The Red Jacket Formation of Southeastern Saskatchewan

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This report describes a proposed redefinition of part of the Jurassic stratigraphy in southeastern Saskatchewan. The need for a redefinition has arisen because of difficulties in attempting to extend stratigraphic picks of the Shaunavon Formation and upper member of the Gravelbourg Formation from their type area in southwestern Saskatchewan into southeastern Saskatchewan.

In an attempt to redress these difficulties and in conformity with the North American Stratigraphic Code (American Association of Petroleum Geologists, 1983, Article 23, Remark b), the author proposes the establishment of a new stratigraphic unit in the southeast, the Red Jacket Formation, which is separated by an arbitrary lithofacies cut-off from the Shaunavon Formation and upper member of the Gravelbourg Formation. The Red Jacket Formation is named after a village near the type section of the formation in the Tide Water North Wapella Crown 14-22-15-1 (Lsd. 14-22-15-1W2M) well.

Included in this report is a description and discussion of the type section, as well as the boundaries, distribution, lithology, age and correlation of the Red Jacket Formation. A west to east cross-section showing correlation of Jurassic strata between southwestern and southeastern Saskatchewan is included in the accompanying map package. A description of core from the type section is given in the Apppendix. This work is part of a broader study by the author of the oil-bearing Jurassic sandstones occurring at various levels in the Wapella–Moosomin area (Figure 2 and cross-section in map package).

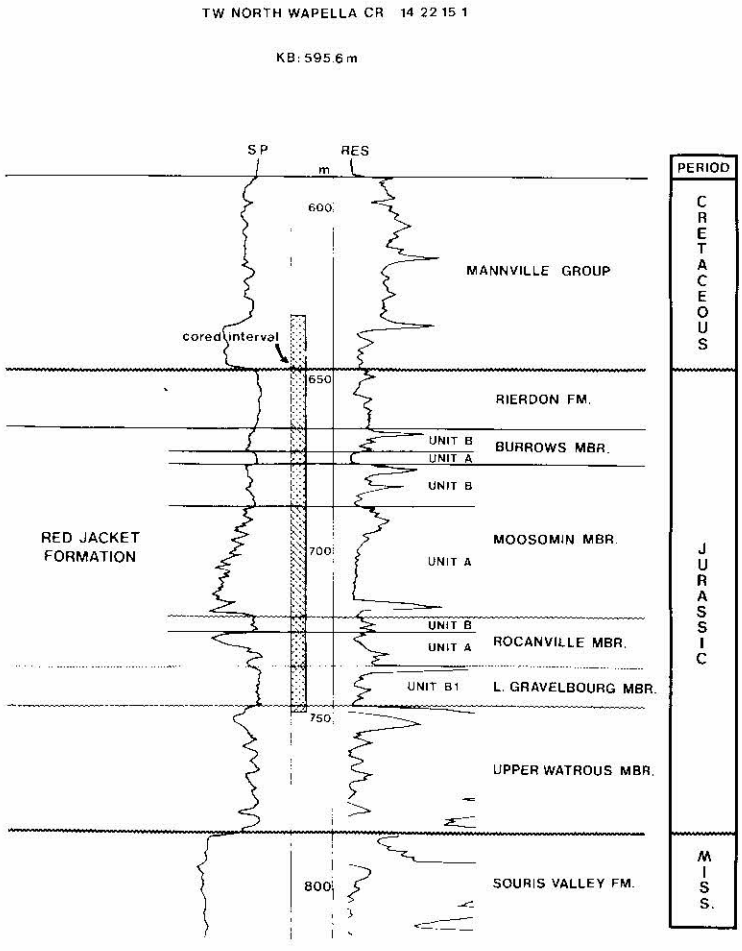


Figure 1 – Type section for the Red Jacket Formation in the TW North Wapella Crown 14-22-15-1 well, illustrating proposed stratigraphic subdivision and cored interval .

1. Stratigraphy

a) Type Section

The type section selected for the Red Jacket Formation is fully cored in the Tide Water North Wapella Crown well 14-22-15-1 (Lsd. 14-22-15-1W2M) between 2183.0 and 2452.0 ft. (665.4 and 747.4 m) below the Kelly Bushing (K.B.). This well exhibits the typical lithologies and geophysical well log responses common to the Red Jacket Formation and is the only well possessing a continuous core through all of the formation, as well as contiguous strata. The well is illustrated as number 14 in the cross-section (in map package). The cored interval in this well is illustrated in Figure 1.

Generally, recoveries of the 1.5 inch diameter wireline core of the Red Jacket Formation in the Tide Water North Wapella Crown well is fair (approx. 60 to 80 percent) to good (approx. 80 to 100 percent). However, a few intervals less than 10 ft. (3.0 m) in thickness demonstrate poorer recoveries. Unfortunately, the core is largely broken up due to repeated handling. Thus many contacts are not well preserved or are completely absent, especially in interlaminated and mudstone sections of the core.

The Red Jacket Formation has been divided into three members (Figure 1), all of them named after villages near their type section in the TW North Wapella Cr 14-22-15-1 well.

The lower member is herein named the Rocanville Member after the village in Twp. 16, Rge. 31W1. The Rocanville Member occurs in the type section for the Red Jacket Formation between 2360.0 and 2410.0 ft.(719.3 and 734.6 m).

The middle member is named the Moosomin Member after the town in Twp. 14, Rge. 31W1. The Moosomin Member is found in the type section for the Red Jacket Formation between 2215.3 and 2360.0 ft. (675.2 and 719.3 m).

The upper member is named the Burrows Member after the village in Twp. 15, Rge. 1W2. It occurs in the type section for the Red Jacket Formation between 2183.0 and 2215.3 ft. (665.4 and 675.2 m).

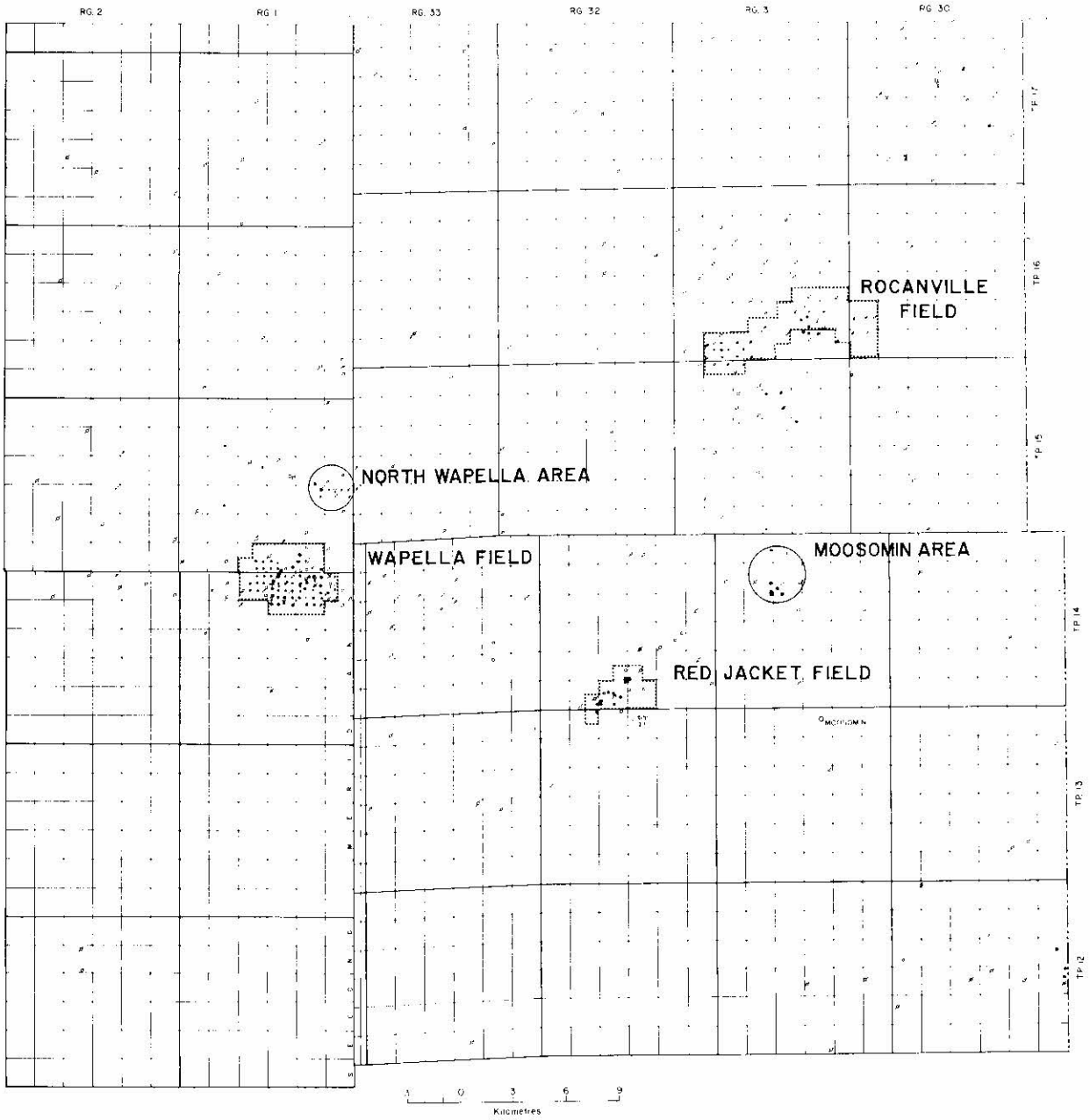


Figure 2 – Location map of the study area referred to in the text as the Wapella–Moosomin area.

Discordances and apparent changes in lithofacies in some portions of the Red Jacket Formation complicate the correlation and recognition of these members. Distinctive lithologic characteristics of these members are best observed in core from the Wapella–Moosomin area of southeastern Saskatchewan (Figure 2).

Further subdivision of each of these members into a lower Unit A and an upper Unit B is at present restricted to the Wapella–Moosomin area, where there is sufficient well and core control. Subdivision using only log responses is hampered by 1) the similarity of lithologies between overlying and underlying units, 2) abrupt lithofacies changes, and 3) lateral variability in thickness as the result of numerous discordances which have locally thinned or completely removed individual units.

2. Definition of the Lower and Upper Boundaries

a) Definition of the Base

The base of the Red Jacket Formation occurs in the type section at 2410.0 ft. (734.6 m). Although this contact is missing in core from the type section, it is found to be sharp in other cores in the Wapella–Moosomin area. There appears to be a discontinuity between the Lower Gravelbourg Member and the overlying Rocanville Member of the Red Jacket Formation. The pick on a geophysical log is readily made in the Wapella–Moosomin area where porous sandstone of the Rocanville Member of the Red Jacket Formation rests on the limestone of the Lower Gravelbourg Member. This same contact however, is difficult to recognize in some wells to the south and west of this area due to a general lack of contrast in geophysical log responses with the underlying Lower Gravelbourg Member.

A similar lack of contrast is also locally present between the Lower and Upper Gravelbourg Members west of the arbitrary lithofacies boundary shown on the cross-section location map (in map package). For example, in wells 9 and 10 on the cross-section, slightly sandy limestones of the Lower Gravelbourg Member exhibit scarcely different SP/Res responses from the overlying silty, slightly calcite-cemented sandstones of the Upper Gravelbourg Member. The distinction between the Lower and Upper Gravelbourg Members originally proposed by Klingspor (1958, p. 34) has, in fact, never been formalized in southwestern Saskatchewan. It is only common usage which has brought about the subdivision of the Gravelbourg Formation into an upper and lower member. This lack of formalization has caused some confusion regarding the boundary between the Upper and Lower Members of the Gravelbourg Formation.

An unconformity at or near the top of what has been tentatively called the "Lower Gravelbourg" by Milner and Blakslee (1958) and other authors in southwestern Saskatchewan appears to have a counterpart in southeastern Saskatchewan. Vigrass (1952) noted the presence of a horizon of abundant bluish chalcedonic chert in what is currently regarded as the "Lower Gravelbourg" in southwestern Saskatchewan. He interpreted this horizon as an unconformity and used this interpretation to account for the variation in thickness of underlying strata. A similar horizon was also identified in southeastern Saskatchewan and southwestern Manitoba (Stott, 1955). Francis (1956), Klingspor (1958) and Kreis (1987) later adopted this "minor unconformity" or disconformity, which occurs at the top of a weathered dolomite with abundant bluish chalcedonic chert, as the pick for the top of the Lower Gravelbourg in southeastern Saskatchewan. It is noted that, in addition to bluish chalcedonic chert and weathered dolomite at this horizon, there are commonly euhedral bipyramidal quartz crystals.

The presence of chert and bipyramidal quartz has been interpreted as evidence for "vanished evaporites" (i.e., unpreserved evaporites) by Friedman (1980) in the Little Falls Dolostone (Late Cambrian) of Herkimer County, New York. In this locality, euhedral quartz crystals occur in vugs in dolomite, sandstone and associated stromatolitic dolomites. This observation is noted in connection with chalcedonic chert and euhedral bipyramidal quartz crystals found at the apparent unconformity in southwestern and southeastern Saskatchewan.

Detailed examination of drill cuttings and core makes it apparent that the chalcedonic chert-bearing horizon in southeastern Saskatchewan lies below a fossiliferous olive-grey (5Y4/1) calcareous mudstone, which in turn is overlain by or interbedded with an oolitic, very light grey (N8) to light olive-grey (5Y6/1) limestone. This mudstone and limestone unit is referred to in the cross-section (in map package) as Unit B1 of the Lower Gravelbourg Member in southeastern Saskatchewan. The underlying dolomitic limestone unit with weathered dolomite, chalcedonic chert and sporadic euhedral bipyramidal quartz at its top is referred to as Unit A1 of the Lower Gravelbourg in southeastern Saskatchewan.

Extensive geophysical log correlations appear to show that the mudstone and limestone of Unit B1 in southeastern Saskatchewan correlate with what was tentatively called "Lower Gravelbourg" in southwestern Saskatchewan by earlier stratigraphers (e.g., Milner and Blakslee, 1958). It would then appear that, although there is general agreement on the boundary between the Upper and Lower Gravelbourg Members in southwestern Saskatchewan, the top of the Lower Gravelbourg Member in southeastern Saskatchewan has been picked at a lower horizon, namely at the well-defined unconformity at the top of Unit A1. The acceptance of Unit B1 as the top of the Lower Gravelbourg Member in southeastern Saskatchewan is a revision of an earlier identification of the top of the Lower Gravelbourg Member (Kreis, 1987).

The cross-section (in map package) shows the suggested correlation and location of the apparent unconformity at the top of Unit A1 in southeastern Saskatchewan (i.e., wells 9 to 14). Defined by bluish-grey chalcedonic chert, weathered dolomite and sporadic euhedral bipyramidal quartz, it is interpreted to be the counterpart of the one illustrated in southwestern Saskatchewan (i.e., wells 1 to 3). In southwestern Saskatchewan, the Lower Gravelbourg Member is subdivided

by this apparent unconformity into a Unit A and a Unit B. It is important to note that the presence of a cherty dolomite with or without euhedral quartz has not been observed in the intervening wells 4 to 8. A dashed line through these wells shows the suggested correlation between units of the Lower Gravelbourg Member in southwestern and southeastern Saskatchewan.

The presence of a horizon defined by bluish-grey chalcedonic chert, weathered dolomite and sporadic euhedral bipyramidal quartz in both southwestern and southeastern Saskatchewan is deemed to reflect an interlude of evaporitic to subaerial conditions before the return of marine conditions. The lack of evidence for an unconformity or evaporitic conditions in wells 4 to 8 may reflect the limit to which the Lower Gravelbourg sea receded.

b) Definition of the Top

The cross-section (in accompanying map package) shows that the top of the Red Jacket Formation occurs everywhere at the base of the calcareous mudstones of the Rierdon Formation. These mudstones commonly overlie a fossiliferous calcite-cemented sandstone subunit at the top of the Red Jacket Formation. Where this sandstone occurs, it is taken to be the uppermost portion of the uppermost unit, namely Unit B of the Burrows Member. This unit is generally composed of poorly sorted, very fine to fine-grained clear quartz sandstone. This sandstone is typically less than 1.5 m in thickness, light olive-grey (5Y6/1) in colour, silty, argillaceous and calcite cemented, and contains minor amounts of pyrite and a trace of glauconite. However, it is the abundance of well-worn *Gryphaea nebrascensis* and other pelecypod shell debris that characterizes this subunit. Christopher (1964) suggested that the presence of *G. nebrascensis* dates the sediment as Callovian in age, in which case this subunit would belong to the Rierdon Formation.

This calcite-cemented *Gryphaea*-bearing sandstone subunit is interpreted as a lag deposit at the base of the overlying Rierdon Formation and is therefore thought to lie unconformably on underlying strata. The presence of *G. nebrascensis* in this sandstone was not detected; however, where this sandstone is not highly calcite-cemented, it is indistinguishable on geophysical logs from underlying sandstones of the Red Jacket Formation. For these reasons, this sandstone subunit is placed in the uppermost portion of Unit B of the Burrows Member at the top of the Red Jacket Formation. For a more detailed discussion of the probable age and correlation of this subunit, the reader is referred to Christopher (1964, 1966) and Kreis (1987).

Where this uppermost sandstone subunit is not developed, an interbedded and burrow-mottled sandstone and mudstone sequence is found which is difficult to distinguish on geophysical logs from the overlying Rierdon Formation. In these instances, careful correlation with adjacent wells exhibiting more obvious contacts on geophysical logs, or use of available core, becomes necessary.

In the type section for the Red Jacket Formation in the Tide Water North Wapella Crown 14-22-15-1 well (Lsd. 14-22-15-1W2M), the calcite-cemented *Gryphaea*-bearing sandstone is present and the upper boundary for the Red Jacket Formation is taken to be at 2183 ft. (665.4 m) (Figure 1).

3. Distribution

The Red Jacket Formation occurs in southeastern Saskatchewan, east of the previously described arbitrary cut-off for the Shaunavon Formation and Upper Member of the Gravelbourg Formation. It extends eastward and southward, respectively, to the Manitoba and North Dakota borders, and to the north as far as the eroded edge of the Jurassic. The Red Jacket Formation was largely removed by erosion in the north half of the Wapella–Moosomin area during the Late Jurassic or Early Cretaceous. The areal distribution of the Red Jacket Formation is illustrated on the map accompanying the cross-section (in map package). The extent to which its subdivisions may be picked has not yet been defined.

The Red Jacket Formation varies in thickness from zero at its northern eroded edge (erosional edge of the Jurassic) to approximately 90 m in the Wapella–Moosomin area. In the Tricent et al. Coothill well (Lsd. 6-14-14-33W3M), the Red Jacket Formation is 88 m thick, due to an apparent thickening of Unit A of the Rocanville Member at the expense of Unit B1 of the Lower Gravelbourg Member (Figure 3). Other locally thickened sections have also been detected.

4. Lithology

The Red Jacket Formation comprises a complex succession of sandstones, siltstones, mudstones and minor carbonates. Sandstones and mudstones dominate, and are commonly interbedded and interlaminated. The Appendix gives a detailed core description of the type section for the Red Jacket Formation.

a) Rocanville Member

Unit A:

In the Wapella Field area, the base of Unit A comprises a slightly silty sandstone which directly overlies the limestones and calcareous mudstones of Unit B1 of the Lower Gravelbourg Member. In the type section log, the basal contact of Unit A occurs at 2410 ft. (734.6 m). Unfortunately, this contact is missing in the type section core, but in other wells in the area it is found to be sharp and locally erosional. Siltstone and interbeds of calcareous mudstone and argillaceous limestone also characterize Unit A of the Rocanville Member.

Unit B:

In the type section, the contact between Units A and B of the Rocanville Member is located at 2379.6 ft. (725.3 m). In the type section core, the overlying Unit B of the Rocanville Member consists of limey greenish-

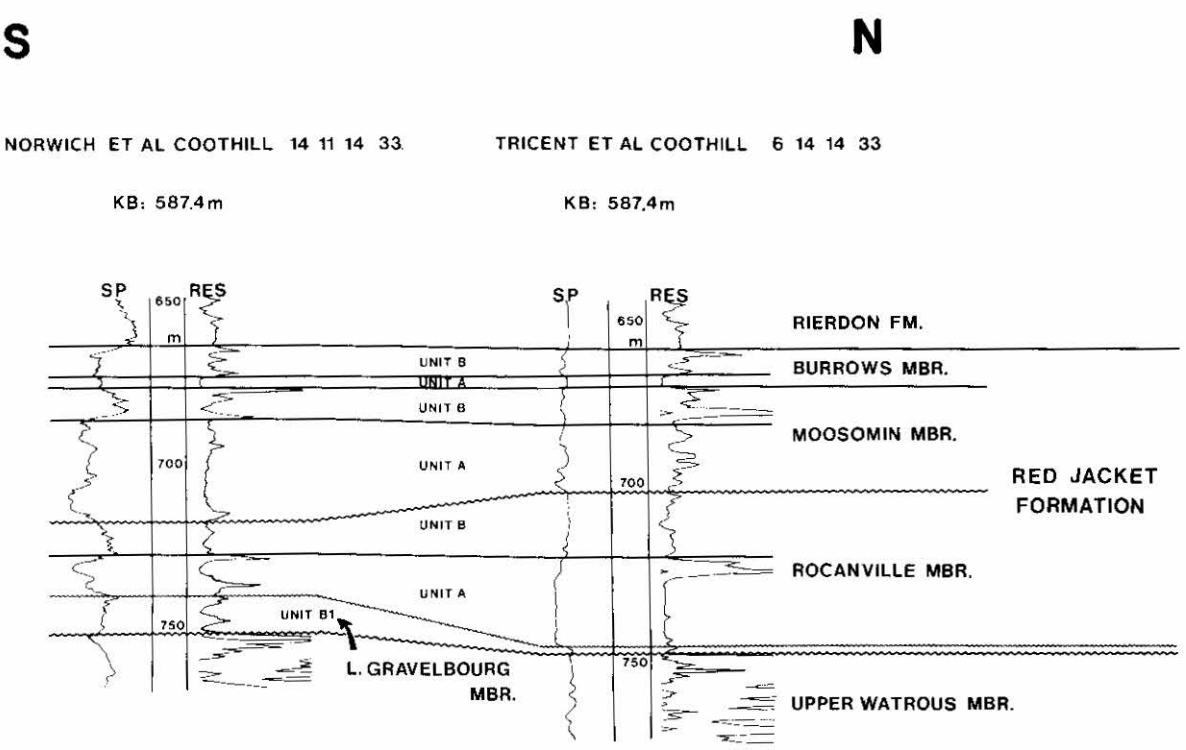


Figure 3 – North-south cross-section showing thickening in Unit A of the Rocanville Member at the expense of the underlying Unit B1 of Lower Gravelbourg Member.

grey (5GY6/1) mudstones which are typically dolomitic, and minor interbeds of yellowish-grey (5Y8/1) to light olive-grey (5Y6/1) and pale yellowish-brown (10YR6/2) limestone.

In many other wells in the Wapella – Moosomin area, the mudstones and argillaceous limestones present in the upper half of Unit B are very hard, dolomitic and quite variegated near the top. Colours vary from pale reddish brown (10R5/4) to moderate yellowish brown (10YR5/4) and greyish orange (10YR7/4).

b) Moosomin Member

A discontinuity appears to exist between the Rocanville Member and the overlying Moosomin Member. This contact is generally sharp and irregular, and the uppermost beds of Unit B of the Rocanville Member are typically dolomitic and variegated in shades of red and orange, colours commonly associated with sediments which have been subaerially exposed and subsequently oxidized.

The base of the Moosomin Member is found at 2360.0 ft. (719.3 m) in the type section for the Red Jacket Formation.

Unit A:

Unit A of the Moosomin Member is invariably thicker than the overlying Unit B. It is characterized by a sequence dominated by sandstone, mudstone and locally siltstone, and minor stringers of limestone. The sandstones of Unit A vary in colour from light olive grey (5Y6/1) to yellowish grey (5Y8/1) and, where oil stained, pale yellowish brown (10R6/2) to dark yellowish brown (10YR4/2). These sandstones are generally moderately sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz, with trace to locally abundant amounts of pyrite, mica and carbonaceous fragments. They can also be variably cemented. Iron-carbonate nodules up to 6 cm across have also been observed in cores and large wood fragments have been intersected which span the entire cross-sectional surface of the core (i.e., 8 cm across).

These sandstones are commonly interbedded and interlaminated with noncalcareous to weakly calcareous, micaceous and carbonaceous olive-grey (5Y4/1) to medium grey (N5) mudstones. Perhaps the most distinctive characteristic of this unit is the occurrence of carbonaceous material and abundant, typically large (up to 1 mm across) mica flakes.

The contact between Units A and B of the Moosomin Member appears to be gradational, and is placed at 2257.0 ft. (687.9 m). The gradational nature of this contact and the similarity of lithologies between Units A and B make this subdivision difficult.

Unit B:

The Unit B rocks comprise greenish-grey (5GY6/1) to dark greenish-grey (5GY4/1) mudstones interbedded

with yellowish-grey (5Y8/1) to light greenish-grey (5GY8/1) sandstones. The sandstones tend to consist of very fine to fine-grained, subangular to subrounded clear quartz with varying silt and argillaceous content. Mica and pyrite are important accessory minerals in Unit B, as in Unit A, but carbonaceous fragments are relatively scarce. The sandstones in Unit B tend to contain more cement than in Unit A. The mudstones are also more commonly calcareous than in Unit A, in places grading vertically into argillaceous limestones.

The upper 10 to 15 m of Unit B is generally characterized by a moderately to intensely bioturbated, interbedded and interlaminated sandstone/mudstone sequence. This bioturbation gives the interval a readily recognizable burrow-mottled texture. Locally, bioturbation has been so intense as to homogenize the sediment into sandy and virtually structureless rock.

c) Burrows Member

Unit A:

The base of the Burrows Member is defined by a sharp irregular contact, suggestive of a discontinuity, which in the type section occurs at 2215.3 ft. (675.2 m). At this contact, olive-grey (5Y4/1) to medium grey (N5) sandy mudstone or argillaceous sandstone commonly infills cracks in the underlying greenish-grey (5GY6/1) bioturbated sandstone/mudstone of Unit B of the Moosomin Member.

Unit A is characterized by olive-grey (5Y4/1) to medium grey (N5) claystone and mudstone. Generally, the lower 10 to 40 cm is a silty, micaceous, locally argillaceous and calcareous, very fine grained, clear quartz sandstone, which in many places is interlaminated with micaceous siltstone and argillaceous laminae. Sporadic interlaminations of micaceous and locally sandy siltstone are common near the base and the top of the unit. Numerous interlaminations of crushed thin-shelled pelecypods typically form pavements 1 to 2 mm thick throughout the unit.

Unit A is informally recognized by many workers in the Wapella–Moosomin area as the "Jurassic" or "Shaunavon" shale marker.

Where this unit has not been removed by a Late Jurassic to Early Cretaceous erosional event, it provides an invaluable and ubiquitous datum in the Red Jacket Formation.

Unit B:

The upper contact of Unit A is gradational into the overlying Unit B of the Burrows Member. Unit B represents a return to the bioturbated, interbedded and interlaminated, calcareous sandstone/mudstone lithofacies, similar to the upper 10 to 15 m of Unit B of the Moosomin Member. In the type section, the contact between Units A and B of the Burrows Member is defined at 2203.5 ft. (671.6 m), while the top of Unit B occurs at 2183.0 ft. (665.4 m).

The *Gryphaea*-bearing and poorly sorted sandstone subunit which commonly occurs at the top of the section is included in Unit B of the Burrows Member as discussed earlier (in section 2b).

5. Age and Correlation

The Red Jacket Formation of southeastern Saskatchewan is correlated with the Shaunavon Formation and the Upper Member of the Gravelbourg Formation in southwestern Saskatchewan (cross-section in map package).

The base of the Red Jacket Formation rests upon Unit B1 of the Lower Gravelbourg in southeastern Saskatchewan. The upper contact of the Red Jacket Formation is taken to be the base of the overlying light olive-grey (5Y6/1), calcareous mudstones of the Rierdon Formation. Fauna such as the oyster *G. nebrascensis* and the ammonite *Kepplerites* date the Rierdon Formation as Callovian (Christopher, 1964).

Imlay (1980) assigned a Bajocian age to the Gravelbourg Formation and the Lower Member of the Shaunavon Formation of southwestern Saskatchewan, and placed the Upper Shaunavon Member into the Bathonian. The Red Jacket Formation may therefore be assigned a Bajocian/Bathonian age. A possible exception to this age is the *Gryphaea*-bearing sandstone of the uppermost subunit of Unit B of the Burrows Member.

No flora or fauna which permit recognition of the Bajocian/Bathonian boundary have been identified in the Red Jacket Formation. A bioclastic limestone stringer capped with a coral rubble composed of well-worn pieces of the coral *Actinastrea* occurs, however, in the Moosomin Member of the Aberford Wapella 12A-34-14-1 well (Lsd. 12A-34-14-1W2M) at approximately 724.7 m. Paterson (1968, p. 14) recorded a basal conglomerate of the Upper Shaunavon in southwestern Saskatchewan as containing derived *Actinastrea*, suggesting that the Bajocian/Bathonian boundary in this well might lie at the top of the limestone stringer.

Imlay (1980, p.68-69) showed the Shaunavon Formation of southwestern Saskatchewan to be equivalent to the Bowes and Firemoon Limestone Members of the Piper Formation of northeastern Montana and northwestern North Dakota. He also correlated the Gravelbourg Formation of southwestern Saskatchewan with the Tampico Shale Member of the Piper Formation, and the Kline Member of the Nesson Formation in northeastern Montana and northwestern North Dakota. He also recognized an unconformity in the Gravelbourg Formation of southwestern Saskatchewan. In his correlation chart, Imlay (1980, p. 89-69) showed the Tampico Shale to be equivalent to Gravelbourg strata above an apparent unconformity defined by chert pebbles (Figure 4). This would appear to be the same unconformity observed between Units A and B of the Lower Gravelbourg Member in southwestern Saskatchewan, as was previously described (in section 2a).

Attempts at correlating the Red Jacket Formation with the Jurassic strata in Manitoba were unproductive. Although Stott (1955, p. 6) showed the Shaunavon and

Gravelbourg Formations of Saskatchewan to be equivalent to the Reston Formation of Manitoba, in another correlation chart (p. 36) in the same report, he showed the Reston to be equivalent to the Gravelbourg Formation and the Lower Shaunavon Member (J-2B) of the Shaunavon Formation.

It also appears that Francis (1956) was correct in his suggestion that Stott (1955) picked the Reston Formation stratigraphically much higher in east-central Saskatchewan than in southeastern Saskatchewan.

It would appear that inconsistencies in the definition and correlation of the Reston and Manitoba Formations in

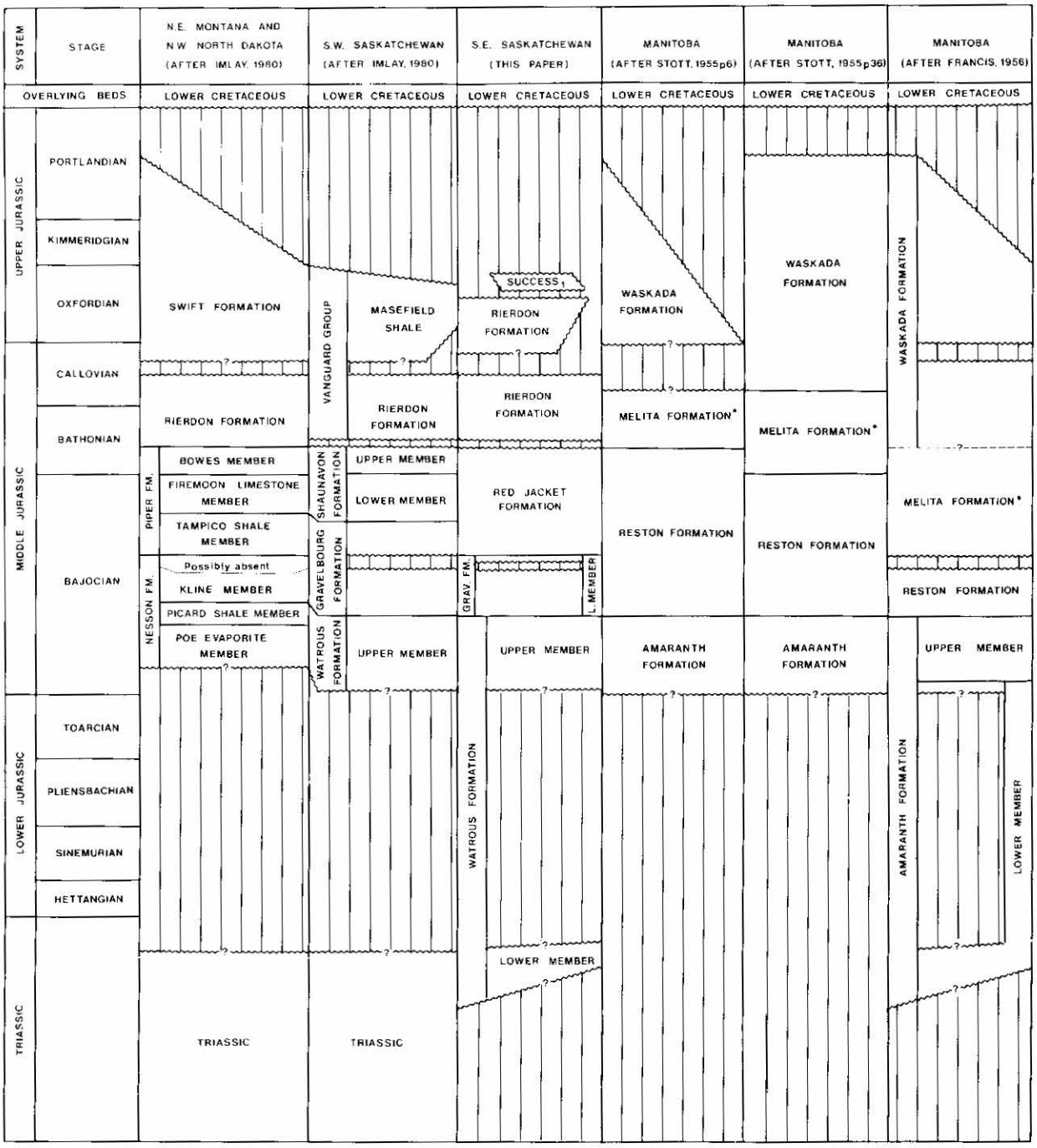


Figure 4 – Stratigraphic correlation chart showing correlation of Red Jacket Formation with equivalent strata in conterminous areas. Note that the Melita and Reston Formations of Stott (1955, p. 6) are shown correlated with their lithostratigraphic equivalents, but Stott believes their contact to be the Bathonian/Callovian boundary.

Manitoba require resolution before their correlation with Saskatchewan strata can be understood. This is reflected in the correlation chart in Figure 4.

6. References

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7. Appendix A

The following core description is for the type section of the Red Jacket Formation in the Tide Water North Wapella Crown 14-22-15-1 well, and includes strata immediately above and below.

Intervals are given in feet below K.B., with the metric equivalent in parentheses on the line beneath. The figure on the third line is the length of the interval in metres.

The grading scale for grain size of sandstone and mudstone is based on the Wentworth scale as follows:

Size Class	Grain Diameter
Very coarse grained	2 to 1 mm
Coarse grained	1 to 0.5 mm
Medium grained	0.5 to 0.25 mm
Fine grained	0.25 to 0.125 mm
Very fine grained	0.125 to 0.06 mm
Silt	0.06 to 0.004 mm
Clay	0.004 mm or less

The sorting classification used follows Payne (1942), who employed Wentworth size classes:

Well sorted	90 percent in 1 or 2 size classes
Moderately sorted	90 percent in 3 or 4 size classes
Poorly sorted	90 percent in 5 or more size classes

The Geological Society of America (second printing, 1951) colour chart was used.

The term "laminae" in this report refers to layers less than 1 cm in thickness, while "bed" refers to layers 1 cm thick or greater.

The following terms are used as a measure of mineral and fossil abundance:

Abundant	greater than 10 percent
Minor	1 to 10 percent
Trace	less than 1 percent

Tide Water North Wapella Crown 14-22-15-1W2

K.B: 1954 ft.(595.6 m)

Jurassic

Rierdon Formation top . . . . . 2120 ft. (646.2 m)
Red Jacket Formation:
  Burrows Member top . . . . . 2183 ft. (665.4 m)
  Moosomin Member top . . . . . 2214 ft. (674.8 m)
  Rocanville Member top . . . . . 2360 ft. (719.3 m)
Gravelbourg Formation:
  Lower Gravelbourg Member top . . . 2410 ft. (734.6 m)
Watrous Formation:
  Upper Watrous Member top . . . . . 2451 ft. (747.1 m)

Mississippian

Souris Valley Formation top . . . . . 2572 ft. (783.9 m)

Jurassic

Rierdon Formation

2161.0-2183.0 (658.7-665.4) (Rec. 5.2 m) Mudstone: light olive grey (5Y6/1), slabby parting, hard, highly calcareous, trace to minor amounts of disseminated pyrite, fossiliferous. A sparse assemblage of belemnites, pelecypods (*Gryphaea nebrascensis*), ostracodes and am-

monite shell fragments (*Kepplerites*?). Locally, mudstone grades abruptly into claystone or siltstone beds up to 1.5 m thick.
Lower contact missing.

Red Jacket Formation

Burrows Member

2183.0-2189.0 (665.4-667.2) (Rec. 0.91 m) Sandstone: light olive grey (5Y6/1), hard, very fine to fine grained, subangular to subrounded, clear quartz, poorly sorted, calcite cemented, silty, slightly argillaceous with minor amounts of very fine disseminated pyrite, a trace of glauconite and abundant broken-up well-worn *Gryphaea nebrascensis* and other unidentified pelecypod shells.
Lower contact not preserved.

2189.0-2191.0 (667.2-667.8) (Rec. 0.23 m) Mudstone: greenish grey (5GY6/1) to dark greenish grey (5GY4/1), hard, slabby parting, slightly calcareous to locally highly calcareous. Locally, abundant pelecypod molds (possibly *Pleuromya oblongata* and *P. simplex*?).
Lower contact missing.

2191.0-2194.1 (667.8-668.8) (Rec. 0.92 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, slightly calcareous, swelling clays, abundant molds of pelecypods and the occasional ostracode. Moderately laminated with lenticular and parallel laminations of micaceous silt.
Lower contact missing.

2194.1-2196.5 (668.8-669.5) (Rec. 0.73 m) Sandstone: bioturbated, mottled, greenish grey (5GY6/1) to light olive grey (5Y6/1), hard, very fine to fine grained, clear quartz, subangular to subrounded, moderately sorted, well cemented with calcite, locally abundant pelecypods. Locally abundant fine-grained disseminated pyrite. Very fine grained pyrite locally replaces pelecypod shells. Disturbed greenish grey (5GY6/1) calcareous mudstone laminations common over lower third.
Lower contact sharp.

2196.5-2199.5 (669.5-670.4) (Rec. 0.80 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous. In gradational contact with interlaminated, silty sandstone below.

2199.5-2203.5 (670.4-671.6) (Rec. 1.20 m) Sandstone: moderately to intensely bioturbated, highly interlaminated with mudstone and siltstone, light olive grey (5Y6/1), moderately friable, moderately sorted, very fine grained, subangular, clear quartz, slightly calcareous, very silty (up to 30 percent), minor amounts of mica, slightly argillaceous, trace of indeterminate bone fragments and occasional poorly preserved pelecypod shell. Local patches of minor amounts of very fine grained disseminated pyrite. Occasional sandy, calcite infilled, vertical fractures < 1 mm across.
Lower contact gradational.

2203.5-2215.3 (671.6-675.2) (Rec. 3.60 m) Claystone: medium grey (N5) to olive grey (5Y4/1), hard, slabby to flaggy parting, locally slightly calcareous, occasional parallel lamination of abundant pelecypod shells (possibly *P. oblongota* and *P. simplex*?). Occasional parallel laminations of micaceous silt and locally very fine grained clear quartz. Sandy, olive grey (5Y4/1) mudstone from this interval infills crack in the underlying greenish grey (5GY6/1) unit.
Lower contact sharp.

Moosomin Member

2215.3-2226.9 (675.2-678.8) (Rec. 3.00 m) Sandstone (80 percent) and Mudstone (20 percent): moderately to intensely bioturbated, intermixed, mottled, light greenish grey (5GY8/1) to greenish grey (5GY6/1). Sandstone is hard, comprising, very fine to fine grained, subangular to subrounded clear quartz, locally abundant poorly preserved pelecypods and trace amounts of mica and indeterminate fish fragments. Moderately sorted, argillaceous (< 5 percent), silty (< 5 percent) and well-cemented with calcite. Locally abundant disseminated pyrite and occasional nodules up to 2 cm across. Mudstone is greenish grey (5GY6/1), hard, with slabby partings, locally abundant pelecypods, high calcite content and up to 30 percent scattered, very fine to fine-grained clear quartz. Patchy, pale yellowish-brown (10YR6/2) oil-staining over lower 30 cm.
Lower contact gradational.

2226.9-2231.0 (678.8-680.0) (Rec. 0.96 m) Mudstone: interlaminated, greenish grey (5GY6/1) to dark greenish grey (5GY4/1), hard, slabby parting, calcareous. Laminated with micaceous siltstone and silty, micaceous, very fine to fine-grained clear quartz sandstone which locally exhibits pale yellowish-brown (10YR6/2) oil-staining.
Lower contact missing.

2231.0-2237.0 (680.0-681.8) (Rec. 1.47 m) Mudstone: moderately bioturbated, mottled, yellowish grey (5Y8/1) to greenish grey (5GY6/1). Mudstone is hard, calcareous, with the occasional pelecypod mold and traces of mica and fine-grained disseminated pyrite. Limestone bed from approximately 2231.5 to 2232.1 (680.16 to 680.34 m). This limestone is very sandy and bioturbated over upper half, argillaceous, highly fossiliferous

(abundant pelecypod shells), peloidal (indeterminate carbonate grains <1 mm across) with traces of unidentified bone fragments and patches of very fine grained disseminated pyrite <0.5 cm across. Mudstone is gradational with argillaceous, silty, micaceous, poorly sorted, very fine grained sandstone over lower 40 cm.
Lower contact missing.

2237.0-2243.5 (681.8-683.8) (Rec. 1.43 m) Sandstone: yellowish grey (5Y8/1) to greenish grey (5GY6/1), hard, very fine to fine grained, subangular to subrounded, clear quartz, argillaceous, silty, trace of mica, trace of very fine grained disseminated pyrite. Small-scale ripples are observed at several intervals. Mudstone interbed from approximately 2239.5 to 2240.5 (682.6 to 682.9 m). The mudstone is greenish grey (5GY6/1), slightly dolomitic and exhibits trace amounts of mica.
Lower contact of unit gradational.

2243.5-2257.0 (683.8-687.9) (Rec. 3.11 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, slightly calcareous to calcareous, trace of mica, trace of pyrite, trace of indeterminate fish(?) bone fragments. Moderately bioturbated sandstone interbeds up to 40 cm thick found between approximately 2247.0 and 2251.0 (684.9 and 686.1 m). Sandstone is composed of very fine to fine-grained clear quartz, is well cemented with calcite, slightly argillaceous, silty (up to 30 percent) with trace amounts of pyrite, carbonaceous fragments and indeterminate bone fragments.
Lower contact gradational.

2257.0-2292.0 (687.9-698.6) (Rec. 6.40 m) Sandstone (60 percent) and Mudstone (40 percent): interbedded and interlaminated. Sandstone is yellowish grey (5Y8/1) to dusky yellowish brown (10YR2/2) where oil stained. It is hard, moderately to poorly sorted, made up of very fine to fine-grained, subangular to subrounded clear quartz. It is variably calcite cemented, silty (up to 30 percent) and slightly argillaceous (<3 percent), with trace amounts of mica (flakes up to 1 mm thick), pyrite (nodules up to 3 mm across) and carbonaceous fragments. Sandstone is interlaminated and interbedded with greenish-grey (5GY6/1) to olive-grey (5Y4/1) mudstone. The mudstone is locally slightly calcareous, sandy (up to 30 percent very fine to fine-grained clear quartz) and highly interlaminated with siltstone and silty, micaceous, very fine grained sandstone. Mudstone interbeds range up to 90 cm in thickness. Silty, micaceous and carbonaceous laminations become increasingly common over lower 3 metres.
Lower contact very gradational.

2292.0-2306.0 (698.6-702.9) (Rec. 3.17 m) Sandstone (70 percent) and Mudstone (30 percent): interbedded and interlaminated. Sandstone ranges in color from yellowish grey (5Y8/1) to light olive grey (5Y6/1) and dark yellowish brown (10YR4/2) where oil stained. The sandstone is generally friable but local calcite cemented zones up to 15 cm thick are observed. It is moderately sorted, containing very fine to fine-grained, subangular to subrounded clear quartz, with locally abundant mica and carbonaceous fragments, and trace amounts of pyrite. Abundant interlaminations of argillaceous, silty, micaceous and slightly carbonaceous sandstone and occasionally olive grey (5Y4/1), sandy mudstone. Mudstone interbeds up to 30 cm in thickness with abundant interlaminations of silty, micaceous and carbonaceous, very fine grained clear quartz. The mudstone itself has as much as 40 percent scattered, very fine grained clear quartz.
Lower contact missing.

2306.0-2317.0 (702.9-706.2) (Rec. 1.92 m) Sandstone: yellowish grey (5Y8/1) with oil-stained patches of dark yellowish brown (10YR4/2). It is moderately friable, moderately to well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz. There are trace amounts of fine grained disseminated pyrite, mica and carbonaceous fragments. Locally, abundant interlaminations of argillaceous, silty, micaceous and carbonaceous material. There are occasional interbeds of sandy (up to 30 percent very fine to fine grained, clear quartz) olive grey (5Y4/1) mudstone of less than 15 cm thickness.
Lower contact missing.

2317.0-2323.0 (706.2-708.1) (Rec. 0.82 m) Sandstone: interlaminated, yellowish grey (5Y8/1) to pale yellowish brown (10YR6/2) where oil stained. It is friable, moderately to poorly sorted, containing very fine to fine grained, subangular to subrounded clear quartz with up to 30 percent silt and minor quantities of mica and carbonaceous fragments. Interlaminations of highly argillaceous, micaceous and carbonaceous material are common.
Lower contact missing.

2323.0-2349.0 (708.1-716.0) (Rec. 4.58 m) Sandstone: yellowish grey (5Y8/1) to pale yellowish brown (10YR6/2) where oilstained. It is friable, moderately to well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz. Generally it is silty (up to 20 per-

cent) with minor mica (flakes up to 1 mm across) and trace amounts of fine-grained disseminated pyrite and carbonaceous fragments. Locally, there are parallel to wavy interlaminations of slightly argillaceous, micaceous and carbonaceous material. Sandy, micaceous and carbonaceous mudstone interbeds measuring up to 10 cm thick are common between approximately 2328.0 and 2338.0 (709.6 and 712.6 m). Locally, these mudstones are interlaminated with silty, micaceous sandstone. Lower 40 cm also interbedded with olive-grey (5Y4/1) mudstone up to 10 cm thick.
Lower contact missing.

2349.0-2360.0 (716.0-719.3) (Rec. 2.29 m) Sandstone: light olive grey (5Y6/1) to dark yellowish brown (10YR4/2) in patchy oil-stained areas. Sandstone is hard to moderately friable, well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz with trace to minor amounts of mica and carbonaceous fragments (with the occasional carbonaceous wood fragment up to 4 cm across). It is well cemented with calcite over upper half, exhibiting high angle planar (up to 20°) and current ripple bedding. Laminations are defined by abundant mica (flakes up to 1 mm across) and organic detritus.
Lower contact missing.

Rocanville Member

2360.0-2364.5 (719.3-720.7) (Rec. 0.61 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, moderately to locally highly calcareous, sandy (up to 10 percent scattered very fine to fine grained quartz). A 2 cm thick layer of calcite and slightly oxidized, pyrite-cemented, poorly sorted, fine-grained, subrounded clear quartz sandstone occurs at the top of the material recovered in this interval. This sandstone layer is cemented with calcite and slightly oxidized pyrite.
Lower contact is sharp and irregular.

2364.5-2373.5 (720.7-723.4) (Rec. 2.29 m) Limestone: yellowish grey (5Y8/1) to light olive-grey (5Y6/1), very hard, dolomitic, highly argillaceous, slightly sandy (up to 5 percent scattered, very fine to fine grained clear quartz). Dark greenish-grey (5GY4/1) calcareous mudstone break between approximately 2367.5 and 2369.0 (721.6 and 722.1 m). Upper contact displays a 10 cm long vertical fracture infilled with overlying greenish grey (5GY6/1) mudstone.
Lower contact sharp.

2373.5-2376.0 (723.4-724.2) (Rec. 0.46 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous, sandy (up to 5 percent scattered, very fine to fine grained, clear quartz).
Lower contact missing.

2376.0-2378.4 (724.2-724.9) (Rec. 0.74 m) Limestone: pale yellowish brown (10YR6/2), very hard, dolomitic, slightly argillaceous, trace to minor amounts of pyrite (commonly in patches <0.5 cm across), traces of mica and scattered, very fine grained clear quartz. A few poorly preserved pelecypod shells and a trace of indeterminate fish(?) bone fragments are also present.
Lower contact gradational.

2378.4-2379.6 (724.9-725.3) (Rec. 0.34 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, becomes increasingly calcareous towards top, one large (4 cm across) mold of pelecypod shell fragment and trace amounts of indeterminate bone fragments. Occasional laminations of silty, micaceous, very fine to fine grained, subangular to subrounded, clear quartz.
Lower contact poorly preserved.

2379.6-2390.0 (725.3-728.5) (Rec. 1.89 m) Sandstone: yellowish grey (5Y8/1) to dark yellowish brown (10YR4/2) in small (<3 cm) patches of oil staining. It is moderately friable, moderately to well sorted, containing fine-to medium-grained, subangular to subrounded, slightly calcite-cemented clear quartz with trace to minor amounts of mica. Excellent porosity in a well-sorted medium-grained interval between approximately 2383.0 and 2385.0 (726.3 and 727.0 m). Becomes siltier and finer grained above and below this interval. In gradational contact with underlying sandstone.

2390.0-2395.5 (728.5-730.1) (Rec. 1.07 m) Sandstone and Siltstone: interlaminated, interbedded, yellowish grey (5Y8/1) to light olive grey (5Y6/1), moderately hard. Sandstone is moderately hard, moderately sorted, slightly calcite cemented, composed of very fine grained, subangular clear quartz with abundant silt (up to 50 percent), minor amounts of mica and an occasional pyrite nodule (up to 1.5 cm across). Abundant interlaminations and interbeds of sandy (up to 30 percent very fine grained clear quartz), argillaceous siltstone over lower two-thirds.
Lower contact gradational.

2395.5-2397.7 (730.1-730.8) (Rec. 0.55 m) Mudstone: olive grey (5Y4/1), hard, slabby parting, trace amounts of very fine grained disseminated pyrite, carbonaceous fragments and indeterminate bone fragments. Becomes calcareous over lower 15 cm.
Lower contact missing.

2397.7-2400.0 (730.8-731.5) (Rec. 0.65 m) Sandstone: white (N9) to yellowish grey (5Y8/1), moderately friable, moderately calcite cemented, very fine grained, subangular, clear quartz, showing a trace of mica and locally abundant pyrite nodules (nodules up to 3 cm across present over lower half). Becomes increasingly interlaminated with very silty and slightly argillaceous material over lower two-thirds.
Lower contact sharp.

2400.0-2401.5 (731.5-732.0) (Rec. 0.15 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous with a trace of pyrite and very fine grained, scattered quartz.
Lower contact of unit missing.

2401.5-2403.0 (732.0-732.4) (Rec. 0.34 m) Limestone: light olive grey (5Y6/1) to yellowish grey (5Y8/1), hard, dolomitic and argillaceous, with trace amounts of mica and very fine grained disseminated pyrite. Grades up from a calcareous greenish-grey (5GY6/1) mudstone over lower 15 cm.
Lower contact missing.

2403.0-2405.2 (732.4-733.1) (Rec. 0.82 m) Limestone: yellowish grey (5Y8/1), hard, dolomitic, slightly argillaceous, locally abundant bean-shaped ostracodes and trace amounts of mica and pyrite.
Lower contact of unit gradational.

2405.2-2406.9 (733.1-733.6) (Rec. 0.52 m) Siltstone: greenish grey (5GY4/1), hard, slabby parting, argillaceous, minor to locally abundant mica and sandy (up to 30 percent very fine grained clear quartz).
Lower contact gradational.

2406.9-2410.0 (733.6-734.6) (Rec. 0.91 m) Sandstone: interlaminated, yellowish grey (5Y8/1), moderately hard and moderately to poorly sorted. Consists of very fine grained, subangular clear quartz and is argillaceous, very silty (locally up to 40 percent) with minor to abundant mica and a trace of carbonaceous fragments over lower half. Grades into a siltstone over lower 30 cm.
Lower contact missing.

Lower Gravelbourg

2410.0-2410.7 (734.6-734.8) (Rec. 0.20 m) Limestone: olive grey (5Y4/1), very hard. This limestone is dominated by ovate to subspherical peloids up to 2 mm in length and 1 mm across. The peloids contain significant amounts of silt-sized pyrite. The limestone matrix is slightly argillaceous with minor pyrite and a trace of mica. The uppermost 1.5 cm interval contains calcareous, olive-grey (5Y4/1) mudstone and rounded, medium- to coarse-grained olive-black (5Y2/1) carbonate grains (peloids), silt (approximately 20 percent) and trace amounts of glauconite in an olive-grey (5Y4/1) matrix. This is immediately underlain by a 2 to 3 mm layer of fibrous calcite and pyrite.
Lower contact of unit sharp.

2410.7-2416.5 (734.8-736.6) (Rec. 1.77 m) Limestone: light olive grey (5Y6/1), very hard, slightly argillaceous with trace amounts of mica and scattered, very fine grained clear quartz. Becomes increasingly interlaminated over lower half with silty, slightly argillaceous laminae with abundant silt-sized disseminated pyrite. Lower contact sharply defined by a 0.5 cm band of interlaminated, peloidal and sandy (up to 30 percent very fine to fine-grained clear quartz) mudstone with abundant disseminated pyrite and trace amounts of mica and glauconite.

2416.5-2431.5 (736.6-741.1) (Rec. 2.92 m) Mudstone: olive grey (5Y4/1), hard, platy to fissile parting, calcareous with abundant thin-shelled pelecypods <0.5 cm across. Pelecypods so abundant as to form laminae <1.0 mm thick which consist entirely of crushed shells. An interbed of olive grey (5Y4/1), highly fossiliferous (abundant pelecypods), sandy (up to 20 percent very fine grained clear quartz) limestone with abundant very fine grained disseminated pyrite and a trace of mica and glauconite occurs between approximately 2421.5 and 2422.0 (738.1 and 738.2 m).
Lower contact sharp, defined by a 10 cm band of highly fossiliferous (pelecypod shell hash), glauconitic, peloidal, pyritic and sandy (up to 10 percent very fine to fine grained clear quartz) mudstone at base.

2431.5-2432.2 (741.1-741.32) (Rec. 0.22 m) Limestone: light olive grey (5Y6/1), very hard and massive. Occasional vertical hairline fracture lined with very fine grained pyrite. Lower contact sharp and irregular, defined by a 1.5 cm thick band of calcite- and pyrite-cemented, fine-grained argillaceous sandstone at the top of the underlying mudstone.

2432.2-2434.0 (741.1-741.9) (Rec. 0.61 m) Mudstone: light olive grey (5Y6/1), hard, silty to locally sandy (up to 40 percent very fine grained clear quartz) with minor very fine grained disseminated pyrite and trace amounts of mica and glauconite.
Lower contact of unit missing.

2434.0-2437.0 (742.2-742.8) (Rec. 0.55 m) Sandstone: light olive grey (5Y6/1), hard and moderately sorted. It consists of very fine grained, subangular to subrounded clear quartz and is calcite cemented. Has minor amounts of mica, very fine grained disseminated pyrite (occasional patch <0.5 cm across) and a trace of carbonaceous fragments. It becomes increasingly argillaceous and silty towards

base.
Lower contact appears gradational.

2437.0-2440.0 (742.8-743.7) (Rec. 0.46 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, moderately calcareous, sandy (up to 30 percent very fine to fine grained clear quartz), with minor mica and trace amounts of carbonaceous fragments and disseminated pyrite.
Lower contact missing.

2440.0-2444.0 (743.7-744.9) (Rec. 1.07 m) Siltstone: light olive grey (5Y6/1), hard, calcareous, argillaceous with traces of mica and pyrite. Calcareous, greenish-grey (5GY6/1) mudstone break between approximately 2441.0 and 2441.5 (744.0 and 744.2 m).
Lower contact of unit gradational.

2444.0-2451.5 (744.9-747.2) (Rec. 0.91 m) Mudstone: light olive grey (5GY6/1), hard, flaggy parting, highly calcareous (approaching limestone composition).
Lower contact of unit not preserved.

2451.5-2452.0 (747.2-747.4) (Rec. 0.23 m) Sandstone: greenish grey (5GY6/1), moderately hard, moderately to poorly sorted, very fine to fine grained, clear quartz, argillaceous, silty (up to 30 percent), minor mica, minor to locally abundant glauconite and pyrite, minor subrounded very pale orange (10YR8/2) carbonate fragments and trace to minor amounts of greyish blue (5PB5/2) to dusky blue (5PB3/2) subrounded to rounded chalcedonic chert nodules up to 3 mm across.
Lower contact of unit sharp and irregular.

Upper Watrous Member

2452.0-2459.0 (747.4-749.5) (Rec. 0.31 m) Dolomite and Anhydrite: interbedded. Dolomite is very pale orange (10YR8/2) to light olive grey (5Y6/1), while the anhydrite is light bluish grey (5B7/1) to light grey (N7). Dolomite is massive, brecciated, with fractures infilled by gypsum. Interbeds consisting of light bluish-grey (5B7/1) to light grey (N7) anhydrite intermixed with greyish-blue (5PB5/) to dusky blue (5PB3/2) chalcedonic chert. Locally euhedral, bipyramidal quartz crystals and chalcedonic chert nodules occur as apparent void-fill in the dolomite.
Very poor recovery.