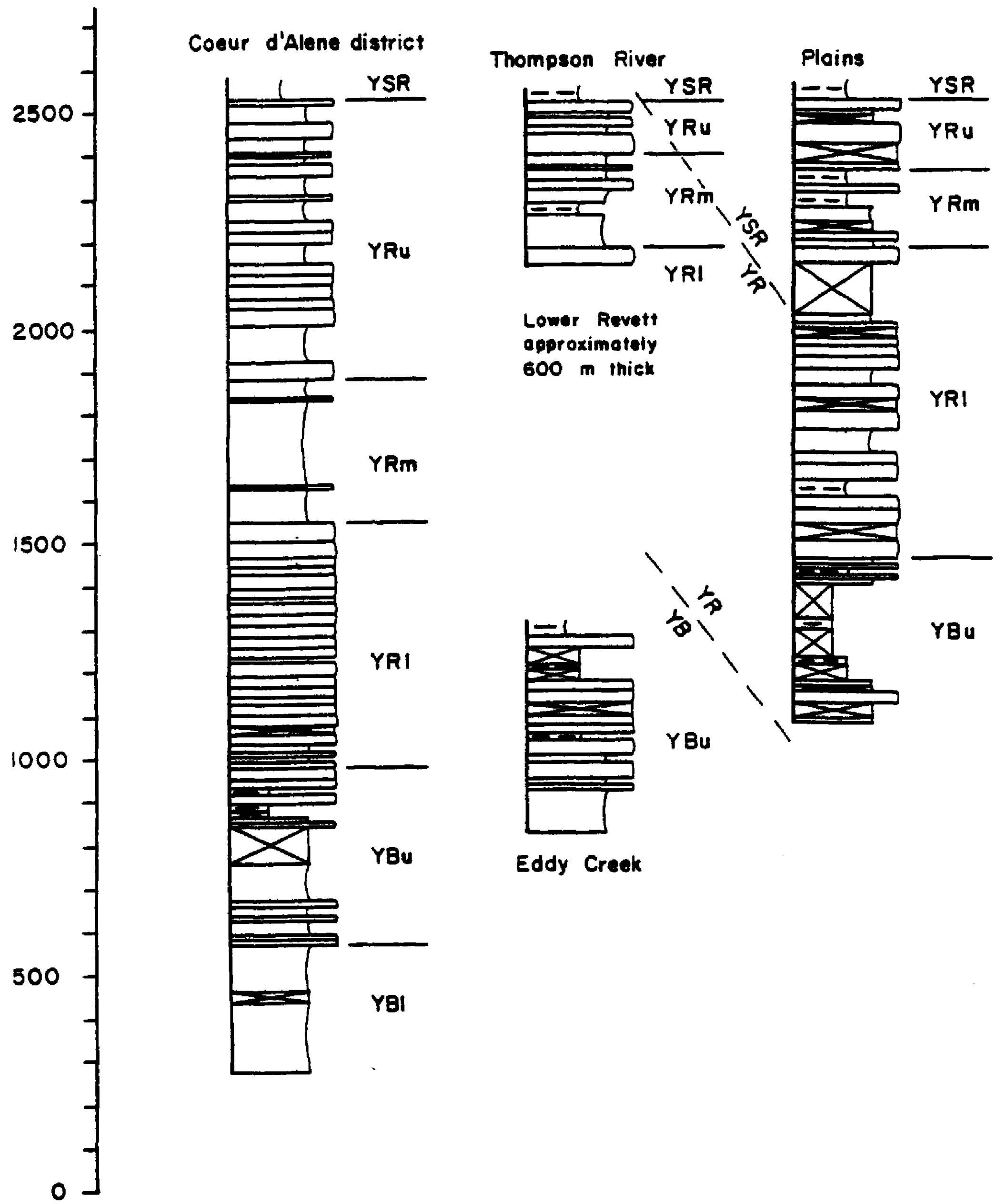


Figure 19. Section of the Revett Formation as mapped at Plains compared with a composite section of the Burke and Revett Formations in the Coeur d'Alene district and a composite section of the Burke and Revett Formations at Eddy Creek and Thompson River. Scale in meters.

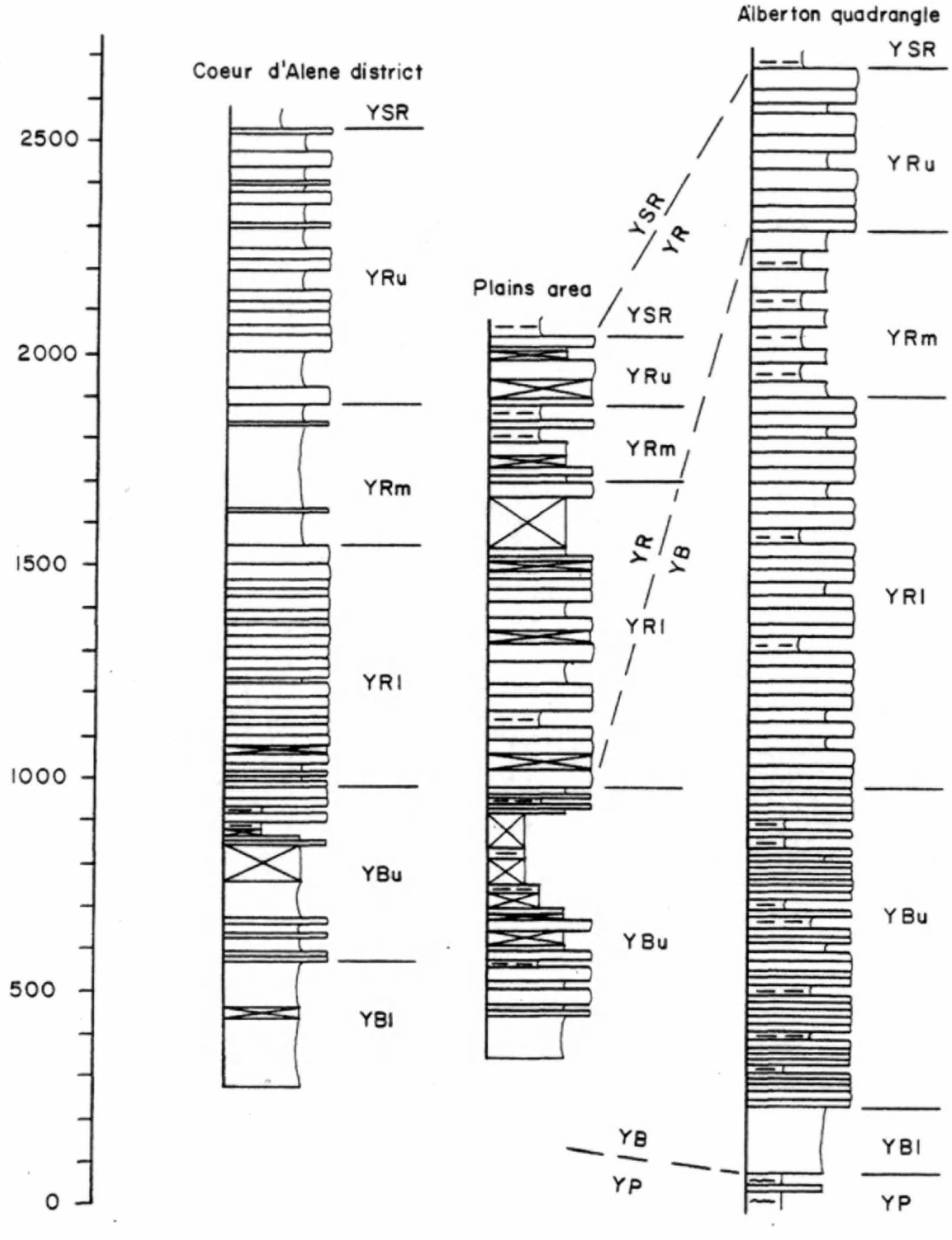


Figure 20. Composite section of the Burke and Revett Formations as mapped on the Alberton quadrangle compared with a composite section of the Burke and Revett Formations in the Coeur d'Alene district and with a composite section of the Burke and Revett Formations at Eddy Creek and Thompson River. Scale in meters.

FACIES CHANGES

Although apparent facies changes within the Burke Formation are complicated by major thrusts (Figure 6), facies changes within the Revett Formation on the Flathead Reservation can be summarized as follows: 1) The percent quartzite within the Revett decreases to the north. 2) Concomitant with the decrease in quartzite, the percent siltite and argillite increases. 3) The average thickness of individual quartzite beds decreases to the north. 4) The average thickness of quartzite intervals decreases to the north. 5) The abundance of cross-bedded quartzite decreases to the north. 6) The thickness of the Revett decreases from an estimated 1800 meters (Wells' upper Burke and Revett) at the southern end of the Flathead Reservation to approximately 400 meters to the north at Big Draw.

SYNTHESIS

GENERAL STATEMENT

The environment of deposition for the Burke and Revett Formations can be interpreted by analyzing the rock types within their stratigraphic framework.

STRATIGRAPHIC SEQUENCE

As illustrated in figure 17 and appendix E, rocks of the Burke and Revett Formations form several discrete lithostratigraphic packages, which exhibit several vertical trends from the top of the Prichard through the lower Revett: 1) sedimentary structures indicative of shallow water and subaerial exposure increase upward; 2) average grain size increases upward; 3) quartzite units increase upward in abundance and thickness; and 4) evidence of reworking, such as scours, increases upward. Thus, as developed below, the Burke and Revett Formations combine to form a coarsening- and shallowing-upward sequence.

The coarsening- and shallowing-upward sequence formed by the lithostratigraphic sequence of the Burke and Revett Formations is similar to coarsening- and shallowing-upward sequences in modern deltas (Miall, 1979). Therefore, I believe the rocks of the Ravalli Group were deposited by a large, tide-dominated delta. I believe the Ravalli Group delta was tide-dominated for two reasons: 1) the abundance of tidalites (Coleman and Wright, 1971); and 2) the presence of strongly bimodal bipolar paleocurrents at some locations. Boyce (1973) postulated a similar model. My interpretation differs from that of Boyce (1973) in one respect: I interpret most of the Revett quartzite units to be fluvial, as do Bowden (1977a, 1977b), White et al. (1977), White and Winston (1977, 1982), and Alleman (1983).

Figure 21 illustrates the relation of the lithostratigraphic sequence of the Burke and Revett Formations to despositional environments in a tide-dominated delta. The following section describes this coarsening- and shallowing-upward sequence and relates it to the environments of deposition in a tide-dominated delta.

Prichard-Burke Transition Zone

The lowest rocks in figure 17 are the laminated argillite and local siltite of the Prichard-Burke transition zone. Sedimentary structures in this interval include graded strata, flat-laminated strata, and rare current ripple cross-laminated strata. Oscillation ripples and desiccation cracks do not occur in this interval.

The lack of oscillation ripples and desiccation cracks indicate that rocks of this interval were deposited subaqueously below wave base. The abundance of graded strata and flat-laminated fine-grained strata indicates that these rocks were deposited as suspended load in a relatively sediment-starved environment.

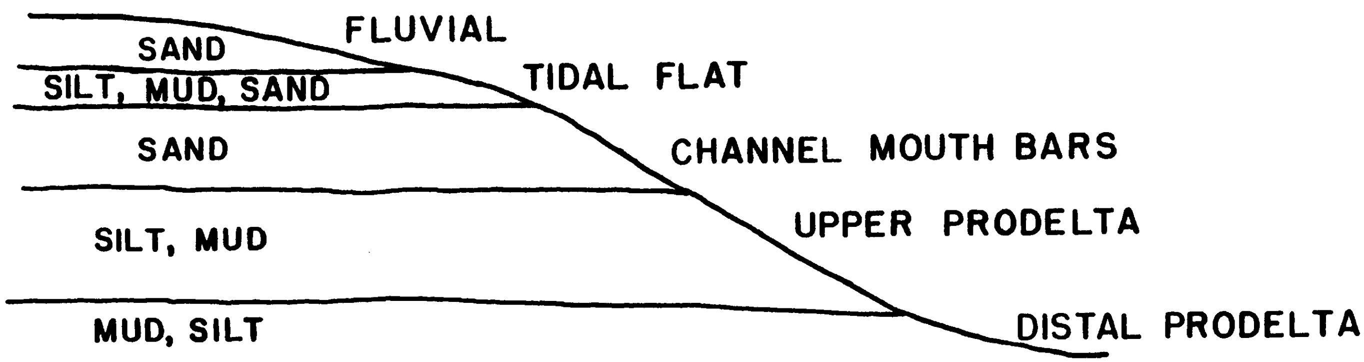


Figure 21. Interpreted environment of deposition for the upper Prichard, Burke and Revett Formations. Modified from Boyce (1973).

These sub-wave base, fine-grained rocks resemble suspension-deposited distal prodelta silt and mud (Donaldson et al., 1970; Allen, 1970).

Lower Burke

The lower member of the Burke Formation contains siltite and rare coupleted green argillite. The percent sand grains within the siltite increases stratigraphically upward. Common sedimentary structures in this interval include graded strata, flat-laminated strata, and current ripple cross-laminae. Load casts occur locally. Small-scale scours, synaeresis cracks, oscillation ripples and mud chips are rare in this interval. Quartzite beds near the top of this interval increase in thickness and abundance upward. Desiccation cracks do not occur in the lower member of the Burke Formation.

The absence of desiccation cracks and scarcity of oscillation ripples indicates that rocks of the lower Burke were deposited in an area which usually remained below wave base. The overall increase in grain size in this interval - siltite grading up to quartzite - indicates that as this sequence was deposited, it gradually progressed from a relatively sediment-starved environment to an environment which received abundant sediment.

The subaqueous, commonly sub-wave base siltite and local quartzite of the lower Burke resembles the suspension- and traction-load deposits of many prodelta slopes (Coleman et al., 1970; Allen, 1970).

Upper Burke

The lower Burke is overlain by thick-bedded tabular to lenticular quartzite with local siltite, thin-bedded tabular to lenticular quartzite, and coupleted argillite of the upper Burke. Quartzite and siltite in this interval commonly form current-ripple cross-laminated and flat-laminated beds with local load casts and oscillation ripples. Quartzite commonly forms moderately-sorted, tabular beds, but locally occurs as lenticular beds. Cross-bedded quartzite rarely occurs in this interval. Local coupleted purple argillite intervals contain mud cracks and mud chips. Local coupleted green argillite intervals contain synaeresis cracks and fluid escape structures.

Quartzite in this interval was deposited as traction load in a subaqueous, near-surface environment with abundant sediment input, as indicated by the abundance of current ripple cross-laminated and flat-laminated quartzite beds with local oscillation ripple caps. Depositional processes laid down tabular, and less commonly, lenticular beds. Local intervals of desiccation-cracked argillite support the conclusion that these quartzite beds were deposited adjacent to an occasionally exposed, shore facies environment, whereas local intervals of coupleted green argillite and siltite indicate that this interval interfingered with subaqueous environments.

As mentioned above, the upper Burke contains an interval of tidalites: thin-bedded tabular to lenticular quartzite, siltite, coupleted purple argillite, and coupleted green argillite. Siltite in this interval resembles coupleted purple argillite except that it lacks well-defined clay layers. Sedimentary structures present in these rock types are described above, in chapter 2.

Tide-dominated river mouths tend to develop bars which consist of smooth, flat bulges seaward of the river mouth (Coleman and Wright, 1971). In the tide-dominated Ord river of Australia, these tidal bars average 10 to 22 meters high, 2 kilometers long, and 300 meters wide (Coleman and Wright, 1975). Presumably, these bars would form relatively wide, sheet-like sand bodies similar to those in the upper Burke. Meckel (1975) describes similar estuarine bars in the Colorado river delta which are tens of meters high and several hundred meters wide.

Most tide-dominated river mouth bars contain two-dimensional and three-dimensional large ripples. The scarcity of large scale cross-stratification in this interval is therefore puzzling, although Meckel (1975) reports that flat lamination is the most abundant sedimentary structure in estuarine bars in the Colorado river delta. Perhaps the best explanation for this problem is related to the fine-grained size of the Burke. Recent observations of bedforms in modern environments indicate that fine sand is transported by upper flow regime flow by currents at a wide range of velocities and depths (Figure 22). Lower flow regime transport of fine sand occurs for only a restricted field of velocities and depths. This indicates that for rocks composed of fine-grained sand, like the quartzite units of the Burke and Revett, flat lamination should be a more abundant sedimentary structure than cross-stratification.

Tide-dominated deltas characteristically have vast tidal flats adjacent to their river mouths. These tidal flats develop because sand, silt, and mud from the rivers is plastered along the adjacent coast as the result of long-shore drift and high tidal activity. Tide-dominated deltas with large tidal flats include the Klang-Langat (Coleman et al., 1970; Coleman and Wright, 1975), the Ord (Coleman and Wright, 1975), the Burdekin (Coleman and Wright, 1975), and the Colorado (R.W. Thompson, 1968, 1975; Meckel, 1975). The major tidal channels in these areas are large, sand-filled bodies with large-scale cross-strata indicative of reversing currents. The bimodal-bipolar paleocurrents from large-scale cross strata at the Plains section probably record deposition in a similar environment. Smaller tidal channels which cross the tidal flats of modern tide-dominated deltas are characterized by current-ripple cross-laminated sandstones which reflect bimodal or polymodal current

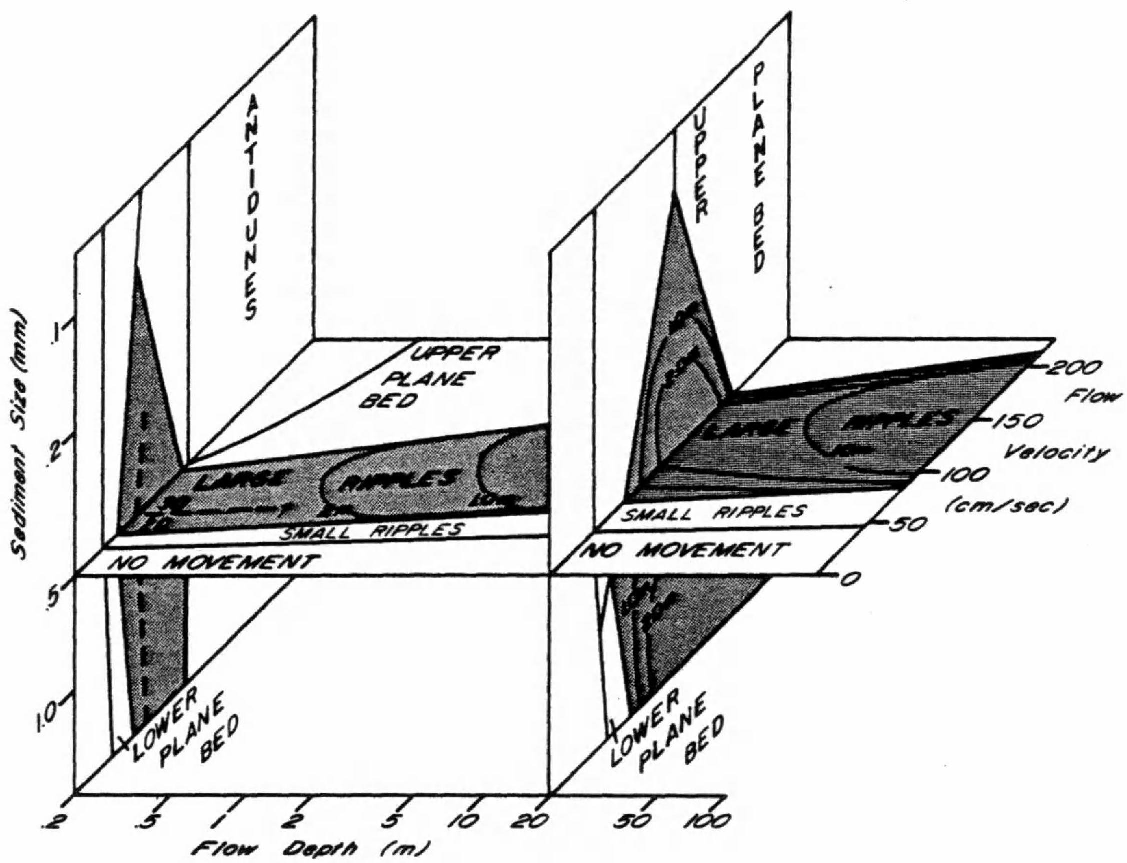


Figure 22. Generalized depth - velocity - size diagram showing relationships among bed phases in flumes and natural flows for a wide range of flow depths. In the field for large ripples, ripple height is contoured approximately. From Harms et al. (1980). After Rubin and McCulloch (1980).

directions (Meckel, 1975). The thin-bedded tabular to lenticular quartzite may locally record deposition in a similar environment.

Quartzite of the Revett Formation

The upper Burke is overlain by thick-bedded tabular to lenticular quartzite and cross-stratified quartzite of the Revett. Quartzite units in the Revett are commonly thicker, better sorted, and more commonly cross-bedded than quartzite units in the Burke Formation.

Rocks present in this interval probably represent deposition in several environments: local intertidal channels, rare beaches, and commonly in a fluvial environment. Thick intervals of quartzite with large-scale cross-stratification indicating unimodal sediment transport were probably deposited in a fluvial environment. Intervals of quartzite with large-scale cross-stratification indicating bimodal bipolar sediment transport were probably deposited in an intertidal environment. Local quartzite beds containing heavy mineral laminae may have been deposited on the backshore of beaches. This is supported by the association of heavy mineral laminae with low-angle, possibly foreshore cross-strata which are underlain by a zone of paleocurrent reversals at Mosquito Lake. All of these deposits were deposited in an environment of abundant sediment supply.

Several lines of evidence indicate that the fluvial environment was probably dominated by a vast network of braided streams - a braidplain (terminology of Allen, 1975). 1) Unimodal paleocurrent roses from the Revett Formation exhibit small variation, which is more characteristic of braided streams than meandering streams (Selley, 1976, 1978; Potter and Pettijohn, 1977). 2) Areas dominated by unimodal paleocurrents, such as Mosquito Lake, rarely contain vertical accretion deposits (Appendix E; Walker and Cant, 1979). 3) Braided streams would occur abundantly during Precambrian time because land plants, which stabilize meandering stream banks, had not yet evolved (Schumm, 1968; McGowen and Groat, 1971).

Therefore, I agree with Bowden (1977a), White and Winston (1982), and Alleman (1983) that the Revett fluvial system was dominated by braided streams and sheet floods. However, I disagree with White and Winston (1982), and Alleman (1983), who postulated that the Revett depositional system contained fan deltas or coalescing alluvial fans. Both of these systems should contain coarse-grained clastic material, should be deposited adjacent to a highland/source area, and should exhibit wedge-shaped geometries along depositional strike (c.f. Rust, 1979; Galloway, 1976; Boothroyd and Nummedal, 1978; Dutton, 1982; Boothroyd, 1976; Boothroyd and Ashley, 1975; Wescott and Ethridge, 1980). The Revett contains none of these diagnostic characteristics, and therefore there is no evidence that alluvial fans or fan deltas existed in the Revett depositional system.

Alleman (1983), based on analogy with other fluvial deposits (Turnbridge, 1981; Collinson, 1978; Williams, 1971; Rahn, 1967; Scott et al., 1969; Bull, 1963; McKee et al., 1967; McGee, 1897; Wasson, 1977; Steel et al., 1977; Steel and Aasheim, 1978; Friend, 1978; Heward, 1978; Laming, 1966; Turner, 1974), developed a sheet flood model for the quartzite of the Revett Formation. This model accounts for several characteristics of the Revett: 1) the abundance of tabular, sheet-like beds, whose width to height ratio is commonly much greater than 50:1; 2) tabular to lenticular quartzite beds locally lack scoured bases; 3) well-defined channel edges rarely occur in the quartzite units of the Revett Formation; 4) flat-lamination is the most abundant sedimentary structure in many Revett quartzite units; 5) unimodal paleocurrent directions occur at many locations of the Revett (Figure 9); 6) within individual tabular to lenticular quartzite beds, flat-laminated quartzite commonly passes upward to silty quartzite with no ripple cross-laminae in between; and 7) point bar deposits appear to be absent in the Revett Formation. I concur with this model for deposition of the fluvial quartzite of the Revett Formation.

CONCLUSIONS

The Burke and Revett Formations represent a major fluviodeltaic system which generally prograded north to northeastward into the "Belt Sea" during Middle Proterozoic time. Two lines of evidence support northward progradation: 1) Facies changes. In the Revett Formation, fluvial quartzite is concentrated at the southern end of the formation. Northward, this quartzite interfingers with finer-grained rocks, siltite and coupleted argillite, which were deposited on the margins of the "Belt Sea". 2) Paleocurrent patterns in the Revett Formation reflect north to northeastward sediment transport. Although the degree of rotation at specific locations is unknown, this parameter agrees well with the facies changes described above, and therefore, the regional trend of these paleocurrent patterns appears to be valid.

The general progradation of this system indicates that, while these sediments were deposited, the overall rate of deposition exceeded the overall rate of subsidence. Deposition did not always exceed subsidence, though, for the Burke and Revett Formations record several transgressive/regressive cycles. For example, the fine-grained rocks of the middle Revett may represent a period of time when deposition approximately equaled subsidence, or when the rate of subsidence was slightly greater than the rate of deposition. Similarly, the fine-grained rocks of the St. Regis Formation represent a period of time when deposition approximately equaled subsidence. In contrast, the subaqueous, sub-wave base sediments of the Wallace Formation were deposited during a period when subsidence exceeded deposition. Many factors control deposition and subsidence rates; therefore, at this time, it is impossible to speculate about what specific factors produced these basin-wide changes.

Figure 23 is a generalized east - west cross section for the Burke and Revett Formations, illustrating interpreted facies changes and environments of deposition. Several trends are evident in this cross-section. 1) Distributary mouth bar deposits increase in thickness and abundance eastward. 2) On the southern end of the Flathead Reservation, the upper Revett may represent either a fluvial system, or possibly a beach and barrier system. 3) Northward and eastward, the Revett fluvial system interfingers with tidal flat facies, which presumably accumulated on the margins of active deltaic lobes. Work by Alleman (1983), Don Winston (pers. comm., 1983), and Brian White (pers. comm., 1983) indicate that the coupleted purple argillite of the eastern facies of the Revett Formation pinches out to the west, where it interfingers with the "siltite-argillite" rock type - a subaqueous rock type characterized by irregular, discontinuous laminae of siltite and argillite. Alleman (1983) proposed that the siltite-argillite rock type was deposited at the "Belt Sea" margin, and that this rock type represents a

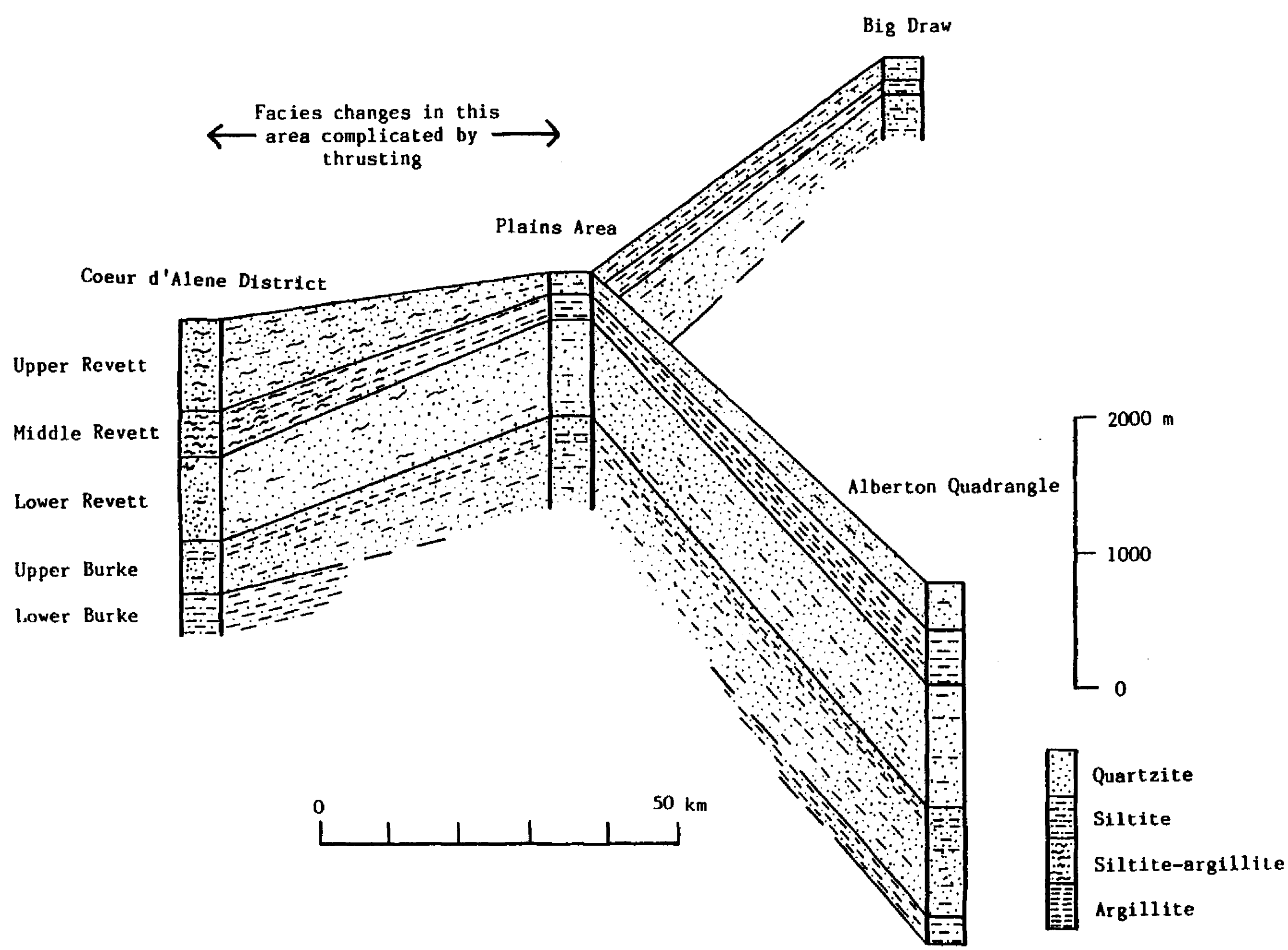


Figure 23. Generalized east - west cross section of the Burke and Revett Formations.

distal facies of the quartzite rock types. Alternatively, this rock type may record deposition in a swamp or marsh environment during a period when deposition approximately equaled subsidence.

Although data east of the Purcell anticlinorium are scarce, it appears that Winston's (1982) proposed Jocko line may have influenced sedimentation in this region. Certainly, the Burke and Revett are much thicker south of this line than to the north. However, until more is known about thicknesses and facies relations of these formations on the Flathead Reservation, it is impossible to conclude with certainty that the Jocko line exists and was active in this area during Middle Proterozoic time.

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APPENDIX A: METHOD OF STUDY

All stratigraphic sections except the Magpie Peak section were measured in the field using a Jacob's staff and Brunton compass. Exposed rocks were painted every five feet, and numbered every ten feet. While describing the sections, I compiled a graphic and written log at a scale of one inch equals ten feet.

The Magpie Peak section consists primarily of float, and therefore I was unable to describe this section using the methods described above. Instead, I prepared a detailed (1 inch = 500 feet) map of the ridge line, noting percent rock types, mineralogy, sedimentary structures, etc. in my field notes. Subsequently, I converted this map and field notes to a detailed cross section, which I used to compile the stratigraphic sections for Magpie Peak.

APPENDIX B: ADDITIONAL BURKE FORMATION STRATIGRAPHY

Mike Lis (written comm., 1983), based on work between Libby and Kalispell (Figure B-1), describes three intervals within the Burke. His classification, which is illustrated diagrammatically in figure B-2, is described below.

Burke Formation Stratigraphy by Mike Lis

"Upper" Burke (about 2200 feet) is composed of siltstones with lesser amounts of pelitic sandstone. Bedding thicknesses, in both rock types, vary from approximately 1/2 inch to 2 feet. The siltstones are generally medium gray, weathering to light gray and light purple. The sandstones are light to medium gray, weathering to light gray and cream-buff colors.

"Middle" Burke (about 1800 feet) consists of light gray and white, massive sandstones, light gray to cream colored, well-laminated, cross-bedded sandstones with lessor amounts of medium gray to light gray weathering siltite, siltstone and shale. The upper and lower thirds are dominantly sandstone and siltite. The middle third is dominantly siltstone and shale. One to two percent magnetite is common throughout this unit, particularly the lower third.

"Lower" Burke (about 900 feet). The upper third of this subdivision consists of lithologies similar to those of the "Upper" Burke and the middle part of the "Middle" Burke. Medium gray siltites and siltstones weathering light gray to light purple, and light to medium gray, well-bedded, impure sandstones

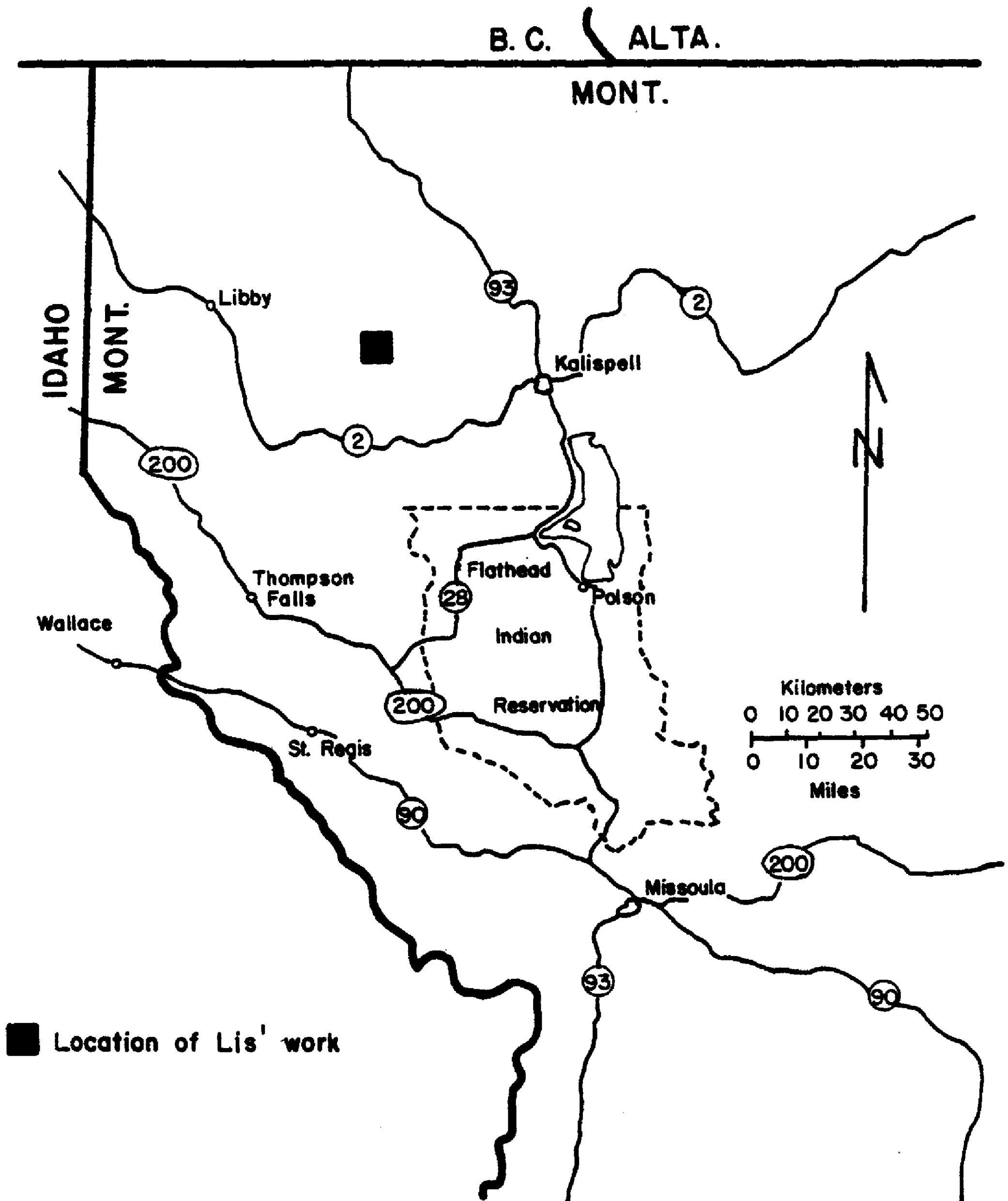

Figure B-1. Location of Lis' work.

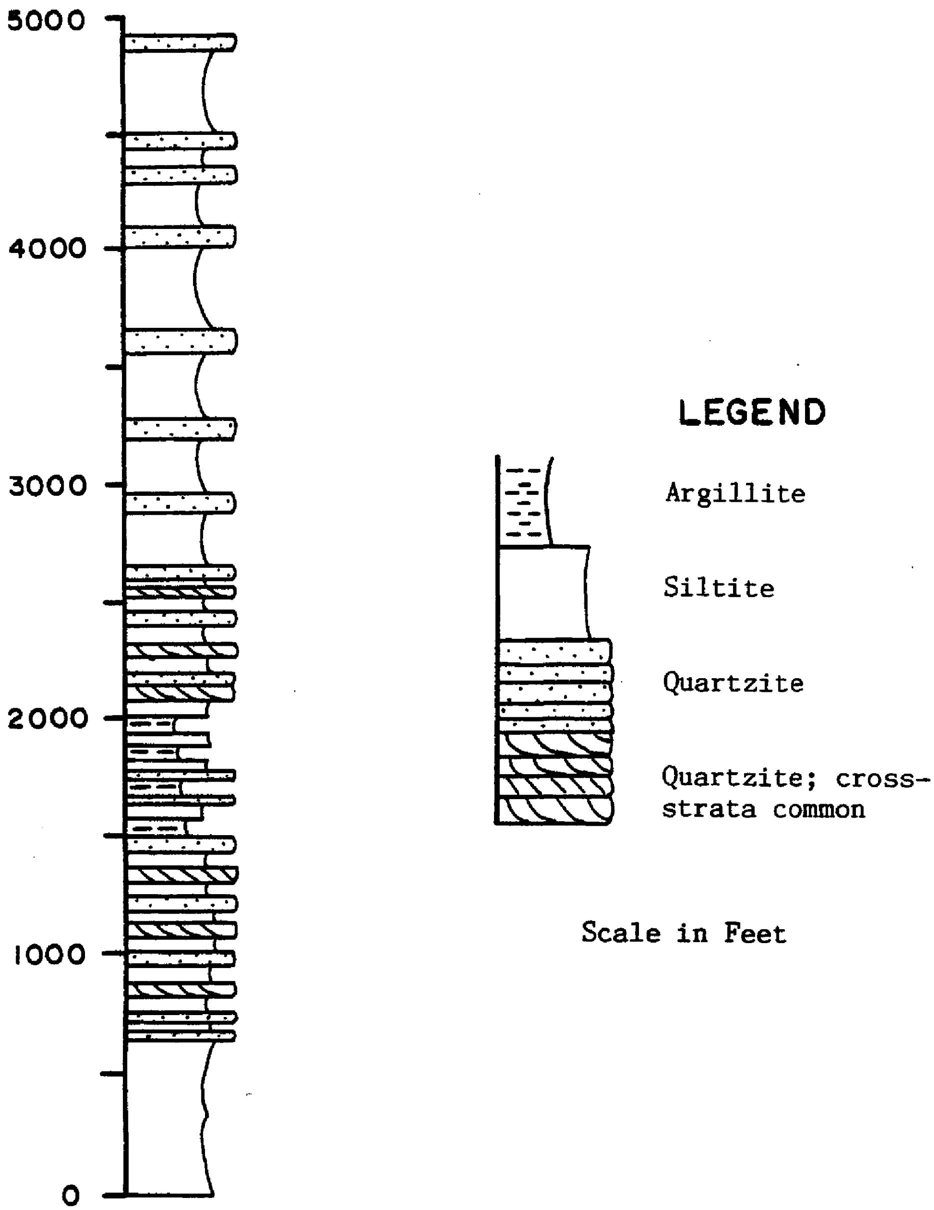

Figure B-2. Generalized stratigraphic section of the Burke Formation in the Libby/Kalispell area. Drawn from description by Lis (see text).

weathering light gray to buff. Up to two percent magnetite is common in this part. The lower two-thirds (about 600 feet) is a massive, blocky weathering, green hued siltite. Load casts, cross-beds and sedimentary features are common.

The relationship between this Burke section and the Burke sections I examined to the south is unclear. The lower and middle members described by Lis appear to resemble the entire Burke section where I have examined it. However, the upper member described by Lis does not resemble the upper part of the Burke Formation in my study area. Future studies may help clarify this puzzle.

APPENDIX C: MARKOV CHAIN ANALYSIS

Markov Chain analysis is a statistical technique to test whether rock types in a vertical sequence occur randomly. If transitions between rock types are not random, inferences can be made concerning the presence of cycles of rock types which presumably represent depositional cycles. Thus, this technique can be used to validate and strengthen facies models (Miall, 1973; Carr, 1982; Powers and Easterling, 1982). Miall (1973) provides a good introduction to the use of Markov chain analysis; Powers and Easterling (1982) document improved methodology for Markov chain analysis.

Using Powers and Easterling's (1982) methodology, I tested the Burke and Revett stratigraphic sections I examined for the Markov property. The results indicate that the hypothesis of random successions of rock types can not be rejected; therefore I was unable to construct statistically significant small-scale lithostratigraphic sequences or cycles. This confirms Alleman's (1983) assertion that fining-upward and coarsening-upward sequences occur with equal frequency in the Revett.

The following tables present transition matrices and probability matrices for the stratigraphic sections I examined.

Abbreviation	Rock Type
G	Coupleted green argillite
P	Coupleted purple argillite
S	Siltite
Q	Tabular to lenticular quartzite
X	Cross-stratified quartzite
T	Sum

Table C-1. Abbreviations used in transition and probability matrices.

Ravalli Section

Transition matrix

	G	P	S	Q	X	T
G	0.00	1.00	3.00	0.00	0.00	4.00
P	1.00	0.00	4.00	11.00	0.00	16.00
S	2.00	7.00	0.00	10.00	0.00	19.00
Q	0.00	8.00	13.00	0.00	3.00	24.00
X	0.00	0.00	0.00	3.00	0.00	3.00
T	3.00	16.00	20.00	24.00	3.00	

Number of iterations required for calculating expected values for probability matrix = 5

Probability Matrix

	G	P	S	Q	X	T
G	0.00	0.86	1.17	1.84	0.13	4.00
P	0.65	0.00	5.73	8.99	0.64	16.01
S	0.86	5.52	0.00	11.80	0.85	19.02
Q	1.39	8.97	12.22	0.00	1.38	23.96
X	0.10	0.64	0.88	1.38	0.00	3.00
T	3.00	16.00	20.00	24.00	3.00	

Chi-squared = 16.69 This is $<$ 0.90 value.

Degrees of freedom = 11.0

Crow Creek Section

Transition Matrix

	P	S	Q	T
P	0.00	1.00	1.00	2.00
S	0.00	0.00	10.00	10.00
Q	3.00	6.00	0.00	9.00
T	3.00	7.00	11.00	

Number of iterations required for calculating expected values for the probability matrix = 15

Probability Matrix

	P	S	Q	T
P	0.00	0.36	1.65	2.01
S	0.71	0.00	9.35	10.06
Q	2.29	6.64	0.00	8.93
T	3.00	7.00	11.00	

Chi-squared = 2.42   This is < 0.90 value

Degrees of freedom = 1.0

Plains Section Revett

Transition Matrix

	P	S	Q	X	T
P	0.00	4.00	8.00	0.00	12.00
S	5.00	0.00	74.00	7.00	86.00
Q	7.00	75.00	0.00	29.00	111.00
X	0.00	7.00	28.00	0.00	35.00
T	12.00	86.00	110.00	36.00	

Number of iterations required for calculating expected values for probability matrix = 9

Probability Matrix

	P	S	Q	X	T
P	0.00	2.65	8.45	0.94	12.04
S	2.66	0.00	75.50	8.41	86.57
Q	8.42	75.16	0.00	26.65	110.24
X	0.92	8.18	26.05	0.00	35.15
T	12.00	86.00	110.00	36.00	

Chi-squared = 5.66 This is < 0.75 value

Degrees of freedom = 5.0

Mosquito Lake Section

Transition Matrix

	P	S	Q	X	T
P	0.00	27.00	5.00	0.00	32.00
S	31.00	0.00	32.00	5.00	68.00
Q	3.00	40.00	0.00	27.00	70.00
X	0.00	3.00	27.00	0.00	30.00
T	34.00	70.00	64.00	32.00	

Number of iterations required for calculating expected values for probability matrix = 4

Probability Matrix

	P	S	Q	X	T
P	0.00	14.45	12.94	4.61	32.00
S	14.95	0.00	39.05	13.92	67.93
Q	14.45	42.15	0.00	13.46	70.07
X	4.60	13.40	12.01	0.00	30.00
T	34.00	70.00	64.00	32.00	

Chi-squared = 98.82 This is >> 0.995 value

Degrees of freedom = 5.0

Big Draw Section

Transition Matrix

	G	P	S	Q	X	T
G	0.00	0.00	3.00	0.00	0.00	3.00
P	1.00	0.00	21.00	15.00	0.00	37.00
S	1.00	21.00	0.00	21.00	0.00	43.00
Q	1.00	16.00	24.00	0.00	3.00	44.00
X	0.00	0.00	0.00	3.00	0.00	3.00
T	3.00	37.00	48.00	39.00	3.00	

Number of iterations required for calculating expected values for probability matrix = 4

	G	P	S	Q	X	T
G	0.00	0.80	1.22	0.93	0.05	3.00
P	0.80	0.00	20.13	15.30	0.80	37.03
S	1.14	18.79	0.00	21.84	1.14	42.91
Q	1.01	16.61	25.42	0.00	1.01	44.05
X	0.05	0.80	1.22	0.93	0.00	3.00
T	3.00	37.00	48.00	39.00	3.00	

Chi-squared = 17.41 This is < 0.95 value

Degrees of freedom = 11.0

Plains Section Burke

Transition Matrix

	G	P	S	Q	X	T
G	0.00	0.00	0.00	2.00	0.00	2.00
P	0.00	0.00	4.00	5.00	0.00	9.00
S	0.00	3.00	0.00	11.00	0.00	14.00
Q	2.00	6.00	10.00	0.00	3.00	21.00
X	0.00	0.00	0.00	3.00	0.00	3.00
T	2.00	9.00	14.00	21.00	3.00	

Number of iterations required for calculating expected values for probability matrix = 7

Probability Matrix

	G	P	S	Q	X	T
G	0.00	0.23	0.39	1.32	0.07	2.01
P	0.23	0.00	1.93	6.53	0.35	9.03
S	0.39	1.93	0.00	11.15	0.59	14.07
Q	1.31	6.49	11.09	0.00	1.99	20.89
X	0.07	0.35	0.59	2.00	0.00	3.01
T	2.00	9.00	14.00	21.00	3.00	

Chi-squared = 8.29 This is < 0.75 value

Degrees of freedom = 11.0

Eddy Creek Section

Transition Matrix

	G	P	S	Q	X	T
G	0.00	0.00	0.00	1.00	0.00	1.00
P	0.00	0.00	2.00	4.00	0.00	6.00
S	0.00	0.00	0.00	16.00	0.00	16.00
Q	2.00	4.00	14.00	0.00	2.00	22.00
X	0.00	0.00	0.00	2.00	0.00	2.00
T	2.00	4.00	16.00	23.00	2.00	

Number of iterations required for calculating expected values for probability matrix = 15

Probability Matrix

	G	P	S	Q	X	T
G	0.00	0.03	0.11	0.86	0.01	1.01
P	0.08	0.00	0.68	5.21	0.08	6.04
S	0.22	0.46	0.00	15.22	0.22	16.12
Q	1.68	3.47	14.99	0.00	1.69	21.82
X	0.02	0.05	0.22	1.71	0.00	2.01
T	2.00	4.00	16.00	23.00	2.00	

Chi-squared = 4.75 This is < 0.10 value

Degrees of freedom = 11.0

Snowstorm Peak Section

Transition Matrix

	G	R	S	Q	T
G	0.00	0.00	1.00	0.00	1.00
P	0.00	0.00	1.00	0.00	1.00
S	1.00	1.00	0.00	14.00	16.00
Q	0.00	0.00	14.00	0.00	14.00
T	1.00	1.00	16.00	14.00	

Insufficient data

Revett Lakes Section Burke

Transition Matrix

	G	P	S	Q	X	T
G	0.00	0.00	0.00	2.00	0.00	2.00
P	0.00	0.00	2.00	4.00	0.00	6.00
S	0.00	2.00	0.00	4.00	0.00	6.00
Q	2.00	3.00	4.00	0.00	8.00	17.00
X	0.00	0.00	0.00	6.00	0.00	6.00
T	2.00	5.00	6.00	16.00	8.00	

Number of iterations required for calculating expected values for probability matrix = 9

Probability Matrix

	G	P	S	Q	X	T
G	0.00	0.13	0.15	1.52	0.21	2.01
P	0.15	0.00	0.48	4.74	0.65	6.02
S	0.15	0.41	0.00	4.80	0.66	6.02
Q	1.53	4.04	4.86	0.00	6.49	16.93
X	0.16	0.42	0.50	4.94	0.00	6.02
T	2.00	5.00	6.00	16.00	8.00	

Chi-squared = 15.69 This is < 0.90 value

Degrees of freedom = 11.0

APPENDIX D: CROSS-STRATIFICATION DATA

Mosquito Lake Section

Footage	Strata	Cross-strata	True Azimuth	True Dip
800	N74W 60N	N88W 53N	251.3	13.6
897	N61W 58N	N43W 82S	55.4	43.5
950	N57W 59N	N27W 88S	79.4	43.6
1009	N53W 61N	N56W 71S	33.2	48.1
1021	N53W 61N	N75W 58S	16.4	64.5
1024	N50W 66N	N65W 78S	16.2	38.9
1034	N55W 66N	N78W 87S	352.2	35.1
1045	N55W 66N	N47W 77S	47.8	37.8
1115	N55W 63N	N51W 76S	40.9	41.2
1117	N55W 63N	N57W 89S	30.7	28.1
1120	N55W 63N	N67W 87S	12.0	32.2
1203	N61W 65N	N71W 85S	9.7	31.5
1210	N61W 65N	N80E 69N	297.2	36.0
1211	N61W 65N	N72W 88S	5.9	29.0

Distribution of true azimuths for Mosquito Lake

Class Midpoint	Percent	Number
0.0	28.57	4
30.0	35.71	5
60.0	14.29	2
90.0	7.14	1
120.0	0.00	0
150.0	0.00	0
180.0	0.00	0
210.0	0.00	0
240.0	7.14	1
270.0	0.00	0
300.0	7.14	1
330.0	0.00	0

Number of Measurements = 14

Mean Azimuth = 18.4

Standard Deviation = 66.59

Plains Section

Footage	Strata	Cross-strata	True Azimuth	True Dip
1534	N37E 22N	N30W 06S	143.0	20.4
1535	N37E 22N	N75W 12N	93.8	20.6
1550	N23E 30N	N07E 53N	261.8	25.2
1551	N23E 30N	N30E 52N	307.6	22.4
1557	N12E 33N	N25E 55N	309.3	23.7
1558	N12E 33N	N42E 44N	354.0	21.4
1635	N17E 31N	N35E 44N	334.6	16.9
1642	N20E 20N	N31E 51N	306.5	31.5
1665	N24E 27N	N79E 20N	65.9	22.1
1737	N15E 26N	N45E 27N	24.3	13.3
1855	N28E 26N	N18E 67N	284.0	41.5
1962	N18E 27N	N27E 45N	308.2	18.7
1983	N22E 26N	N58E 43N	358.4	25.9
2010	N12E 27N	N85W 13N	73.9	28.3
2020	N20E 30N	N73W 14N	83.0	32.2
2030	N22E 28N	N85E 12N	85.8	24.8
2046	N32E 29N	N04W 58S	246.5	37.2
2715	N20E 30N	N20E 54N	290.0	24.0
2641	N20E 30N	N87E 26N	56.7	30.2
4488	N08E 30N	N50W 10N	83.6	36.2

Distribution of true azimuths for Plains

Class Midpoint	Percent	Number
0.0	10.0	2
30.0	5.0	1
60.0	15.0	3
90.0	20.0	4
120.0	0.0	0
150.0	5.0	1
180.0	0.0	0
210.0	0.0	0
240.0	5.0	1
270.0	10.0	2
300.0	25.0	5
330.0	5.0	1

Number of Measurements = 20

Mean Azimuth = 1.4

Standard Deviation = 75.59

APPENDIX E: LOCATION OF MEASURED STRATIGRAPHIC SECTIONS

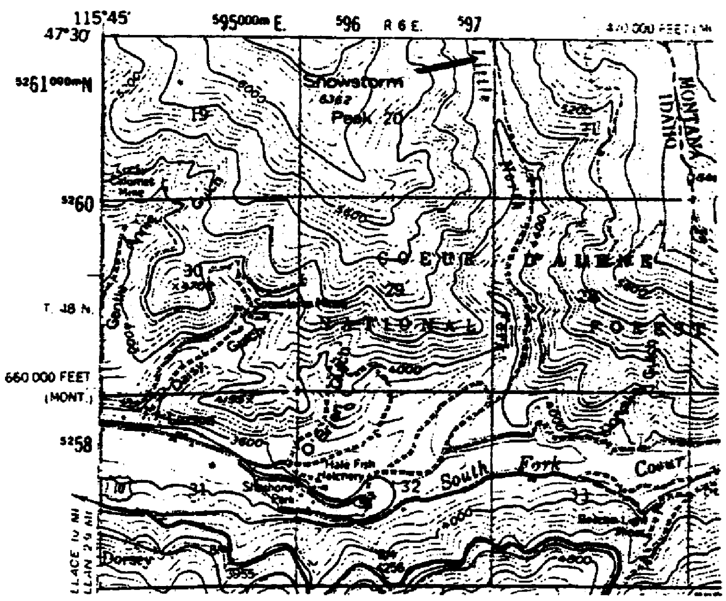

Figure E-1. Location of Snowstorm Peak section. Base Map from Saltese, Idaho-Montana Quadrangle.

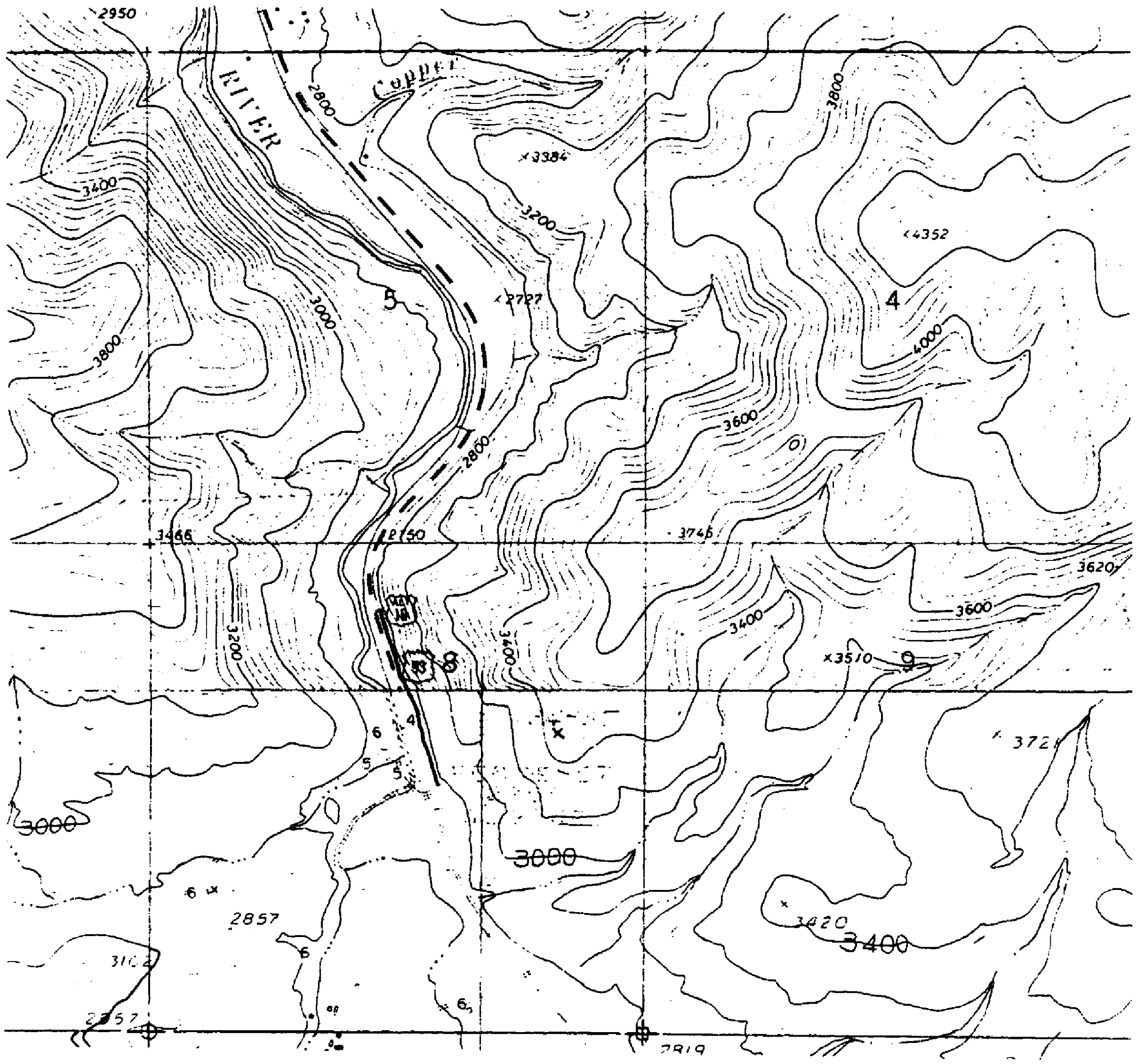

Figure E-2. Location of Ravalli section. Base map from Arlee N.W. and Ravalli, Montana Quadrangles.

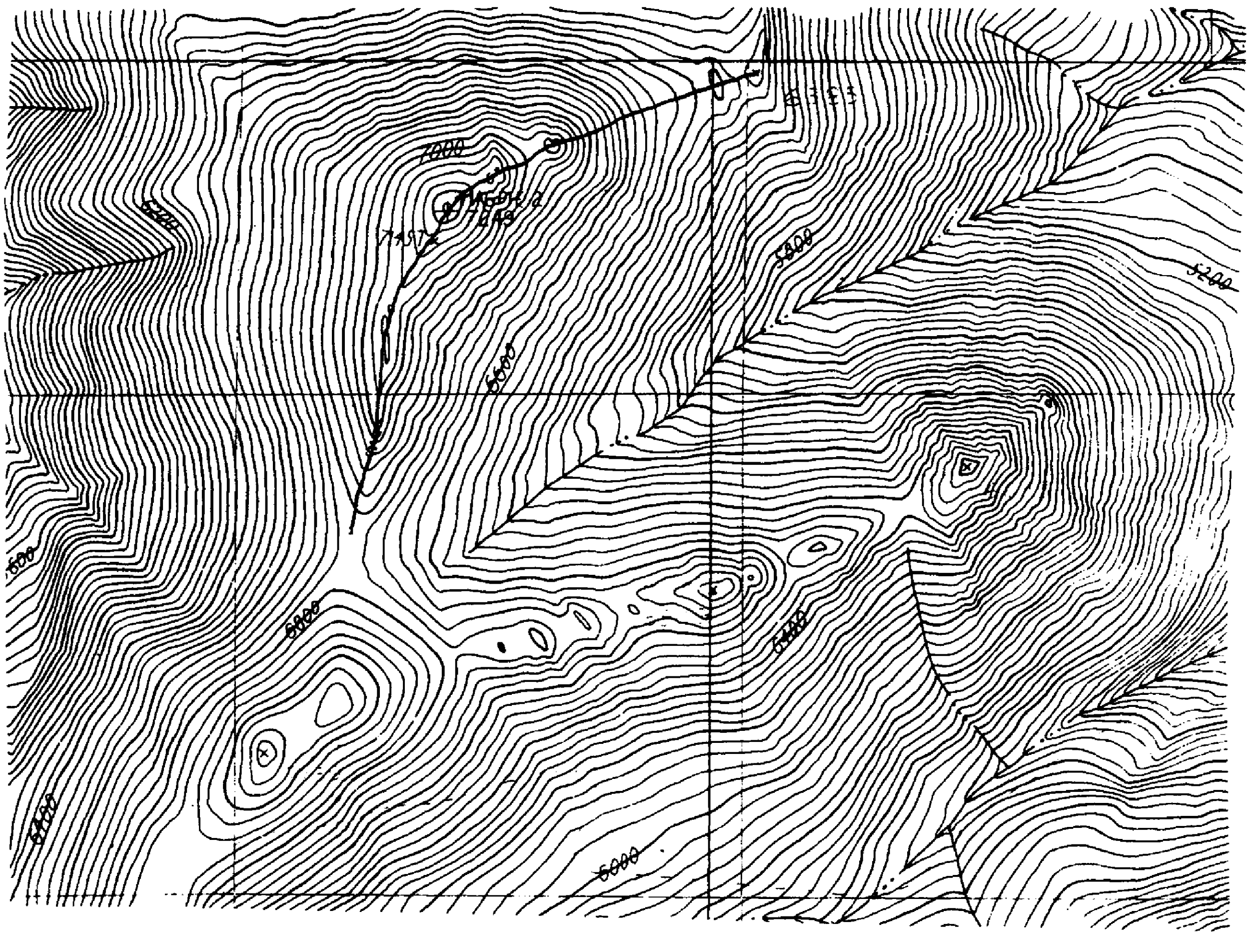

Figure E-3. Location of Magpie Peak Section. Base map from Huson, N.W. Montana Quadrangle.

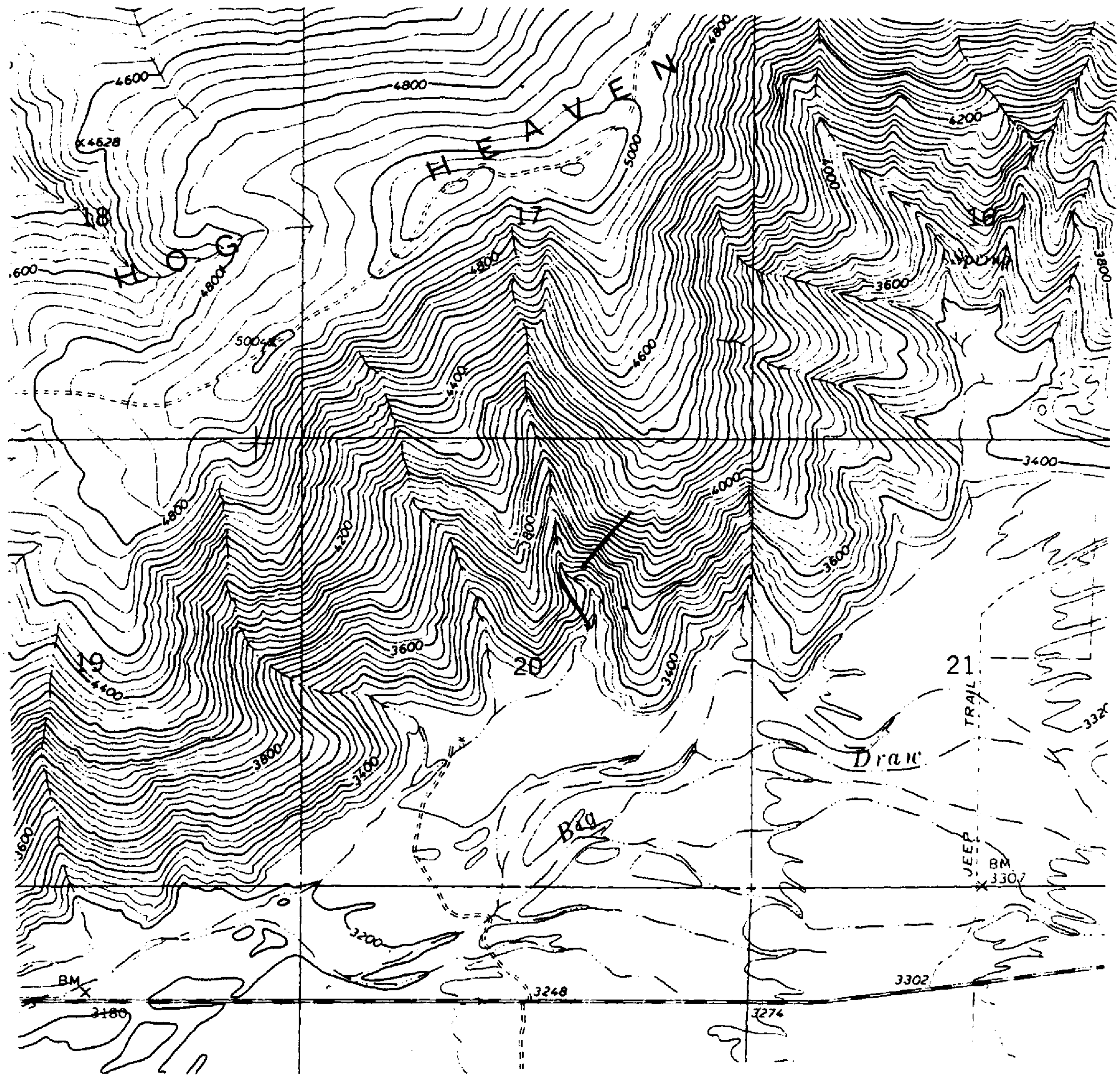

Figure E-4. Location of Big Draw section. Base map from Irvine Lookout Tower, Montana quadrangle.

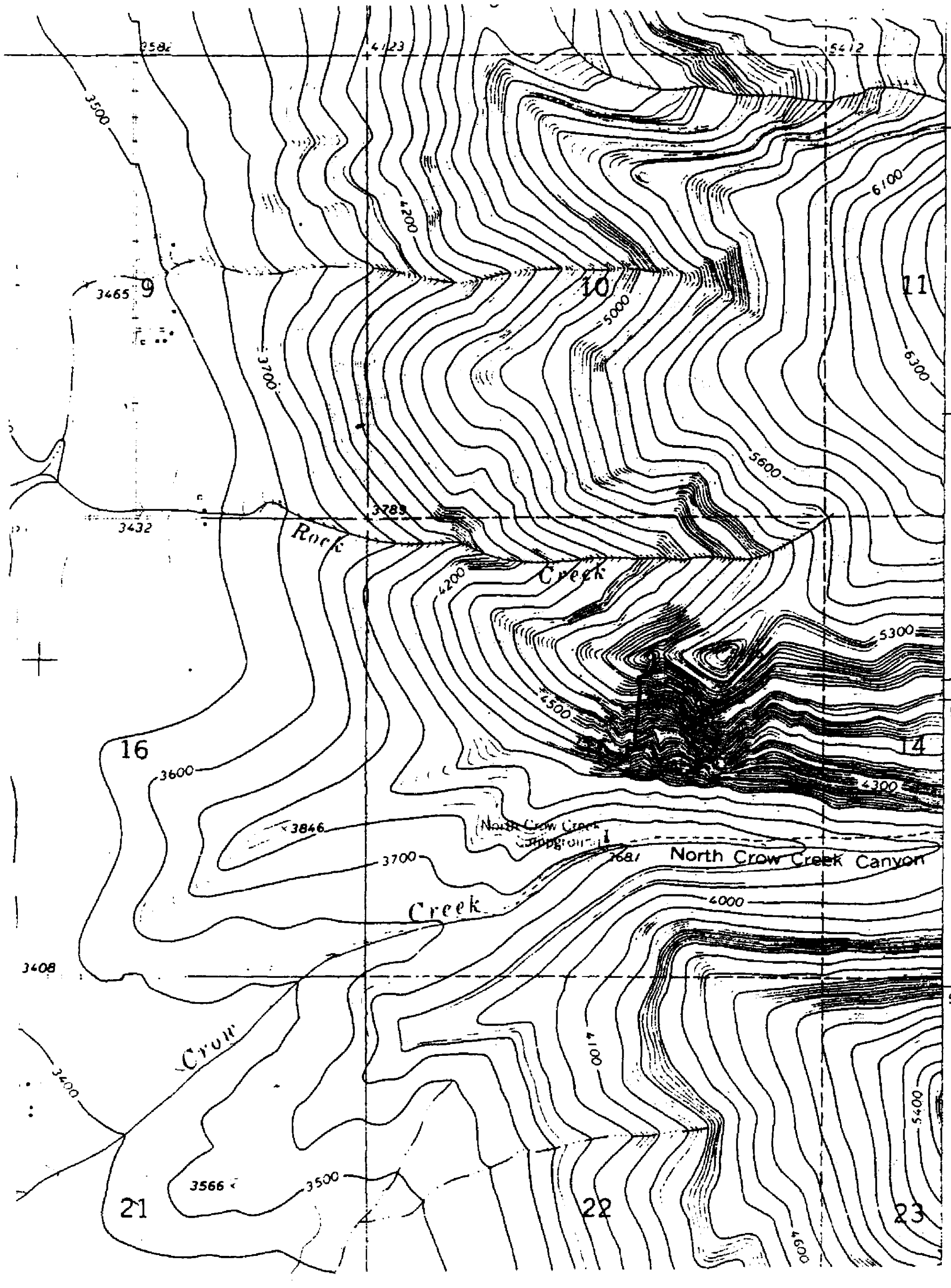

Figure E-5. Location of Crow Creek Section. Base map from Ronan, Montana quadrangle.

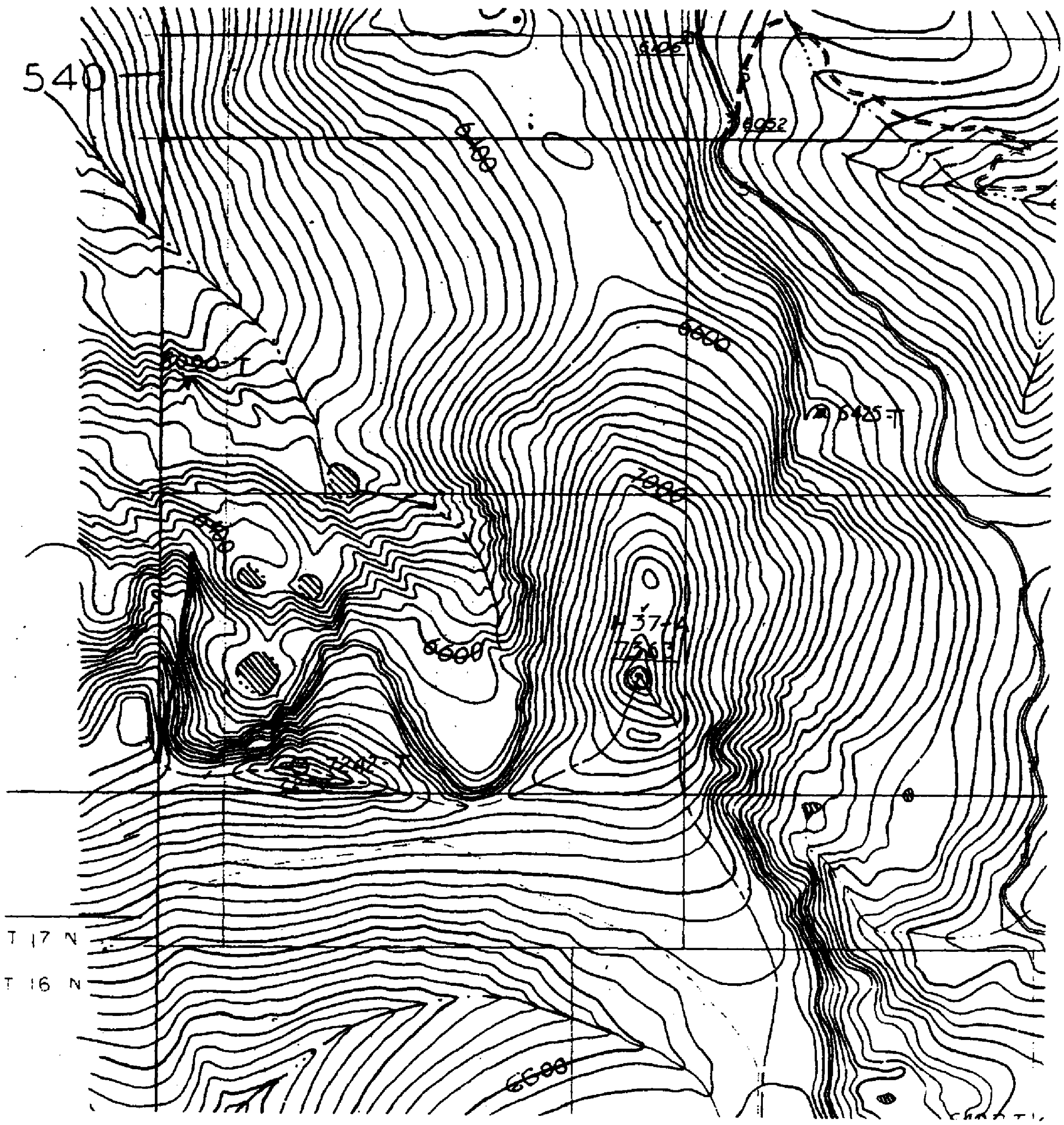

Figure E-6. Location of Mosquito Lake section. Base map from Huson N.E., Montana quadrangle.